Integrity Assessment of a Tailings Storage Facility Characterized with the Willowstick Method

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Abstract

To ensure long term stability of a tailings storage facility (TSF) and impounding earthen embankment which has entered the end of life closure phase, a Willowstick geophysical groundwater seepage investigation was conducted to characterize problematic groundwater flow paths into and out of the TSF. Previous studies yielded mixed results and were unsuccessful in identifying groundwater flow paths and patterns infiltrating the impoundment as well as preferential seepage flow paths escaping the impoundment. This paper will discuss the application of the Willowstick method and the results of the investigation to help the Client determine targeted remediation efforts for successful closure.

Keywords: Targeted Remediation, Groundwater Flow Paths, Seepage, Willowstick, Geophysical Method

Introduction

One of the greatest challenges facing the mining industry, with regard to active mining practices and eventual mine closure, is the long-term liability involved in requirements to monitor and protect groundwater. Groundwater quality can be a perpetual concern and understanding the source, location and distribution of groundwater into and through tailings structures is becoming increasingly more important for the successful operation and eventual closure of the TSF. This paper considers a high-speed, minimally invasive mapping technology called the Willowstick Method. This method has been specifically designed for mapping preferential flow paths or areas of highest interconnected porosity (transport porosity) within the subsurface. The method has proven effective in delineating and characterising subsurface aqueous systems in many complex hydrogeologic settings for numerous mining clients in a variety of applications.

Willowstick Method Overview

The Willowstick Method is a unique application of magnetometric resistivity (MMR) (Jessop, Jardani, Revil and Kofoed, 2018). Most earthen materials are fundamentally electrical insulators with electrical conductivities ranging between 10^{-12} and 10^{-17} S/m. Yet in situ measurements of electrical conductivities range from 10^{-1} to 10^{-8} S/m, which is many orders of magnitude higher. This discrepancy is due to the conduction of electric current by way of ions dissolved in the groundwater. After determining the groundwater of interest, 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. A specific signature frequency is used, 380 Hz, which avoids the harmonics of the power frequencies that are in common use around the world. With adherence to the Biot-Savart Law, which precisely describes how magnetic fields are generated by electric currents, the distribution of subsurface electric current flow can be mapped by carefully measuring the magnetic field with a portable instrument that has been designed for this purpose.

