Willowstick Technologies

White Paper
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willowstick

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1. Executive Summary

1.1 What is the problem to be solved?

Since the beginning of time, there has been a curiosity and a need to understand activity below the surface of the earth. Thousands of years ago the need was principally driven by the requirement to find water. To address the issue, society tried a variety of techniques from divining rods, to dowsing sticks, to enlightened drilling.

While the need to find water is still critically important in many regions of the world, it is supplemented by the need to better understand where water flows. Mining, drilling, large construction projects such as dams and reservoirs, and environmental remediation projects, all depend on an ability to see, understand, and predict subsurface water flows.

Given the critical need to understand subsurface water-flow activity, one has to wonder why this problem has not already been resolved. Surely if scientists can build telescopes to see 10-15 billion light years into space, they should be able to develop technology that enables us to see a few hundred meters beneath our feet. In fact, there are more compelling reasons to see below the earth than there are reasons to see above it.

It turns out that seeing a few hundred meters beneath the earth is more complicated than one might expect. A variety of attempts to characterize groundwater behavior have yielded inaccurate or unpredictable results, or they have proven to be too expensive, or too terrain-specific. These failed efforts have reinforced the idea that identifying groundwater flow paths would always be problematic and best served by a "trial and error" approach.

Nothing could be further from the truth. Industries do not have economic models that enable them to consistently spend significant amounts of time and capital only to find that they consistently dig in the wrong place. If a carpenter found that he was constantly cutting boards that did not fit in the locations they were meant to fit in, is it likely that he would replace the traditional "measure twice cut once" adage with a new "first cut then measure" model that was even less precise? The cost of digging multiple wells to see if you found the groundwater in question has become so expensive that it is not sustainable. Groups seeking to identify subsurface water flows must find a better approach than "dig and hope."

1.2 What is the best way to solve the problem?

Recent advances have begun to address the "what's under your feet" problem. As one might expect, these advances have come in the form of the enlightened application of technology, which has proven to be successful in other industries. Most significant productivity improvements of the past century have at their core one or more technology breakthroughs. The technology innovations are based on a handful of scientific advances that have been applied concurrently across industries. Advancements in physics, miniaturization, chemistry, and solid-state electronics have become engines that fuel great advances across all industries. As new waves of improvement in technologies such as magnetics and petabyte scale data management are delivered, they too will energize the order and magnitude of improvements in geophysical technology.

It was obvious to those familiar with medicine that Magnetic Resonance Imaging (MRI) breakthroughs would only be gated by the rate of increase in computing power since the physics and science behind magnetics have been known for decades. However, now that MRI instruments are able to employ multiple processors, and with the inclusion of "big data" manipulation, it is possible to render high-resolution slices (images in 3 dimensions) of the body in real-time.

The dramatic improvements that have been achieved in our own technology are only now achievable due to relatively recent computing advancements. Early implementations of Willowstick technology required as long as 15 minutes to acquire a GPS signal create the electrical circuit wait for the magnetic waves to be generated, then read and verified at the end of the process. The time delays made it impossible for us to collect the readings necessary to create high resolution, 3D images under the earth. Currently, technology improvements have advanced to the point that more data is collected in a 10 second reading than was previously collected in 15 minutes. More advanced CPU technology has made it possible to collect "data dense" surveys that have as little as 2.5 meters between each measurement station. This level of granularity enables us to identify and characterize deep flow paths (300 meters plus) and enables geophysical image creation in real-time. While computing power and petabyte level data manipulation still prevent some new technology advancements, one can at least contemplate a time when sophisticated magnetic instruments will be able to see into the earth with similar levels of acuity as they now enjoy for the human body.

There are more compelling reasons to see below the surface of the earth than there are reasons to see above it

It should surprise no one that the technology adoption curve for geophysical technology has lagged the adoption curve in other industries. Why has that been the case? How does our industry address this problem?

The answer is principally a matter of economics. New technology has been more rapidly adopted in the oil and gas marketplace where the financial advantage of tracking hydrocarbons through the subsurface is blatantly obvious. Unfortunately, the economics of water management have been nowhere near as compelling and the relatively low value derived by tracking or locating subsurface water has slowed the pace of technology adoption.

However, managing water assets is becoming sufficiently valuable, therefore the pace of technology adoption is increasing. Historically, there has been a concentration of financial resources into countries where water has been plentiful, and away from countries that lack water, but that is about to change—not because dry countries are suddenly becoming wealthy, but because wealthy countries are suddenly becoming dry.

Geophysical technology, especially magnetic imaging of groundwater paths and patterns, has reached the point that it is no longer a parlor trick, but instead represents a real solution to a series of vexing problems that are triggered by the inability to see or even accurately predict what is going on below the earth. The cost of the "dig and hope" approach has become so expensive and inefficient that a mature, technology-based solution is being welcomed with open arms.

Ultimately, the most persuasive motivation to employ advanced geophysical techniques is to preserve or even enhance the value of one's underground assets. While these assets might not have been visible because of past technology limitations, they have always been important. It would be irresponsible not to manage them as one would any other asset.

The economics of managing groundwater are about to change--not because the dry countries are becoming wealthy, but because the wealthy countries are becoming dry

In the case of assets such as a dam, the water in it, its potential to generate hydroelectric power, or its capability to store the waste products of a mineral extraction process it is essential to:

- Definitively quantify the value of this asset
- Reliably assert whether it is growing or declining
- Specify the security of that asset
- Compare the characteristics of that asset to its similar characteristics one year or even five years prior

The idea that these "assets in the ground" were safe and would be able to continue to provide value in perpetuity with little or no effort on the part of the asset owners has come under fire. Perhaps if managing assets had been taken more seriously in the past, the industry would already have insisted on a more rapid adoption of new technology to protect those assets.

The disastrous rupture of Samarco Dam, the spillage from two large tailings ponds, and the widespread calamity that followed, has caused every owner to carefully consider whether they are fulfilling their full fiduciary duty regarding their assets. Samarco will soon become a "verb" when oversight committees, risk managers, board members, and even large shareholders ask management to explain the steps they have taken to avoid being "Samarcoed."

1.3 How does the Willowstick method work?

The Willowstick technology is a sophisticated application of known scientific principles. Since the laws of physics are known and consistent, Willowstick was able to build a set of instruments that track and measure minute anomalies in the strength of a signature magnetic field generated under a closely monitored set of conditions. When the results of the measurements deviate from the results that are expected or predicted based on scientific principles, an anomaly is revealed. In most cases the anomaly is manifest by the presence or absence of groundwater.

Willowstick's instruments detect and analyze magnetic current as it passes through earthen materials or concrete structures. While identifying signals, the system reduces noise (random interference created by man-made conductive culture) through a series of software filters developed by Willowstick. Enhancing the signal and reducing the noise enables Willowstick to reliably detect subsurface flow paths deep below the earth's surface.

