Integrated Hydrogeological Fieldwork Campaign Design To Identify Infiltration From Tailings

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Abstract

For fieldwork design, an advantage is to have a previous hydrogeological conceptualization of the study area, and enough data gathered throughout time to identify potential trends. An action plan that prioritizes tasks, leading to a staged field campaign design increases effectiveness. It has been concluded that to identify potential infiltration and seepage paths from tailings deposits the integration of continuous groundwater monitoring through hydrochemical sampling, geophysics, water level recording in monitoring wells, sonic drilling and test pits, along with tailings and natural soil analysis, improve the understanding required to assess and mitigate the infiltration potential of tailings.

Keywords: Infiltration Monitoring, Field Data, Geophysics, Tailings.

Introduction

Water management at a tailing's storage facility involves the superficial water flows and the interception, collection and treatment of seepage. Control measures may be required to prevent levels exceeding regulatory licenses and tailings guideline documents (Ritcey 1989). The liquefaction phenomenon, internal and external erosion, seepage and overtopping are some of the main waters induced failure modes of tailings facilities (ICOLD and UNEP 2001). Increasing the pulp density of the tailings typically presents a viable option for reducing water handling and subsequent storage requirements.

According to COCHILCO 2019, conventional tailings, which until a few years ago were the most frequently used, are deposited with a significant water content with solids concentrations (Cp) between 30% and 50%, while technological developments have facilitated water extraction processes, allowing thickened tailings to reach a Cp between 55% and 75%. The Cp of paste tailings can exceed 75-80%.

The application of tailings dewatering technologies to increase water recovery from tailings is an appropriate step to reduce water losses in tailings storage facilities caused by evaporation, infiltration, and retention in pore voids (Cacciuttolo and Atencio 2022), leaving a greater amount of water available for metallurgical processing. At the same time, the volume of water to be managed is limited, which not only reduces seepage but also reduces water pumping costs to and from the processing plant. A Thickened Tailings Storage Facility (TTSF) presents little water to be stored compared to conventional tailings, hence offering significant advantages by reducing stability and environmental challenges. Nevertheless, liberated water after deposition might still be available for a potential seepage and cannot be ruled out entirely.

This study aims to design an integrated field campaign to identify, monitor, characterize and prevent potential seepage challenges, estimating whether seepage is occurring or not, to be quantified and managed if necessary. The works described here could be adapted to any type of tailings deposit.

Thickened Tailings Storage Facilities

Through thickened tailings disposal (TTD) technology a sloped surface is obtained without particle segregation. For a concentration of 53% by weight, the slope at rest of the deposited tailings is 2% and can increase to 6% if the concentration rises to 65% (SERNAGEOMIN 2007). This allows self-supporting tailings storage facilities with sloping beach surfaces, requiring relatively small dams (Cacciuttolo and Atencio 2022).

In the water balance of a TTSF, the seepage and evaporation losses from the tailing's storage facility (as shown in Fig. 1) are minimised, helping to ensure the sustainable use of water. The mining industry needs to carefully manage water, because water use in the mining industry is becoming increasingly more important (Welch 2003). Copper mine tailings consist of a slurry of ground rock, water, and chemical reagents that remain after mineral processing. The composition of mine tailings varies according to the mineralogy of the ore deposit and how the ore is processed (Cacciuttolo and Atencio 2022).

This study focuses on the design of the field studies carried out at a TTSF resulting from a copper mineral process at a mining complex in an area with an arid climate. The ore is processed to produce mainly copper concentrate through a milling and flotation process completely operated with seawater. The copper mine is active, and the tailings disposal is based on thickening tailings to 65% solids using a combination of paste and high-density thickeners. Conceptually, the higher the Cp, the lower the percentage losses due to infiltration. The tailings are deposited downstream from the embankment via a spigot system in thin layers (between 10 to 20 cm thick) on beaches with 2% to 3% slopedslopes. The TTSF facility includes a drainage system, canalization structure, tailing ponds, online monitoring and environmental monitoring wells subject to local regulations.