Figure 1 shows an illustration of the instrument, which is hand-carried to

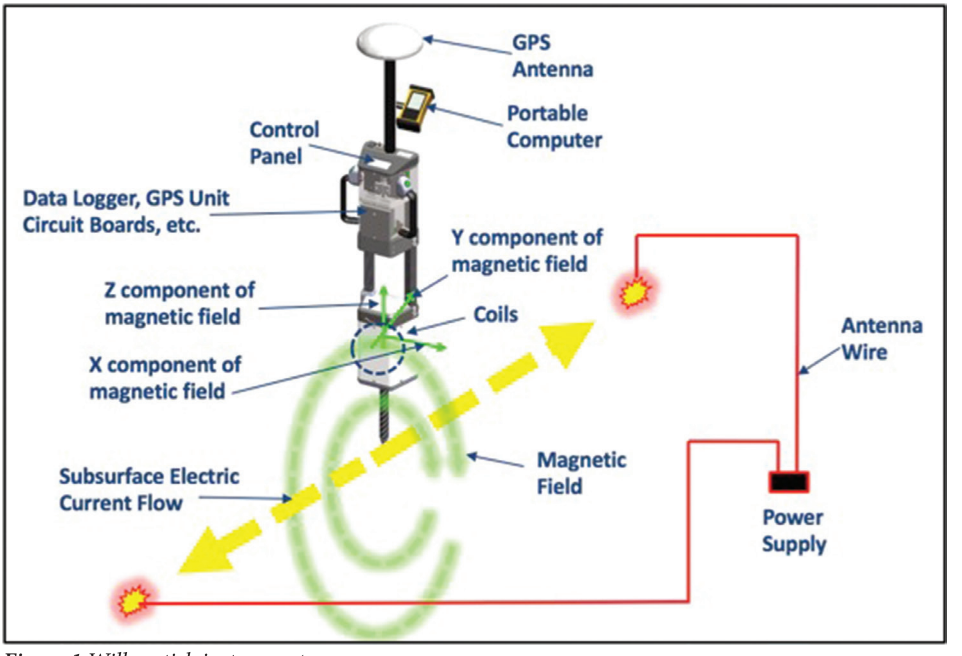

Figure 1 *Willowstick instrument*

each measurement station. The principle components of the instrument are a magnetic field receiver, a global positioning system (GPS) and a handheld computer. The magnetometer consists of three coils arranged orthogonally. The magnetic coils are high-inductance and yet compact due to a proprietary design. The inductance of each coil is approximately 90 Henries. The size is about 5.7 cm in length and 3.8 cm in diameter. As a critical element to data processing, measurement station coordinates are obtained from the GPS and recorded with the magnetic field data. These magnetic field components are then measured at numerous stations to define the electric current's subsurface distribution and flow patterns. Magnetic field data is processed and compared to the predicted magnetic field from a theoretical homogenous earth model to highlight the deviations from the uniform model. Finally, magnetic field contour maps and inversion models are created and interpreted in conjunction with other hydrogeologic data to provide enhanced definition of preferential groundwater flow paths.

Similar to an angiogram, which uses radioactive dye as a contrast agent to image and visualise the flow of blood through the human body, the Willowstick Method uses a signature electric current as a contrast agent to image and visualise the location of water through the subsurface (Figure 2). The application of the methodology is based on the principle that, as a general rule, water infiltrating and flowing through mine workings substantially increases the conductivity of the earthen materials through which it flows.

Case Study

Background

As part of TSF closure operations, the mine owner in Mexico has actively monitored groundwater conditions in and around the TSF. Water monitoring and treatment is frequently part of these TSF closure plans (Lottermoser, 2012). In 2019, the mine owner contracted Willowstick Technologies to help characterize preferential groundwater flow in and out of the tailings impoundment with the expectation that the results would improve future monitoring and possibly help the owner identify remediation measures.

Approach to the Work – Six study areas were conducted on the Tailings Dam to bias electric current perpendicular to each study

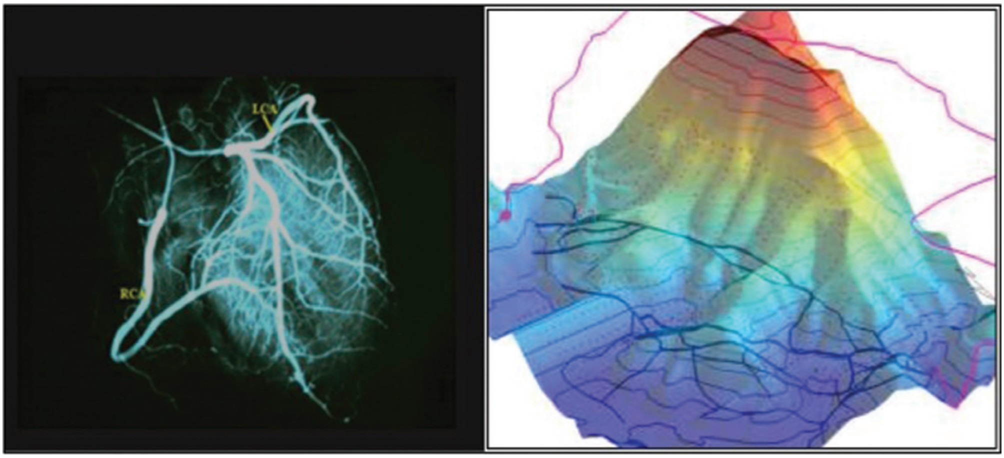

Figure 2 *Angiogram (left) and Willowstick Method (right)*

area. These six study areas resulted in six surveys named Survey 1 through Survey 6 for simplicity. Surveys 1 and 2 and part of Survey 3 covered the eastern embankment of the tailings storage facility (TSF). Surveys 4 and part of Survey 3 included the southern embankment of the TSF. Surveys 5 and 6 covered the western embankment of the TSF. Due to access restrictions, a survey of the northern abutment of the TSF against the mountain was not part of the investigation.