The software used to read the measurements, create models, and recognize patterns is as innovative and unique as the instruments that generate the readings. Either would be novel and valuable alone. Together they provide high-resolution data for making effective remediation decisions that has never been available through another methodology.

The method works by inducing an electric current directly into the area of interest. The electric current travels via wire to a second electrode creating an electric circuit. Whenever an electric circuit is created it generates a magnetic field. By measuring the intensity of the magnetic field as it passes through the subsurface, Willowstick analysts are able to pinpoint preferential water flow paths and patterns. This patented methodology works in the following manner:

- Creates an electrical circuit and introduces current directly into the area of interest generating tens or hundreds of thousands of measurements
- Biases or targets the electrical current in a way that sheds the most light on the area of interest
- Observes the electric current as it follows water-bearing zones utilizing higher conductivity as a path of least resistance to complete the circuit
- Measures the actual magnetic field and compares it to the predicted magnetic field within the study area
- Creates a 2 dimensional model that plots all ratios created by comparing the observed intensity of the magnetic field with the expected intensity highlighting zones of greater or lesser current
- Utilizes a variety of proprietary algorithms and models such as Vector Correction Mapping (see Figure 1) to constrain the range of options available to our software to model the flow path in a way that most closely represents the actual under-the-ground situation
- Employs proprietary filtering algorithms to eliminate interference from man-made conductive culture or any other known anomalous features
- Applies inversion models to gain a 360° perspective of the flow paths, including location and depth
- Uses 3D models created as part of the investigation to predict future behavior based on trends, trajectory, and timing

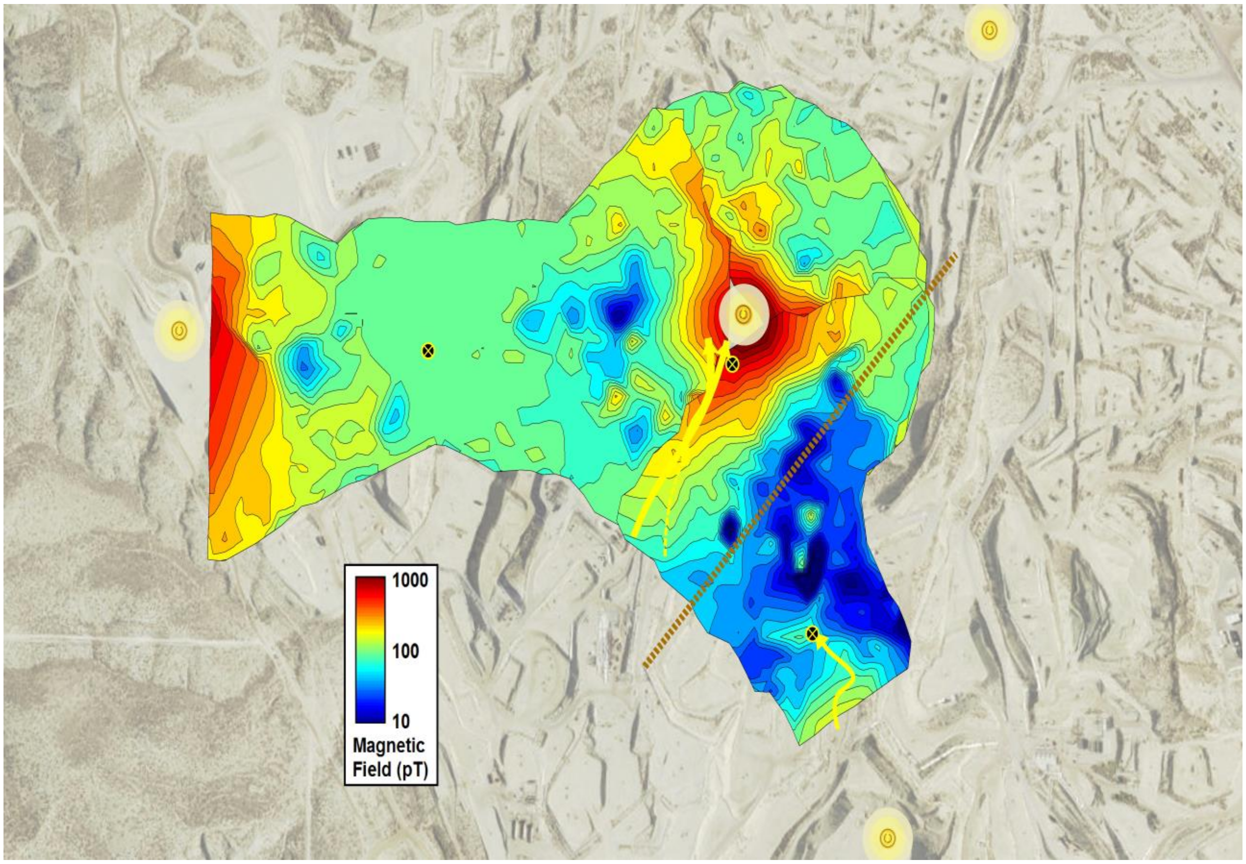

Figure 1 – 2D Vector Correction Map

During each Willowstick survey, the instruments take hundreds of thousands of readings. This "big data" solution enables unassailable conclusions that are instantiated through software models and predictive analytics. A data-dense solution delivers a degree of precision that eliminates guesswork and delivers solutions based in reality, not on "trial and error."

1.4 Why try technology first?

Starting every groundwater investigation with a Willowstick study enables you to narrow the range of your investigation and target your data gathering activities to the areas where groundwater flow paths have already been confirmed. There is no longer any reason to blindly dig multiple wells in the hope that at least one will highlight the seepage you seek. For many years carpenters have relied on the adage "measure twice cut once." Geologists would benefit greatly if they adopted a "map first drill later" frame of mind.

There is no longer any reason to blindly dig multiple wells
in the hope that at least one of them will highlight the seepage you seek

Taking the time and extending the effort to use all available technology to aid your groundwater characterization makes sense for many reasons:

- ## Significantly reduce time and expense while increasing accuracy

  The patented process combines data from highly sensitive magnetic resonance instruments with any other geophysical data, such as monitoring wells, in order to define a robust 3-dimensional model that represents the reality occurring under the earth. This results in a cost-effective, timely, and accurate image of current subsurface conditions so engineers, owners, geophysicists, and hydrologists have the information they need to make correct decisions.

- ## Evaluate the subsurface using fewer observation wells

  In most cases a Willowstick geophysical investigation will identify areas requiring further investigation without incurring the expense of performing an invasive well-drilling operation over the entire site. Even if drilling becomes necessary, it occurs later in the process and targets the well drilling effort at the most likely locations.

