WILLOWSTICK
GEOPHYSICAL INVESTIGATION

Of:

Recycle Tailings Pond Dam
Pogo Mine, Alaska

(Identify Preferential Seepage Flow Paths through Dam)

Prepared For:

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i. EXECUTIVE SUMMARY

This report presents the results of a Willowstick® geophysical investigation to identify, map and model preferential seepage flow paths out of Pogo Mine's Recycle Tailings Pond impoundment (RTP dam). The application of the Willowstick technology, as applied to the RTP dam, is based on the principle that water seeping out of the impoundment substantially increases the conductivity of earthen materials as a general rule. As the signature electric current flows between strategically placed electrodes (located up-gradient and down-gradient of the dam) it concentrates in the more conductive zones (i.e., in areas of highest transport porosity) where water seeps relatively freely through and/or beneath the embankment. Magnetic fields generated from the distribution of electric current were used to identify preferential electric current flow paths. The concentration and distribution of electric current was then interpreted and modeled to characterize how and where seepage potentially escapes the impoundment.

Due to conductive culture in and around the study area (i.e. power cables, metallic pipe lines and wire mesh netting, etc.), some of the magnetic field measurements were adversely influenced by stray electric current flowing onto near-surface conductors. As a result, measurement stations influenced by near-surface conductive culture were removed from the data set. Figure *i* summarizes the results of the investigation.

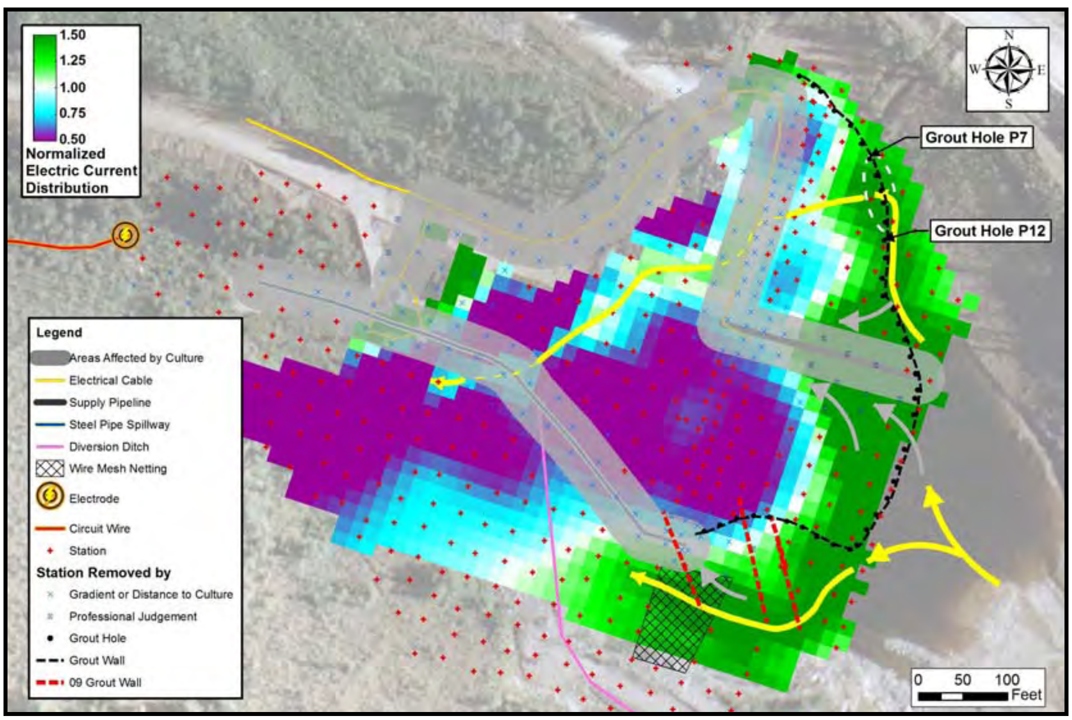

Figure *i* – Preferential Seepage Flow beneath Dam (Plan View)

Locations where measurement stations were removed due to influence of near-surface conductive culture are shaded with a transparent gray cloud. After filtering, the data set was reduced and subjected to an inversion algorithm designed to predict the distribution of electric current flow in three dimensional space beneath the surface of the dam. The inversion model is referred to as an Electric Current Distribution (ECD) model.

Figure *i* presents a horizontal slice taken through the ECD model at elevation 2000 feet (near the interface between fill material and native foundation soil and/or rock). The light-blue to dark-green shading (going up the scale) identifies increasing levels of electric current density. The dark-blue to purple shading (going down the scale) indicates weak electric current flow. The yellow lines and arrows highlight preferential electric current flow paths beneath the dam. The gray arrows highlight electric current that follows near-surface conductive culture.

Electric current flowing through and beneath the dam bifurcates upstream of the embankment and flows north and south around the dam rather than through and/or beneath the central part of the embankment. Due to the wire mesh netting and supply pipeline that run down into the pond (coming in contact with the pond water), electric current flows onto these conductive features and follows them up and over the embankment toward the return electrode located down-gradient of the dam. Electric current flow through the subsurface, however, clearly skirts around the dam's upstream toe and grout curtain to the south and north.

Electric current flowing to the south appears to flow around the secondary grout curtains (shown as red dashed lines in the figure). However, electric current flow through the south abutment area rapidly weakens as evident by the rapidly fading dark green shaded flow path. This flow path is **<u>not</u>** continuous through the study area. This is likely a result of the secondary grout curtains minimizing seepage through the south abutment as designed.

On the north side, electric current flows along the upstream toe and grout curtain until it finds a path beneath the grout curtain. This occurs between grout holes P7 and P12 as shown in the figure. This area is highlighted by a white dashed oval. After passing beneath the grout curtain at or about elevation 2000 feet, seepage preferentially flows beneath the north abutment area as highlighted by the yellow lines and arrows shown in the figure. The thin dashed yellow lines are based on conjecture, and are drawn for visual purposes to create connectivity through the study area. These inferred flow paths were interpolated in the ECD model from measurement stations unaffected by near-surface conductive culture.

Near the dam's downstream toe, seepage appears to flow beneath the spillway to the south for a short distance before turning west and following the alignment of the creek channel—appearing to originate from the south abutment when in fact it originates from the north abutment. The flow path beneath the north abutment is interpreted to be the primary seepage flow path out of the RTP impoundment. This is because it is relatively strong and continuous through the study area. The flow path beneath the south abutment is secondary and not likely the primary source of seepage observed downstream in the collection system and monitoring wells.

The information contained in this report can be used by Aspen Hydrologic Services and Pogo Mine in making informed, guided and cost effective decisions concerning further evaluation of seepage flow beneath the RTP Dam.

1.0 INTRODUCTION

1.1 General

This report presents the results of a Willowstick® geophysical investigation performed by Willowstick Technologies, LLC (Willowstick) for Aspen Hydrologic Services, LLC (Aspen) to identify, map and model seepage flow paths out of the Recycle Tailings Pond (RTP) impoundment at Pogo Mine. The Pogo Mine is located in East Central Alaska, approximately 90 miles east of Fairbanks (see Figure 1).

Figure 1 – Project Location Map

1.2 Background

Pogo Mine is currently owned by Sumitomo Metal Mining Co., Ltd (Pogo). The mine began operations in 2006. The RTP impoundment is located in close proximity to the eastern reaches of the mine site in the Liese Creek valley upstream of the main camp and milling facilities and downstream of the dry stack tailings facility (see Figure 2).

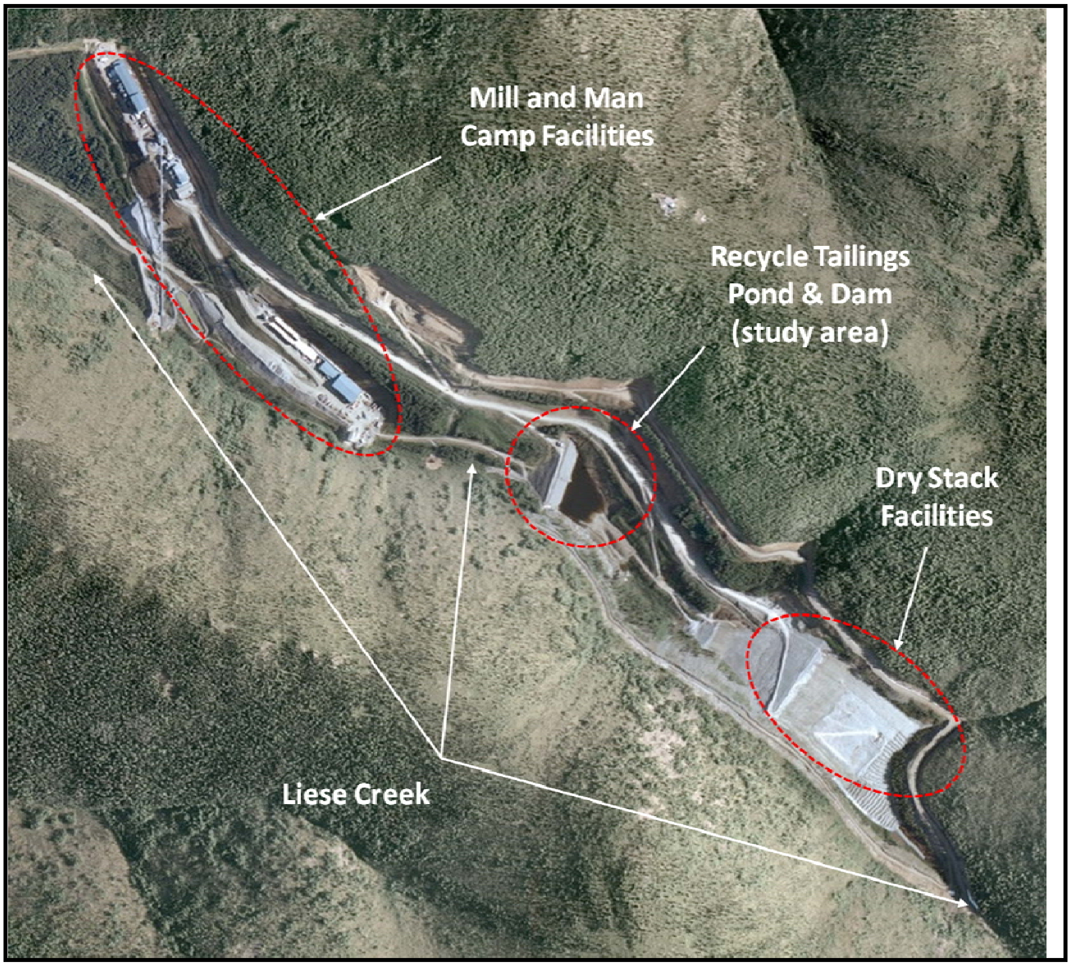

Figure 2 – Site Map and Study Area

The RTP dam and other structures were constructed in 2004 and 2005. The RTP dam consists of a rock filled embankment with a LDPE liner placed over the upstream face of the embankment and a grout curtain located beneath the upstream toe of the dam (see Figure 3).

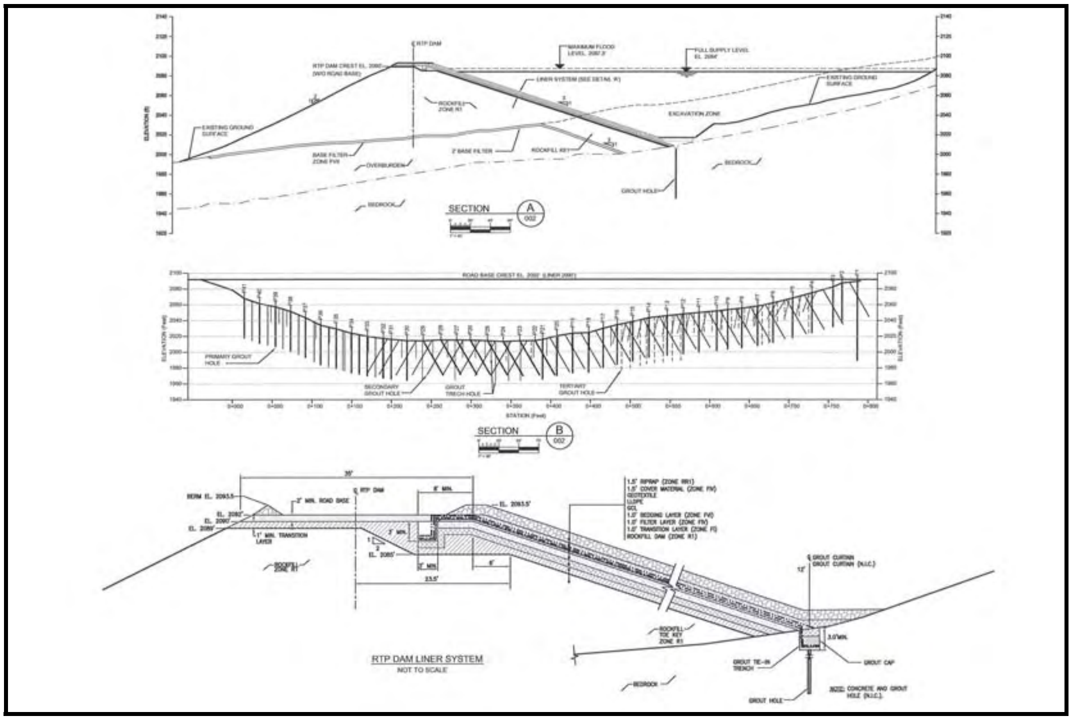

Figure 3 – Dam Cross Section, Liner and Primary Grout Curtain Systems (Drawing provided by Pogo Mine)

Shortly after filling the dam in 2006, seepage was observed downstream of the embankment. It was thought to be originating beneath the south abutment. The primary grout curtain beneath the south abutment was designed to cut-off water below the dam's embankment but not necessarily around and through the dam's south abutment. Also, the grout curtain consists mostly of vertical grout holes which may not have adequately intercepted joints and fractures potentially existing in dam's foundation. As a result, in 2009, three secondary grout curtains were constructed. These secondary grout curtains were located perpendicular to the primary grout curtain in front of the south groin area and installed in crisscrossing angular holes beneath the south abutment (see Figure 4).

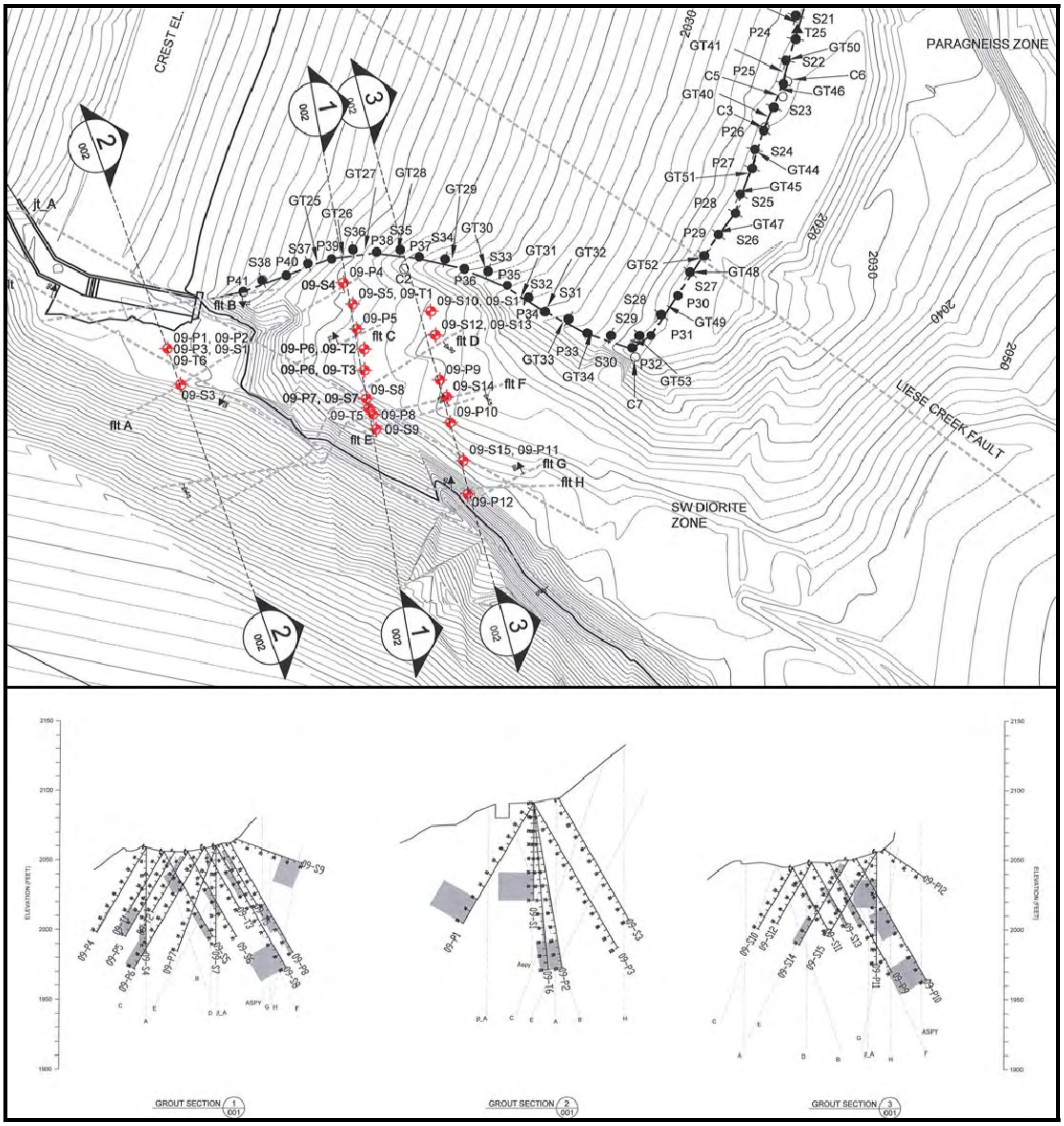

Figure 4 – Plan and Profile views of Secondary Grout Curtain
(Drawing provided by Pogo Mine)

Following completion of the secondary grout curtains, it was reported that only a small percentage of seepage was cutoff.

1.3 Purpose of Investigation

The purpose in performing a Willowstick geophysical investigation is to help identify, map and model preferential seepage flow paths through and/or beneath the RTP dam prior to a third grouting phase.

Because saturated strata act as good subsurface electrical conductors, the geophysical technology employed for the investigation energizes the pond water with a signature electric current. This electric current follows the water-saturated zones out of the impoundment beneath and/or through the dam's embankment and subsurface grout curtains. By identifying preferential electric current flow paths out of the pond, the technology can successfully answer questions about where water seeping from the impoundment originates and how it moves through and/or beneath the embankment.

Although the technology can identify zones of preferential groundwater flow, it does not directly identify the water volume or the flow direction. It is safe to assume the direction of seepage is downstream. Seepage flow rates, however, should be determined by other field methods.

This report presents the Willowstick methodology, how it was applied to the RTP impoundment and the findings of the investigation, interpretation and recommendations. The information contained herein can be used by Aspen and Pogo in conjunction with other data to better understand seepage conditions.

2.0 WILLOWSTICK METHODOLOGY

2.1 Technology Explained - See Appendix A

The Willowstick technology has been successfully used on many earthen dams to identify, map and model preferential seepage flow paths. If the reader is unfamiliar with the methodology, the reader is referred to Appendix A – White Paper - Willowstick Technology Explained. The White Paper presents detailed information about how the technology is used to characterize zones of highest transport porosity or subsurface preferential flow paths. The White Paper can also be used as a reference to help explain certain concepts of the exploratory and diagnostic process. See "Table of Contents" at the beginning of Appendix A for a quick reference guide to find specific sections that can help clarify certain aspects of the survey and modeling process.

3.0 CONTRACT AND WORK SCHEDULE INFORMATION

3.1 Contract Information

Aspen is currently under contract with Pogo to provide technical services of which Willowstick is an approved subcontractor. On July 8th, 2011 Willowstick was authorized by Aspen to perform the geophysical groundwater investigation of the RTP impoundment.

