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Hydro-geophysical characterization and modeling of hydrological processes in mine tailings

Elyasse El Mrabet, Eric Rosa, Vincent Cloutier, Brahim Maylal
Groundwater Research Group, Université du Québec en Abitibi-Témiscamingue (UQAT).

Summary

This study focuses on the use of electromagnetic and electric geophysical measurements with thermal imagery for estimating water contents in tailings. The Glencore Fonderie Horne Quémont-2 site, located in Rouyn-Noranda (Quebec, Canada), is targeted for data acquisition. Ground penetrating radar (GPR) measurements were conducted for estimating the relative dielectric constant (ε_r) of tailings based on electromagnetic wave velocity. *In situ* moisture probes and laboratory tests allowed establishing a relationship between ε_r and tailings water content. Thermal images acquired using a drone were further used for monitoring the changes in tailings surface temperatures during infiltration following brief watering periods. These tests were conducted to evaluate if surface temperatures can be used to estimate water contents and to document the spatial heterogeneity in infiltration processes. Electrical resistivity profiles were also realized to estimate the porosity and water content of tailings. Ultimately, the project provides novel approaches for studying hydrological processes in mine tailings.

Background

Hydrological processes occurring in tailing ponds are often studied using in situ probes, piezometers and observation wells, boreholes, pilot scale experiments and field samples collected for conducting laboratory experiments. These tools and approaches are highly relevant because they allow for conducting precise hydraulic and geochemical measurements based on broadly applicable protocols. Nevertheless, such invasive approaches generally provide point specific information, whereas evaluating the heterogeneity in hydraulic properties and processes at different scales remains challenging. Numerical models can help addressing this question, but models and simulations must ultimately rely on field observations. In this sense, the improvement of current practices for the study of hydrological processes within tailings requires the development of innovative and complementary methods. Non-invasive geophysical and remote sensing approaches represent promising tools to complement invasive approaches. Fitting in this context, this study aims at developing geophysical and remote sensing approaches for studying hydrological processes in tailing ponds. The focus is set on the use of electromagnetic (ground penetrating radar, GPR) and electric (resistivity and induced polarization) geophysical approaches along with remote sensing (thermal imagery by drone). The Quémont-2 site, located near the city of Rouyn-Noranda, in Québec, Canada, is targeted for data acquisition. The site is a property of Glencore Fonderie Horne. This tailings pond, which covers approximately 102 ha (Figure 1), was used successively for the deposition of sulfurous residues, slag and for co-deposition (composed of tailings generated by the hydrometallurgical treatment of fresh slags from the smelting process and the UTAF processing sludge). The tailing pond will soon reach its full capacity and reclamation plans are currently being developed in order to minimize environment impacts. A precise understanding of the hydrological and geochemical processes occurring in the tailings is critical in order to develop an optimal reclamation plan.

Figure 1 Study site.

Methods

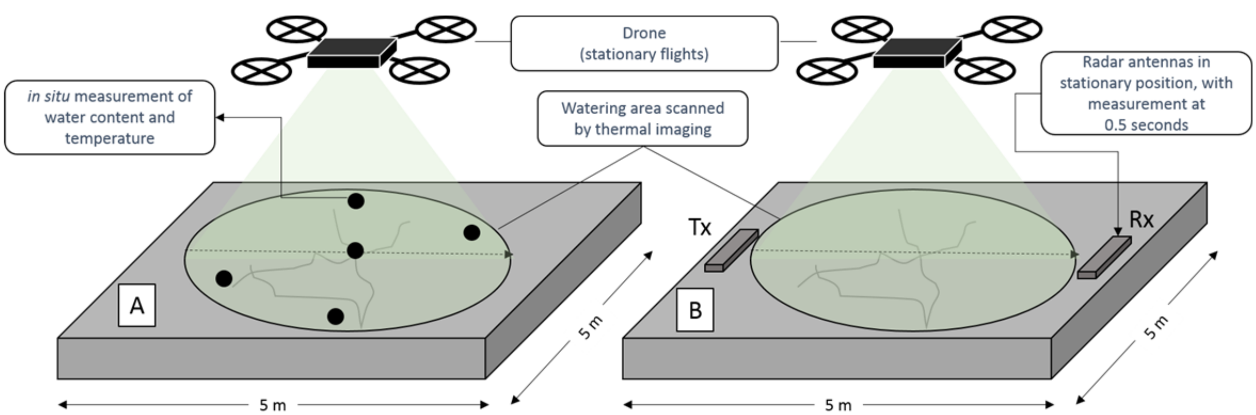
A *Pulse Ekko Pro* GPR from *Sensors & Software* was used for conducting systematic common mid-point profiles over grids in two areas of the tailings pond. Data were collected using 100 Mhz and 50 Mhz antennae. The data was processed using the *Reflex2D* and *EkkoProject* software. The GPR data is used for estimating the velocity of the electromagnetic wave (v), which is related to the dielectric properties of the media and to the EMW velocity in a vacuum (C_0):