- ## Catch complex and acute changes in the subsurface early

  A Willowstick geophysical investigation is usually a small fraction of the total cost of characterizing a site's groundwater by other means and an even smaller percentage of the cost of remediating a problem. Too often, critical decisions are based on interpolations from scattered well data that fail to depict complex and acute changes in the subsurface early enough to prevent costly damage. Better data means better decisions and fewer surprises.

- ## Enable better management of high value assets

  The ease and relatively low cost of performing follow-up surveys make proactive asset management and risk mitigation more feasible. Many Willowstick customers have recognized that their dam, tailings pond, or their landfill represent a significant asset to them that deserves to be managed as any other asset. A thorough and comprehensive Asset Management Program requires periodic readings by managers and owners who recognize the value of comparing slight changes in groundwater conditions from one period to the next. This ensures that remediation measures are taken promptly before the value of the asset is further depreciated.

- ## Eliminate trial and error when placing remediation solutions

  The groundwater characterization process may be the last example of the mission critical process that relies on taking expensive actions *before* any diagnostic evaluation takes place.

  In the medical community, when all other non-invasive tests have been conducted to try to identify the source of a problem, the "last resort" is known as "exploratory surgery." No one wants to submit themselves to an invasive and expensive surgery in hopes that the surgery will yield an answer that was not visible through all other methods, yet the "dig and hope" approach has been the norm in the geophysical world. This is especially true when trying to characterize subsurface water flows. Wells are routinely drilled with no attempt to determine the subsurface geologic conditions through more modern, non-invasive geophysical methods.

  It is difficult to imagine how great the value would be if one were to arrive at work each morning and immediately open a window on the screen that enables you to see the most current state of the subsurface water flows in much the same way a dam owner might look out the window to see how high the dam has risen.

If wells, cut-off walls, or grout curtains are required, the time to take action is only after the initial geophysical reconnaissance is completed, so the remediation efforts occur in the right place, using the right methodology, early enough to prevent damage to assets.

2. Willowstick Technology

2.1 What is Willowstick technology?

Willowstick Technology is comprised of a series of hardware and software innovations that map, model, and predict groundwater paths and patterns. The hardware components of the technology are embodied in the Willowstick Instrument, which enables skilled technicians to collect a series of readings of the magnetic field produced by the distribution of electric current. The readings can be collected on land, on water, on the surface, or at depth or anywhere between. The electric current we use to establish the circuit is 0.3-1.7 amps. At this level of current the highly sensitive instruments are able to identify our unique signal and map the data.

Figure 2 illustrates a typical Willowstick configuration designed to identify and track groundwater flow paths through a dam. Our data scientists, geologists, and geophysicists use the magnetic field data collected by our instruments to create 2D and 3D images of the subsurface water flow paths. As part of the investigation process, the Willowstick Instrument collects tens of thousands, or in some cases, hundreds of thousands of data points. They are used to create images of the subsurface electric current flow paths. Willowstick analysts use our proprietary inversion algorithms to render 3D models of subsurface groundwater flow patterns. These models form the basis for the predictive analytics we make to produce the final report for our customers. Our Final Report is the work product delivered at the conclusion of each project. It includes maps, models, predictions as well as an analysis of the subsurface situation. Most importantly, the reports contain specific recommendations and location coordinates (latitude, longitude, and depth) for remediation measures and ongoing monitoring efforts.

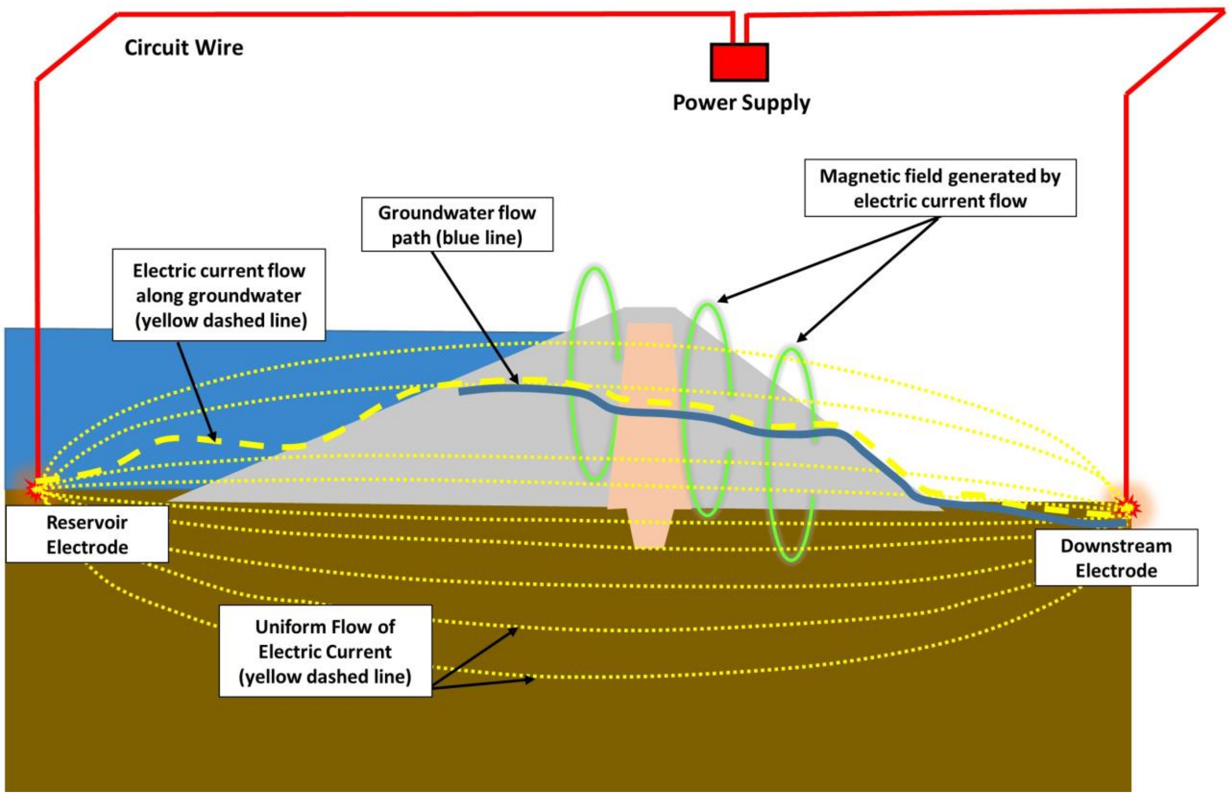

Figure 2—Typical Willowstick Configuration to Detect Dam Seepage

2.2 How was Willowstick developed?

The Willowstick Method was created when Dr. Jerry Montgomery, working as chief geophysicist for a large mining company, was trying to track a deep lead vein located below a conductive shale layer. His efforts to use traditional resistivity techniques proved ineffective because the electric current could not penetrate the conductive shale layer.

