TAILINGS POND OUTFILTRATION MONITORING WITH ELECTRICAL CONDUCTIVITY SURVEYING

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10.50 ap. - 11.10 ap.

Introduction

Geosto Oy developed the NOVEL-EM electromagnetic surveying method for the detection and monitoring of contaminated mining water between 2013 – 2015 in the Finnish Green Mining programme. The system consists of hand-held electromagnetic (EM) frequency domain measurements for establishing a baseline, and subsequent monitoring surveys. In addition, other electrical conductivity measurements are used as support, and a special processing methodology was developed.

This presentation includes the findings and experience gained during the ten-year period from 2013 – 2022 and from surveys conducted at several operating mining sites. The system included a measurement technique, processing, and software development. The EM method and hand-held instrumentation were selected for this purpose due to the applicable depth range, cost-efficiency in field work, and high accuracy in measured responses and time-lapse differentiation.

Method and theory

The hand-held short coil spacing instrument typically has coil spacing between 1 – 4 metres. It operates either in geometric or frequency sounding modes and within a frequency range of 1 – 50 kHz. The depth range covered depends on the electrical conductivity of the ground, but usually stays between 1 – 10 metres. The situation is very suitable for shallow groundwater layer observations (when the water level is situated within reach of the system and less than 5 metres from the ground surface). The main idea is to first measure the baseline response at several frequencies and within a depth range of 0 – 10 m, and after each time-lapse survey, solve the differences at the same points. For surveying, we used the GSSI EMP-400 Profiler instrument, which can simultaneously record three frequencies in the 1 – 16 kHz range, either in HCP or VCP modes. The surveyed lines were at staked points close to the edges of the waste area, and placed in natural, non-disturbed ground. The surveyed point locations are within ±1m of subsequent line point recordings.

Figure 1 depicts the apparent depth ranges D_a surveyed in the frequency domain, calculated as the square-root of skin-depth values from EM theory (Saksa 2014) and for the EMP-400 system. Various soil types and resistive rock are also marked on corresponding curves. However, depth penetration in itself does not guarantee resistivity mapping from an embedded groundwater layer. The layer or volume must be situated well within the maximum depth penetration, the resistivity difference must create a measurable signal, and the EM instrument and site conditions must enable low noise levels in data. We evaluated the stability and accuracy of the EMP-400 unit at a system level and found that in the 1 – 16 kHz band, an accuracy of ±10 ppm can be achieved for the secondary field imaginary (Im) component (Saksa and Sorsa, 2017). The real component is used as a relative indicator and for magnetic responses.

Baseline data holds crucial importance as all later data are compared against it. Preferably, the baseline should be recorded before or in the very early stage of waste disposal activities. Regarding mining that has taken place over a period of years or decades, or for closure stage conditions, Figure 1 also shows the EM response variability with geology, which is then present and makes the detection of small resistivity changes resulting from water chemistry particularly difficult and uncertain to infer.

During data processing, there are several factors which influence the recorded EM baseline-monitoring data and which has to be compensated before the differences can be evaluated. They can be divided into instrument and survey site, hydrological, and meteorological categories. In the first category, EM system calibration and stability have to be controlled (pre-survey site calibration, on-site point measurements, frequency cross-correlations), measurement points have to be the same and changes in surface conditions have to be recorded and treated. In-house EMDC1D, PLOT, CONVERTER and GROUNDMODEL software modules were developed for various modelling modes, water chemistry calculations and presentations.

