Electromagnetics applied to baseline studies and monitoring of water storage facilities

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Summary

An evaporation pond filled with acid-sulphate ground water from a nearby mine, was shown to be leaking from changes in the chemistry of adjacent borehole groundwater measurements. Coverage of the pond with time-domain electromagnetic measurements recording full time-series data was used to identify the leakage pathways into the groundwater aquifer. Post processing of the raw dataset, including optimised specification of the window timing, facilitated successful imaging of the contaminated subsurface over the critical depth interval, between the highly conductive residual muddy cap and the ground water below. The rapidly acquired high resolution data was necessary for the construction of a 3D subsurface conductivity model, for effective communication of the results.

Introduction

Poorly designed and fabricated tailings dams, evaporation ponds and water storage facilities are a common threat to groundwater aquifers especially in regions of high subsurface water movement. Leakages not only endanger the environment, but also affect the viability of the mine where waste water disposal is critical to environmental management and the ore processing cycle. The loss of environmental bonds is also a concern where an expensive clean up is required.

In this example, an evaporation pond was filled from dewatering of an associated underground nickel-sulphide mine. A rapid increase in the groundwater level, accompanied by chemical changes in monitoring bore measurements, indicated the presence of leakage pathways into the groundwater aquifer below. Leakage of the mine water is a concern due to elevated pH levels, saline water in the near surface environment and potential concentrations of heavy metal ions; consequently, the pond was emptied and efforts made to identify the position and nature of the leak.

In order to investigate the leak, two options were discussed: firstly, resistivity methods such as tomography and applied potential methods and secondly electromagnetic profiling of the pond surface. Although there were merits in the galvanic methods, EM was chosen because of its high resolution and rate of acquisition. The alternative direct current resistivity survey required high voltage transmitters which would have had safety and compliance implications. Carrying out a detailed resistivity/tomography survey could have been very costly and the lack of resolution may have missed a narrow steep pipe-like pathway.

A moving in-loop configuration time-domain electromagnetic survey was chosen because of its speed and ease of execution. Processing of these data were anticipated to be problematic because data inversion can be seriously complicated by spurious geological effects, including negative decays caused by polarisation in the muddy clay lining of the pond.

Full time-series data were consequently recorded, both of the transmitter waveform and the received signal, to ensure the flexibility of post processing options. This is also important as the geophysicist is not normally present during acquisition.

Data Acquisition

A high level of redundancy was planned for the survey as the leakage pathway between the pond and groundwater could either be sourced by a confined fault, or broad permeable zone. The high resolution is also important when constructing a clear 3D model of the subsurface conductivity. Data was therefore acquired on 20 m spaced traverses and 10 m stations. Some areas of the pond surface could not be surveyed due to standing water and muddy areas; however, the presence of water discounted these as possible leakage sites.

The EMIT Smartem V receiver was employed as described by Duncan et al. (1998) and allows full-time series acquisition. A purpose built transmitter loop with receiver coil was constructed on site to be dragged around the site by hand. Rapid acquisition of the EM data was achieved by dragging the loop on a tarpaulin, with the transmitter wire attached to the perimeter; similar to the method discussed by Harris et. al (2006). The transmitter loop was constructed from a single turn of low resistance wire measuring 6 x 6 m and a centrally orientated two-turn centre tapped receiver coil was fixed coaxial to the transmitter.

A base frequency of 75 Hz, with a 50% duty cycle and 10 µs turn-off was used for the transmit signal. The turn off time was established by monitoring the transmitter waveform directly as a second channel. The time-series was recorded at 100 kHz. Raw data files from the Smartem were subsequently restacked to optimise the 10 µs turn-off and 10 µs antenna delay. Stacked data were then re-windowed to improve the resolution in the near surface: <50 m depth. To facilitate this, 40 windows were selected before 1 ms. The effective depth-of-investigation, according to the method by Ward and Hohmann (1988), was calculated to be 90 m for a 200 mS/m half-space: our critical depth interval lies within this range.