He discovered that by placing an electrode in a drill hole bored through the conductive shale layer into the lead layer, and placing a second electrode some distance away from the first, he could energize the two electrodes, create a magnetic field, and measure the field at the surface. He was then able to use the magnetic data generated to track the thickness of the lead zone. He discovered that while the conductive shale layer interfered with his electrical signal, the magnetic field generated by the electric current flow through the lead was unaffected by the overlying layer of shale.

Several years later, while working for the U.S. Bureau of Mines, Dr. Montgomery faced a complex problem that caused him to reexamine his earlier insights. The Bureau needed to identify preferential groundwater flow paths through mine spoils at the Midnight Mine in the State of Washington. They tried several geophysical technologies including traditional resistivity and EM techniques, but were unable to accurately characterize the groundwater flow paths. The Bureau of Mines also tried drilling a number of bore holes (observation wells) to determine preferential flow, but this also proved to be too costly and offered little chance of success.

Remembering the magnetic technology he had utilized earlier, Dr. Montgomery decided that he could enhance his technology to enable it to track groundwater. His experiment involved injecting an alternating electric current directly into the groundwater of interest, with electrodes placed at two ends of the known or suspected water body's extent, and then measuring and recording the magnetic field produced from the flow of electric current through the targeted groundwater.

The application of the new technology at the WellPoint Mine proved highly successful. The results were documented in a Bureau of Mines Report[1] of Investigation in 1996:

- The survey at the Midnight Mine successfully mapped several acidic water seeps back to their source
- The recharge from drawdown effects of a well were successfully identified and mapped using the new technology
- Hydrologists verified that the groundwater maps developed from the new geophysical data provided the correct preferential flow paths of the mine's groundwater in the spoils
- Results of the innovation were verified through data from existing wells and proactively drilling supplementary wells were based on Dr. Montgomery's methodology

The innovative technology represented a totally new concept for all scientists that needed to map groundwater paths. When Congress closed the Bureau of Mines, they gave Dr. Montgomery the option to pursue the patent process privately. Shortly thereafter he filed for a process patent for his innovation. Several years later a patent was granted, U.S. Patent No. 8,688,423 B2. Since that time other technology patents have been filed and are pending with the U.S. Patent and Trademark office. The patent and all rights pertaining to it were acquired when Willowstick Technologies was formed in 2004.

2.3 From prototype to mainstream

During the late 1990s, Dr. Montgomery continued the technology's development and protocols for performing groundwater investigations. In late 2000 he joined forces with a mid-sized engineering consulting firm and worked under their auspices for three and a half years. In the spring of 2004 a new company was formed, Willowstick Technologies, LLC, created under AMP Capital Partners.

[1]Williams B. C., J. A. Riley, J. R. Montgomery, and J. A. Robinson, Hydrologic and geophysical studies at Midnite Mine, Wellpinit, WA: Summary of 1995 field season, *U.S. Bureau of Mines Report of Investigations R19607*, 1996

The Willowstick Technology is now in its 8^{th} generation of development. Since 2004 a number of important enhancements to the Willowstick Technology have significantly improved its reach, accuracy, and reliability:

- The instrument was meticulously redesigned to reduce interference, eliminate data collection errors, and optimize accuracy in unstable environments
- Willowstick generated a series of proprietary software programs that render models of the data including the Ratio Response Map and the Electric Current Distribution map (see Figure 3 on page 12)
- Willowstick created a series of inversion algorithms that render the magnetic field data in 3D
- Cutting edge advancements were made to articulate mapped results in the form of volume data (3D views of the subsurface) revealing the distribution of electric current flow
- Willowstick added GPS technology as well as positioning chips to improve replication from one survey to the next

While the technology has matured, become much more sensitive to faint signals, and is now accompanied by a wide variety of software and hardware innovations, Dr. Montgomery's breakthrough proved the efficacy of using the magnetic waves generated by electrical current to penetrate all types of subsurface terrain and in the process characterize subsurface water flows with an amazing degree of accuracy.

2.4 Does Willowstick really work?

The short answer is, "Of course." Willowstick has successfully completed over 230 projects, each of which affirms the efficacy of the methodology. The technology is based on the application of scientific principles that have been understood for decades and which have already been successfully employed in many other industries such as medicine, computing, and transportation. Over 75% of Willowstick projects are with existing clients, so they have obviously been pleased with previous results. After examining the results of previous studies, our clients have often identified additional areas that need to be characterized. As more customers become interested in managing their hydrology assets, we have seen an increase in studies requesting us to provide an update to a project performed in previous years. In this circumstance they want us to use the precise electrode configuration that was used previously and take readings with identical parameters in order to compare the model of their subsurface water flows today to the flows a year or two ago. In order to effectively manage groundwater assets it is necessary to compare results over multiple periods of time.

To understand the Willowstick approach it is essential to have a basic idea of the physics involved in the methodology. Willowstick is an innovative hardware and software combination, which utilizes known geophysical laws and scientific principles. They are not a black box with something magic inside. Magnetic imaging has become the mainstream methodology in medicine to see and image anything that happens under the skin. The principles of electricity and magnetism employed by Willowstick have been known for decades. We have implemented them in a creative manner that has caused one patent to be granted already and another is pending.

The beauty of applying scientific principles to the study of subsurface water flow paths and patterns is that these principles provide a baseline against which readings and measurements can be compared. Scientific principles are consistent; they do not change from one day to the next. They can be used to calculate the precise strength of an expected magnetic field distribution in a homogenous subsurface such as that presented by earthen materials. When precise instruments measure the strength of magnetic fields through hundreds of thousands of readings, anomalies can quickly surface that affirm the existence of an unanticipated event, taking place beneath the surface. Since the science cannot be called into question the unexpected event must be worthy of further investigation. Most often aberrations in current density are caused by the presence or absence of water. Willowstick analysts use unexpected results to identify patterns and interpret the results.