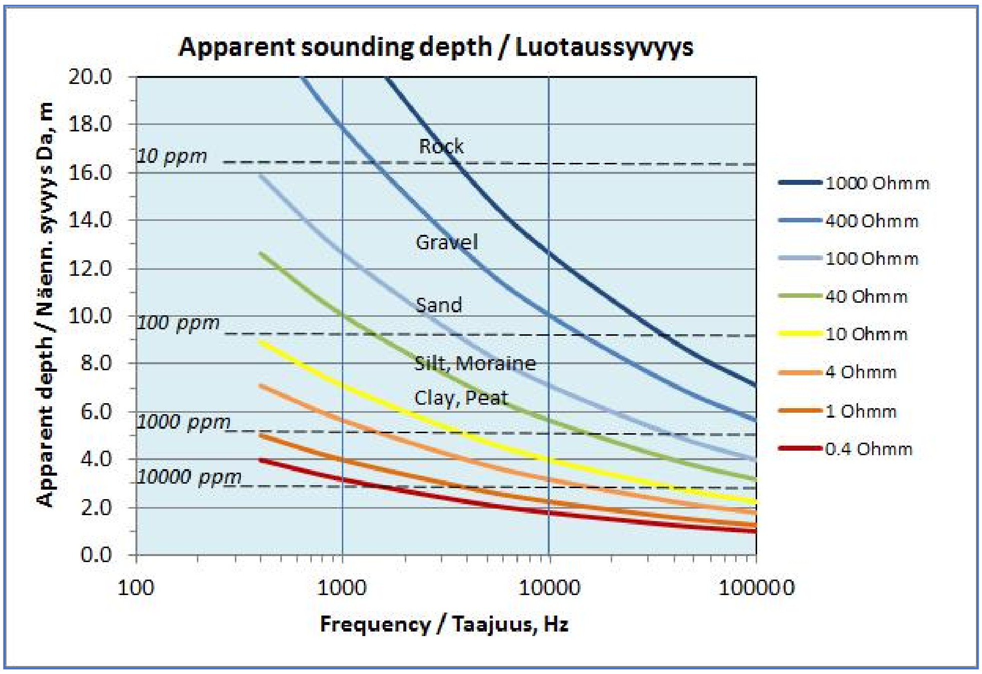

Figure 1. *Apparent depth ranges D_a in small coil-spacing EM frequency domain surveying (Saksa 2014).*

Hydrological changes also influence the measured EM signals. Groundwater level, water infiltration conditions, and the degree of saturation in unsaturated soils can change. In the meteorological category, precipitation over time changes continuously, as does soil temperature (depth profile). Developed processing routines remove and compensate for all these as much as possible. In anomaly pick-up, it is noted if any conditions along the profile section have changed. It is also important to collect associated background data from the site, such as geology-hydrogeology, groundwater standpipe and drilling data, water levels, water drainage arrangements, and changes in infrastructure and land conditions.

Processing of EM Im-components included component static levelling per frequency, corrective-predictive filtering using the developed OXZM-method (outlier, x-z directional and median filtering), final level adjustments, and electrical conductivity (EC) change zone calculations. Change zone detection applies threshold values regarding zone length, change magnitude, and presence at the used frequencies to avoid false or uncertain zone identifications. Each zone is labelled, and a mass index (average conductivity increase in groundwater x length, in mS units) is calculated. Typically, an increase of 50 – 100 ppm is required per frequency in the Im-component for change zone detection, but this depends on the overall apparent resistivity level, noise signal, and the variability of hydrogeological conditions.

Finally, all line data is presented as electrical conductivity change maps, as binary change zone maps, in profile presentations, and as lists of zones. Every monitoring data point has a coordinate, and data tables calculated in this way are transferred and documented in the client's GIS-system, for example, to assess the location for a new groundwater sampling point.

Monitoring examples

At one large Finnish metal mining site, the baseline survey was done in 2013. During the first stage, 10 lines were staked around two tailings ponds at a total length of 7.2 km. The baseline survey formed the basis for all future evaluations. The baseline was also interpreted against geology-hydrology main setting and normally provides some new geological-hydrological information, too. Figure 2 shows the location of the lines around the tailings pond areas.