$$v = \frac{C_0}{\sqrt{\varepsilon_r}} \qquad \text{Equation 1}$$

Surface tailings samples (n=24) were collected at the sites where GPR CMP surveys were conducted. The mass water contents of these samples were measured in the laboratory according to the ASTM D2216-19 procedure. The dry densities were also measured. Laboratory experiments were further realized to evaluate the correlation between ε_r and the water content of tailings. Precise quantities of water were sequentially added to the dry samples and the corresponding volumetric water contents were measured using 5TE, 5TM and GS3 moisture probes. Moisture content values were subsequently used to estimate ε_r based on the calibration equations of these probes, which are generally similar to the Topp et al., (1980) equation. Ultimately, the objective of coupling laboratory and GPR measurements is to develop a GPR based approach for estimating surface tailings water contents over grids and transects, as a complement to point specific measurements conducted using in situ probes.

Thermal images were also acquired using Zenmuse XT2 camera mounted to a DJI Matrice 200 drone during an infiltration experiment. Figure 2 shows a conceptual representation of the experiment. The test consisted in realizing stationary flights simultaneously with measurements conducted using in situ moisture probes (Figure 2A) and continuous GPR data acquisition with fixed antennae (Figure 2B). A know amount of water (of known temperature) was poured at the surface of mine tailings over *in situ* moisture probes and between stationary GPR antennae continuously measuring the EMW signal between the transmitter and receptor. At the same time, thermal images were acquired using the drone, at a rate of 30 images per minute and at an altitude of 50 m. This experiment was realized in order to test if an empirical relationship could be established between the EMW velocity, the surface water content and the surface temperature of tailings. Thermal images were processed using the *Flir Tools* software. Ultimately, the objective of this experiment is to develop a remote sensing approach for documenting infiltration processes in tailings based on thermal images.

Figure 2 Conceptual representation of the experiment conducted to evaluate the relationships between tailings surface temperatures, water contents and EMW velocity.

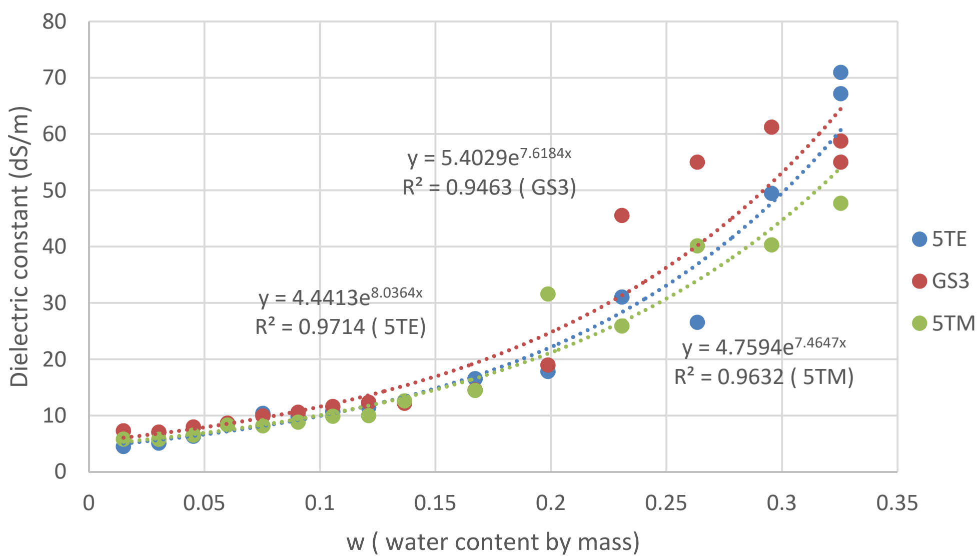


Finally, one resistivity profile was collected using a *SYSCAL Pro SWITCH 72* resistivity meter from *Iris Instruments*. The profile was collected using the Schlumberger, Wenner and dipole-dipole configurations. This approach is used to investigate the electrical properties of tailings in the subsurface. The estimation of porosity and water content is targeted, and empirical laws similar to Archie's law will be employed.