Data Transformation

The resulting decays were transformed to conductivity-depth pseudosections using EMax by Fullagar (1989) (Figure 1). Whilst the data could be inverted using any number of sample-by-sample 1D, or even constrained 2D inversion algorithms, conductivity gradients were sufficiently large to determine the leakage sites, for which a simple transformation was adequate.

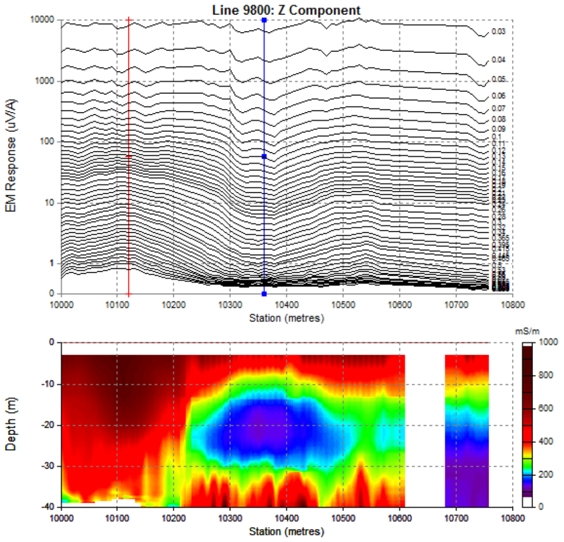

Figure 1: Line 9800 stacked profiles after processing and EMax apparent pseudosection. Line position is shown in Figure 3.

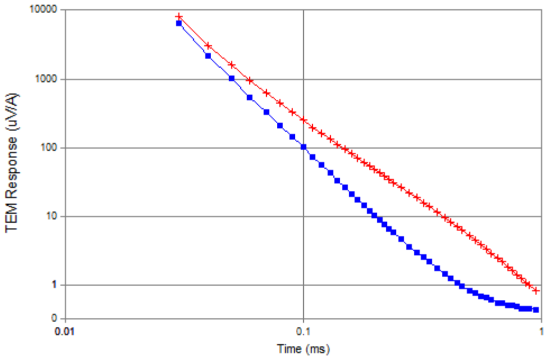

Figure 2: Selected decays from station 10100 (leak, red) and 10350 (resistive area, blue) taken from line 9800 of Figure 1. This illustrates the relative secondary signal between the two areas. By 1 ms the faster decay has reached the noise level.

Salt content of the mine water was greater than that of sea water, being far in excess of the naturally occurring ground water. Conductivity readings for the contaminated groundwater reached 1M mS/m, ensuring that conductivity gradients in the subsurface are large even where leakage areas are small in volume. This is demonstrated by the significant increase in signal from a resistive area of the pond to the main leakage site, illustrated by the corresponding decays in Figure 2.

Results

Conductivity-depth pseudosections were merged and gridded in 3d for integration to a 3d workspace (Figure 3). 500 and 750 mS/m isosurfaces illustrate two significant plumes of elevated conductivity which extend below the pond surface to depth (Figure 4). The right arrow highlights a 500 mS/m area of leakage which is moderately conductive at surface but develops into a highly conductive area that appears to extent beneath the eastern bank. It is the likely pathway contributing to a 15 m rise in the watertable indicated by monitoring of adjacent bores east of the pond. To the southwest a stronger 750 mS/m plume is indicated. This interpreted pathway suggests a larger fluid volume rather than a smaller high flux pathway since the pond has been empty for a period. A small leak around the southern end of the pond was implied by adjacent borehole measurements but could not pinpoint the location, its volume or the severity. The leak is likely to connect with the lower watertable and is an obvious location for immediate remediation works.