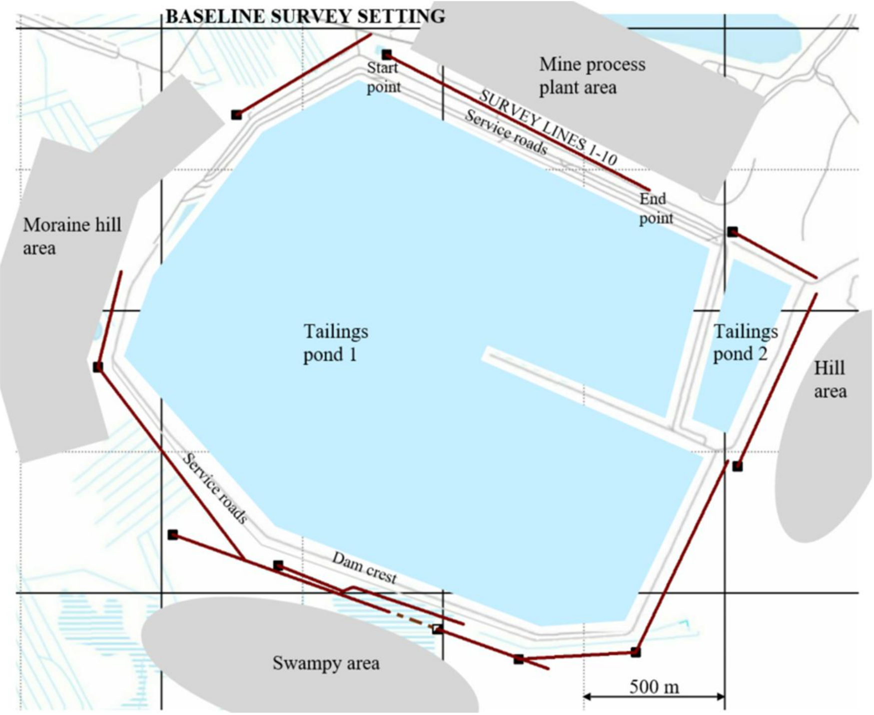

Figure 2. Baseline line network around a mine site and its major tailings ponds.

Monitoring first took place in 2015 and has since been carried out roughly once per year. Many new lines have been added since 2015 based on water management interests and observations of changes in water chemistry. One particular addition was the establishment of lines along certain service roads along the dam perimeter. These can show outfiltration points closest to the wastewater reservoir and therefore enable rapid operational actions like drilling, wells, and water sampling. Figure 3 displays Im-component data from one line, originating from the baseline and from monitoring in 2020.

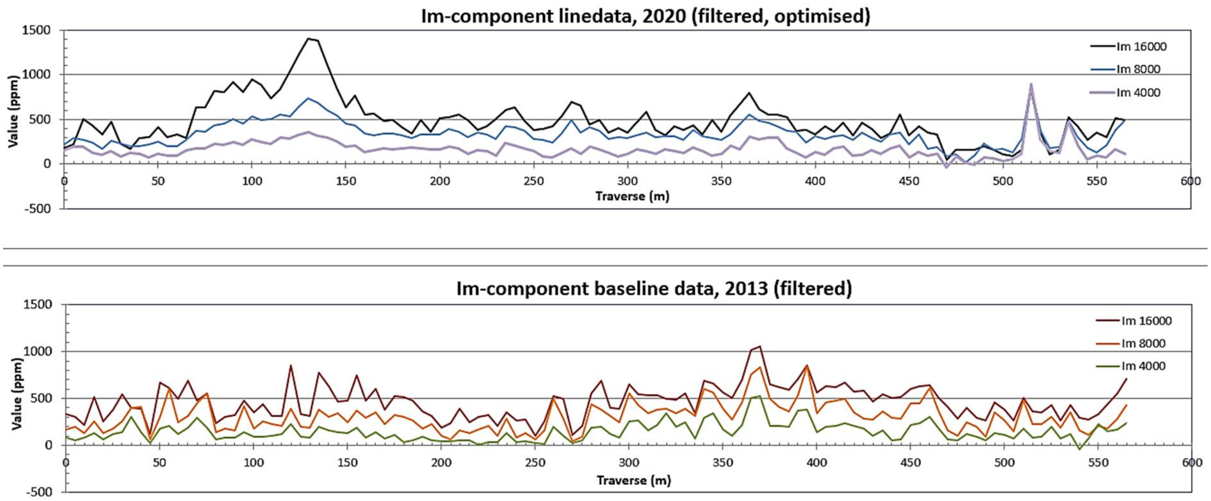

Figure 3. Monitoring line data from 2020 and baseline data from 2013, showing Im-components.