Materials and Methods

This work was developed based on a conceptual hydrogeological model developed for the facility and its surroundings. Model development utilised fieldwork and monitoring records, operational tailings deposition data for a period of over 10 years, coupled with data collected from various hydrogeological monitoring campaigns, including geophysical campaigns and level measurements, downstream of the TTSF. In addition, geophysical surveys, sonic drilling and test pitting were conducted inside the TTSF. The latter work also provided the base details for a numerical infiltration model which is being regularly updated to assess the infiltration potential of the tailings.

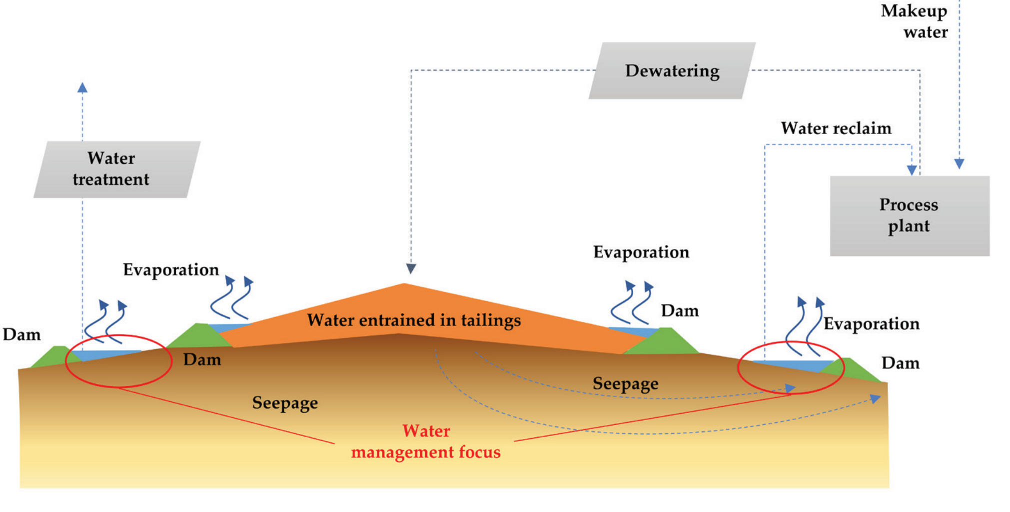

Figure 1 Schematic of a thickened tailings storage facility (Cacciuttolo and Atencio 2022).

Fieldwork Campaign Design

The cross-correlations between the tailings discharge zones and the environmental monitoring suggested a seepage infiltration pattern that was being developed downstream of one of the embankments. Local regulations require the monitoring of groundwater levels and groundwater quality in five monitoring wells downstream of the TTSF. The water quality from these wells is compared to process water and tailings water to identify possible infiltration from the tailings facility. The monitoring well, built 400 m downstream of the wall is called MW-1 (Fig. 2) and it began to be sampled and measured in 2020.

To design a field campaign, it is an advantage to have a previous hydrogeological conceptualization of the study area, coupled with enough data gathered throughout time to identify potential trends along with good geotechnical investigation data from the construction phases of the TSF. Assuming that the data series are long enough, the analysis can focus on their evolution over time in order to determine whether any correlations are possible. Thorough and careful analysis allows distinguishing hydrogeological or environmental issues from technical problems that may arise with field or laboratory equipment. In case of uncertainty or unclear patterns, a subsequent gap analysis helps to increase confidence in the data and strengthen the action plan.

