

CHARACTERIZING GROUNDWATER USING CONTROLLED SOURCE AUDIO FREQUENCY DOMAIN MAGNETICS

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Abstract

Traditional methods for determining the potential flow paths of subsurface pollution require extensive drilling—a time-consuming process which results in significant expense and environmental trauma. The minimally invasive imaging procedure detailed in this presentation generates accurate groundwater maps and models but requires significantly less drilling. As a result, this method entails fewer costs in terms of time, money and ecological disruption. Initial case studies indicate that this procedure may be particularly well suited to the task of environmental remediation.

This procedure relies on the principles of Controlled Source - Audio Frequency Domain Magnetism (CS-AFDM). First, electrodes charge the groundwater in question with a low voltage electrical current.

As the current passes through the water between the electrodes, it emits a magnetic field whose size, shape, magnitude and direction are characteristic of the surrounding aqueous system (Biot-Savart Law).

This field is then read at the surface by a specially tuned receiver, ultimately resulting in maps and models that indicate the attributes of the subsurface water network, including potential flow paths.

Introduction

Characterizing and mapping groundwater are both difficult tasks that have proven to be costly and unreliable in the past. However, there is a great need across many different types of industries to provide reliable information with respect to where groundwater is and how it travels through the subsurface.

Such was the case with a major crude oil producer and a client of Willowstick Technologies. For purposes of this paper, and to protect the client, they shall hereafter be known as XYZ, Inc. (XYZ). As part of an elaborate crude oil extraction system, which used water as a part of that process, a significant amount of waste water was generated that contained high amounts of salts and minerals. XYZ has a permit to inject this saline water back into mother earth in a specific formation, but has the responsibility to monitor and track where the plume extends in the subsurface. As a result, XYZ contracted Willowstick Technologies to perform a survey using its patented geophysical technology called AquaTrack™.

The Technology

The AquaTrack geophysical technology uses Controlled Source – Audio Frequency Domain Magnetism (CS-AFDM). CS-AFDM utilizes a low voltage, low amperage audio frequency electrical current to energize the groundwater of interest. Electrodes are placed in strategic locations to facilitate contact with the groundwater. Following the best available conductor, the electrical current concentrates in highly saturated zones; and, for a given porosity or level of saturation, it concentrates to a greater extent in areas of higher Total Dissolved Solids (TDS) or higher ion content between the energizing electrodes. As the electrical current takes various paths through the area of investigation, it creates a magnetic field (Biot-Savart law) characteristic of the injected electrical current. This unique magnetic field is identified and surveyed from the surface using three highly sensitive coils. The locations of field measurement stations are identified using a Global Positioning System (GPS) unit, and they are recorded

in a data logger along with the magnetic field readings. The measured magnetic field data are then processed, contoured, and interpreted in conjunction with other hydrogeologic data, resulting in enhanced definition of the extent of subsurface water saturation in the vicinity of the study area.

The equipment used to measure the magnetic field induced by electrical current flowing through the groundwater includes: three magnetic sensors oriented in the orthogonal directions (x, y, and z); a Campbell Scientific CR1000 data logger used to collect, filter and process the sensor data; a Global Positioning System (GPS) instrument used to spatially define the field measurements; and a Windows-based, Allegro CE handheld computer to couple and store the GPS data with the magnetic field data. This equipment is mounted on a surveyor's pole and hand carried to each measuring station.



Figure 1 - Field Crew taking magnetic readings using CS-FDM equipment. GPS, Handheld computer, and data logger all shown.

For quality control, a base station is established within the survey area, and base station measurements are taken at the beginning, midpoint and end of each field day. The base data are used to identify any changes in the background magnetic field and/or diurnal drift. Also, at each measurement station, the Campbell Scientific CR1000 calculates the 400-Hertz magnetic field strength which is measured for a sufficient length of time to assure measurement repeatability and validity and compares the signal to the background or ambient magnetic

field strength at numerous frequencies. These data are compared to pre-determined signal

quality criteria and signal to noise ratio criteria to establish data quality and repeatability.