Together, time-lapse measurements show how distinct zones related to changes in water chemistry have developed over the years, Figure 4. The main ones are zones A) and B), and their magnitudes reduced in 2022 due to the establishment of nearby pumping wells. Mass index values for the change zones are shown. The line network has been expanded at the mining site to cover the dam perimeter lines (along the service roads) and to cover monitoring of the rock disposal area at one side. The total line network currently in operation at the mining site is about 23 kms. At certain locations, more detailed EM studies and monitoring have been conducted, for example, to characterise dam structures.

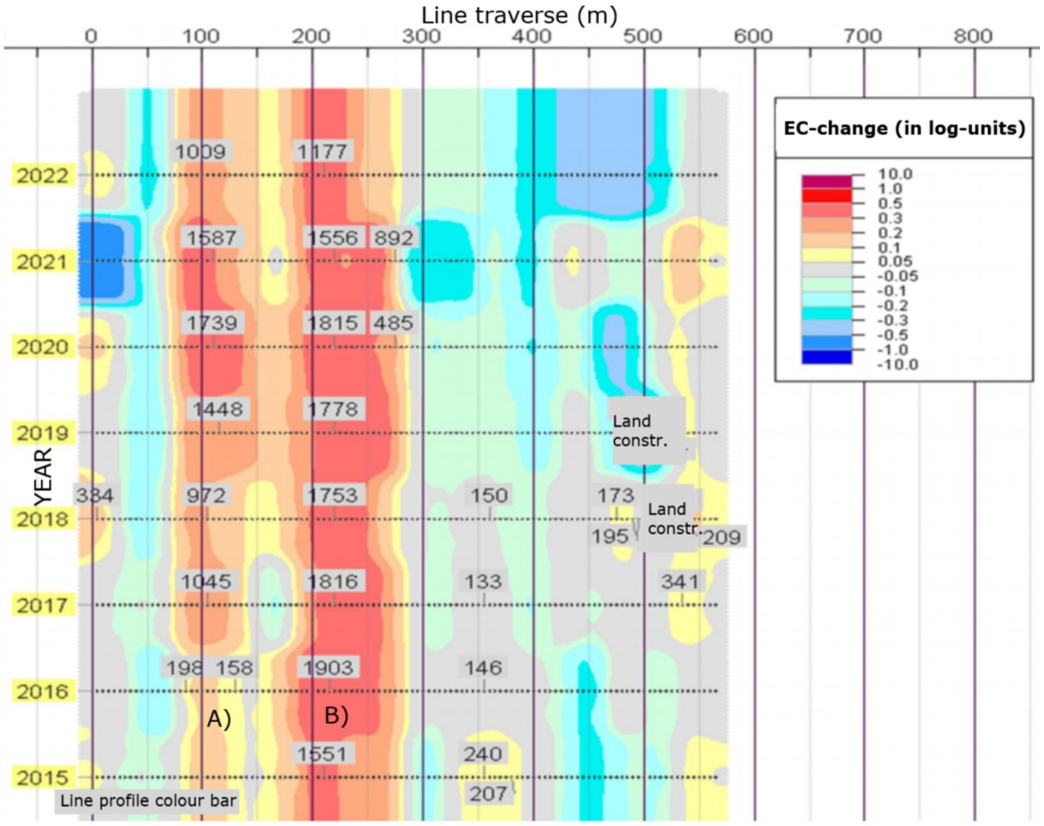

Figure 4. *Figure 3 monitoring of line change zone development through the years, EC changes shown as log-values.*

Conclusions

During 2018, independent evaluation indicated that geophysics-based EC change zones and samples correlate well with direct groundwater sampling electrolyte results. Monitoring has also helped in positioning new groundwater standpipes and other environmental management actions that have been taken. A small number of lines have turned non-measurable due to earthworks at the site and the construction of new power lines. It has been noted that water chemistry change zones can also disappear or change form. The reasons for this include construction activities on the land, tailings pond operations, or other temporal sources of electrolytes. Pumping-related changes in the electrolyte content were also observed.

Acknowledgements

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