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3.2 Work Schedule

Fieldwork was initiated on Tuesday, August 16th, 2011. Fieldwork entailed mapping cultural features pertinent to the investigation, laying out circuit wire around the survey study area, placing electrodes in the pond and down-gradient monitoring well, energizing the subsurface study area, and measuring and recording magnetic field intensities over the surface of the dam. The fieldwork took one week to complete, ending Tuesday, August 23rd. Data reduction, modeling, interpretation and report writing took an additional two weeks to complete. The entire investigation and report was completed in less than a month.

4.0 APPROACH TO THE WORK

4.1 Horizontal Dipole Configuration

Figure 5 shows a typical cross-sectional view of a horizontal dipole configuration used in the seepage investigation of the RTP impoundment.

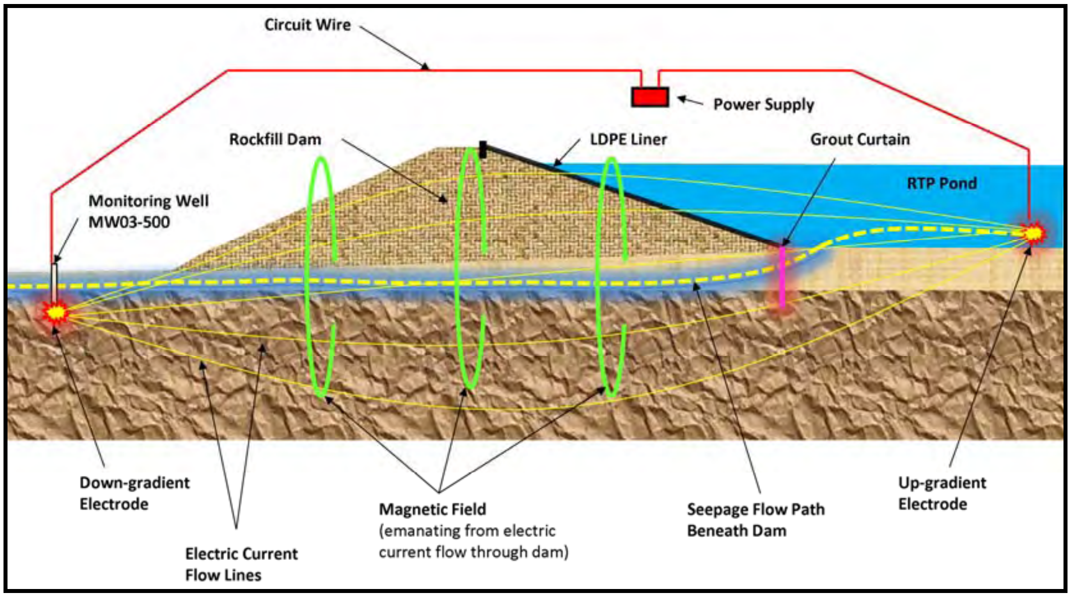


Figure 5 –Horizontal Dipole Configuration
Cross-sectional View

A horizontal dipole configuration places an up-gradient electrode in the pond—directly in front of the dam. A second electrode is placed down-gradient of the dam in a seep or monitoring well in contact with seepage. The overall approach to the horizontal dipole configuration includes injecting and driving electric current between the strategically placed electrodes located on either side of the embankment. An AC electric current with a specific signature frequency (380 hertz) was applied to the paired electrodes. As electric current flowed between the paired electrodes, it generated a recognizable magnetic field that was measured from the earth's surface. The magnetic field was used to identify the location of preferential electric current flow paths. By identifying the electrically conductive flow paths between the strategically placed electrodes, questions can be addressed regarding where seepage preferentially flows through and/or underneath the dam.

4.2 Measurement Station Density

Measurement stations (small red crosses shown in the figures) were established on a 10-meter by 10-meter grid for the survey configuration. Many measurement stations were occupied repeatedly for quality control purposes. The position and elevation of each measurement station was recorded as part of the fieldwork. These spatial locations are critical to quality control measures, data processing, interpretation and modeling. The measurement density or grid spacing was adequate to obtain sufficient detail and resolution for identifying preferential electric current flow paths while at the same time, optimizing funds available for the investigation in order to adequately explore areas of potential interest.

5.0 DATA REDUCTION

5.1 General

A geo-referenced aerial photograph of the dam was used as a base map for presenting the results of the investigation. Some features critical to the investigation have been drawn on the aerial photo to enhance their presence and to supplement the information contained on the base map. Please note that the figures presented here in the body of the report are also provided as full-size figures in the report's Figures Section.

5.2 Summary of Data Reduction, Filtering and Quality Control

After energizing the dam's study area and collecting the magnetic field data, the data was reduced, normalized, and subject to appropriate quality control criteria to prepare it for interpretation and modeling. For more details regarding data reduction and quality control criteria refer to the White Paper (Appendix A).

It should be noted that circuit continuity, magnetic field strength, and signal-to-noise ratios for the survey were strong indicating quality data. The signal-to-noise ratios ranged from 5 to 1300, with an average value of 100. The noise floor (mean ambient field noise, determined from a sampling of several frequencies in the noise spectrum) remained low and constant throughout the investigation. Numerous measurements were repeated throughout the course of the field work, all of which indicated clean, consistent and reliable data.

6.0 SURVEY LAYOUT AND MAGNETIC FIELD MAP

6.1 Survey Layout

Figure 6 presents the survey layout used for the investigation.

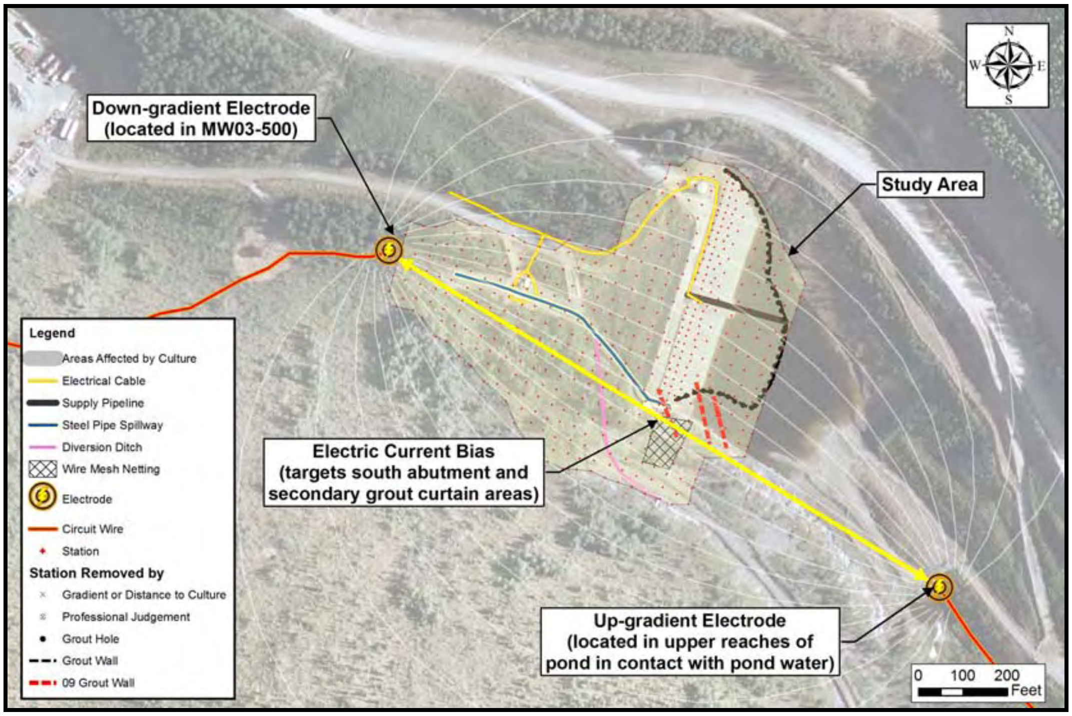


Figure 6 – Survey Layout

This map shows features pertinent to the investigation. The transparent yellow shading shows the survey study area. The red/orange circuit wire connecting the strategically placed electrodes was positioned in a large loop around the study area. These electrodes and circuit wire are located outside the study area as much as possible due to the strong magnetic field influenced around them. Because 100% of the electric current must pass through the circuit wire and electrodes, the magnetic field intensifies near these appurtenances. The white dashed thin lines (between the electrodes) show the general distribution of electric current. The red "+" signs identify measurement station locations. The downstream electrode is located in a monitoring well (MW03-500) which is in contact with seepage from the pond. The upstream electrode was placed in the upper reaches of the pond directly in front of the dam's study area and positioned to bias electric current through the south abutment (see yellow arrow in Figure 6). From the onset of the investigation, the south abutment was of significant interest to Pogo Mine, thus, the reason for the study area covering more of the south abutment than the north abutment.

6.2 Magnetic Field Contour Map

Figure 7 presents the resultant magnetic field contour map created from the injected electric current through the study area.

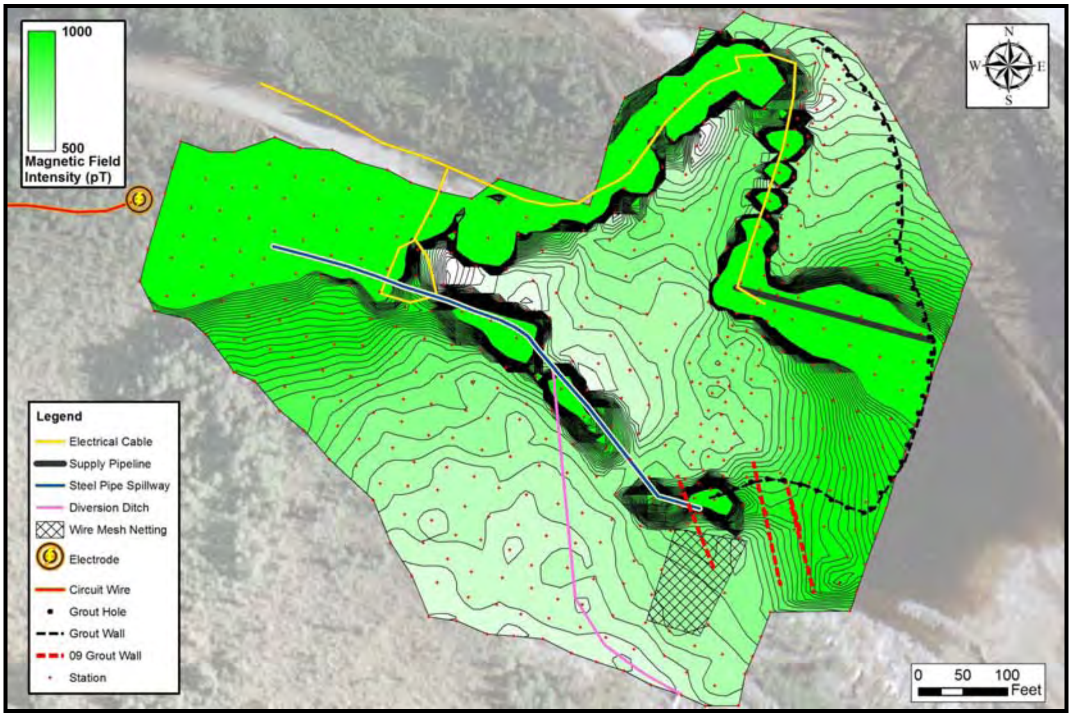


Figure 7 – Magnetic Field Contour Map

As shown, a significant amount of electric current flows onto near surface conductive culture. Conductive culture is any man-made feature such as pipelines, power cables, steel fence lines, or other long continuous conductors. Culture is often present and can be very problematic because it tends to be near-surface and can cause large anomalies that hide some of the magnetic signal coming from the subsurface. This is due in part to the wire mesh netting and supply pipeline that run down into the pond (coming in contact with the pond water). Electric current flows onto these features and follows them up and over the embankment toward the return electrode located down-gradient of the dam. This is evident by the dark green shading in and around the conductive culture noted on the drawing. This interference must be removed before an interpretation of the distribution of electric current flow can be made through the subsurface study area.

7.0 REMOVAL OF NEAR SURFACE INTERFERENCES

Magnetic field measurement stations influenced by near-surface conductive culture were distinguished by three criteria that where applied to the data set. These are as follows:

1. Normalized gradient filter
2. Distance to culture
3. Point-specific professional judgment

These filtering criteria and how they were applied to the data set are presented in detail in Appendix A.

8.0 FILTERED MAGNETIC FIELD MAP

Figure 8 presents the filtered magnetic field map after having applied the criteria used to remove near-surface interferences. Measurement stations removed from the data set are surrounded by a gray transparent cloud.

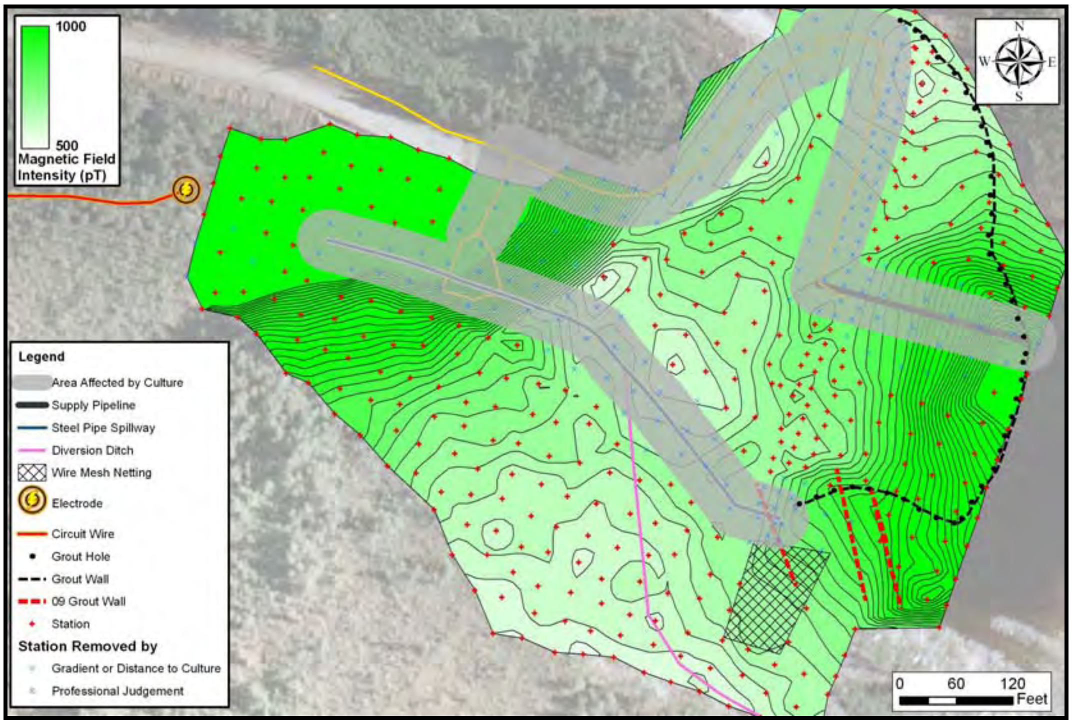


Figure 8 – Filtered Magnetic Field Map

The magnetic field contour lines shown in the figure were interpolated from measurement stations unaffected by near-surface conductive culture. Measurement stations filtered from the data set using the normalized gradient filter and/or distance to culture filter (criterion #1 and #2) are shown with a black "x" in the figure. Stations removed by professional judgment (criteria #3) are shown with a circle around the "x". A very small percentage of measurement stations were removed by professional judgment.

9.0 PREDICTED MAGNETIC FIELD AND RATIO RESPONSE MAP

9.1 Predicted Magnetic Field Map

To identify areas of greater or lesser conductivity through the subsurface study area, a model was created of the site predicting the magnetic field response expected at each measurement station given the position of the circuit wire and electrodes. This prediction is made under the assumption of a homogenous subsurface conductivity environment (see Figure 9). The model predicts the effects of the electrodes, circuit wire and topography on each magnetic field measurement station.

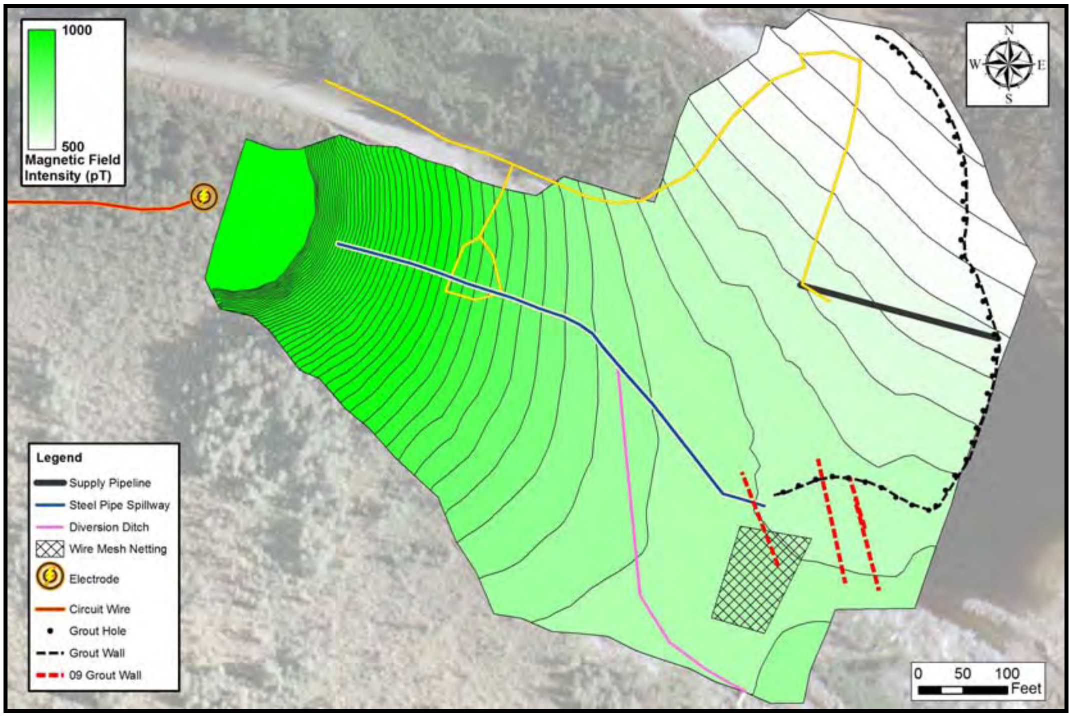


Figure 9 – Predicted Magnetic Field

9.2 Ratio Response Map

By dividing the measured magnetic field (Figure 8) by the predicted magnetic field (Figure 9), a Ratio Response Map (see Figure 10) is created which removes electric current bias from the data set and show areas of anomalous electric current flow (greater or lesser than predicted).