Each survey had measurement stations on a 15m by 15m grid. The grid spacing was adequate to obtain sufficient details and resolution for identifying preferential electric current flow paths. The field work took a total of 7 days to complete and the total size of the surveyed area was 75,000 square meters. Figure 3 shows the survey layouts conducted at the Mexico Tailings Dam. For illustration purposes, we will focus our results on Survey 4 only.

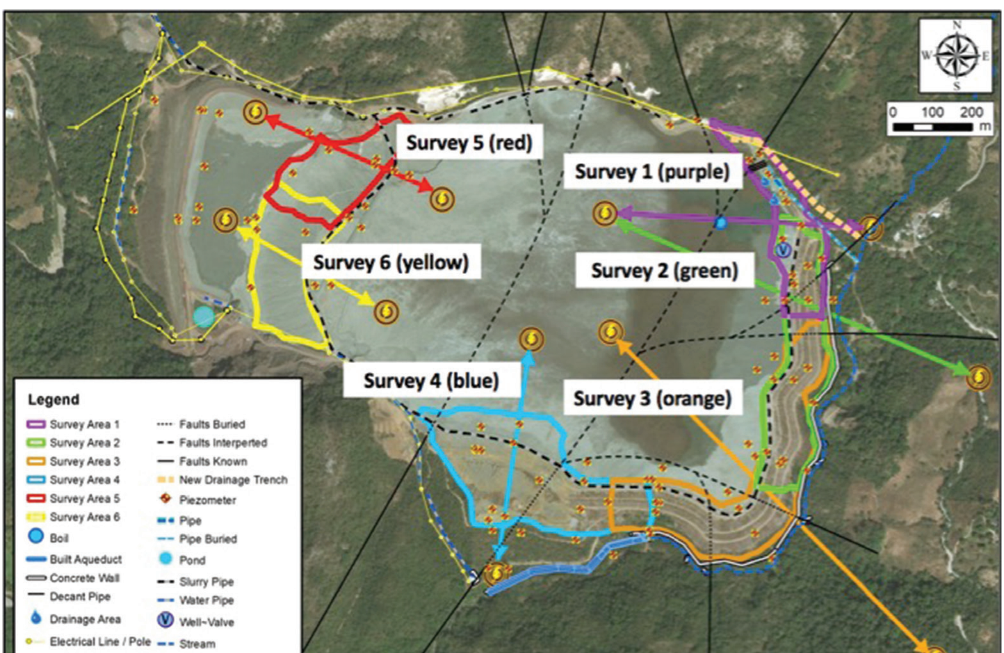

Figure 3 *Survey Layouts (Plan View)*

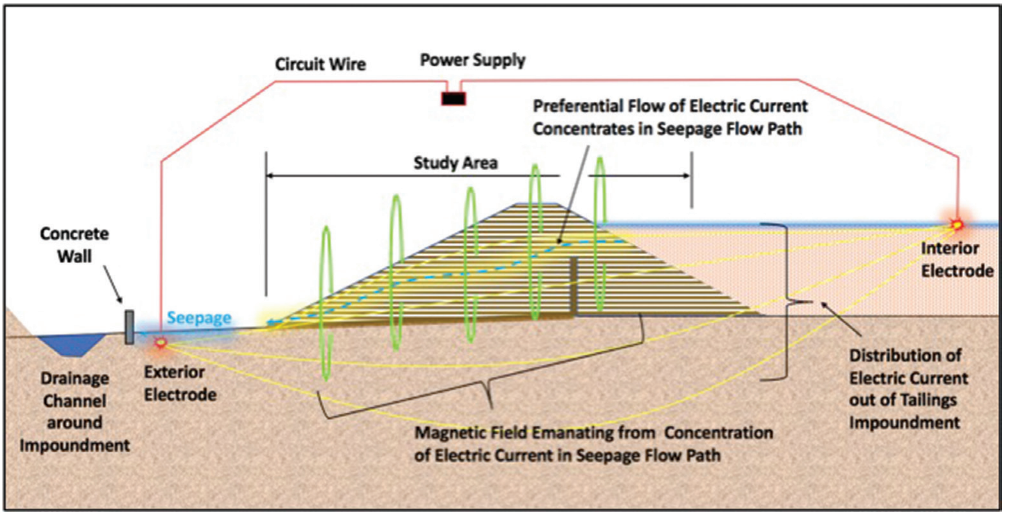

Figure 4 Survey Setup

To map infiltration at this site, an electric current of specific signature frequency was applied by energising from each of several upstream locations to the tailings impoundment to detect preferential paths coming into the impoundment. Then electrodes were placed to energise from the impoundment to each of several downstream locations to detect preferential paths escaping the tailings impoundment (Kofoed et al. 2011). For each configuration, as electric current flowed between electrodes, it generated a signature magnetic field that was measured within the appropriate study area (see Figure 4).

