Geophysical Electromagnetic Measurements for Mine Site Groundwater Monitoring

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Extended Abstract

Water management at the mine sites is an important topic and developed as one theme in Finnish Green Mining programme during 2013 – 2016. Research programme is funded by the Finnish Funding Agency for Innovation, TEKES. Geosto Oy has been developing efficient geophysical methods for improved control of groundwater quality and waste area monitoring in its NOVEL-EM project. Needs arise from environmental safety, water resource protection and trend of increased mining areas. The presentation discusses the methodology, example surveys executed and new advances gained.

Direct current electrical methods have been used for a long time in groundwater investigations. New versatile electromagnetic induction (EMI) based instruments have also recently been made available. They particularly offer suitability to fast near-surface mapping of electrical resistivity and soundings in the depth range of 0 – 15 m. Instruments also suit to varying ground conditions. Integrated use with groundradar (GPR) offers improved discrimination of soil layers and their electrical properties. In addition, for greater depth penetration larger coil spacing (Slingram type), VLF-resistivity, audio- and radiomagnetotelluric and time-domain transient measurements can be selected depending on the surveying requirements of the mine site [1].

Development work has included methodological tests as well as stability and calibration studies have been important part of the EMI development. Example of a baseline measurement setting is described in Figure 1. During monitoring phase time-lapse measurements are compared and differences evaluated. Hydrological background variations are compensated and final data levelling applied.

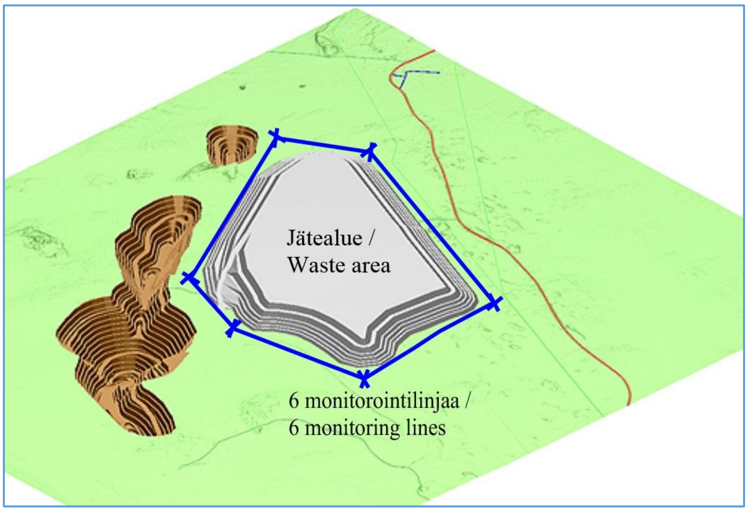


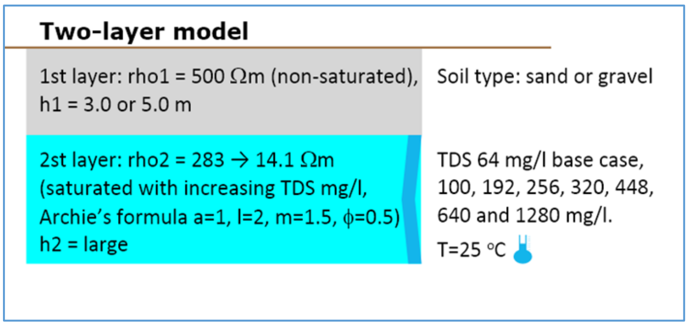
Figure 1*: Basic example setting for electrical conductivity monitoring line network.*

If several surveying methods are used, the best interpretation result is achieved if data modelling scheme can do joint inversion and knowledge from soil-rock layers and structures, their proper-ties can constrain the calculation process. The use of multiple datasets in inversion and a priori soil structural model has been one key areas of development in NOVEL-EM project.

Baseline measurements have provided also useful supplementing data of hydrogeological site conditions. Accurate system calibrations and follow-up during the measurements have proved to be necessary [2]. These include static offsets, drift, user influence and documentation of site conditions and possible changes between measurement rounds. Compensation of hydrological and physical base parameters must be considered. Influential parameters include soil tempera-ture, saturation degree variations and groundwater level fluctuation (distance from ground surface).

Results show that change detection down to 50 – 100 ppm in total dissolved solids (TDS) content in groundwater is possible. This is exemplified with calculations made for hand-held EMI system (GSSI system EMP-400 Profiler) and for groundwater layer at depth of 3.0 m from the ground surface. The electromagnetic induction response imaginary (Im) component values were calculated over frequency range 400 – 40000 Hz. Groundwater base case has salinity 64 mg/l (electrical resistivity 100 Ωm). Then salinity is increased in steps to values shown in Figure 2, from 1.5x times to 20x the base case. Coloured curves depict the increase of Im-component response with water salinity increase. Detection limit is typically around 10 ppm, so 20 ppm was taken as detection threshold limit. Figure 2 shows that with higher >15 kHz frequencies even small 35 mg/l salinity increase is observable. Salinity increase of 130 mg/l from base level is clearly detectable over large (>4 kHz) frequency range as well as all higher than 130 mg/l salinity contents.

a)



b)