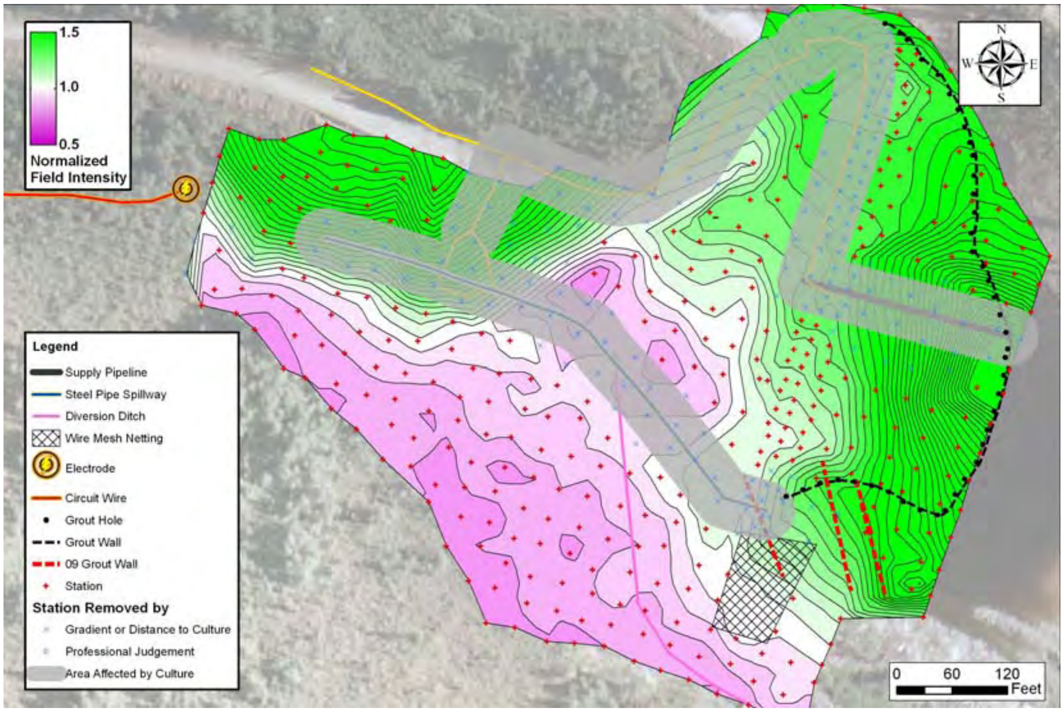


Figure 10 – Ratio Response Map

In Figure 10, the white shaded contours (where the ratio is approximately 1:1) represent areas where the electric current intensity is equivalent to that predicted by the homogeneous model. Areas shaded purple indicate electric current flow is less than predicted, and areas shaded green indicate electric current flow is greater than predicted. It is important to emphasize that the purple shaded areas should not be overlooked. They can provide insightful information and can show preferential paths as revealed by the shape of contour lines, which is generally more important than the color.

10.0 INVERSION MODEL

10.1 Model of Electric Current Distribution

Because magnetic field measurements can only be obtained on the earth's surface, it is difficult to identify the exact horizontal and vertical positions of preferential electric current flow. For this reason, the ratio response data was subjected to an inversion algorithm (mathematical model) designed to predict the distribution of electric current flow in three dimensional space through the subsurface study area. The inversion model is referred to as an Electric Current Distribution (ECD) model. Figure 11 presents a 3D view of the ECD model created for the investigation.

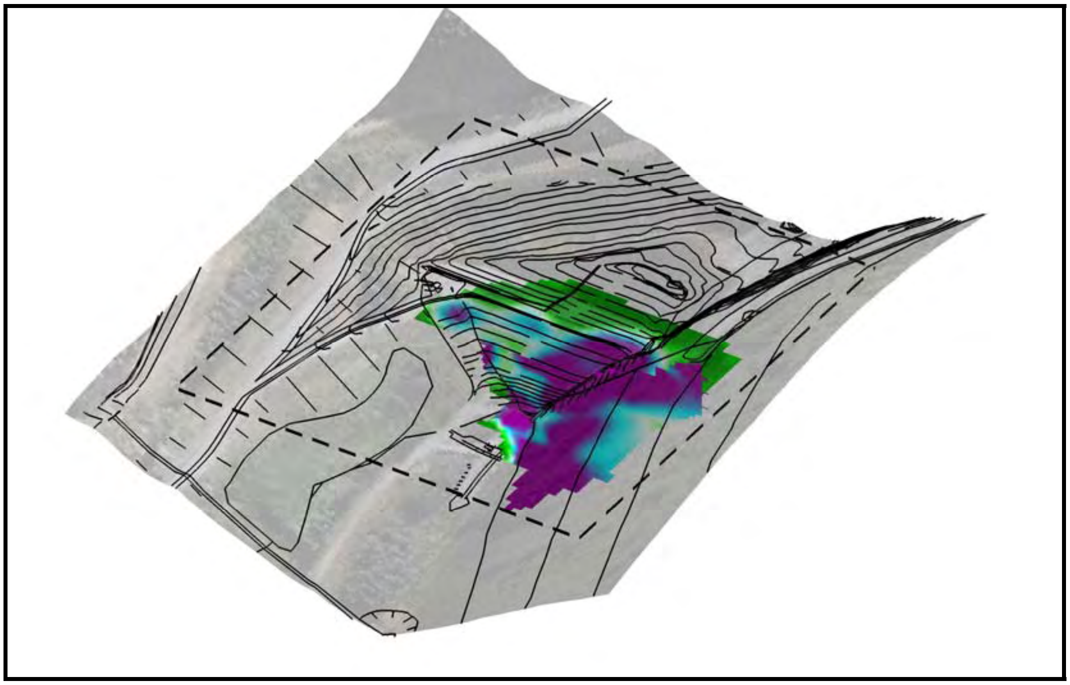


Figure 11 – 3D View of ECD Model

Willowstick uses MATLAB software to generate and analyze ECD inversion model volume data. The model viewer can generate slices at any elevation or cross-section position within the volume as demonstrated in the example above. Because unlimited slices and views can be created, Willowstick will provide all data in electronic format to Aspen Hydrologic and Pogo Mine (including ArcView shapefiles, compiled MATLAB models, etc.) which were used to create the maps, figures and models presented in this report.

10.2 Interpretation of EDC Model

To summarize the more notable findings of the ECD model, Figures 12 through 16 present horizontal slices taken through the model at 20 foot intervals (starting with elevation 2080 feet and then proceeding down through the model including elevation slices 2060 feet, 2040 feet, 2220 feet and 2000 feet, respectively). For reference, the crest elevation of the dam is roughly elevation 2095 feet. The gray clouded areas—where measurement stations were influenced by surface culture—are shown in the elevation slices. These areas were interpolated in the model from measurement stations unaffected by near-surface conductive culture and may not be as accurate as where measurement stations were not removed from the data set. Caution should be used when interpreting data beneath areas void of measurement stations.

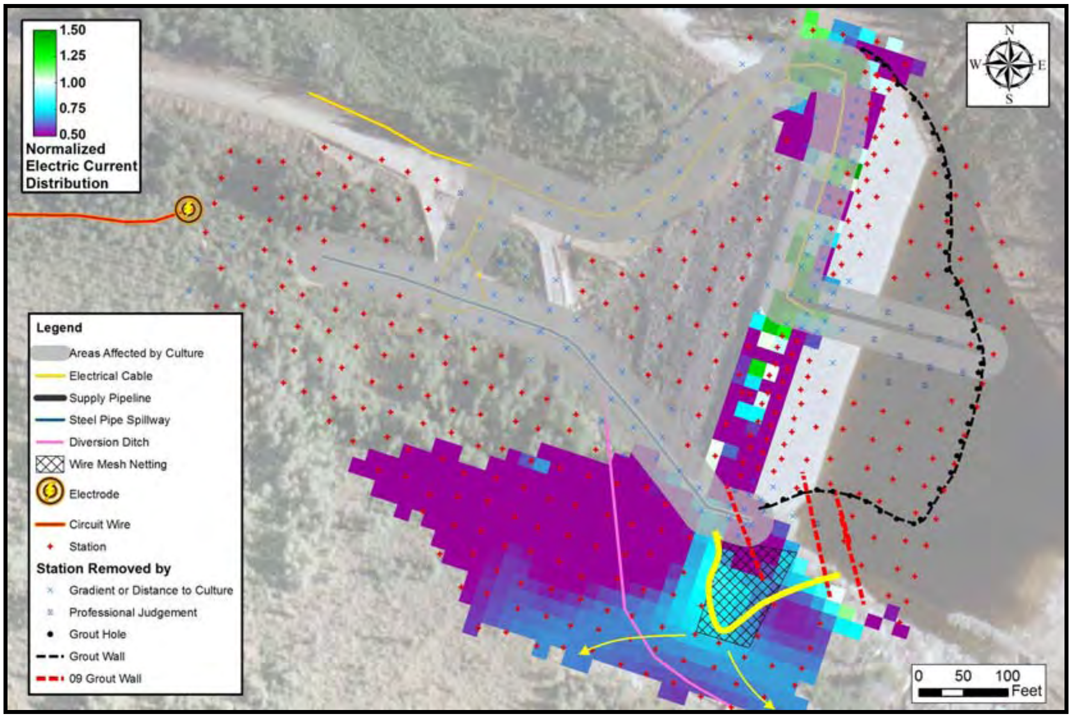


Figure 12 – ECD Model Elevation Slice 2080 Feet

In elevation slice 2080 feet, the yellow arrows identify how and where electric current flows out of the pond and on to conductive culture (i.e. wire mesh netting and steel pipe spillway) located at the south end of the dam. Keep in mind, this elevation slice is near the surface of the ground. At the time of the survey, the mesh netting was in contact with the pond water. The level of the pond was slightly higher than shown in the photograph. Electric current flows onto the netting and spreads out in all directions. It flows off the netting to the west and then flows down toward the steel pipe spillway as noted by the yellow arrow. Electric current then preferentially follows the steel pipe spillway back to the down-gradient electrode.

As can be seen from this elevation slice, not all of the influences from conductive culture were removed. Because electric current spreads uniformly in the wire mesh netting, the filtering criteria broke down and did not identify this feature as a source of interference—nor did professional judgment. Nevertheless, the ECD model identifies electric current straying onto the mesh netting.

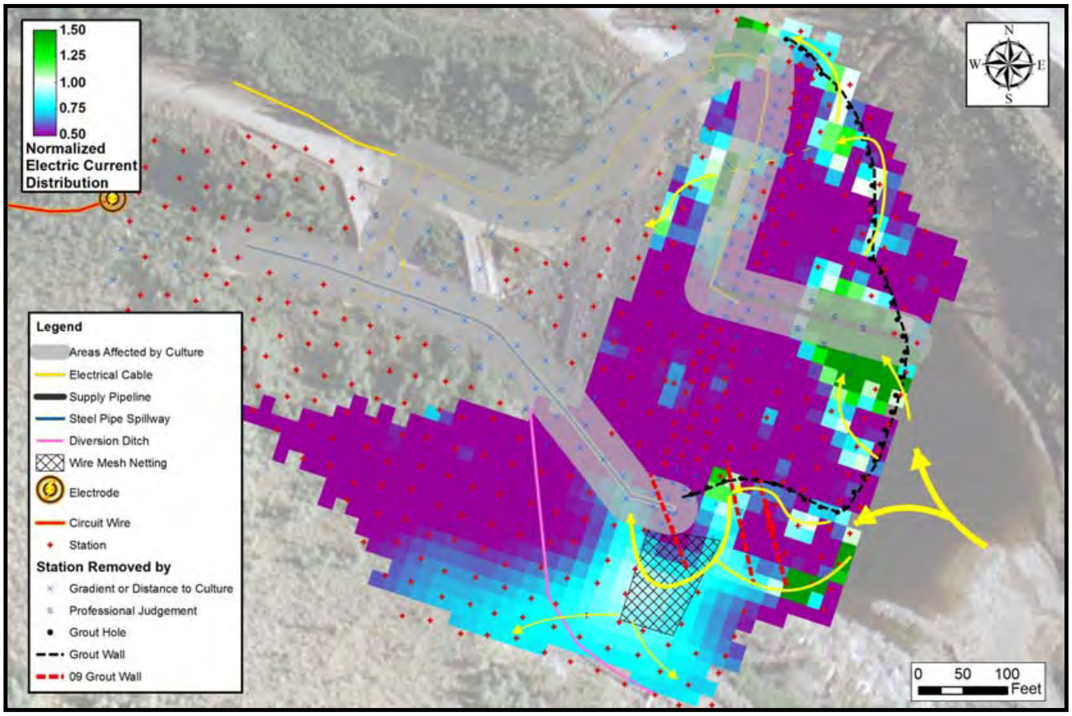


Figure 13 – ECD Model Elevation Slice 2060 Feet

In elevation slice 2060 feet, the yellow arrows further identify how electric current flows out of the pond. Electric current flowing from the east or up-gradient electrode bifurcates in front of the dam. Electric current flowing to the south bifurcates a second time and flows around the secondary grout curtains eventually flowing up onto the mesh netting and spillway. There is no evidence of preferential electric current flow at depth beneath the south abutment in this elevation slice.

Electric current flowing to the north flows onto the supply pipeline submerged into the pond. A small amount follows the toe of the dam and/or grout curtain to the north. Some electric current flowing north gets onto conductive culture at the very north end of the study area, however, some flows through or beneath the dam as highlighted with a thin dashed yellow line. This flow path (through or beneath the dam) is just beginning to develop in the model. Deeper elevation slices will show this flow path with greater clarity.

Another important observation in elevation slice 2060 feet is the amount of purple shading throughout the center portion of the study area. Aside from the two locations where electric current strays onto conductive culture (wire mesh netting and supply pipeline), there is little electric current flow through this elevation slice of the model—suggesting that seepage is not through the dam, but rather, beneath the dam.

There are no new flow paths identified in elevation slices 2040 and/or 2020 feet. The same interpretive marks are provided in these elevation slices as highlighted in elevation 2060 feet. It should be noted that not all of the shallow flow paths are fading as one moves deeper through the model. If a near-surface flow path is relatively wide, it can sometimes cast a shadow down through the model.

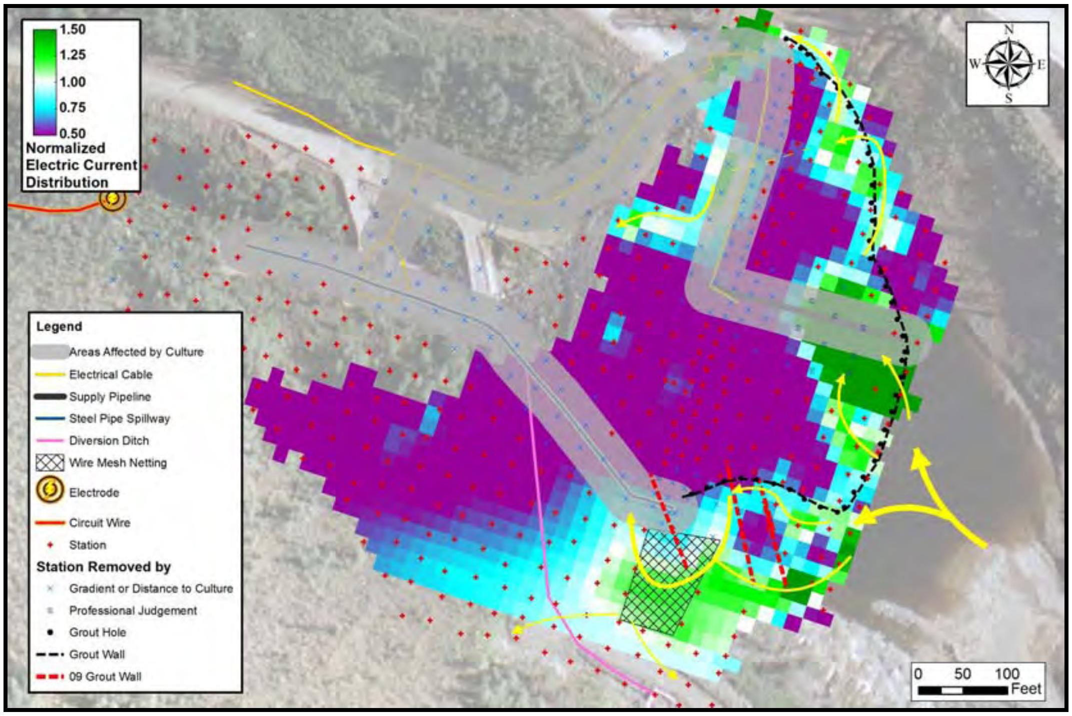


Figure 14 – ECD Model Elevation Slice 2040 Feet

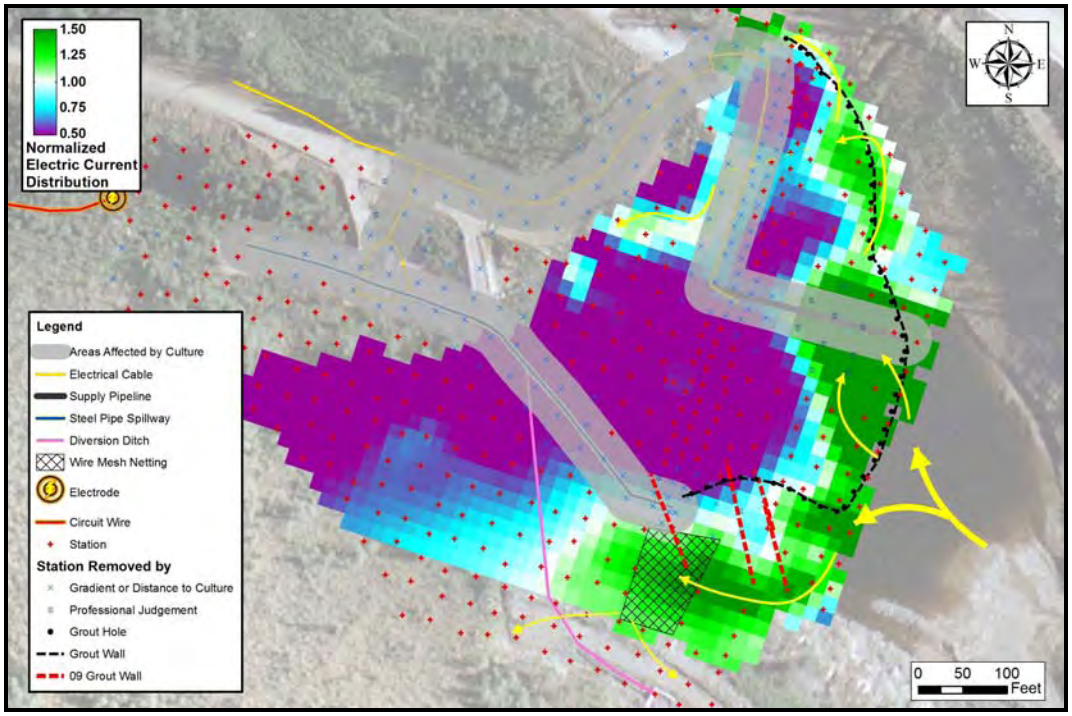


Figure 15 – ECD Model Elevation Slice 2020 Feet

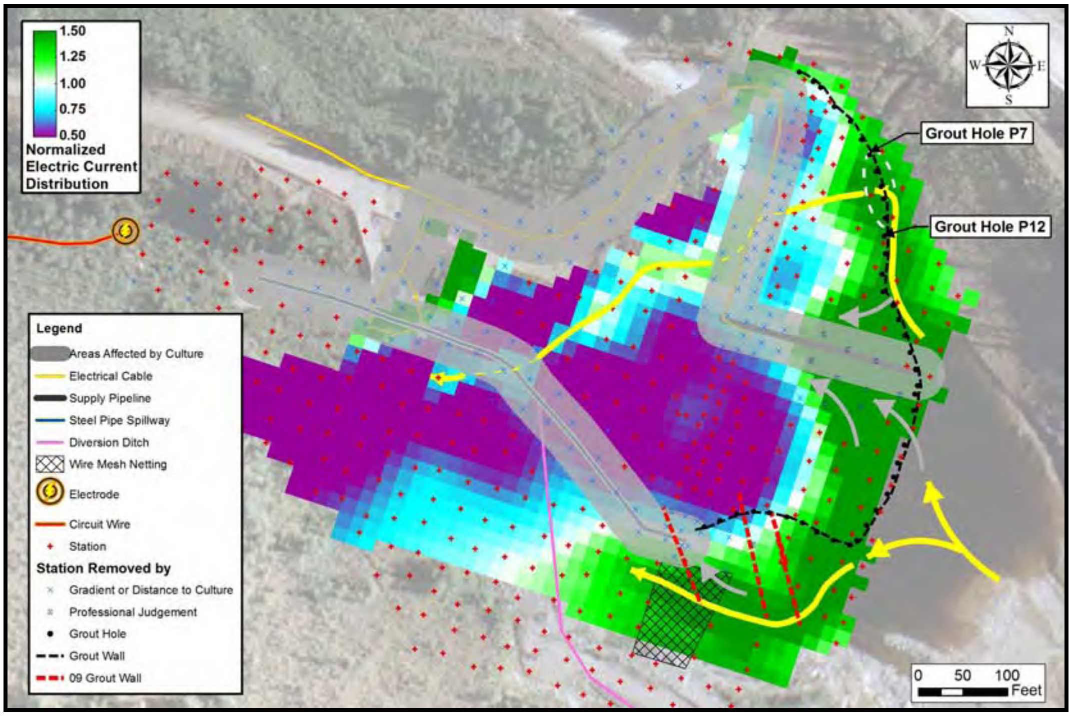


Figure 16 – ECD Model Elevation Slice 2000 Feet

In Figure 16 (elevation slice 2000 feet) electric current flowing onto near-surface conductive culture is highlighted by gray arrows in an effort to distinguish shallow flow paths from deeper flow paths.