An action plan is developed based on prioritizing the tasks according to objectives and relevance, leading to a staged field campaign design (Fig. 3). It is important to plan the sequence in which the works are carried out so that further decisions required along the workflow are well supported,

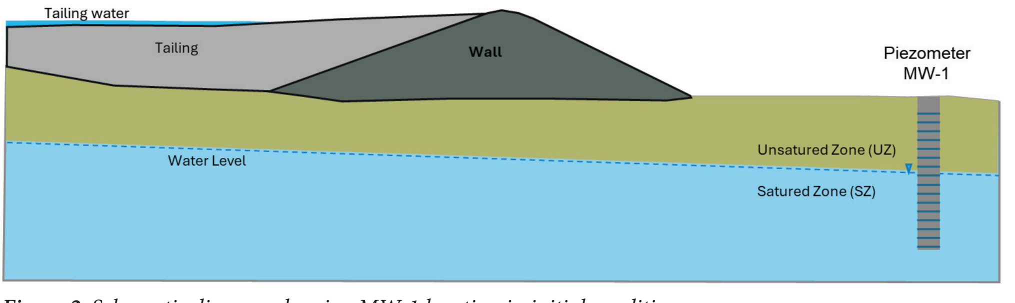

Figure 2 *Schematic diagram showing MW-1 location in initial conditions.*

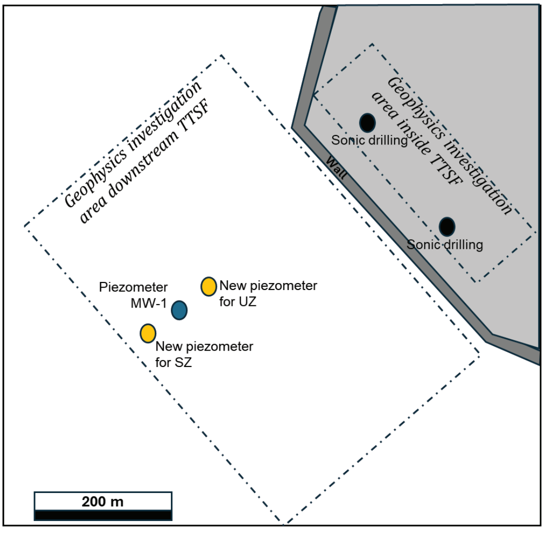

Figure 3 *Schematic diagram showing the spatial location of hydrogeological investigation activities.*

increasing the efficiency of the plan and keeping costs within budget. Wall raises are considered in the future design of the TSF.

After reviewing the available information, data and previous studies, the required field investigation tasks were developed in the following order:

1. Geophysical exploration at the beginning of the action plan allowed for the preliminary confirmation and or discarding of trends and outliers from the groundwater level and hydrochemical monitoring dataset. The TEM and SEV methods allowed for the investigation of large surface extensions and reached reasonable depths at a lower cost than drilling. Both methods proved to be suitable for tailings facilities and their surroundings, . However, better results were achieved combining TEM and NanoTEM outside of the tailings deposition area and using SEV methods inside of the deposition area and in the embankments, where the soil material is no longer in the natural condition.
2. Since geophysics requires ground truthing for technically supported interpretation, in the surroundings of the tailings deposit the drilling campaign was adjusted to cover the areas where high conductivity horizons where identified. Over the course of the drilling campaign, it could be recognized that some local high conductivity layers were related to fine grained material (clay materials) rather than humid or saturated horizons.
3. The previously installed environmental monitoring wells (e.g., MW-1) were screened along most of the well depth. This construction design does not distinguish water inflow areas between groundwater inflows and poses a vertical flow risk in the case of seepage in the UZ to SZ. New wells were constructed with specific goals, besides the groundwater level, hydrochemical and isotopic sampling capacity that the previous well already had implemented. The new monitoring wells were divided into "shallow wells" for UZ monitoring and "deep wells" screened for the SZ monitoring. All wells were implemented with pumping capacity (PVC diameter of 10"), to serve as potential mitigation control infrastructure if necessary. The design of the new monitoring wells is presented in Fig. 4.
4. A geophysical survey was also carried out into the deposition area of the TTSF; were sonic drillings and test pits were also constructed for soil sampling, instrumentalized as VWP and sealed afterwards.