The field data are processed and corrected to account for distance from the source electrode, to reduce the effects of antenna interference and to remove the effects caused by ambient and shallow subsurface sources, if necessary. The processed and corrected data (reduced data) are used to generate contour maps of the induced magnetic field. The CS-FDM data when combined and correlated with known geologic and hydrologic information helps provide the best possible insight to groundwater flow paths and areas of concentration.

Once the field data has been reduced, natural and manmade interferences must then be accounted for. If unknown, these interferences can often be recognized by their specific signature signals in the data, especially by analyzing the vertical field data in conjunction with the horizontal data. Once recognized, these features can be accounted for, corrected, and/or removed from the final reduced data set.

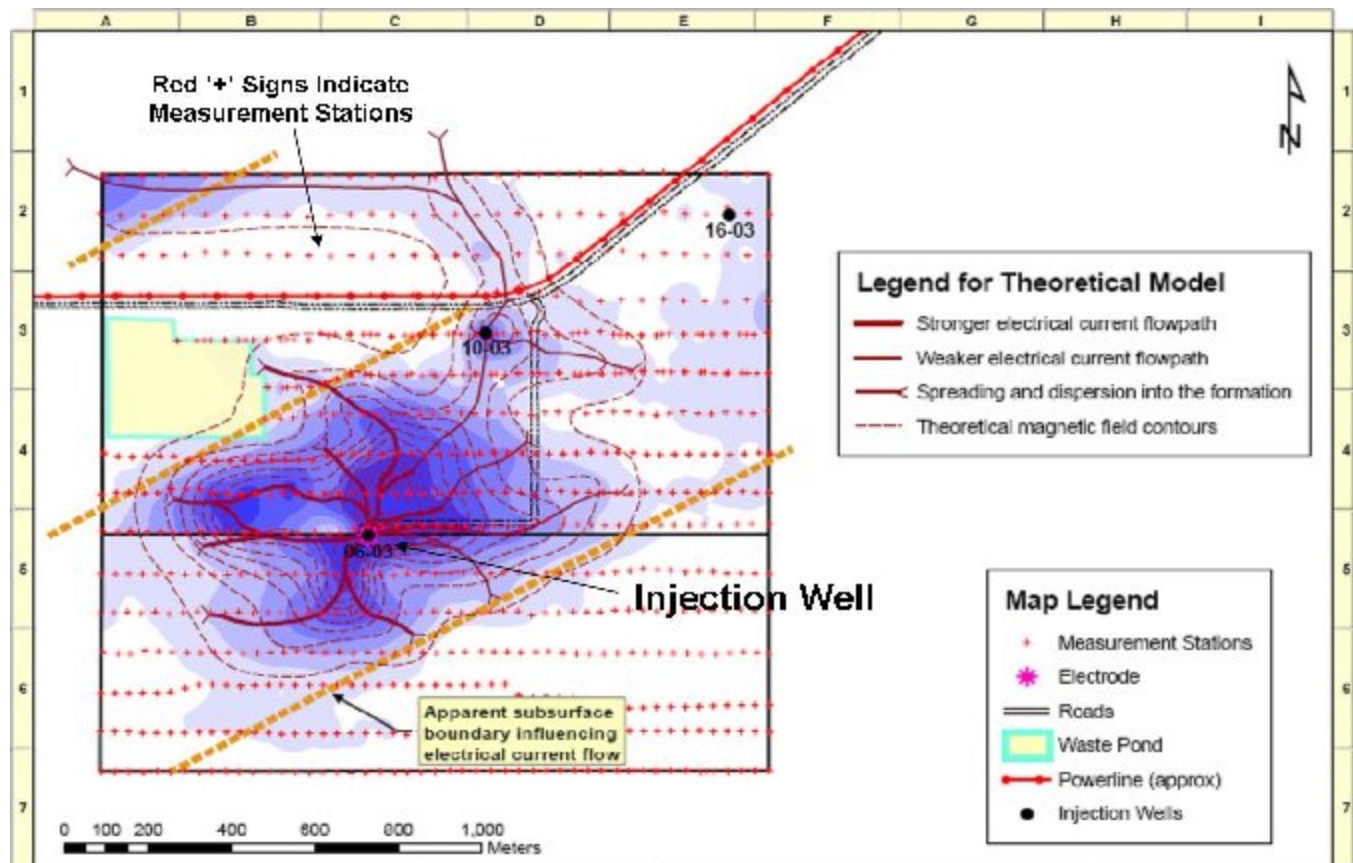


Figure 2 - Magnetic Field Contour Map

The Project

The area of investigation covered an area of roughly 1,600 meters by 1,600 meters (2.5 square kilometers). The fieldwork was completed within a four week period of time under extreme cold weather temperatures. Two horizontal dipole antenna/electrode configurations were employed to energize the subsurface study area. This configuration was designed to investigate the influence high TDS wastewater is having on the formation where the water is being injected, in all directions, out and away from the injection well.

The overall approach to the fieldwork included injecting and driving an electrical current between paired electrodes to determine where electrical current flows and concentrates in the subsurface formation. A 2-amp, 110-volt, AC current with a specific signature frequency (400 Hertz) was applied to the paired electrodes. These electrodes were lowered down hole in contact with the groundwater in the formation. The resulting alternating current, flowing between the paired electrodes, followed and concentrated in the preferential flow paths beneath in the ground. As the electrical current flowed through the subsurface, it generated a recognizable magnetic field that was measured and recorded from the surface of the ground.

Approximately 1,000 magnetic field measurements were obtained from the survey. These measurement stations were established on lines spaced 100 meters apart with measurements taken on

each line at roughly 33 meter intervals (these distances varied slightly depending upon terrain), resulting in an approximate 100 meter by 33 meter grid covering the entire study site. Some measurement stations were occupied twice (two separate surveys were conducted) to provide an overlap between the two survey configurations for quality control and comparison purposes. The X, Y, and Z coordinates of each measurement station were recorded as part of the field work. These spatial locations are critical to data processing, data comparison and interpretation.