Electric current flowing to the south and at depth around the secondary grout curtains appears to stop just west of the netting. Electric current flow in this area rapidly weakens as evident from the rapidly fading dark green shading. Much of the electric current here probably finds circuit completion through the steel spillway pipe. The subsurface portion of the flow path is **not** continuous through the study area. This is likely a result of the secondary grout curtains minimizing seepage as designed.

Electric current flowing to the north flows around the upstream toe of the dam and grout curtain until it finds a path beneath the grout curtain. This occurs between grout holes P7 and P12 as shown in the figure. This area is highlighted by a white dashed oval. After passing beneath the grout curtain, seepage preferentially flows beneath the north abutment area as highlighted by the yellow lines and arrows shown in the figure. The thin dashed yellow lines are based on conjecture, and are drawn for visual purposes to create connectivity through the study area. As mentioned, these inferred flow paths were interpolated in the ECD model from measurement stations unaffected by near-surface conductive culture.

Near the downstream toe of the dam, seepage appears to flow underneath the spillway pipe to the south for a short distance before turning west and following the alignment of the creek channel—appearing to originate from the south abutment when in fact it originates from the north abutment. Elevation slices deeper than 2000 feet do not reveal any additional information. Therefore, no deeper elevation slices are presented.

To further describe how seepage flows beneath the dam and upstream grout curtain, Figure 17 presents a vertical slice of the ECD model taken directly beneath the upstream toe of the dam looking downstream. The grout curtain holes and stationing are noted in the figure.

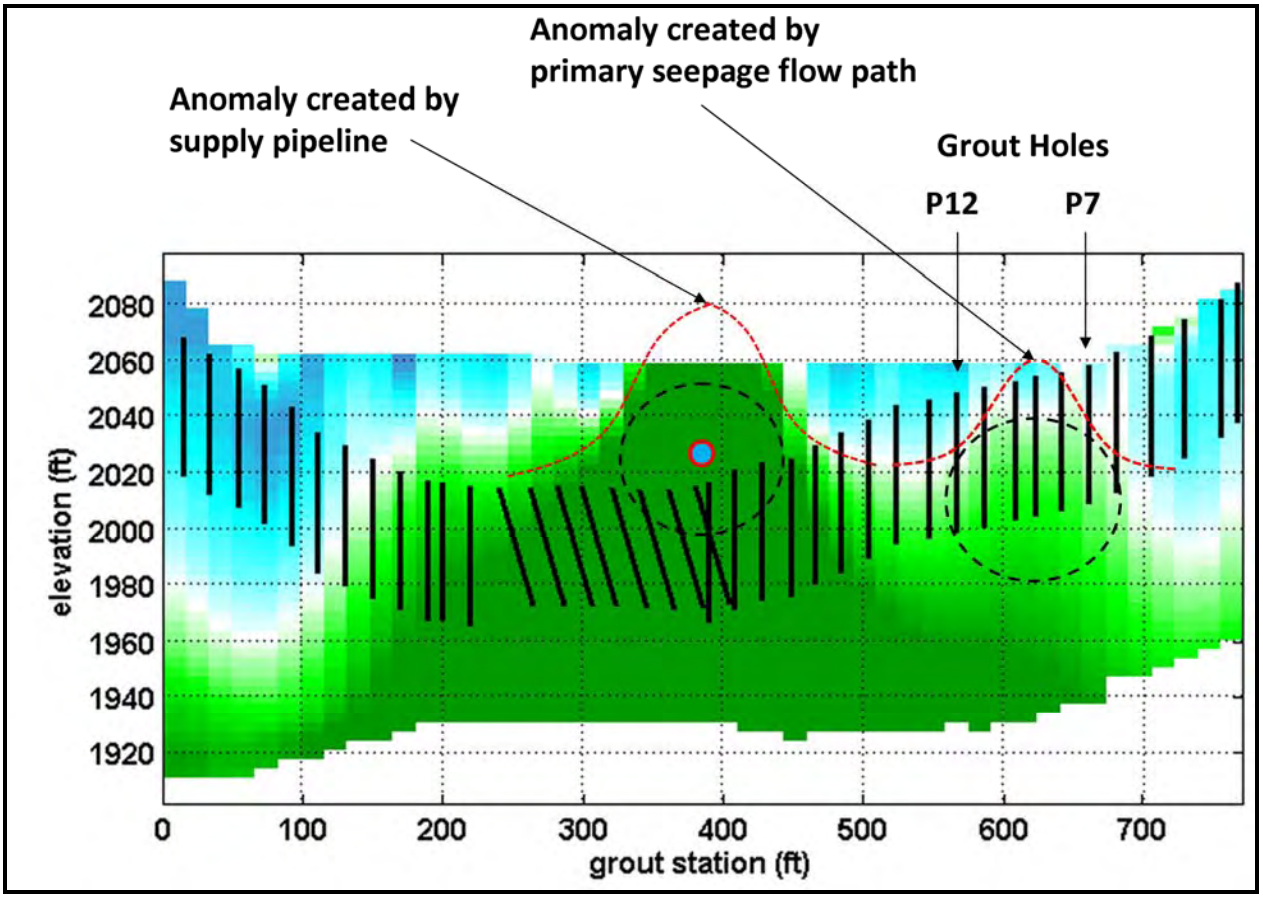


Figure 17 – ECD Model Vertical Slice taken beneath Upstream Toe of Dam (looking downstream)

The ECD model shows two anomalous features. The most dominant anomaly (dark green shading) occurs at about grout curtain station 390 feet. This anomaly is a result of the supply pipeline that runs down into the pond. A significant amount of electric current flows onto the supply pipeline as observed in the profile view. A second anomalous feature occurs between grout curtain station 5+70 and 6+70 (between grout holes P7 and P12 as previously mentioned).

Figure 18 shows a second vertical slice through the ECD model located directly beneath the crest of the dam. This view, however, is looking upstream. Again, those areas with conductive culture are noted. The area beneath the south abutment shows an anomalous feature that has been interpreted as the primary seep path beneath the grout curtain and dam.

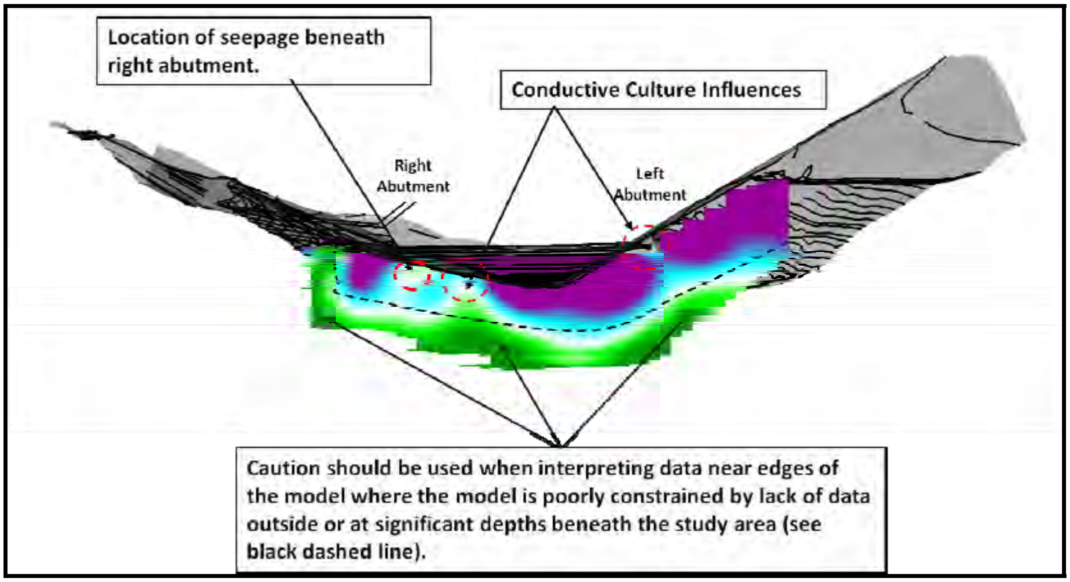


Figure 18 – Profile View beneath Crest of Dam

It should be noted that when evaluating the various slices and views created in the ECD model, caution should be used when interpreting data near edges. Edges of the model are poorly constrained by the lack of data outside the model edges and at depth in the model where dark green shading is apparent.

11.0 SUMMARY OF INVESTIGATION

11.1 Summary of Results

The results show that the Willowstick technology has provided information about seepage flow beneath the RTP dam. One primary seepage path was identified. This seepage flow path, which is believed to contributing the majority of water to the collection system and monitoring wells, occurs beneath the north abutment (see Figure 19).

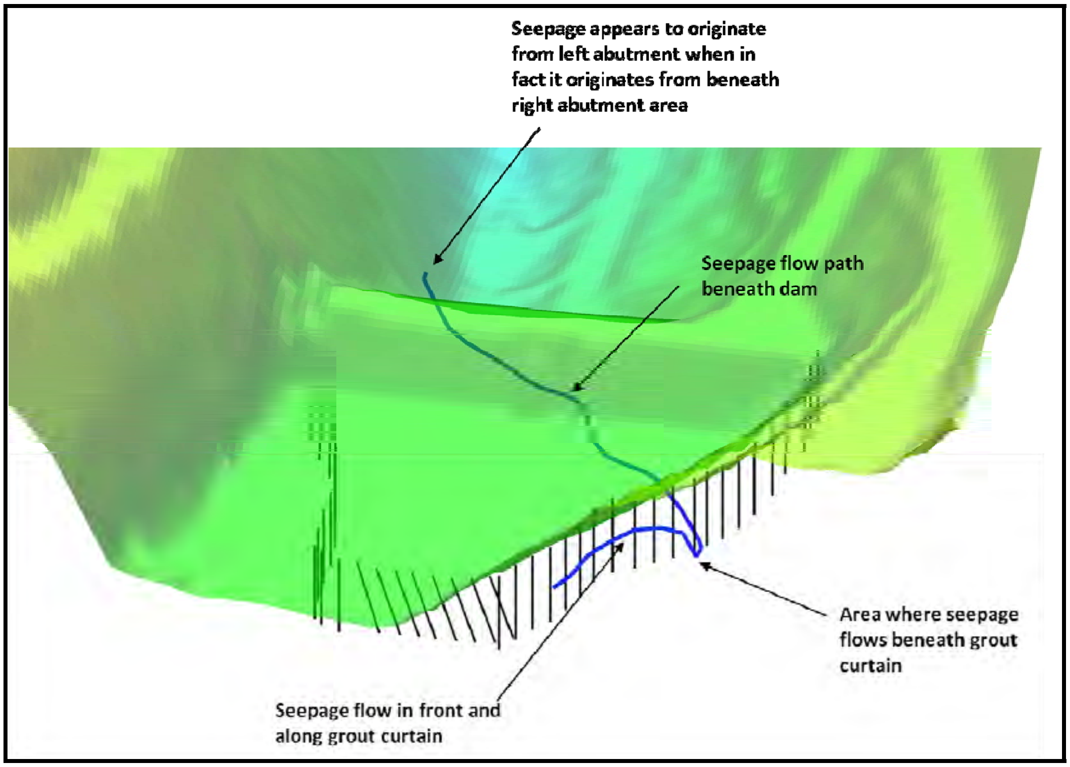


Figure 19 – 3D view of Primary Seepage Flow Path beneath Dam (looking downstream)

Seepage appears to be escaping the impoundment beneath the primary grout curtain between grout holes P7 and P12. As with the south abutment's primary grout curtain, grout holes were mostly vertical and may not have adequately intercepted joints and fractures likely existing in dam's foundation in this area. It's possible that some seepage occurs beneath other areas along the grout curtain that were over shadowed by conductive culture, nevertheless, the primary seep path observed in areas void of conductive culture has been identified. A very subtle seepage flow path possibly exists beneath the south abutment, however, this flow path appears to be cut-off by the secondary grout curtains installed in 2009.

The survey results indicate that the electrode configuration and the measurement station spacing were appropriately designed and applied to the site. Conductive culture was problematic at the site. Conductive culture is often a factor because it tends to be near-surface and can cause large anomalies as experienced in this survey. Fortunately, the locations of these conductive features were known and their influence on the magnetic field was identified and removed from the data set. The principal challenge of every investigation is to establish electric current flow through the subsurface study area that will help define and characterize changes in electrical properties. In any given survey configuration, it should be recognized that the technology's success is largely dependent upon the ability to establish electrical current flow that will follow and stay focused in the targeted medium that it is intended to follow (seepage flow out of the impoundment). The results of the investigation suggest that the signature electric current followed preferential seepage flow paths out of the pond beneath the primary grout curtain between grout holes P7 and P12. Modeling was performed in an effort to estimate depth of seepage which occurs at or about elevation 2000 feet (±20 feet).

It should be noted that although the technology delineated preferential electric current flow paths, it does not directly identify the amount of water seeping along the preferential flow path.

12.0 RECOMMENDATIONS AND CONCLUSIONS

12.1 Recommendations

Willowstick has identified electric current flow paths that reveal where seepage most likely originates beneath the RTP dam. The results obtained from the geophysical survey methodology will help Aspen and Pogo make informative decisions concerning how to further identify, monitor and/or possibly remediate seepage beneath the embankment. It is also recommended that the maps and models be carefully studied, understood and utilized as a planning tool.

12.2 Conclusions

The information contained herein should be compared with known information of the site to further characterize and substantiate subsurface conditions impacting seepage beneath of the RTP dam. Willowstick is committed to assisting Aspen and Pogo with whatever effort is required to fully understand the information presented herein. Willowstick has provided the data in both hard copies (bound report) and electronic formats (including ArcView shapefiles, and ECD inversion models) which were used to create the maps and figures in the report. All of this information will be kept on file at Willowstick's headquarters.

13.0 DISCLAIMER

It should be recognized that the Willowstick geophysical survey methodology and inversion model are new and emerging technologies. The data, interpretations and recommendations obtained from the survey and modeling methodology is based upon sound applied physics and Willowstick's experience in working with and developing the technology. By definition, the evaluation of geologic, hydro-geologic and/or geophysical conditions is a difficult and an inexact science. However, Willowstick feels strongly that the technology has yielded information that can greatly help to characterize seepage beneath the RTP dam.

Willowstick certifies that this geophysical investigation and report were conducted and prepared by those listed in Appendix C – Biographies. Willowstick makes no warranty or representation regarding the acceptability of any findings or recommendations in this report to any governmental or regulatory agencies whatsoever.

APPENDIX A – WHITE PAPER (WILLOWSTICK TECHNOLOGY EXPLAINED)

Table of Contents

1.0 INTRODUCTION

Understanding the location and extent of preferential groundwater flow paths is becoming increasingly more important in a host of applications including: 1) the diagnosis of seepage through earthen dams and levees; 2) optimizing the placement of wells for production and/or monitoring purposes; 3) tracking pollution plumes influenced by groundwater transport; 4) characterizing groundwater infiltration into surface and subsurface mines; 5) identifying and mapping geothermal production zones; 6) delineating salt and fresh water reaction fronts; and 7) optimizing water flood activities in oil and gas recovery operations as well as other in-situ solution mining processes.

A better understanding of groundwater conditions can significantly reduce costs and increase revenues for those dealing with groundwater-related issues. In the case of dams, for example, unchecked seepage may be a precursor to dam failure, threatening lives and property. In the case of a mine, groundwater control may be a key to long term sustainability of the mine. Historically, procedures for characterizing preferential groundwater flow have been costly, time consuming, and often intrusive to the environment.

It is recognized that the most rigorous method of characterizing and delineating subsurface features is by direct observation or by direct measurement of subsurface properties. This, however, is not only intrusive, but generally cost prohibitive and altogether impractical in most situations. A secondary approach is to sample the subsurface at carefully selected locations (e.g. through boreholes) and then interpolate or extrapolate the properties and features between sample locations. This approach has been used extensively in many situations where no practical alternative is known to exist or is deemed available. Although this approach can be effective, it may not be economical and often fails to depict complex and acute changes that can occur in the subsurface. Because of complex geologic settings and the high cost to acquire sufficient hydraulic data to characterize groundwater systems, there is a real need for a new technology to quickly and efficiently provide maps of preferential groundwater flow.

Willowstick® Technologies' researchers understand this need and have developed a technology which has proven effective in delineating and characterizing subsurface aqueous systems in many complex hydrogeologic settings when applied properly. The technology can significantly reduce both time and expense associated with seepage diagnosis or general groundwater characterization. This "*White Paper*" presents a detailed explanation of the Willowstick methodology, including the electrical-hydraulic correlation of aquifers, how the technology works, typical on-site applications, quality control measures, data reduction, and interpretation methods to accurately identify, map, and model subsurface aqueous systems.

2.0 WILLOWSTICK METHODOLOGY

The Willowstick methodology is a unique application of magneto-metric resistivity or MMR for groundwater mapping and modeling, which is high-speed, accurate, minimally invasive, and cost effective. The technology capitalizes on the principle that groundwater substantially increases the electric conductivity of soil and rock through which it flows.

When an AC electric current is injected into the groundwater, the electric current will channel into the water bearing formations and follow paths of least resistance through zones of greatest transport porosity. Such electric current channeling can be mapped by measuring components of the magnetic field generated by electric current flow. The Willowstick method utilizes a 380 Hz signal to maximize the coil magnetometer sensitivity while avoiding all harmonics of traditional 60 or 50 Hz power systems. Injection electrodes are placed in direct contact with groundwater of interest to strategically create an electric circuit that can follow the groundwater's natural course. The measured magnetic field data is processed to remove the contribution of the circuit wire, electrodes, topography and homogenous electric current flow in the earth. The subsequently reduced magnetic field data set is then contoured and interpreted in conjunction with other hydrogeologic data, resulting in enhanced definition of preferential groundwater flow paths.

As an example, consider a leaking dam. Electrodes are placed upstream and downstream of the embankment. The upstream electrode is placed in the reservoir water at sufficient distance from the dam to allow electric current to spread out in the reservoir before reaching the face of the embankment. The downstream electrode is placed in a strategic location (seeps, observation wells, receiving stream or other downstream locations) to facilitate contact with seepage flowing through the dam. Seepage always follows paths of least resistance from areas of high potential (reservoir water body) to areas of lower potential (downstream receiving waters) through areas of greatest transport porosity. The path of least electrical resistance is often the same for many sets of conditions. The electrical current will follow preferential groundwater pathways by concentrating in zones that offer the least electrical resistance through the dam. As the electrical current takes various preferential flow paths through, beneath and/or around the dam, it generates a magnetic field that can be measured in a grid pattern on the surface.

The horizontal and vertical magnetic field magnitudes are measured at each grid station to define the electrical current's subsurface distribution and flow patterns. In nearly all cases, the paths of least resistance for electrical current to follow are the zones of highest transport porosity within the saturated subsurface. Measurement stations coordinates are obtained by Global Positioning System (GPS) and are recorded with the magnetic field data. The measured magnetic data are then processed, contoured, modeled and interpreted in conjunction with existing hydrogeologic information to enhance the subsurface groundwater flow characterization.

3.0 ELECTRICAL-HYDRAULIC CORRELATION OF AQUIFERS

Most earthen materials are fundamentally electrical insulators with electrical conductivities ranging between 10^{-12} and 10^{-17} mho/m. Yet, in situ measurements of electrical conductivities range from 10^{-1} to 10^{-8} mho/m, many orders of magnitude higher. This discrepancy is due to conduction of electrical current by way of ions dissolved in the groundwater and present in the interconnected pore space of the earthen materials. Two modes of electrical conductance occur in saturated materials: 1) pore fluid volume conductivity and/or 2) pore wall surface area conductivity.