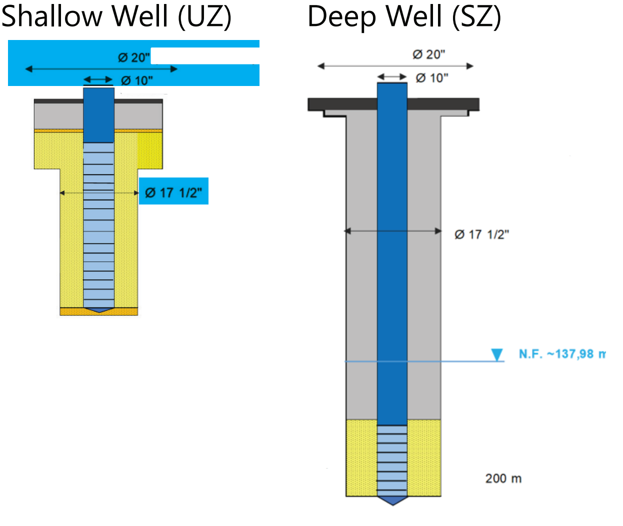

Figure 4 Shallow and deep monitoring wells design for UZ and SZ monitoring.

Results and Discussion

During the first analysis of the environmental follow-up monitoring, unexpected concentrations of certain elements such as bromide (from 5 mg/L to 60 mg/L) were detected in the water of well MW-1 (e.g. electrical conductivity EC increase from 8.000 µS/cm up to 80.000 µS/cm) as well as an increase in the water level, so additional studies were developed to determine if they corresponded to a singular phenomenon or to a more generalized trend in the aquifer (Fig. 5). Evaporation rate in this area is near to 5 mm/day.

Geophysical results downstream of the TTSF showed that the moisture was in a part of the wall that corresponded to a canalization structure and was confirmed by the investigation. Nevertheless, the field campaign continued in 2023 along with new geophysical profiles and monitoring piezometers. According to the fieldwork observations, there was a high degree of certainty that the remediation measures implemented through the drain installation eliminated the infiltration identified in the west abutment, but it was unsure if it was the only cause related to the MW-1 results, or they might be additional causes.

The soil sampling included in situ density analysis, visual humidity estimation (Fig. 6) and several geotechnical laboratory analyses (e.g. water retention curve SWCC, humidity content, granulometry, density, permeability