The methodology also incorporates a prediction of the magnetic field response for any given electrode configuration, assuming a homogenous subsurface. The measured magnetic field is compared to this uniform case distribution to bring out any heterogeneity or preferential flow of electric current. The processed data was used to create a map for a two-dimensional (surface level) interpretation of preferential flow paths (see Figure 5).

The data was then processed through an inversion algorithm to generate a three-dimensional (3-D) model of electric current distribution. This model was presented within the framework of a 3-D site model, creating a powerful tool to explore and explain how electric current (interpreted as preferential groundwater paths in this case) potentially infiltrates and escapes the impoundment (see Figure 6).

Results

For Survey 4, two flow paths highlighted with yellow lines were identified which combine into a single flow path that continues through the dam (see Figure 7). The dark green area, highlighted by a dashed black circle, identifies where electric current is most concentrated downstream of the dam. This anomalous area is believed to be evidence of an old paleochannel that crosses beneath the TSF. It appears that the foundation of the dam was erected deep enough to cut off the paleochannel and thus trapping water behind the Impoundment.

Conclusion

The results from the Mexico tailings impoundment show how the MMR method can be used as a non-intrusive approach to supplement known geological, geotechnical, hydrological and groundwater information to enhance the knowledge of the tailings impoundment's seepage, stability and integrity conditions. The MMR method is superior to other geophysical methods for characterizing groundwater flow paths because the signature electric current targets the groundwater of interest and identifies preferential flow paths. The technology can also be applied to areas