Preliminary results and discussion

Figure 3 illustrates the relationship observed between the dielectric properties and water content of tailings during laboratory experiments. The data suggest a strong correlation between both properties, consistent with what could be predicted from Topp's law. These preliminary results suggest that GPR measurements (which allow for an estimation of ε_r) might have a strong potential for mapping surface water contents in the tailings. Preliminary interpretations conducted on the available CMP data suggest EMW velocities of approximately 0,15 m/ns. These data will be used to calculate tailings water content.

Figure 3 Relationship established between tailings water content and dielectric constant during laboratory experiments.

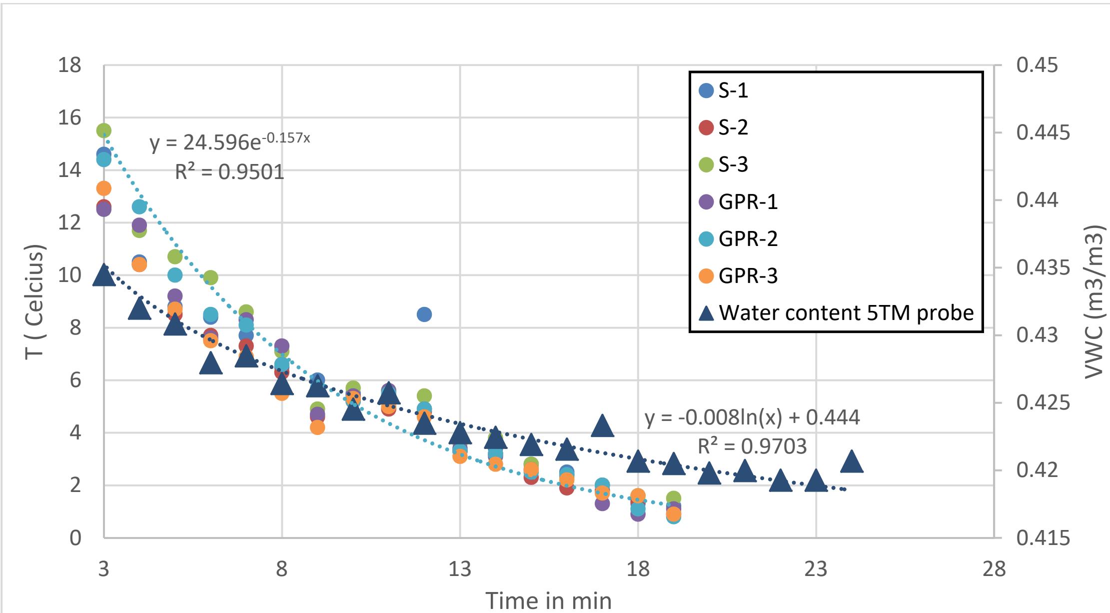


The results obtained from the stationary drone flights also prove to be promising. Figure 4 illustrates the evolution of the surface temperature of three specific points in the thermal images over time, after water was pounded at the surface of tailings. The data shows an exponential decrease of surface temperatures over time. Used for comparison purposes, Figure 4 also illustrates the volumetric water content measured using an *in situ* moisture probe during the same experiment. This figure reveals that volumetric water contents decrease exponentially over time during the experiment, suggesting a gradual infiltration after water was poured at the surface. Preliminary interpretations of these two sets of data allow for establishing a correlation between the volumetric water content and the temperature variation recorded by thermal images:

$$\Theta = 0.4769 - 0.008 * ln\,(20.4 - 6.37 * ln(T)) \qquad \text{Equation 2}$$

This empirical relationship is valid only for the specific temperature conditions under which the experiment was conducted. It nevertheless highlights the potential use of thermal images for documenting infiltration processes in tailings.

Figure 4 Temporal evolution of tailings surface temperatures (left axis) and water contents (right axis) during an infiltration experiment conducted in the field.



Scientific outcomes

Ultimately, the results of the study provide information aimed at optimizing the use of geophysical and remote sensing approaches for complementing site-specific invasive measurements aimed at documenting hydrological processes occurring in mine tailings.

Acknowledgements

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References

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