Hydraulic conduction is a function of interconnected pore volume (effective porosity—sometimes referred to as transport porosity). The larger and better connected the pore spaces, the greater the hydraulic conductivity and the easier and faster water will flow through the earthen material given a sloping potentiometric surface.

Electrical conduction, on the other hand, occurs mainly through the pore fluid and along the pore wall surface area. As groundwater moves through the subsurface it dissolves certain constituents of the geologic materials increasing the amount of ions in the water and its ability to conduct electricity. In most subsurface environments, sufficient ions exist in groundwater to conduct electric current.

Earthen materials can be classified into two "general" categories when correlating electrical and hydraulic properties. These categories include: 1) pore volume dominant materials and 2) pore surface area dominant materials. Pore volume dominant materials have medium to high effective porosities (sufficient interconnected pore space to conduct groundwater). Electrical and hydraulic conductivity in pore volume dominant earthen materials have a positive log-log linear correlation (see Figure 3A). The larger and better connected the pore space, the higher the hydraulic conductivity; and, with the greater volume of water, the electrical conductivity also goes up. Therefore, a positive slope correlation exists between electrical and hydraulic conductivities in pore space dominated earthen materials. This relationship has been documented and supported by many published laboratory and field investigations (Wong et al, 1984).

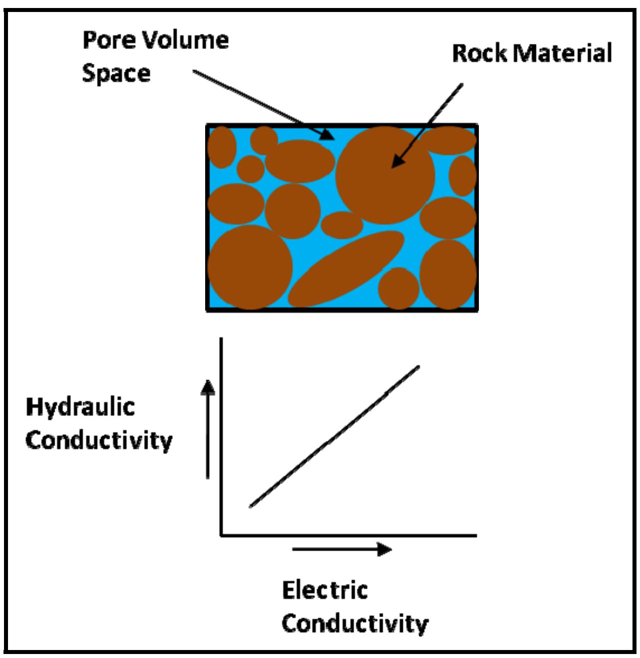


Figure 3A – Hydraulic-Electrical Correlation in Pore Volume Dominant Rock Material

Where pore volume space is relatively small (e.g., in clay) the hydraulic conduction is relativity low. The finer the grain size and the smaller the void space, the more difficult it is for water to flow through the earthen material, therefore, the lower the material's hydraulic conductivity.

Electrical conductivity in pore surface area dominated materials is mainly a function of pore wall surface area. The surface area of clay is significant because the grains are flat in comparison to spheres or prisms for silts and/or small sand grains. This results in earthen materials having large surface areas and small void space. Clay surfaces often have a negative charge. As a result, positively charged ions, dissolved in the pore water, become electrochemically bound to the pore walls, creating an electrical double layer of ions and therefore a relatively conductive surface. The ability to electrochemically bind cations originating in the pore fluid waters is quantified by its cation exchange capacity. In pore surface area dominated material, electrical conduction often occurs along the surface area of the pore walls. Thus, the finer the grain size, the greater the pore surface area and the higher the electrical conductivity.

In pore surface area dominated materials, a log-log linear correlation also exists between electrical and hydraulic conductivities that show a negative slope (see Figure 3B). The finer the grain size, the greater the internal surface area and the greater the electrical conductivity due to cation exchange. At the same time, the greater the internal surface area, the greater the viscous drag on hydraulic flow and consequently the lower the hydraulic conductivity. This negative slope relationship is supported by published laboratory and field investigations (Purvance, 2000).

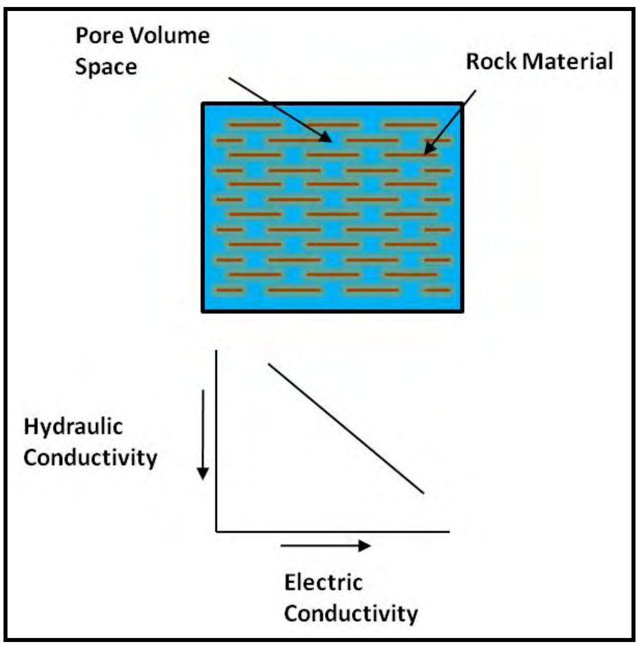


Figure 3B – Hydraulic-Electrical Correlation in Pore Surface Area Dominant Rock Materials

Where pore volume dominated materials exist and where groundwater conductivity is sufficient, the Willowstick technology excels in its ability to accurately map and model preferential groundwater flow paths because the hydraulic conductance closely correlates to the electrical conductance.

Where pore surface area dominated materials exist (clay rich materials), care must be taken in electrode placement and interpretation. Nevertheless, numerous investigations have been successfully performed where clay was the dominate soil type.

When preferential flow paths exist in clay rich environments, a change in hydraulic conductivity normally occurs in the subsurface where groundwater flow transitions from pore surface area dominance (clay soils) to zones of pore volume dominance (secondary porosities—fractures and cracks). In these areas, the hydraulic conductivity and flow rate increase significantly (orders of magnitude). This dramatic change has an impact on electrical conductivity and is normally sufficient to create enough contrast in electrical conductivity to identify anomalous features such as preferential flow paths or the zones of greatest transport porosity.

Based on numerous investigations that have been successfully completed, the Willowstick technology has proven to follow pathways or zones of greatest transport porosity in both pore volume and pore surface area dominated environments.

4.0 SURVEY DESIGN AND ENERGIZING CONFIGURATIONS

The electrode configurations used to carry out groundwater investigations may be classified into two types: a horizontal dipole configuration or a vertical dipole configuration. For most investigations, a horizontal dipole electrode configuration is employed to inject the electric current into the groundwater of interest. Electrodes are specifically placed in contact with the groundwater of interest on either side of the study area. A horizontal configuration establishes a predominantly horizontal flow of electric current in the subsurface beneath the study area (see Figure 4A).

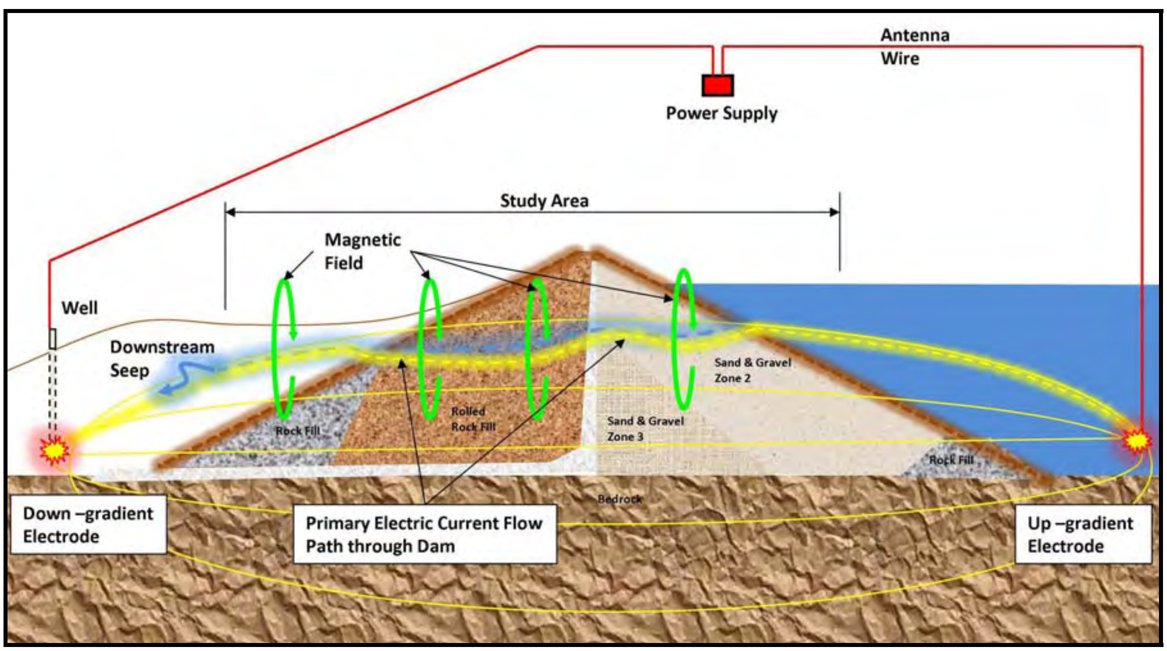


Figure 4A - Typical Horizontal Dipole (Cross Sectional View)

For some investigations, a vertical electrode configuration is necessary, such as when mapping a contamination plume's growth from a central source (see Figure 4B). This type of setup can also be utilized to reduce interference from surface culture like metal pipes, power grid grounding wires, railroad tracks, steel fences, etc.

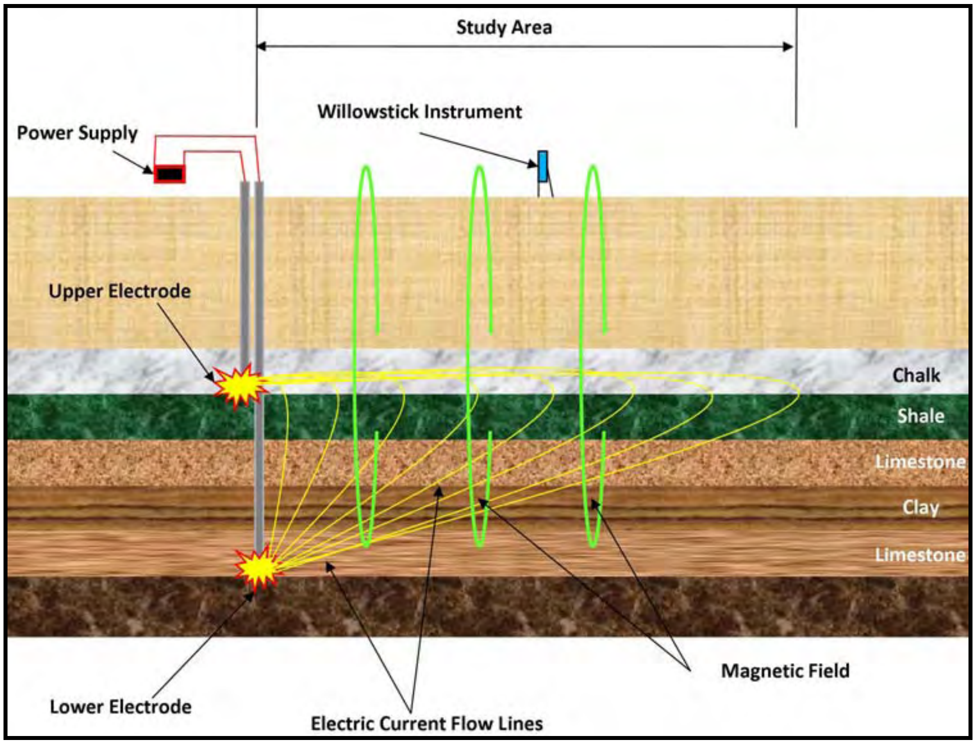


Figure 4B - Typical Vertical Dipole (Cross Sectional View)

Willowstick surveys may cover anywhere from <1 acre to more than 1 square mile (2.6 square kilometers), as long as an electric circuit can be properly established with the groundwater of interest. Small surveys usually target shallow aquifers, whereas large surveys usually target deeper aquifers.

Electrode placement is critical to every investigation. Electrodes are often placed in wells, reservoirs, ponds, seeps springs, canals or other sources where there can be direct contact with the groundwater of interest. In certain circumstances, electrodes can be placed directly in the ground. Electrode placement depends entirely on site-specific conditions and the overall purpose of the investigation. Normally, wells are required of deep groundwater characterization and confined aquifers. However, for shallower applications (unconfined aquifers), wells are often ideal, but not required. In every case, it is preferred that at least one electrode be placed in contact with the groundwater of interest.

The technology can be used to characterize groundwater at significant depths—over 300 meters (1000 feet) as long as the receiver can resolve the magnetic field emanating from the targeted zone of interest. In the case of a vertical configuration, the separation can usually be as far as the deepest available wells in the area. To minimize interference from the circuit wire when employing a horizontal dipole configuration, the circuit wire is strategically placed in a large loop to circumvent the area of investigation. A strong magnetic field is created by electric current flowing in the circuit wire and in-and-out of the electrodes and, generally, very little discernable subsurface information can be obtained near the circuit wire and electrodes. In the case of a vertical dipole configuration, the two circuit wires connecting the power supply to the electrodes is wound in a twisted pair along the ground surface to create a canceling effect on the magnetic field produced by electric current flowing in the two wires, since electric current in each wire flows in an opposite direction. As a result, the circuit wire on the ground in a vertical configuration has little or no effect on the magnetic field measurements. Electrode configurations are designed to allow the maximum amount of electric current to flow through the subsurface area of investigation.

It should be noted that although the Willowstick technology can quickly and accurately infer the location of groundwater and preferential flow paths, it does not necessarily identify the volume of water or the groundwater flow direction along a particular pathway. In most applications, the volume of water and the groundwater flow direction should be determined by other field methods such as pump tests, water bearing formation characteristics, regional groundwater flow, topographic slope, or potentiometric head differences, etc.

Magnetic field measurements are generally taken along lines ranging from 5 to 33 meters (15 to 108 feet) apart with measurement stations on each line spaced at 5 to 33 meter intervals. These distances vary from one project to another depending upon resolution requirements and other site conditions. The grid pattern proposed for any particular investigation is designed to provide sufficient detail and resolution to adequately delineate the groundwater of interest while at the same time optimizing funds available for the investigation.

5.0 EQUIPMENT

The equipment used to create and measure the magnetic field includes the following items:

- Electrodes – ½ inch diameter stainless steel chains (if placed down a well) or ½ inch steel rods approximately 3 feet in length (if placed in the ground).
- Circuit Wire – 10 to 18 gauge insulated solid steel/copper coated wire (size and length dependent upon survey configuration). The circuit wire is used to connect electrodes to the power supply unit.
- Power Source – Portable generator (minimum of 2000 watt capacity) or electrical outlet used to power the circuit.
- Power Supply Converter Unit – Converts 60 hertz or 50 hertz power (depending upon location in the world) to 380 hertz power. This signature electric current source makes it possible to distinguish the Willowstick signal from other electrical currents occurring in the earth.
- Logging Multimeter – Monitors and records the signature circuit voltage and amperage (in real time) for the duration of the investigation.
- Circuit Fault Interrupter – A protection device similar to a Ground Fault Interrupter (GFI device) that shuts the electric circuit down in the event of a surge in electric power.
- Willowstick Instrument – A highly sensitive receiver with three small coil magnetometers oriented in orthogonal directions (X, Y, and Z-axes); a microcontroller used to collect, filter and process the sensor data; a Global Positioning System (GPS) used to spatially define the field locations; and, a Windows-based handheld computer used to couple the GPS data with the magnetic field data and store it for subsequent reduction and interpretation. All of this equipment is attached to a surveyor's pole and hand carried to each measurement station location (see Figure 5A).

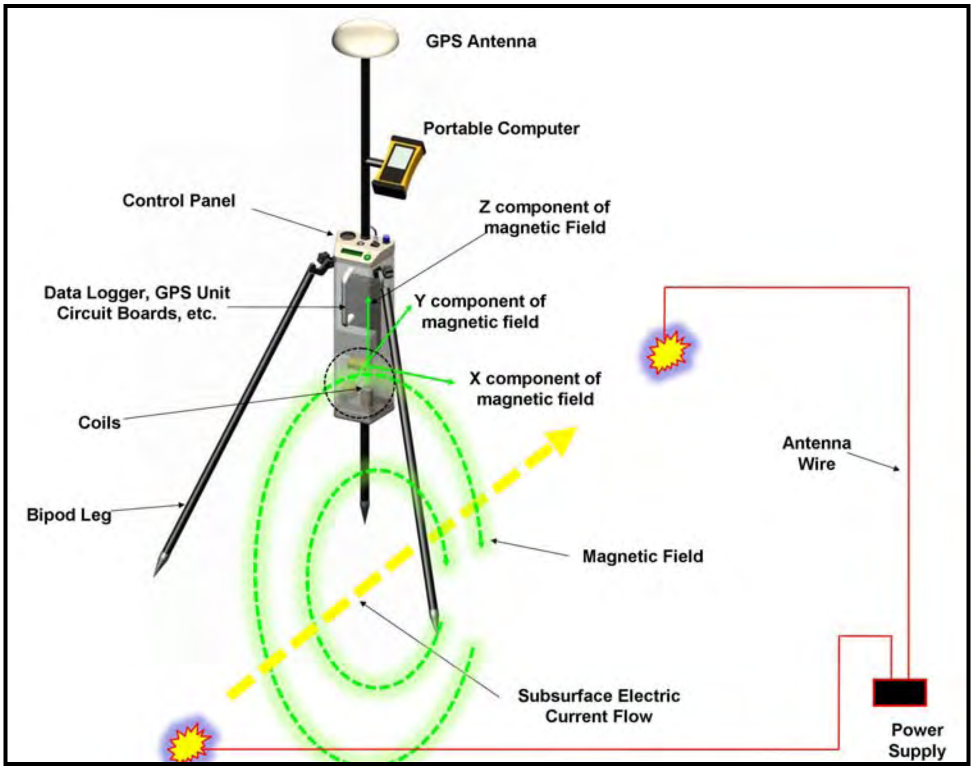


Figure 5A – Willowstick Instrument

6.0 THE PHYSICS BEHIND THE TECHNOLOGY

The Willowstick technology can be explained very simply in terms of the physics involved. The technology is based on a controlled audio-frequency source that injects electrical current into the groundwater to be mapped. The frequency used is 380 Hz, chosen to avoid all harmonics of the 50 and 60 hertz power frequencies commonly in use around the world. Measurements are made of the magnetic field created by electrical current flow through the groundwater of interest.

A well known concept in physics is that an electric current flowing through a wire (electrical conductor) produces a magnetic field around the wire. Following from Ampere's Law, the magnetic field produced by an infinite line current is $B = \mu_0 I / 2\pi R$ where R is the radial distance out from the center of the wire, I is the current in Amps (A), and μ_0 is the permeability of space, $4\pi \text{x} 10^{-7}$ Tm/A (see Figure 6A).