The Results

The magnetic field map or “footprint” map of the conductive highs and lows indicates conductive highs (dark blue) and conductive lows (light blue) beneath the study area. Also shown in the map are a number of cultural influences in the data, such as pipelines and power lines, which were removed before the final interpretation was made.

The very strong contrast between areas of high electrical conductance (current concentration or flow) and areas of low electrical conductance are interpreted as areas where injected wastewater (high in TDS levels) is likely concentrating in the subsurface south of the injection well. An important point of interest observed in this particular magnetic field data is the sharp drop-off of concentrated electrical current flow in the southern reaches of the study area.

The map shows the results of the two CS-FDM surveys, which were overlapped for quality control and comparison purposes. The overlapped portions of the data sets match very closely, with the exception of some dissimilarity caused by the different current biases dictated by antenna / electrode configuration. The complementary information between the two data sets generates a high level of confidence with the resulting antenna / electrode configurations as well as the measured and recorded data, and final interpretation.

The information shown in the map effectively characterizes elevated TDS groundwater levels and/or highly permeable zones where injected TDS wastewater is likely to concentrate and flow. The maps, report and figures provided herein are provided to meet the stated objective of the CS-FDM investigation—to map preferential flow paths out and away from the injection well in an effort to help characterize the influence that high TDS disposal wastewater is having on the subsurface formation, which was located about 350 to 450 meters below the ground surface.

Conclusion

This case study demonstrates the effectiveness of the CS-FDM technology in effectively characterizing plumes of groundwater that contain high ion content or high levels of TDS. Of note, was the technologies ability to see the edges or front of the plume. XYZ, Inc is currently contemplating the use of the technology a second time in order to plot the changes in the plume over time.

Perhaps the most intriguing insight from this case study is the fact that CS-FDM, coupled with other geophysical information as well as thorough collaboration with the client, information was gathered that far exceed that which could have been obtained using stand alone methods or an expensive drilling program. The conclusion therefore, is that CS-FDM can potentially offer groundwater professionals an additional tool to help them simplify complex problems and reduce their costs at the same time.

References

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