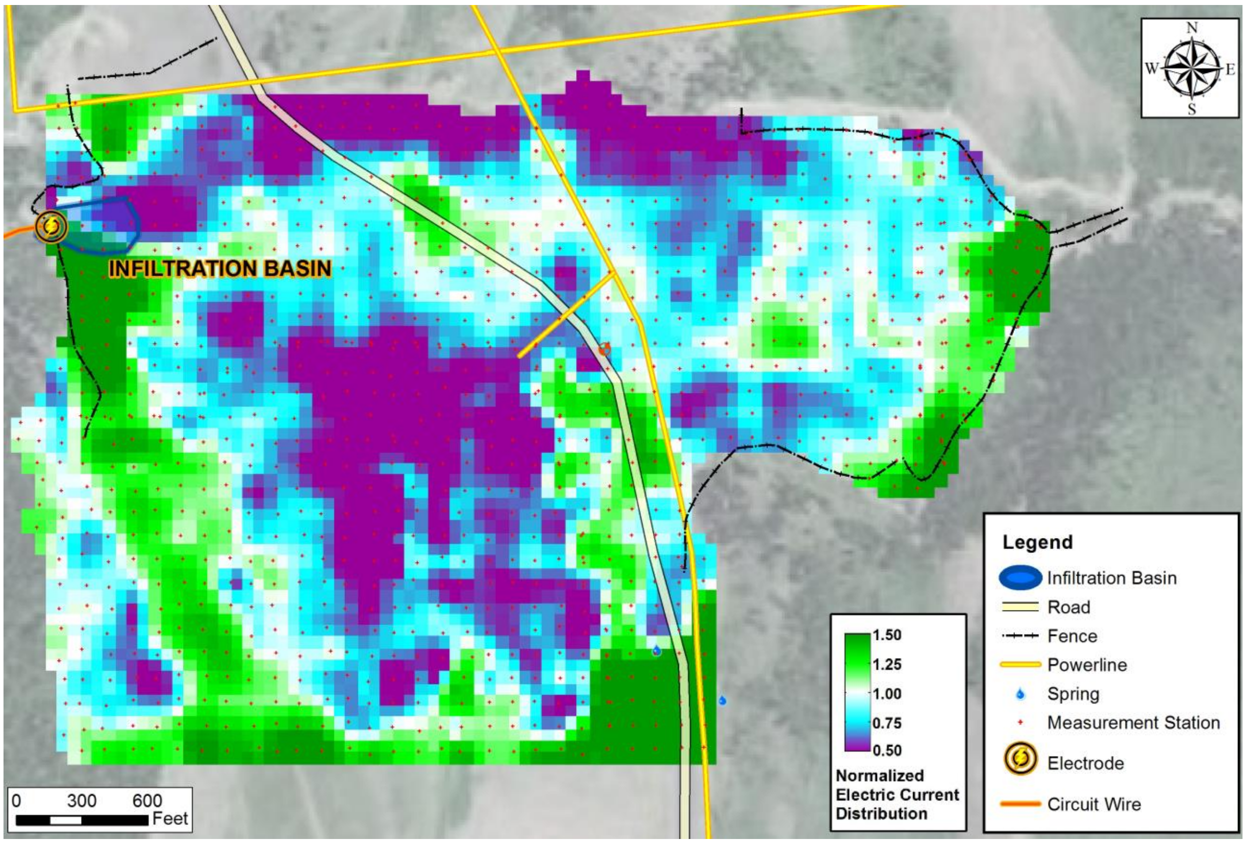

Figure 3- Electric Current Distribution Model
(Elevation slice taken below the surface at a mine site)

Within the next decade, magnetic imaging and characterization of subsurface water flow paths and patterns will have the same revolutionary impact in geophysics that it has had in medicine over the previous three decades. Technology is progressing at such a rate that it will one day be possible to look under our feet and see water flow paths with almost as much certainty as we can see by looking at water on other planets.

It is impossible to even dream of all the benefits to geologists, engineers, asset owners, hydrologists, and geophysicists if they were able to virtually peel back hundreds of meters to observe what is taking place in the subsurface. When this ability becomes possible, even commonplace, thousands of engineers who are uncomfortable making important decisions with little or no data will finally be able to sleep at night. We may even reach a situation similar to medicine wherein doctors share "war stories" about the old days before MRI, Angiograms, and CT scans when they had to make life and death decisions based on little or no hard data. Progress in finding and managing the flow of water is an absolute precondition to continued expansion of the human race. Water is unique in the sense that it may be the only substance that can be as important in its absence as in its presence.

Predicting where the groundwater *might* be

Historically the most rigorous methods of characterizing and delineating subsurface features such as preferential water flow paths have been by direct observation or antiquated subsurface methodologies. Although these approaches can be effective in isolated cases, they are unreliable since they often yield a limited set of data from which broad interpolations and extrapolations must be made. Too often critical decisions are based on interpolations that fail to depict significant changes that can occur rapidly in the subsurface, often from events such as seismic or weather activity.

Water may be the only substance that can be as important in its absence as in its presence

In other industries such as medicine, there would be extensive testing, image creation, modeling, and statistical analyses before any invasive treatment is undertaken. But in hydrogeology, a well-accepted industry practice is to drill holes in a seemingly arbitrary manner hoping to find groundwater flow paths and then implement expensive remediation measures without any definitive analysis of what is really taking place under the surface. No wonder so many questions go unanswered, for example:

- Is the remediation solution performing effectively?
- Was the solution located correctly?
- Did the remediation neglect other hidden groundwater issues?
- Has the remediation effort caused any unintended consequences?

Discovering where the groundwater *actually is*

Willowstick's unique technology tells you where groundwater flows actually are with unassailable 3D images that provide certainty, which leads to quick and decisive corrective actions.

The Willowstick Technology is an innovative, patented, geophysical technology process specifically designed to map, model, and predict preferential groundwater flow paths ***in a non-invasive manner with no detrimental impact to the environment.***

Using technology similar to an angiogram that enables medical professionals to "see" flow paths of blood inside the human body, the Willowstick method is able to quickly render 2D images and 3D slices of subsurface water flows thereby illuminating preferential flow paths