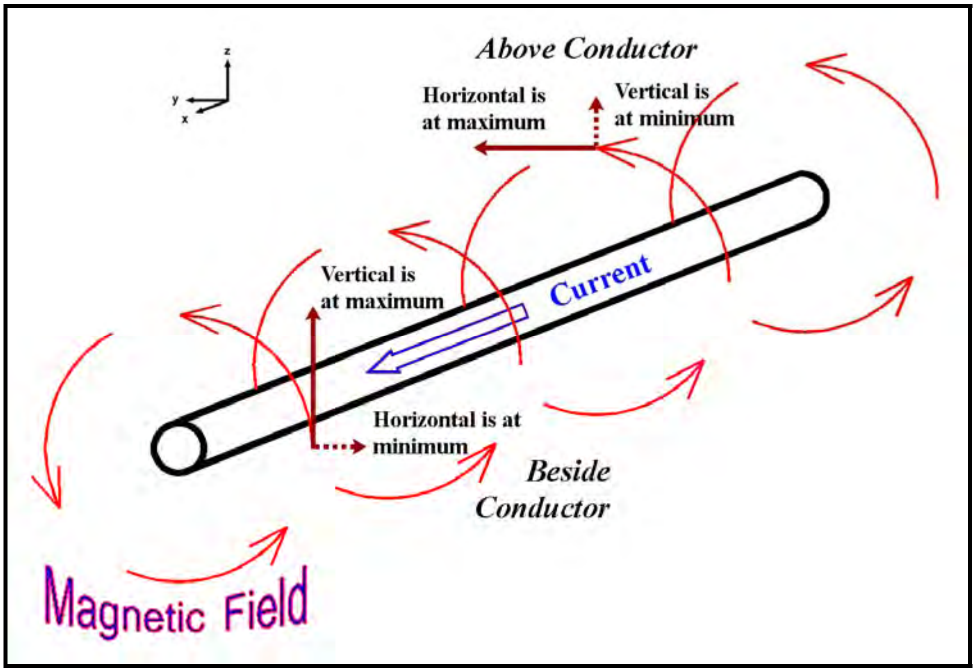


Figure 6A – Magnetic Field Lines around an Electric Current-carrying Wire

The magnetic field's direction is given by the right-hand rule: If the wire is grasped with the right hand so that the thumb points in the direction of the positive current flow, the fingers curl around the wire in the magnetic field direction. The magnetic field attenuates linearly with distance from the wire (R), i.e. when R doubles the field is cut in half. When the current alternates in direction, the magnetic field reverses direction as well, following the alternating current in time.

When electric current is injected into groundwater, the electric current follows the path of least resistance, which in most cases are the zones of highest transport porosity. The preferential flow of electric current carried by the water produces a magnetic field that surrounds the water much like a wire. When the electric current flow direction alternates rapidly in time, the magnetic field alternates in sync with the alternating current. This alternating magnetic field can be measured by very sensitive coils. Hence, the Willowstick technology detects the magnetic field emanating directly from the electric current flowing through the groundwater. The Willowstick technology is thus a magnetic technology, as opposed to the many electromagnetic (EM) geophysical techniques.

Measured differences in magnitude and direction of the magnetic field are used to identify the vertical and horizontal position of subsurface electric current flow. In Figure 6B for example, at Point A left of the current source both the vertical (V) and horizontal (H) components of the magnetic field are positive (up and to the right, respectively), hence they have the same polarity.

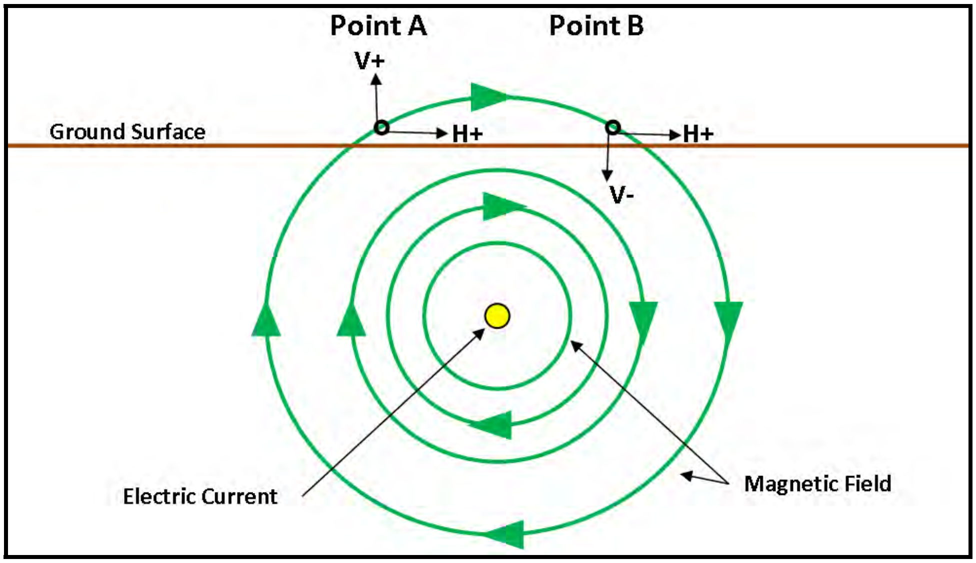


Figure 6B – Magnetic Field Components over an Electric Current Source

At Point B to the right of the current source, the vertical field is negative (downward) while the horizontal component is still positive. Hence, V and H have opposite polarity at Point B. When survey lines cross over the source, there is a change of this relative polarity between V and H signals. In addition to the magnitudes of the magnetic field components, the polarity can help to identify the characteristics of the source electric current flow.

Directly over the source, the horizontal component of the magnetic field has a maximum value and the vertical component is zero. By contouring the maxima of the horizontal magnetic field component, a "footprint" map may be constructed from the Willowstick survey data (see Figure 6C).

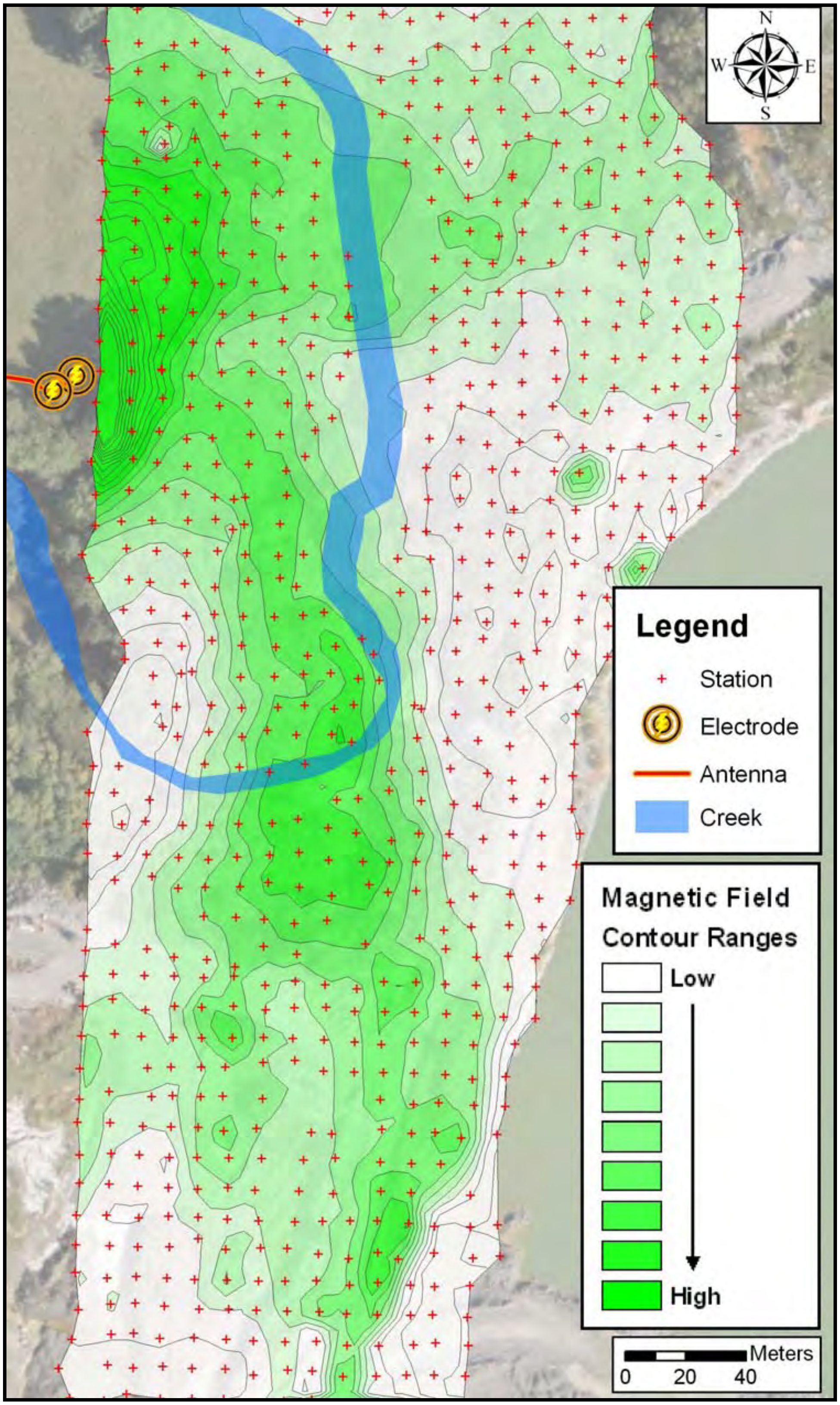


Figure 6C – Typical Magnetic Field "Footprint" Map

The raw horizontal magnetic field contour map—or "footprint" map as it is sometimes called—is used to identify the horizontal position of electric current distribution beneath the study area. The vertical position (depth) can only be determined by further processing and modeling. The initial footprint map simply reveals anomalous areas of high and low electric current flow beneath the study area.

The heart of the technology lies with the Willowstick instrument which consists of three coils arranged orthogonally in the vertical, north-south, and east-west directions. The coils are aligned to measure the three magnetic field components at each measurement station. The Willowstick instrument also has a low noise receiver that amplifies 380 Hz signal and attenuates other signals. A 24-bit analog to digital converter digitizes the conditioned signal and a microcontroller records and processes the digital signal from all three coils simultaneously. A fast-Fourier transform (FFT) is used by the microcontroller to isolate the 380 Hz signal and calculate a precise magnetic field strength. The microcontroller also records data from other sensors to correct for the instrument's alignment and orientation. Data from the microcontroller and sub-meter GPS receiver are integrated and stored on a rugged handheld computer. The handheld computer allows the operator in the field to provide notes and to navigate the survey area.

7.0 QUALITY CONTROL MEASURES

There are basically four criteria used to determine the quality of the magnetic field data measured and recorded by the Willowstick equipment. These are as follows:

1. Circuit continuity between electrodes
2. Signal strength
3. Signal-to-noise ratios
4. Signal repeatability

Circuit Continuity

As stated, the magnetic field is created by a large electric circuit consisting of (1) the power supply, (2) the circuit wire, (3) the electrodes and (4) the subsurface study area itself, located between the strategically placed electrodes. Circuit continuity refers to whether or not an electric current—and how much electrical current—can be driven through the subsurface study area from the given points of coupling with the earth (electrodes). Depending on the size of the study area and depth of investigation, an electric current level between 0.2 and 2 amperes is typically sufficient to generate a strong enough signal for a survey, given that the magnetic sensors are extremely sensitive for their size. In the case where little or no electric current flow can be driven between electrodes, the setup is said to have "poor continuity", and an alternative location must be found for one or more electrodes. Poor continuity usually occurs in very dry areas or where one or more electrodes are isolated by electrically-insulating material.

Signal Strength

The instrument measures the magnetic field strength with three highly sensitive, orthogonally-oriented sensors. Fast Fourier Transform (FFT) algorithms are used to generate the frequency spectrum and isolate the signal. Measurements are statistically analyzed. A warning is issued by the instrument if the signal strength is too low to meet quality control requirements. This takes anywhere from 1 to 2 minutes per station to measure and calculate an acceptable and representative value of the magnetic field strength.

Signal-to-Noise Ratio

The signal-to-noise is computed for each measurement station as the ratio of the signal to the mean ambient field noise, which is determined from a sampling of other non-harmonic frequencies in the spectrum. The signal to noise value is contoured and presented for each survey area in an investigation to help indicate the degree of data reliability (see Figure 7A).

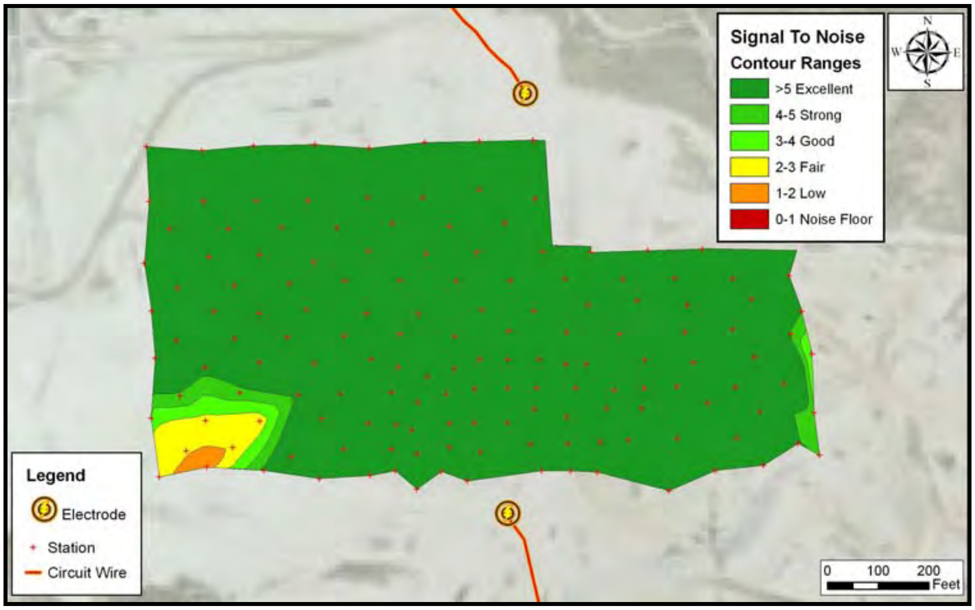


Figure 7A – Typical Signal to Noise Map

Signal-to-noise ratios are determined for every recorded measurement in an investigation and are monitored to insure that the signal is at least two times as strong as any background noise. If the signal-to-noise ratio falls below a value of 2, the data is considered unreliable. A low signal-to-noise ratio in a particular area indicates one of the following conditions:

1. The electrical current, injected into the groundwater, cannot reach the low signal-to-noise area because the electrode configuration biases electric current away from the area of low signal-to-noise.

2. There is no substantial pathway or conductive zone between the electric current source and the area showing a low signal to noise ratio. In other words, there is a resistive barrier between the source current and the area in question.

3. There is no conductive media in the particular area for the electrical current to concentrate or follow;

4. The electric current flow is highly dispersed throughout the study area and not concentrating in any one particular area or pathway which can result in a low anomalous magnetic field and low signal-to-noise ratios.

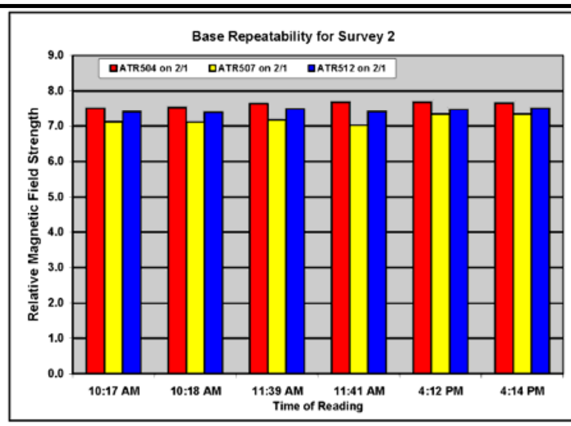
Considering the vastly different possibilities of geologic, electrical and hydrologic conditions, every project is highly unique and the principal challenge of every survey is to establish electric current flow that will follow and stay focused in the targeted study area. The degree of success is largely dependent upon this factor—whether or not the electric current follows the saturated medium that it is intended to follow, based upon its electrical properties. Signal-to-noise maps are prepared for every investigation to show that the signal strengths as well as electric current distribution through the area of investigation are acceptable. If certain signal strength and signal-to-noise criteria are not met, then it can generally be inferred either that there are no preferential flow paths through the study area or a different electrode configuration needs to be employed to better bias electric current flow through the area of interest.

Signal Repeatability

Measurement repeatability is determined from base station readings and other repeated field measurements taken throughout the course of the fieldwork. Base stations are established in the survey and are measured and recorded several times per day (morning, mid-day and evening) by each instrument. Repeat stations are read at the start and end of each new survey line. In a typical investigation, repeat measurements normally fall within acceptable deviation (less than 5% from the mean). Examples of repeat base station readings for a typical survey are shown in Figure 7B. Note that the difference in instruments shown by this graph is adjusted as part of the normalization and data reduction process. For each instrument in this example, the calculated deviation in base readings falls within 2.5%.

Magnetic Field Base Readings for Survey 2

Receiver ID	Date	Aquatrack Signal
ATR504	2/1/2010	7.506
ATR504	2/1/2010	7.522
ATR504	2/1/2010	7.641
ATR504	2/1/2010	7.678
ATR504	2/1/2010	7.677
ATR504	2/1/2010	7.656
ATR507	2/1/2010	7.116
ATR507	2/1/2010	7.108
ATR507	2/1/2010	7.165
ATR507	2/1/2010	7.021
ATR507	2/1/2010	7.332
ATR507	2/1/2010	7.337
ATR512	2/1/2010	7.397
ATR512	2/1/2010	7.385
ATR512	2/1/2010	7.492
ATR512	2/1/2010	7.405
ATR512	2/1/2010	7.458
ATR512	2/1/2010	7.506



The average measurement repeatability is within 2.5% for the thee instruments. Differences between instruments were adjusted as part of the normalization and data reduction process.

Figure 7B – Typical Signal Repeatability

8.0 DATA NORMALIZATION AND REDUCTION

The analysis of the magnetic field data entails reduction of the data to processed and corrected data sets ready for modeling and interpretation. The data is subject to a number of comparisons and corrections to account for: (1) differences between instruments used in the investigation; (2) atmospheric noise including diurnal magnetic variations, ionosphere activity, etc.; (3) ground noises or man-made interferences (power grid grounding wires and other long continuous conductors including metal pipelines, railroad tracks, steel fence lines, etc.); and (4) effects of the electric current bias (electrode and circuit wire locations).

Correction for differences between Instruments

After assembly, each Willowstick receiver instrument is carefully tested and calibrated. Sensors are matched and calibrated to measure within 0.5% error or 1 part in 200 of each other. Subsequent use and wear during the instrument's lifetime such as shipping and handling may cause an instrument's calibration to drift. Differences between instruments used on any particular project tend to vary somewhat more than the 0.5% calibration error. Typically, instruments will measure somewhere between 1 and 2% deviation on any given project.

To account for instrument differences, each instrument takes measurements at the same position (base station) numerous times throughout the course of the survey (see Figure 7B). The mean of each instrument's base readings is compared to the total mean of all base readings, allowing for slight adjustments to be made that effectively normalize the instruments.

Drift Correction

The magnetic field signal may drift over the day up and down. The largest source of drift is the transmitter current. The transmitter current is logged continuously throughout the day by a multimeter. Normally the variation in the electric current is small (1 to 2 % of the mean), but in some locations where water levels are changing the transmitter current may fluctuate by more than 10 %. To correct for any drift caused by the transmitter current (Figure 8A), the mean of the current is normalized to 1 and then a correction factor is calculated for any deviation from the mean. This is then applied to the magnetic field over the course of the survey.

To make sure the transmitter's electric current source is the only cause of magnetic field drift, a static receiver monitors the magnetic field at the base station. This magnetic field log (Figure 8B) is then corrected for any effects due to the transmitter current. Normally correcting for the transmitter's electric current will smooth any variations in the static receiver's magnetic field log; however, sometimes there are variations in the magnetic field that cannot be attributed to the AC power source. When these variations are encountered, the same process that was used to calculate a correction factor for the transmitter's electric current is used to calculate a correction factor from the static receiver and apply it to the rest of the measurements. These extra variations are rare but can occur due to extraneous natural or man-made sources.