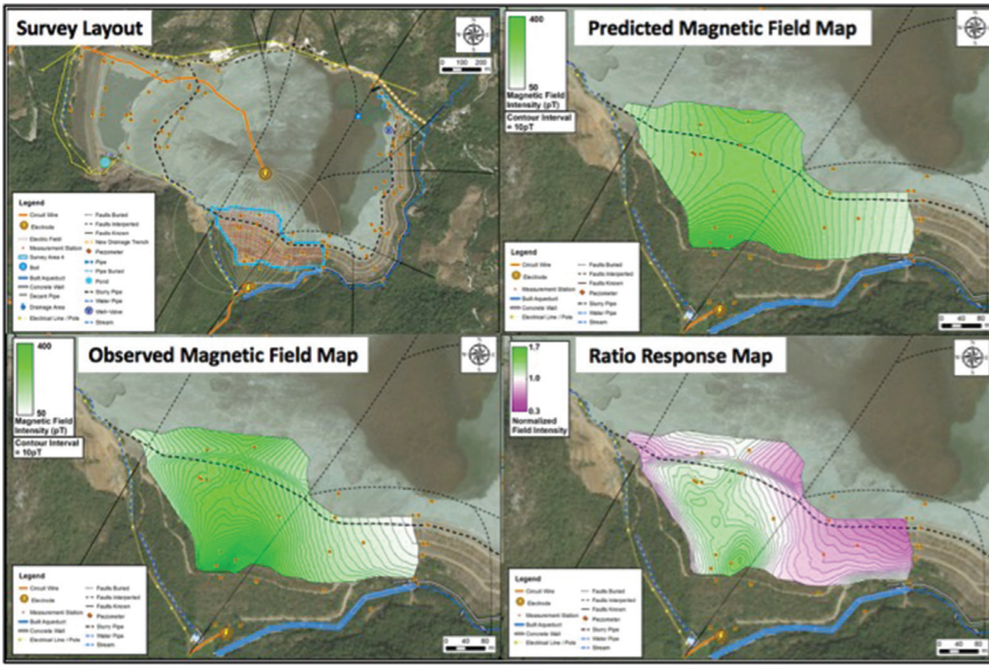

Figure 5 Steps to Create Data Results and 2D Maps

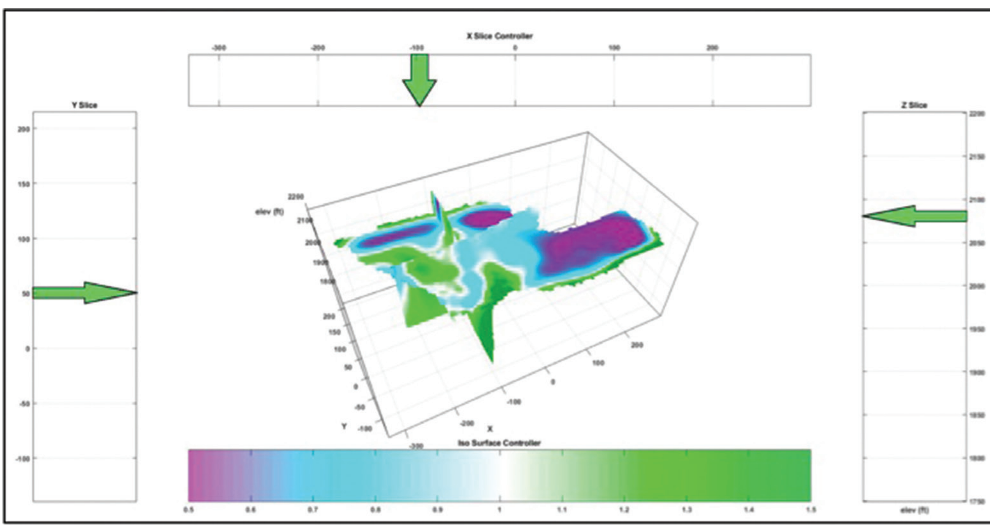

Figure 6 3-D Electric Current Distribution Inversion Model

that are difficult to access, because each measurement is collected in freespace, where traditional well drilling equipment and other geophysical techniques cannot access.

This information can then be used to cost-effectively support the design of tailings impoundment stabilizations and future tailings impoundment raising, ultimate closure and post-closure and to provide long-term safety and stability.

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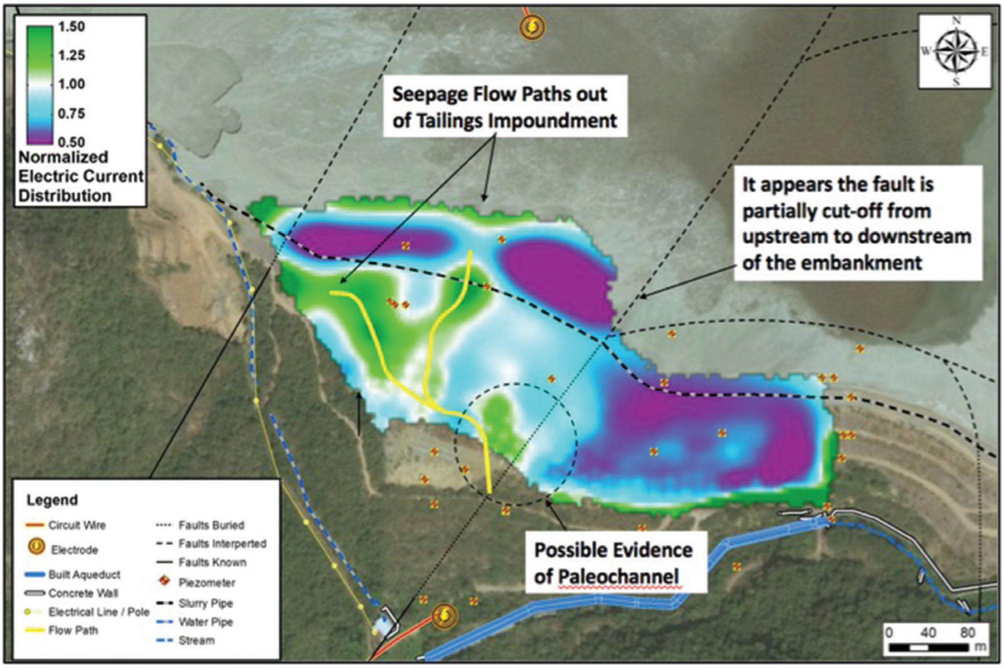

Figure 7 Summary Results for Survey 4

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