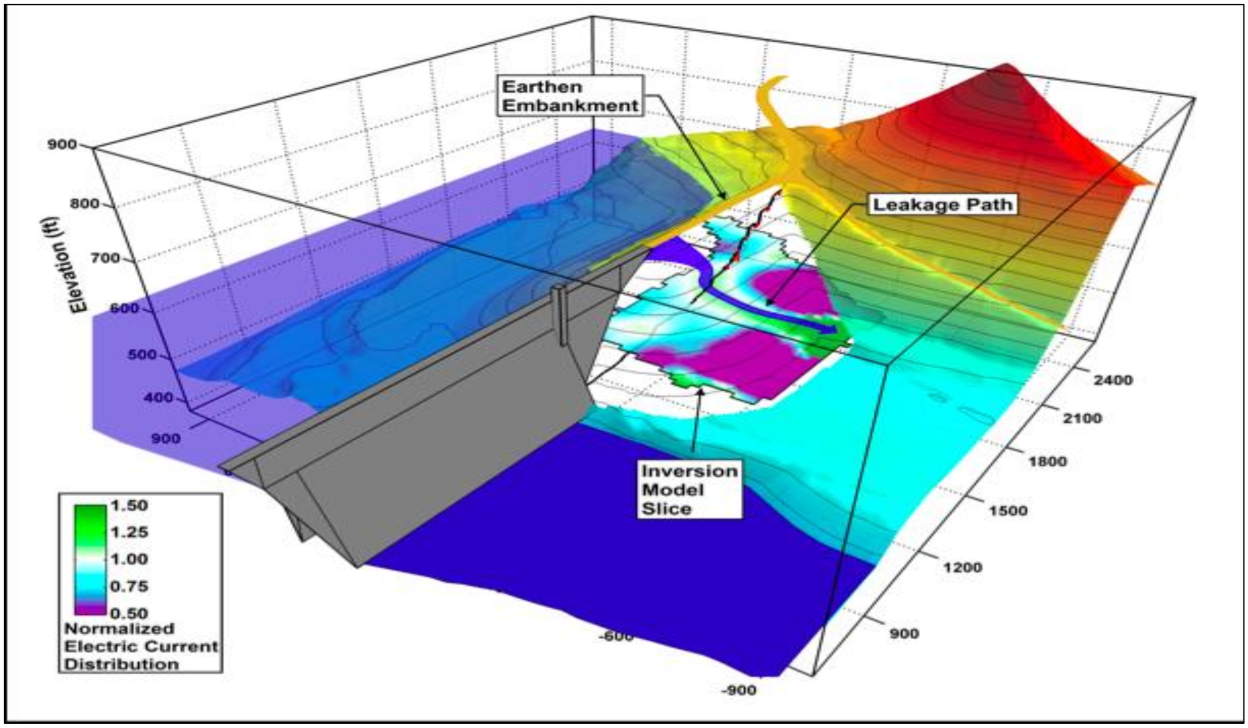

Figure – 4 Sample 3D Electric Current Distribution Model

The Willowstick Instrument is used to measure subtle changes in the magnetic field associated with subsurface electric current flow. It is capable of detecting the magnetic field produced by as little as 1/10th of an amp from up to a mile away. The instrument is attached to a surveyor's pole and hand-carried to each measurement station as defined by the size of the grid in question and specified by GPS coordinates.

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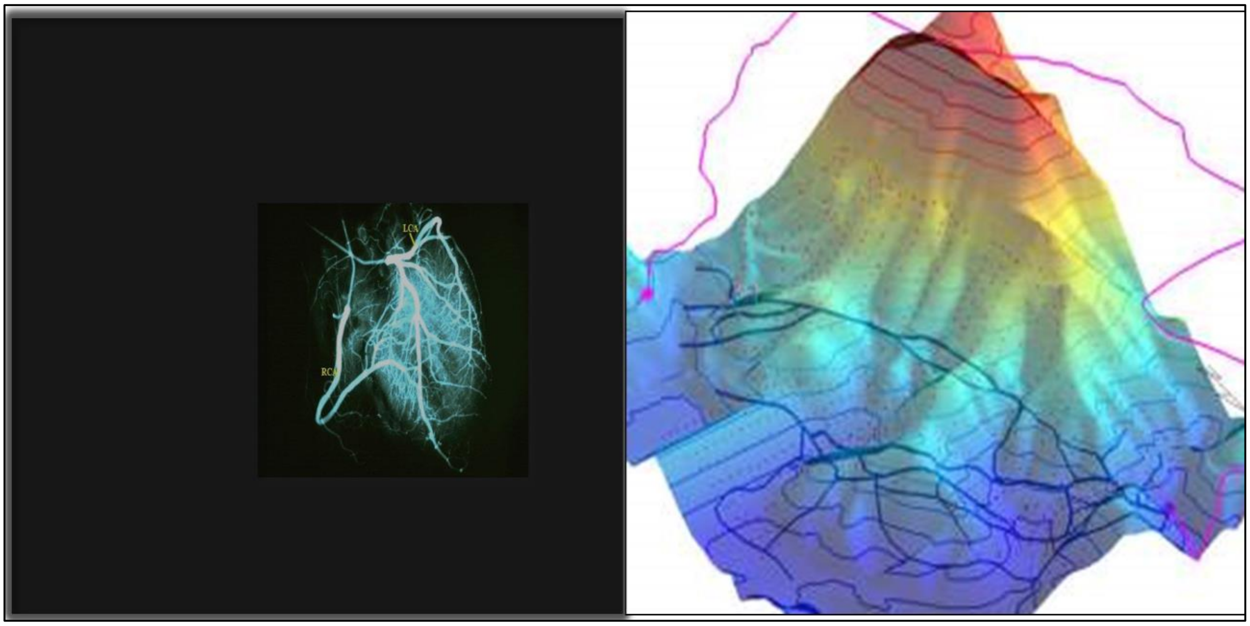

Figure 5 - Comparison of Magnetic Methods to Identify Subsurface Patterns Non-invasively

2.5 Unique aspects of Willowstick technology

Although the Willowstick method evolved from other electric and magnetics-based technologies, several differences are important to understand.

Briefly, the Willowstick methodology is specifically designed for mapping groundwater.

The method involves placing electrodes in direct contact with the groundwater to create an alternating current (AC) electric circuit that follows the groundwater's natural course.