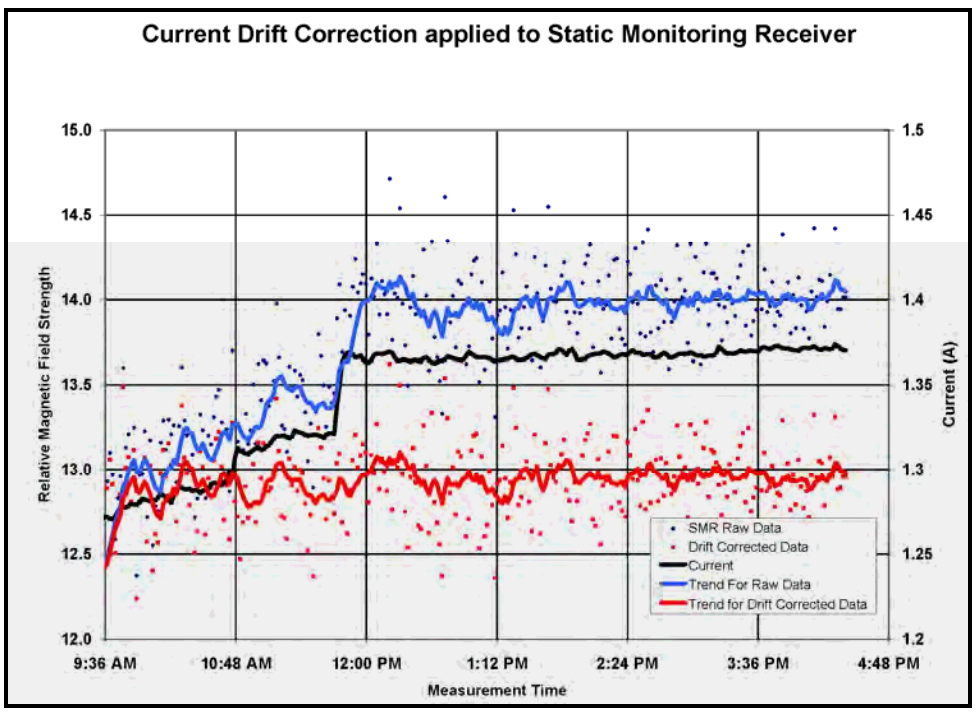


Figure 8A – Correction for Transmitter Current

Correction for Electrodes, Circuit Wire, Electric Current Bias and Conductive Culture

When analyzing, interpreting and/or modeling magnetic field data, it is important to keep in mind that in general there are three strong influences that affect the electric current flow through the subsurface.

These are (1) groundwater flow paths; (2) cultural features; (3) electric current bias—i.e., electrode and circuit wire placement.

1. The technology is based on the principle that its signature electric current is strongly influenced by the presence of groundwater or areas of greatest transport porosity where groundwater accumulates and/or flows relatively freely through the subsurface. In most settings when the electrodes are placed properly, the electrical current will naturally gather and concentrate in areas or pathways of higher hydraulic conductivity.

2. The magnetic field may be influenced by near-surface culture, which is any conductive man-made feature such as metal pipelines, power system grounding wires, steel fence lines, railroad tracks or other long continuous conductors. Culture is not always present, but it is often a factor and sometimes very problematic because it tends to be near-surface and can cause large anomalies that overshadow the magnetic signal generated from subsurface electric current flow. The best approach, when surveying an area with conductive culture is to identify the conductive features before a survey is initiated and strategically design the survey to avoid "*as much as possible*" any long conductive feature. Because conductive features sometimes exist within a study area, avoiding conductive culture can be difficult. Fortunately, the locations of most of these features are known. Therefore, the influence of near surface conductors can be removed and taken into account when interpreting the data. This will be explained later in this paper.

3. The magnetic field in any given survey is always subject to electrical current bias because of the placement and position of electrodes and circuit wire. Because electric current must travel from one electrode to the other in order to complete its circuit, the electrodes and circuit wire are a chief source of extraneous magnetic fields. It is always true that 100% of the electric current must flow through the circuit wire and concentrate in and out of the points of coupling (the electrodes), and hence the magnetic field tends to grow much stronger as it nears these appurtenances.

In order to properly interpret the magnetic field data, it is critical that these influences be identified and separated out. This is accomplished primarily with finite element computer codes that predict the terrain-corrected electric current flow and resulting magnetic field model for the given survey setup based on a homogeneous earth scenario. Magnetic field effects from the circuit wire, and in some cases from conductive cultural features, can also be predicted. Once the effects from electric current bias, circuit wire, and conductive culture are removed, the data will more easily reveal electric current flow patterns and through modeling will yield an interpretation of groundwater flow based on the distribution of electric current flow beneath the study area.

9.0 CRITERIA TO DISTINGUISH NEAR-SURFACE INTERFERENCE

Stray electric current flowing onto near-surface conductive culture can be problematic for interpreting electric current flow at depth. Therefore, in some cases it becomes necessary to remove near surface interference in order to properly interpret the distribution of electric current flow in the subsurface. Near-surface interferences are distinguished by three criteria:

1) Normalized Gradient Filter
2) Distance from Culture
3) Point-specific Professional Judgment

Normalized Gradient Filter

An analysis of magnetic field gradients provides a good way to separate signals caused by near-surface conductors from signals that originate at depth. In Figure 9A, both shallow (red dot) and deep (green dot) conductors are represented by energized wires running perpendicular to the page through the points shown.

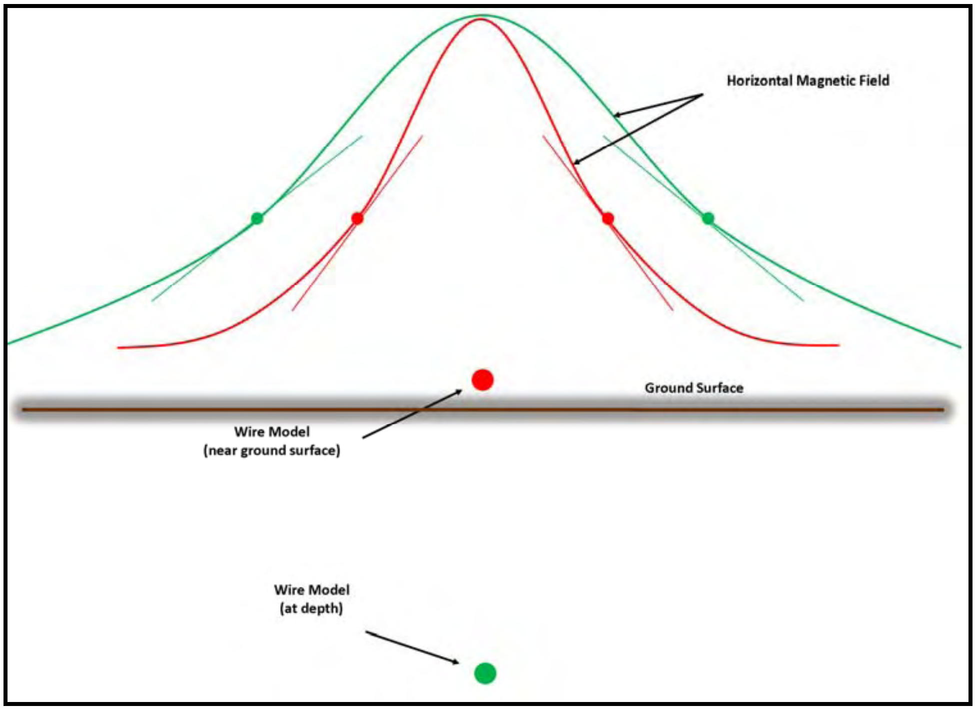


Figure 9A – Normalized Gradient Filter

The red and green curves show the horizontal magnetic field measured at ground level for the corresponding wires. Figure 9A demonstrates that near-surface conductors (red) cause anomalies having much steeper slopes or higher gradients than signals originating from depth (green); therefore, measurement stations influenced by electric current flowing on near-surface or above ground conductive culture can be identified and removed from the data set with a magnetic field gradient cutoff.

Although the gradient filter method is effective, by itself, it does not separate out all cultural influences. Steep gradients can occur over very short distances, and they can sometimes pass detection due to discrete station spacing, especially where the grid is sparse and near survey edges. It is also important to consider that near-surface electric currents may be much weaker than those at depth, but can still influence readings within a very short proximity—sometimes less than the typical station spacing. The influence in such a case may be significant even if it does not cause a measureable high gradient. For this reason, another criterion specifically for the removal of readings near culture is necessary.

Distance from Conductive Culture

In some cases, measurement stations can be taken too close to conductive culture (e.g. an unknown buried power line or pipeline, grounding grid wire, etc.). The objective of this filter is to remove additional measurement stations that cannot be trusted given the high probability that they are influenced by surface culture. The cutoff distance for this filter is determined by modeling and careful analysis of the data because some cultural features will carry more electric current than others.

Point-Specific Professional Judgment
The gradient filter and distance from culture criteria remove the majority of measurement stations affected by near-surface conductive culture. Nevertheless, in some cases there still remains a "gray zone" where some data slips past these two criteria and should be considered by subjecting it to point-specific professional judgment. Removal of measurement stations using professional judgment usually takes place only when the above criterion breaks down due to survey edges or gaps in the data as mentioned or from unknown and/or buried conductive culture. In any event, professional judgment is used as the final criteria to determine the quality of all measurement stations.

Filtered Magnetic Field Map
If a measurement station is determined to be influenced by stray electric current flowing onto conductive culture, the measurement station is removed (filtered) from the data set. Magnetic field contour maps are then generated that reflect magnetic field measurements unaffected by surface culture. Stations that passed the quality control measures are shown with red crosses ("+" signs) in the figures. Measurement stations removed after the three criteria have been applied are shown with an "x" centered within a larger gray semi-transparent circle. Stations removed by professional judgment are shown with a circled "x" within the larger gray semi-transparent circle.

10.0 MAGNETIC FIELD CONTOUR MAP

The horizontal magnetic field map or "footprint map" helps identify the electrical current distribution beneath the study area. When studying the magnetic field contour map, keep in mind that electric current will follow long conductors or conductive zones that facilitate movement of electrons between paired electrodes (see Figure 10A).

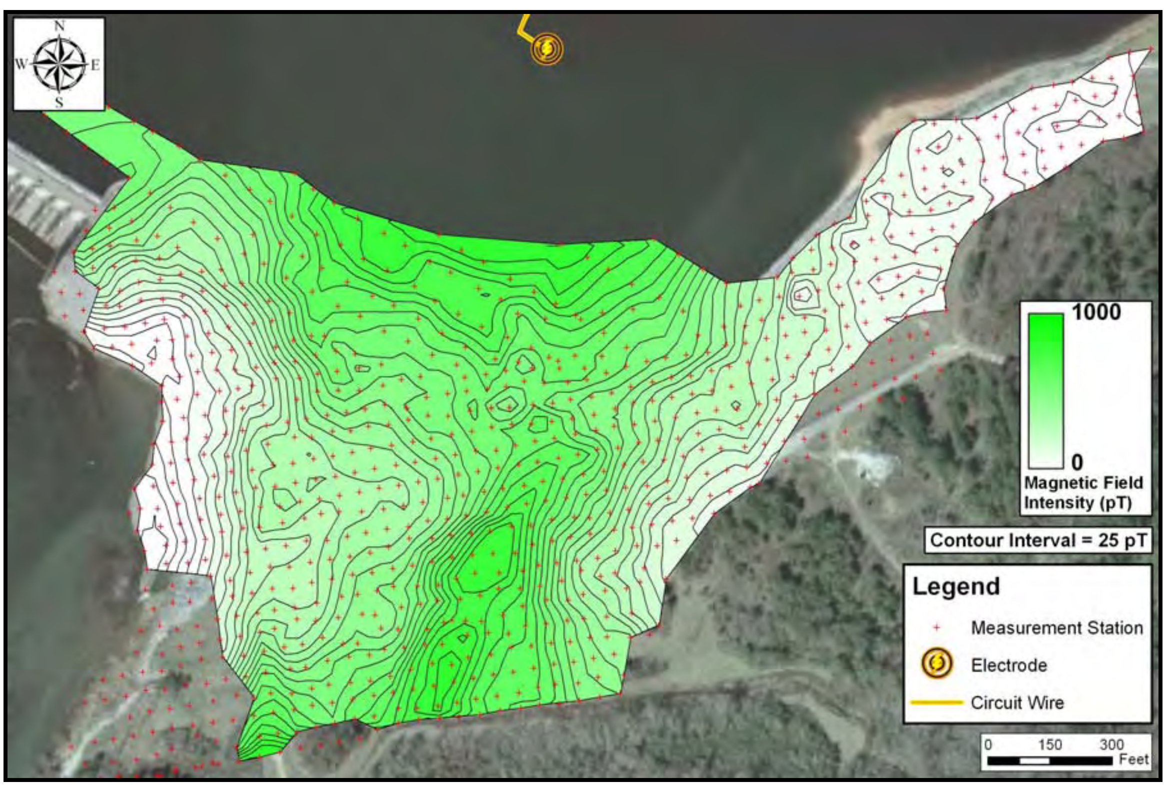


Figure 10A – Example Magnetic Field Contour Map

The shape of the contour lines reveals electric current flow patterns related to subsurface conductive pathways. Magnetic field contour intervals are generally 25 to 50 pT (Pico Tesla). The sensitivity of the Willowstick instrument is within ±10-14 pT with a 95% confidence interval. Thus, contour intervals conservatively present the fluctuations in the magnetic field data.

It is generally more important to pay attention to the shape of contour lines rather than the shading that indicates relative magnetic field strength. Although the contour shading helps distinguish between areas of high magnetic field (dark green) and low magnetic field (light green—almost white), it can be somewhat misleading if interpreted directly as locations of subsurface electric current flow related to areas of higher porosity in the saturated zones because the magnetic field is affected by the electrical current bias and possible conductive culture for the given antenna/electrode setup.

Interpreting a magnetic field contour map could be compared to interpreting a topographic map. On a topographic map, the ridge lines connecting the peaks could be thought of as pathways offering the easiest path to traverse. In the same way, these lines in the magnetic field maps represent paths of least resistance for electrical current to follow, although it undergoes some measure of dispersal and re-concentrating in more complex ways than can be fully described or modeled. By identifying these high points and ridges and connecting them together through the study area, the center position of preferential electric current flow can be identified.

11.0 PREDICTED MAGNETIC FIELD MAP AND RATIO RESPONSE MAP

Predicted Magnetic Field Map

In order to identify areas of greater or lesser conductivity, a model is created which predicts the magnetic field response expected at each measurement station given the position of the circuit wire, electrodes, and topographic changes. The model usually assumes a homogeneous subsurface environment. Figure 11A shows a typical predicted magnetic field for an investigation.

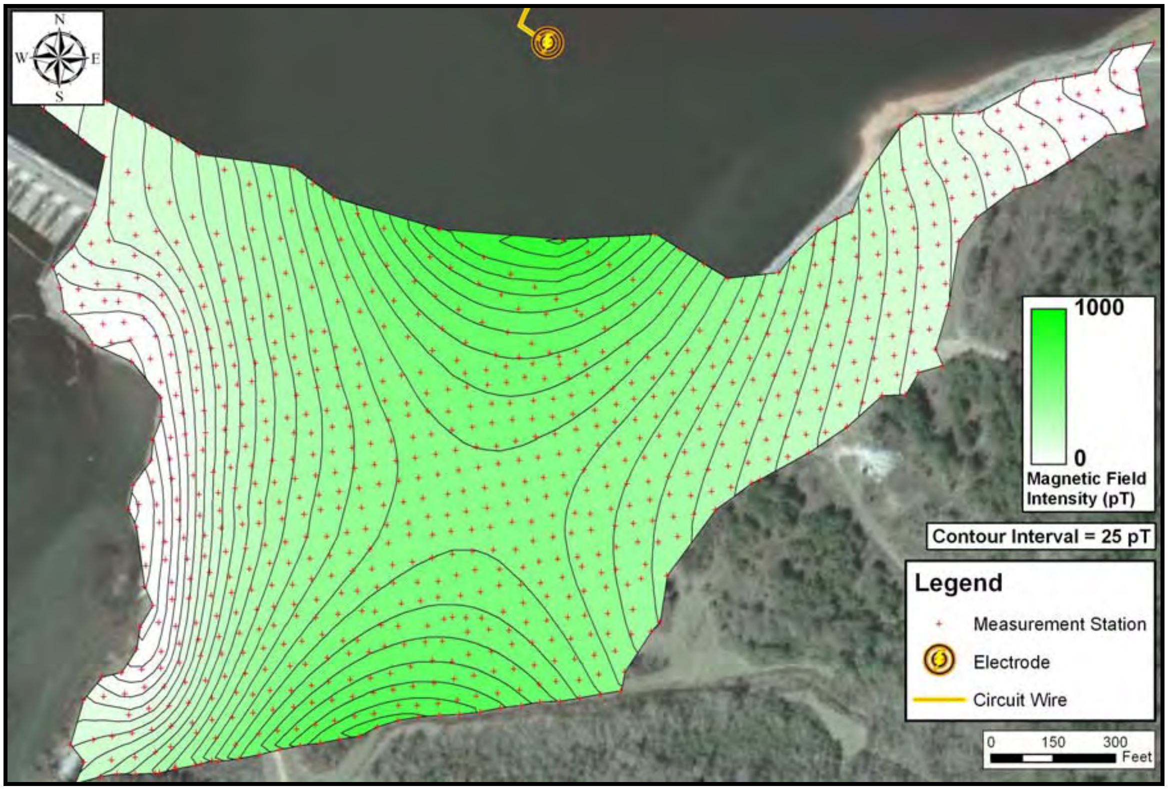


Figure 11A – Example Predicted Magnetic Field Map

The predicted magnetic field model is an important tool that helps to emphasize the subsurface heterogeneity by removing the "background" or homogeneous electric current flow between the electrodes and along the circuit wire. Even though the predicted magnetic field is used to remove the electrodes and circuit wire influence, it is still helpful to have the electrodes and circuit wire located out and away from study area because "eddy" currents can be induced in the ground resulting in secondary magnetic fields. Secondary magnetic fields are difficult to predicted and remove from the data set. This is why the circuit wire and electrodes are placed outside the study area. The comparison of the original survey data with the predicted magnetic field model is best presented in the form of a Ratio Response Map.

Ratio Response Map

To better distinguish areas of greater or lesser conductivity through the subsurface study area, the observed magnetic field map (Figure 10A) is divided by the predicted magnetic field model (Figure 11A), creating a Ratio Response Map (Figure 11B). The Ratio Response Map removes the effect of electric current bias created from the circuit wire and electrodes, thereby showing areas of greater or lesser magnetic field intensity than that predicted by the model.