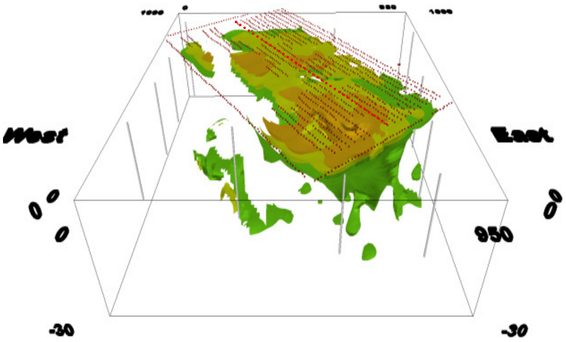

Figure 3: Isometric projection of 500, 625 and 750 mS/m conductivity isosurfaces with a factor of 10 vertical exaggeration: green through brown colours. EM stations in and along wall of pond are shown in dark red. Profile corresponding to red dashed line is shown in Figure 1. View from above and south. Expanded view is shown in Figure 4

Discussion

Where water storage leakages create conductivity gradients in the subsurface, electromagnetics offers a rapid and cost effective method for leak identification. Importantly, the system configuration can be adjusted post acquisition to suit the depth-of-investigation and target scale required. The use of electromagnetics however, is not limited to the identification of leakage pathways but can also be used for baseline monitoring of dam wall integrity and initial groundwater levels.

We recommend water-storages be surveyed before construction to identify possible leakage pathways and proximal groundwater, so appropriate precautions can be made. It is also recommended to survey the dam walls after completion and before first fill to complement this data and develop a baseline 3d map of the subsurface conductivity. Subsequent surveys can then be compared, for identification of more complex discharge areas and perched zones which may not be diagnosed as threats to the ground water aquifer. This also identifies areas that may have spurious EM signals which complicate the interpretation where no baseline data exists.

Knowing the location, pathway and cause of leakage is vital in planning how remediation is carried out. If the leak is at an isolated breach in the dam for example, this could be repaired by local re-lining of the breach. Narrow faults or permeable pathways however, could be lined or grouted by boreholes drilled from surface.

References

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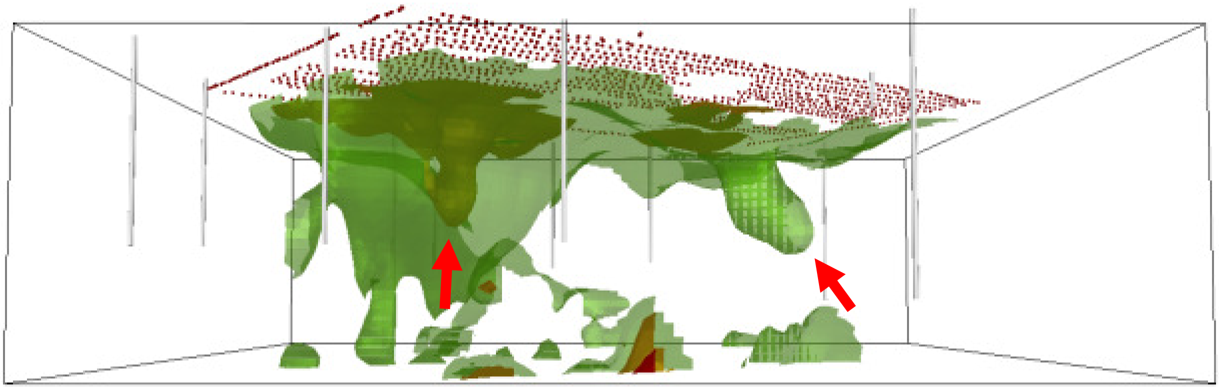

Figure 4: Isometric projection of 500 and 750 mS/m conductivity isosurfaces with a factor of 10 vertical exaggeration: green and brown colours respectively. EM stations in and along wall of pond are shown in dark red. Monitoring boreholes are shown in grey. Two lobes marked by red arrows in the 500 mS/m surface demonstrate seepage pathways for acid-sulphate pond water. The left (southern) pathway is higher volume as it is also visible at 750 mS/m. View from below and east.