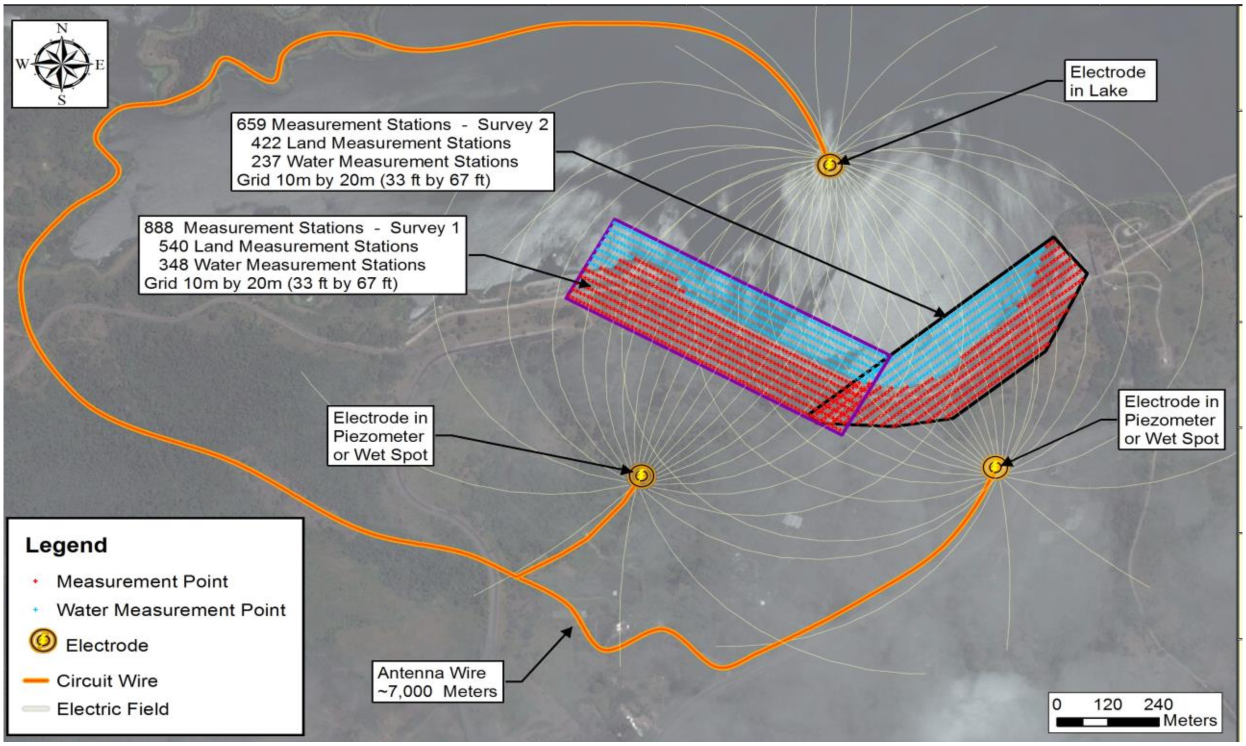

Figure 6 - Sample Layout of Two Surveys with Three Electrodes (two on land and one in the reservoir), the Circuit Wire, the Measurement Grid, and the Magnetic Field

A specific signature frequency is often used, 380 Hz, that avoids the harmonics of the power frequencies in common use around the world. With adherence to the Biot-Savart Law (that precisely describes how magnetic fields are generated by electric currents), the distribution and relative density of subsurface electric current flow can be mapped by carefully measuring the intensity of the magnetic field along predefined points on a grid.

Measured data is processed and compared to the expected magnetic field from a theoretically homogeneous model to highlight the deviations from the "uniform" model.

Finally, we generate 2D and 3D maps and models to interpret and predict the enhanced definition of preferential groundwater flow paths.

This unique technology provides many advantages for mapping groundwater, such as:

- It capitalizes on the conductivity-enhancing effect of water on subsurface materials
- It targets the groundwater at specific depths by selectively injecting electric current into the water-bearing zone of interest
- The technology's signature magnetic field is not attenuated by conductive overburden
- Operating at a low frequency allows characterization of groundwater at significant depths up to 300m (1000ft)

- It highlights conductive zones and can also detect outer surfaces or areas of non-conductive zones
- The Willowstick technology patents include unique innovations that enable recognition of extremely faint signals. The effectiveness range is an order of magnitude greater than most other EM techniques
- The density of Willowstick data is unparalleled. Readings can be taken as often as every 2.5 meters. This degree of data density produces more accurate models and leads to highly reliable conclusions rather than mere guesswork
- Electric current flow paths can be detected by their concomitant magnetic field. Our years of experience has shown these to be strong indicators of zones of highest interconnected porosity (sometimes referred to as “transport porosity”)
- The Big Data readings generated by the Willowstick instruments require the power of the most modern computing platforms since many surveys produce hundreds of thousands of data elements. Massive volumes of dense data readings are necessary to create the 3-dimensional images that Willowstick uses to detect patterns
- The distribution of electric current can be used to model (predict or infer) a qualitative distribution of hydraulic conductivity in the subsurface

2.6 Applications where the Willowstick Technology excels

The Willowstick Technology has consistently proven valuable in complex hydrogeological settings such as:

- Identifying and mapping groundwater flow paths
- Diagnosing seepage through earthen dams and levees
- Pinpointing minute leaks in freshwater and waste water pipes
- Characterizing groundwater infiltration into surface and subsurface mines
- Identifying leaks and seepage from mine tailings ponds
- Finding water bearing zones in a dry area
- Tracking pollution plumes influenced by groundwater transport
- Detecting leaks in headrace tunnels and tracking the flow of the water as it exits the tunnel
- Optimizing well placement for production and/or monitoring purposes
- Guiding drill paths to avoid aquifers
- Identifying and mapping geothermal production zones
- Delineating salt and fresh water reaction fronts
- Optimizing water flood activities in oil and gas recovery operations as well as other in-situ solution mining processes

2.7 Applications where Willowstick may not be a good fit

- Applications where groundwater in question has virtually no dissolved ions. This situation is extremely rare representing less than 1% of groundwater Willowstick has characterized

- Applications in which the requirement is to measure the volume of the water flow without regard to flow path, direction, or depth.
- Applications of steep terrain where the subsurface water flow path is several hundred meters from the surface.

2.8 Willowstick methodology compared to other geophysical methods

All geophysical technologies have applications in which they work best. Years ago, traditional geophysical methodologies were new and many gained a bad reputation. They were not ready to be adopted as broadly as they were. After 12 years and over 230 successful projects, Willowstick's unique technology is stable, reliable, and highly accurate. It differs from all other geophysical methods in two major ways.

First, it measures the intensity of magnetic fields, capitalizing on the principle that water content is the dominant factor in facilitating the conductivity of subsurface flow paths through soil and rock.

Second, by directly energizing a conductive groundwater medium with strategic electrode placement, the electric field can be targeted more effectively to "illuminate" the target of interest with little or no interference from overlying layers.

In addition to these all-encompassing differences, Willowstick is also unique in many specific ways from other electromagnetic (EM) methodologies. Here are a few relevant examples:

- **Passive methods lack sensitivity to groundwater**

  Passive methods are able to detect variations in the earth's natural fields such as gravitational, magnetic and spontaneous potential. While they have their roles, passive methods are not well suited for groundwater characterization because they lack the ability to identify and track groundwater. Even if, a passive method is able to accurately guess at the presence of groundwater flow it is still difficult to measure and interpret.

- **Active methods lack precision and are unable to collect and process the massive volume of data necessary to define precise results**

  Active geophysical methodologies transmit man-made signals such as sound waves or electric currents into the earth based upon some action taken by the person using the instrument. When man-made signals pass through, or are modified by subsurface materials, they can be measured in order to yield important information about the composition of those materials.

  Active methodologies are better suited for groundwater characterization than passive methods since they identify and track subsurface water flow. However, active techniques lack precision in their recommendations because they focus on data collection and analysis while leaving the harder job of creating models and predictive analysis undone. Since they energize a large area of the subsurface, they are forced to compute and analyze averages between disparate data sets and then to try to make sense of the earth's response. The result is a series of inconsistent responses that are difficult to interpret and not sufficiently granular to detect small changes in subsurface conditions.