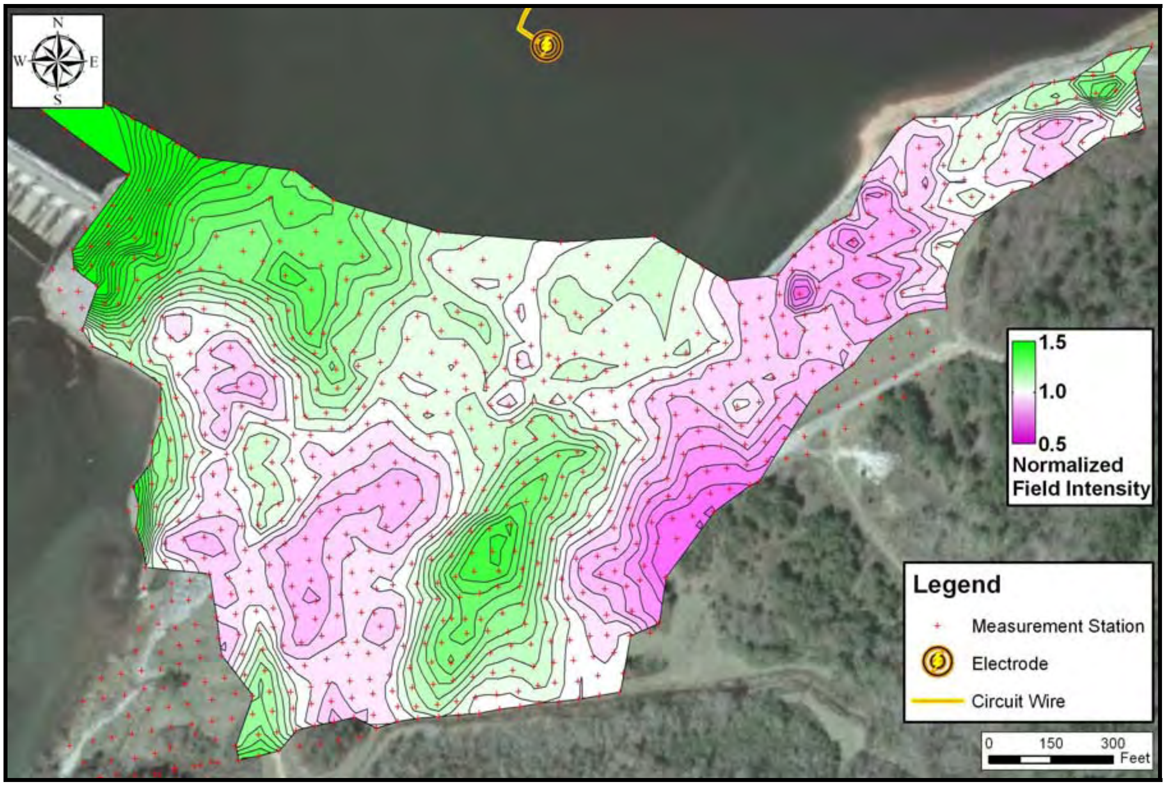


Figure 11B – Example Ratio Response Map

The white shaded areas (where the ratio is approximately 1:1) indicate where electric current intensity is approximately equivalent to that predicted by the homogeneous model. Areas shaded pink or purple indicate where electric current flow is less than predicted, and green shows where electric current flow is greater than predicted. It is important to emphasize that pink or purple areas should not be overlooked. They can provide insightful information and can help identify potential preferential flow paths as revealed by the shape of contour lines, which is more important than the color shading.

12.0 MODELING

The filtered magnetic field map, predicted magnetic field map, and ratio response map are provided to identify the horizontal location and distribution of electric current flow through the subsurface study area. It is much more difficult to determine with any degree of accuracy the vertical distribution of electric current flow because the magnetic field can only be measured from the surface of the ground. As a result, modeling is employed to help estimate the vertical distribution of electric current flow.

Willowstick has developed two modeling methodologies used to identify the horizontal and vertical distribution of subsurface electric current flow. One methodology is called the Electric Current Flow "ECF" model because it uses discreet channels or ribbons of current to simulate the observed magnetic field at the earth's surface. These ribbons represent where electric current concentrates strongly in the subsurface (see Figure 12A).

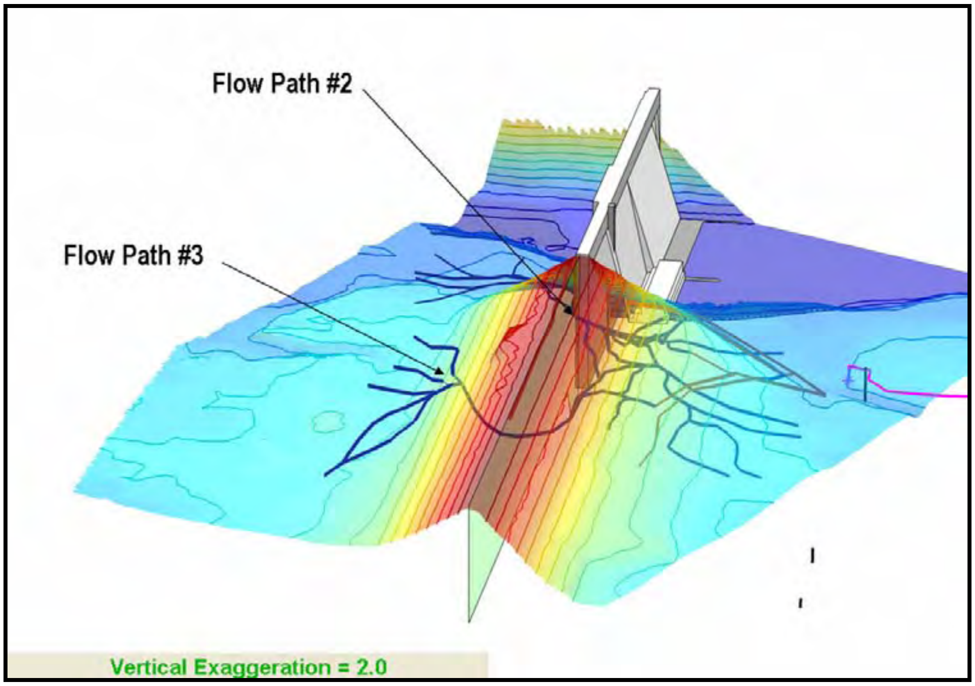


Figure 12A – Typical ECF Model

Modeling is accomplished by simulating electric current flow along these ribbons to generate a theoretical magnetic field response at each measurement station. The depth of the flow path is modified and adjusted until the model produces a magnetic field response that compares with the measured data. This type of model requires well-focused or well-defined anomalous features to yield accurate results.

In some cases, electric current flows more homogenously than heterogeneously. As a result, it is difficult to use the ribbon method to model results with low contrast or weak gradients. For this reason, an inversion algorithm was developed to predict the electric current flow distribution in three-dimensional space (based on the ratio response magnetic field data). This type of model is referred to as an Electric Current Distribution (ECD) model. Figures 12B and 12C present horizontal and vertical slices, respectively, through examples of an ECD model.

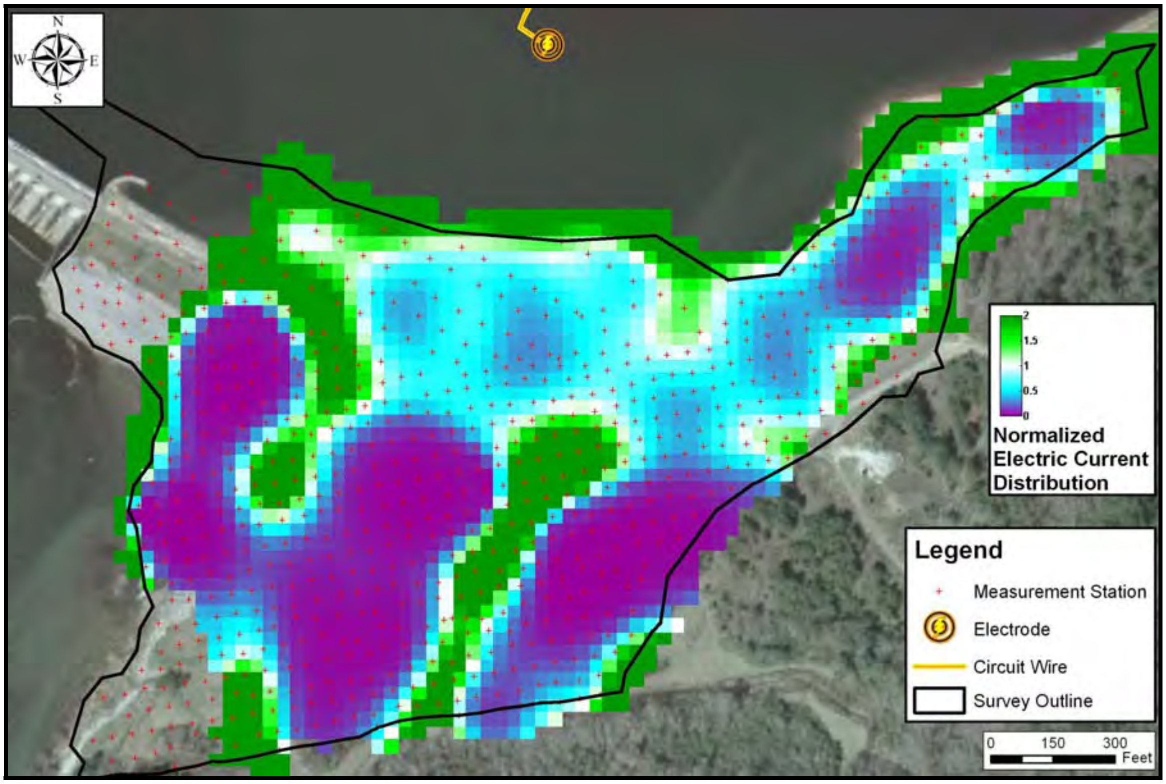


Figure 12B – Example of Electric Current Distribution (ECD) Model Horizontal Slice

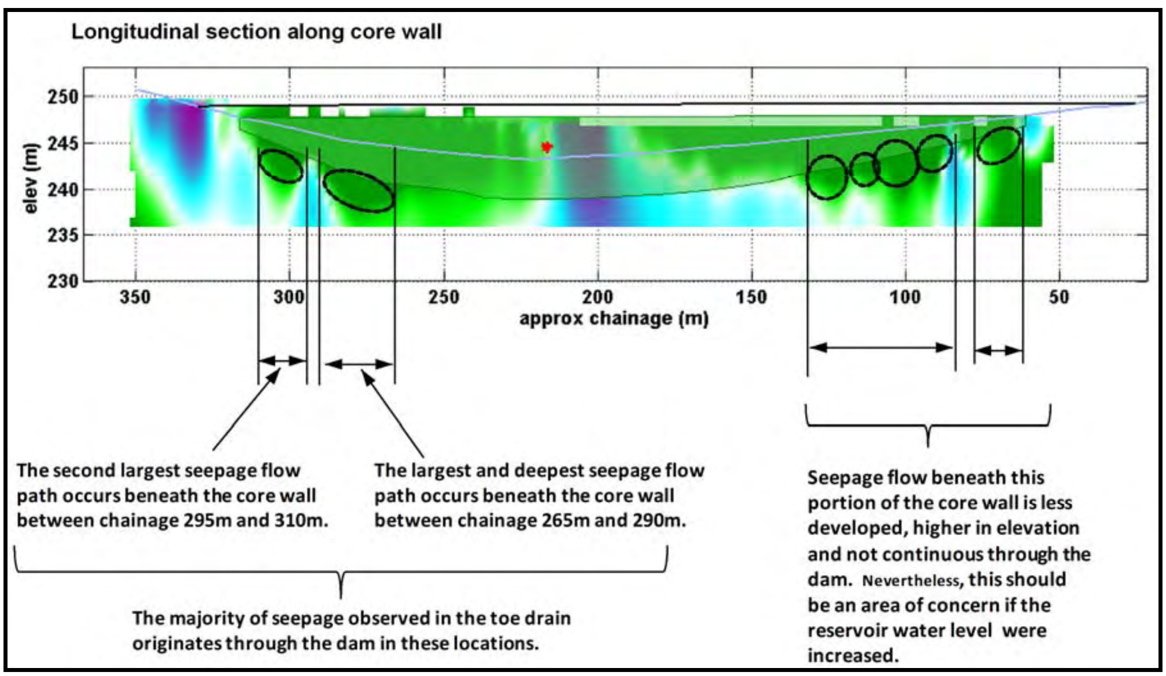


Figure 12C – Example ECD Vertical Slice along a Core Wall

In Figures 12B and 12C, the green shading identifies areas of higher conductivity where electric current is believed to be more concentrated while the purple shading identifies areas of lower conductivity where electric current is observed to be less concentrated.

Willowstick uses MATLAB software to generate and analyze ECD models in the form of volume data. The model viewer can generate slices at any elevation or cross-section position within the volume (as the examples above shows). Because unlimited slices and views can be created, it is beyond most investigations to show all possible slices of interest. Therefore, Willowstick provides all data in common electronic formats and any specific formats requested by clients (including XYZ data files, ArcView shapefiles, compiled MATLAB models, and anything used to create the maps, figures and models presented in the reports). This enables clients to view, compare, and analyze the results of the investigation on their own.

13.0 SUMMARY

The modeling and interpretation of electric current flow distribution through the subsurface reveals groundwater flow paths in most geologic settings, and is based upon widely known and accepted scientific theory and principles. Proper data interpretation requires an understanding of site geology, groundwater physical principles, electromagnetic theory and experience working with and developing the technology. A great deal of effort has been put forth to eliminate error in the data collection, data reduction / normalization, modeling and interpretive process. As with this relatively new technology, it is continually improving. Without exaggeration, the “*Willowstick*” instrument, data collection, reduction, and modeling processes improve daily.

The accuracy of the technology and its margin for error are yet to be fully quantified. As of the date of this paper, the technology has proven to be very helpful in characterizing groundwater problems as well as guiding characterization efforts in a much more rapid and cost effective pace. The Willowstick survey method is intended to provide a quick and accurate characterization of groundwater conditions. However, for highly detailed information additional exploratory work may be required. The technology is viewed as a means to guide and direct traditional subsurface exploratory work in order to improve groundwater characterization efficiencies (cost and time) and to arrive at conclusive and quantitative answers about a specific groundwater problem. The technology is not viewed as a means of providing absolute answers with calculated margins of error, risk or vulnerability classifications.

The results obtained from a Willowstick geophysical investigation should be used to make informative decisions concerning how to further confirm, monitor and possibly remediate groundwater problems through a given area of investigation. The information contained in the Willowstick methodology should be compared with known information or it should be used to target areas to obtain additional information in an effort to fully characterize a site. There is no technology better suited for this assignment.

14.0 CONTACT INFORMATION

For more information about how Willowstick Technologies can help you with your groundwater or seepage problems visit our web site at www.willowstick.com or call the main office at (801) 984-9850.

15.0 PATENT

The Willowstick method of identifying, mapping and modeling seepage through subsurface environments is protected by Patent 5,825,188; other patents pending.

APPENDIX B – PROFESSIONAL BIOGRAPHIES

VAL O. KOFOED, P.E.

President / Principal Engineer

Education

- B.S. – Civil Engineering (1983)
  Brigham Young University, Provo, UT

Professional Experience – 28 Years

- Willowstick Technologies, LLC 2004 – present

President and Consulting Engineer. Responsible for daily operations of all groundwater characterization investigations.

- Sunrise Engineering, Inc. 1983 – 2004

20 years experience as a Consulting Engineer. Principal Engineer from 1987 to 2004. Responsible for Hydrogeology Division and water resource engineering related projects.

- Western Utility Contractors 1982 – 1983

$1^1/_2$ years experience as Project Engineer. Estimator and Project Engineer on water resource construction projects.

Registration

- Registered Professional Civil Engineer
  Utah (#172947)
  Arizona (#20923)

JERRY R MONTGOMERY, PH.D

Consulting Geophysicist / Inventor, AquaTrack Methodology

Education

- B.S. – Physics (1965)
  Weber State University, Ogden, UT
- Ph.D. – Geophysics (1973)
  University of Utah, Salt Lake City, UT
- Post Doctoral Studies – Geostatistics (1974)
  University of Leeds, Leeds, England

Professional Experience – over 40 Years

- Willowstick Technologies, LLC 2010 – present

Consulting Geophysicist. Assist with continuing development of the AquaTrack technologies.

- Willowstick Technologies LLC 2004 – 2010

Chief Geophysicist. Assisted in spinning off the AquaTrack technology and Hydrogeology Division from Sunrise Engineering into it own business unit (Willowstick). Responsible for interpretation and further improvement of the AquaTrack hardware and software including other new groundwater mapping technologies.

- Sunrise Engineering, Inc. 2001 – 2004

Research and Development Director. Responsible for improving the AquaTrack technology, taking it from an analog to a digital technology.

- Self-employed 1996 – 2001

Inventor and patent of the AquaTrack technology. Conducted contracted AquaTrack surveys.

- Bureau of Mines 1990 – 1996

Staff Scientist and Researcher. Involved in bio research for removal of heavy metals. Developed electromagnetic tracking and monitoring equipment for monitoring groundwater plumes, biological process, and in-situ leaching.

- U.S. Army, Dugway Proving Grounds 1986 – 1990

Operations Research Analyst. Served as Contracting Officers Representative for diverse contracts. Devised unique technique for analyzing time dependent data and helped developed NBC projection for M1 tank, Apachy, LCAC's and C117's.

- ASARCO, Inc. 1968 – 1986

Chief Geophysicist. Responsible for organization, direction and interpretation of geophysical surveys. Developed programs to study minerals, groundwater and environmental problems. Developed new geophysical technologies and expanded theories to implement and improve geophysical interpretation.

RONDO N. JEFFERY, PH.D

Consulting Physicist

Education

- Ph.D. –Physics (1970)
  University Illinois – Urbana/Champaign
- M.S. – Physics (1965)
  Brigham Young University, Provo, UT
- B.S. – Physics (1963)
  Brigham Young University, Provo, UT

Professional Experience – 30 Years

- Willowstick Technologies, LLC 2010 – present

Consulting Geophysicist. Assist with continuing development of the AquaTrack technologies.

- Willowstick Technologies, LLC 2004 – 2010

Physicist. Assists with all aspects of research and development. Responsible for the electronic design and construction of the AquaTrack receiver.

- Weber State University 1980 – present

Professor of higher education and research. Taught courses in electronics, solid-state physics, engineering physics, nuclear physics lab, and astronomy. Participated in numerous research and development projects. Authored many publications and presentations.

WEI QIAN, PH.D

Consulting Geophysicist

Education

- Ph.D. –Electromagnetic Geophysics (1992)
  University of Uppsala, Sweden
- M.S. – Electromagnetic Geophysics (1986)
  China Earthquake Administration, Beijing, China
- B.S. – Geophysics (1983)
  Beijing University, China

Professional Experience – 30 Years

- Willowstick Technologies, LLC — 2010 – Present

Consulting Geophysicist. Responsible for interpretation and further improvement of the AquaTrack hardware and software including other new groundwater mapping technologies.

- KMS Technologies, Houston, TX — 2008 – 2010

Project Manager, EM modeling services. 3D modeling for the EM imaging and monitoring of oil/water replacement during oil field production; time domain sensor development for marine EM; development of TEM data imaging and interpretation methodologies and software.

- Geophysical Consultant — 2002 – 2008

Geophysical data processing and interpretation for environmental, geo-engineering and mining applications; project management for environmental, geo-engineering and mining applications.

- Fugro Airborne Surveys/High-Sense Geophysics Ltd./Aerodat, Inc. — 1994 – 2002

Senior Geophysicist. Geophysical data processing and interpretation for environmental, geo-engineering and mining applications; project management for environmental, geo-engineering and mining applications.

- Geological Survey of Canada — 1994 – 2002

Research Geophysicist, EM data modeling and inversion. Algorithm development in electromagnetic modeling and inversion.

MICHAEL L. JESSOP

Geophysicist

Education

- M.S. – Geophysics (2005)
  University of Utah, Salt Lake City, UT
- B.S. – Geophysical Engineering (2002)
  Montana Tech, University of Montana, Butte, MT

<u>Professional Experience – 8 Years</u>

- Willowstick Technologies, LLC 2005 – present

Staff Geophysicist. Responsible for data analysis & modeling using MATLAB™ programming package to understand probable groundwater flowpaths observed in the AquaTrack data. Assists with data interpretation and quality control.

- Gradient Geophysics, LLC 2002 – 2003

Geophysics Field Crew. Worked with and directed crews on geophysical field surveys including resistivity, IP, and magnetic data acquisition.

MICHAEL WALLACE

Geophysicist

<u>Education</u>

- M.S. – Geophysical Engineering (2006)
  Montana Tech, Butte, MT
- B.S. – Physics (2003)
  Hampden-Sydney College, Hampden-Sydney, VA

<u>Professional Experience – 6 Years</u>

- Willowstick Technologies, LLC April 2006 – present

Staff Geophysicist. Responsible for data reduction and data quality control. Also responsible for Reduction program and Field program. Assists in modeling using MATLAB program and with data interpretation.

- Curtin University Exploration Geophysics Department, Perth WA 2004

Exchange Student. Assisted with land seismic, seismo-electrics, and Time Domain EM surveys over gas reservoir. Built portable audio magnetotelluric survey system.