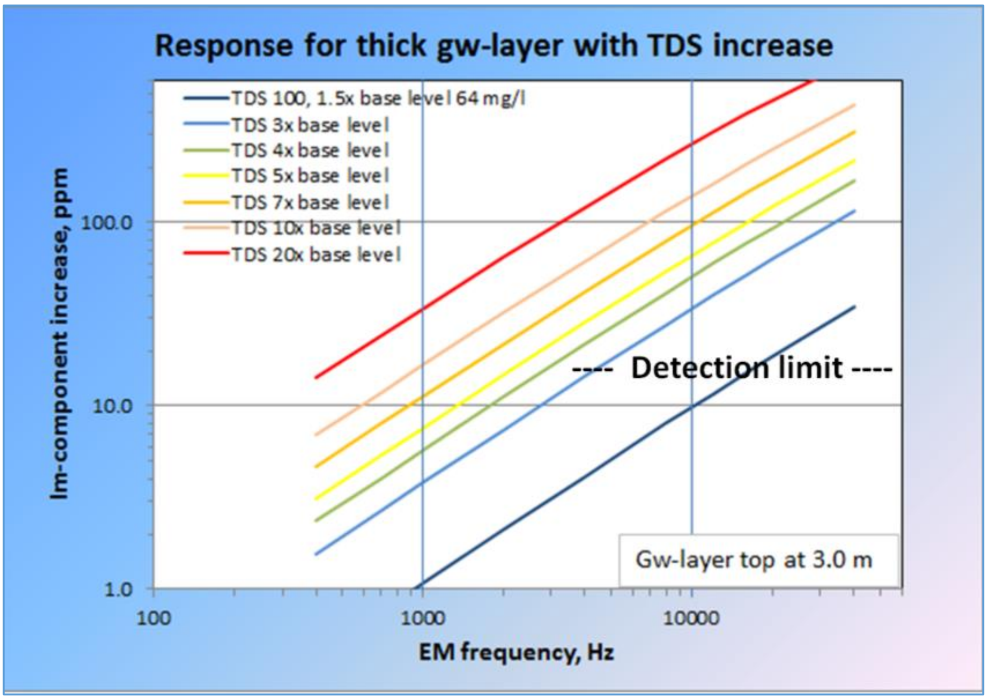


***Figure 2**: a) used model parameters, b) detectability of groundwater layer with increasing salinities over EMI frequencies.*

If the groundwater layer is deeper seated or as middle-layer has limited thickness (from sounding point of view), the measurable responses are weaker and so the detectability limit gets higher. Soil type can also have significant influence to responses: soils containing fine-grained component like clay, silt and moraines have higher electrical conductivities by nature and groundwater quality changes are less distinguishable. Similar situation applies if the baseline water salinity is very high – change detection limits arise.

If influence of distinct aqueous ions as electrolyte is of interest, an electrolyte was formulated in the NOVEL-EM project where solute ionic contents can be entered and resulting electrical conductivity of the solution is calculated. This is also useful if there are electrically conducting metals and minerals mixed with the solute that sums up in the total conductivity estimation.

Changes in surface water chemical variations can also take place and can be distinguished from subsurface variations. Locating of the change areas is vital for verification and other actions. For example, watercourse areas where sulphate layering has occurred and deposits settled to lake bottom, can be mapped for remediation actions.

In direct leakage detection variations in soil and bedrock geology are mixed with groundwater originating responses. Importance of background data and its interpretation plays a larger role. Particularly this can be challenging in mining areas if within the surveyed areas there are miner-alised bedrock volumes close to the ground. On the other hand, we have noted that sometimes the observed mineralisations can explain elevated metal and other substance levels and so prevent false environmental alarms.

Same methodology can be used also in earth dam structural investigations and monitoring although depth range can be larger depending on the dam measures. Example measurement tested against known leakage channel indicated positive and high-resolution localisation capability, Figure 3.

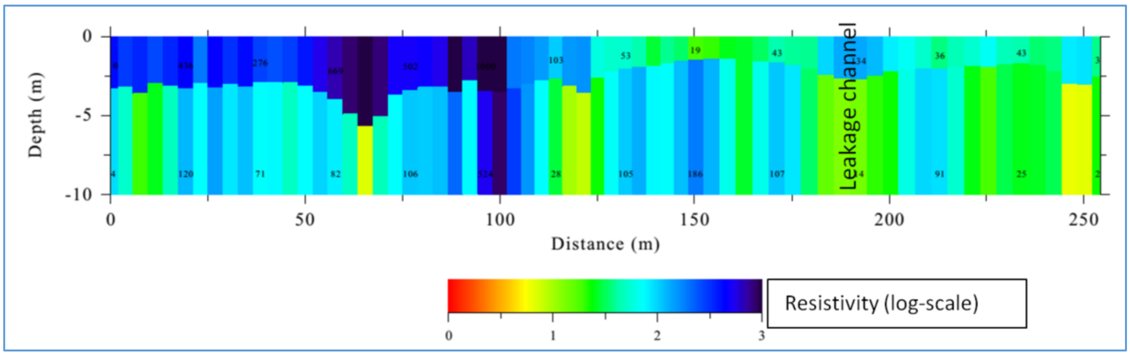


***Figure 3**: Measured and modelled two layer resistivity profile over a leakage channel.*

Main uses for groundwater quality monitoring are to supplement the groundwater standpipe and well chemical data and provide comprehensive coverage around the waste disposal areas at the mine sites. This leads to improved environmental safety. In addition, several other uses can be found for water management like positioning of new monitoring wells, pumping wells for contamination remediation or dewatering purposes.

Key words: Mine wastewater, dam, monitoring, geophysical measurement, electrical conductivity

References

[1] Reynolds, J. M. (2011). An Introduction to Applied and Environmental Geophysics. Wiley-Blackwell. 2nd edition. 696 p.

[2] Saksa, P. & Sorsa, J. (2015). Calibration and 3-D Effects in Hand-Held Electromagnetic Frequency Domain System Measurements. Environmental and Engineering Geophysical Society, SAGEEP Conference 2015, Abstract, 1 p.