- **3D seismic**

  In some instances, 3D seismic technology has proven useful in characterizing groundwater. This technique uses the propagation of sound waves through the subsurface to identify changes in material properties. This method is better suited for characterizing subsurface geologic structure rather than water flow paths and patterns, but it has been used on occasion to locate groundwater bodies.

  The significant cost of a 3D seismic interpretation and the difficulty performing surveys in steep terrain or thick vegetation has prevented 3D seismic characterizations from becoming a mainstream solution for groundwater characterization.

- **Ground penetrating radar (GPR)**

  Ground penetrating radar (GPR) has also been used to characterize groundwater. This technique uses electromagnetic wave propagation and scattering to identify changes in electrical properties. This technique can be very accurate when used in the right way. However, depth resolution is only viable for a few meters, and the process is so time consuming that it is not practical for covering large areas.

- **DC resistivity and electromagnetic (EM)**

  Electrical methods such as DC resistivity and electromagnetic (EM) are commonly used for groundwater characterization. Both methods energize the subsurface volume as a whole and require non-conductive overburden to achieve good penetration and signal fidelity. Of course the common drawback of these methodologies is that they both rely on computing averages from many number signals that have traveled through a large volume of subsurface material. Any possible conclusion is imprecise and so nebulous that it does not instill sufficient confidence to undertake a more expensive investigation. Practically everyone in the industry can share one or multiple horror stories of projects that went off the tracks due to correct but imprecise data generated from resistivity studies. Of course, if these methodologies are applied in environments with surface water or in the presence of a highly conductive culture, the averages they rely upon become especially flawed. Since resistivity is generally a less expensive solution than magnetic wave imaging, many groups seeking to characterize groundwater flow paths often try resistivity before they come back to us for a solution that is more accurate and in the end costs less.

- **Drilling Wells and Logging Results**

  The most common and accepted method for characterizing groundwater is by direct measurement, which usually involves well drilling and logging.

A drawback to well logs is they fail to reveal more information than what is immediately in or around the drill hole

In order to fully characterize a site, a significant number of drill holes are normally required. Even then, a tracer solution or some other geophysical continuity test is often used to establish linkage between drill holes. While drilling is a perfectly viable approach, it is certain to be costly. Since the number of wells necessary is impossible to predict, the costs are not predictable before the drilling process begins. A much better approach is to use a reliable geophysical technique, create a reliable image of the subsurface, and then use the insight gleaned from the reliable methodology to determine the precise number and location of wells to be drilled.

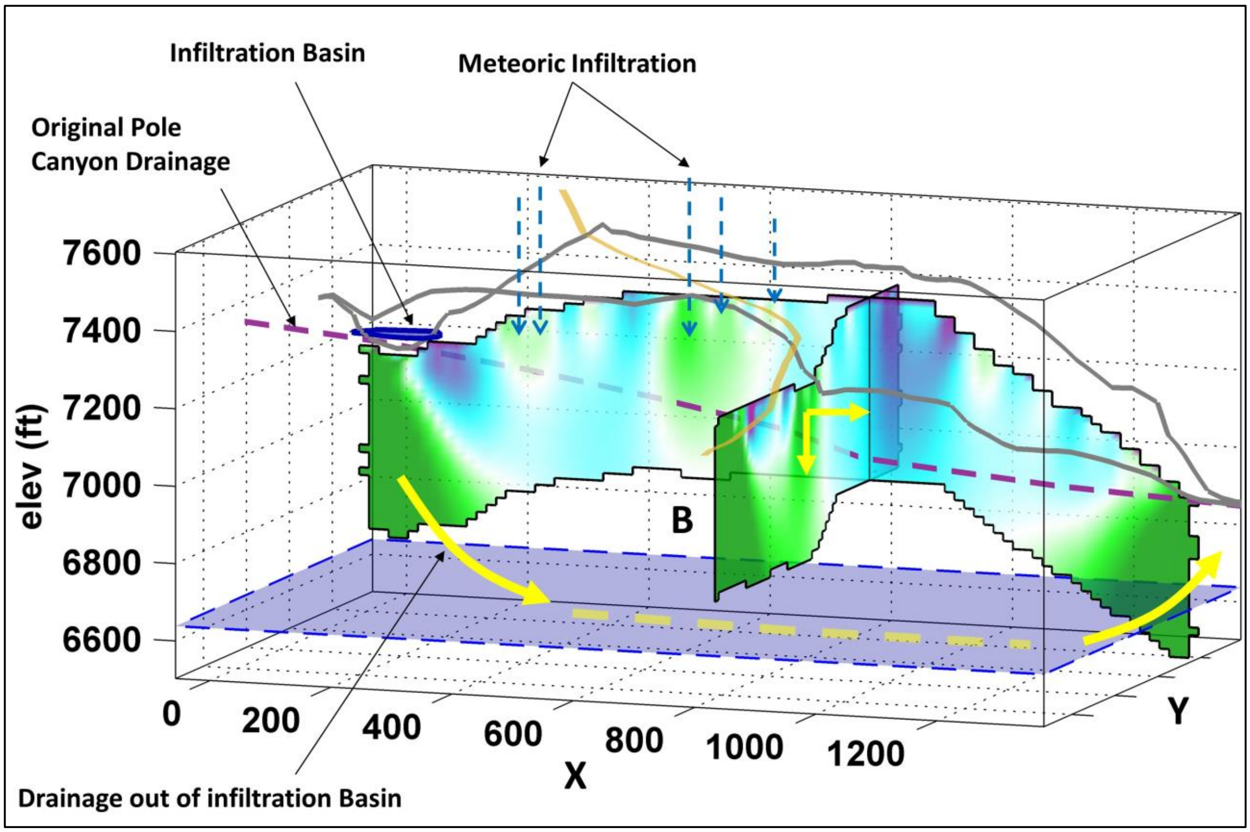

Figure 7 - 3D Data Highlights the Pattern

Summary

Modeling and interpretation of electric current flow distribution through the subsurface is a powerful tool for characterizing groundwater flow paths in most geologic settings. It is based upon widely 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 errors in the data collection, data reduction/normalization, modeling and interpretive process.

The Willowstick survey method is intended to provide a quick and accurate characterization of groundwater conditions. The technology is a means to guide traditional exploratory work and noninvasively arrive at conclusive answers about specific groundwater issues.

A Willowstick survey is particularly useful in helping identify and confirm groundwater flow path locations. The results obtained from a Willowstick geophysical investigation should be used in conjunction with all known information at a site to make the most informed decisions regarding the best approach to monitor and remediate groundwater problems.