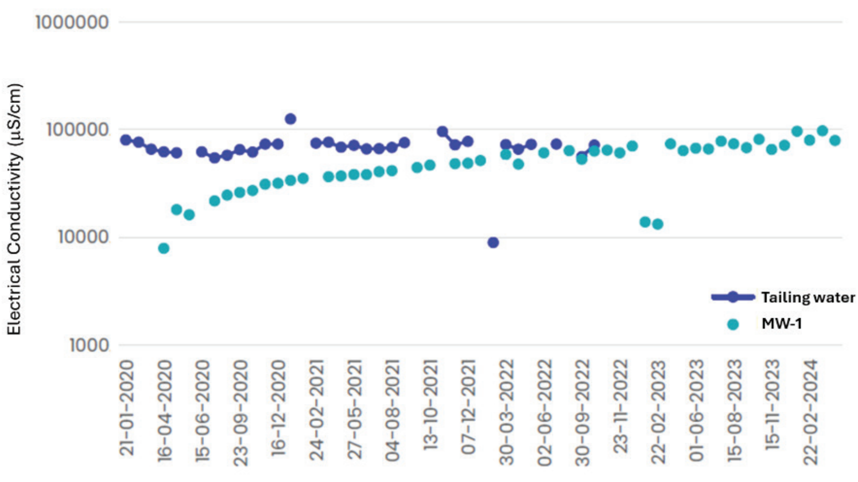

Figure 5 *Increase in EC in MW-1 compared to EC in tailing water.*

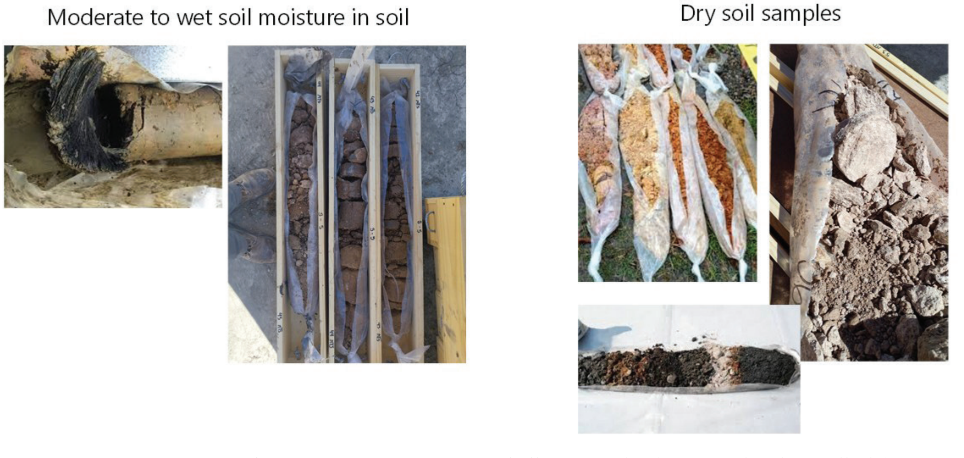

Figure 6 *In situ inspection of moisture content in sonic drilling samples (image: Claudia Mellado).*

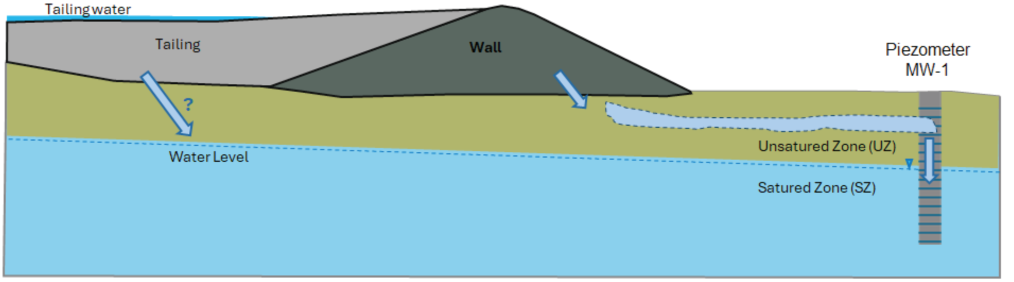

Figure 7 *Schematic diagram showing the seepage mobilized by the UZ and entering the well through the screens.*

and soil classification). They showed no further signs of humidity at more than 50 m depth from the surface.

Hydrochemical and isotopic monitoring provides valuable insight for the hydrogeological interpretation of potential seepage, because tailings operate with 100% seawater, to avoid extracting water from the aquifer. The water is transported from the sea into the mining facilities through a long pipeline and because of this, potential seepage from the tailings deposit has a seawater imprint, which makes it possible to differentiate between the infiltration water and the water from the aquifer due to sharp differences in their hydrochemical signature.

According to the interpretation of the results (Fig. 7), high conductivity horizons are likely associated to fine grain material and/or to infiltration recognized in the UZ. The infiltration in the drainage system in the embankment area that reached the monitoring well MW-1 and which entered through the upper screens in the UZ, was controlled in this area given that the UZ was found to be dry. However, there might be other infiltration paths that explain the on-going unexpected rising values of certain parameters on monitoring well MW-1. The UZ in this area reaches up to 150 m depth and is characterized by geological heterogeneity due to the mixture of alluvial and fluvial deposits. Some of these layers of fine grain materials with low permeability enable local flowing paths in the UZ in case seepage occurs.

Conclusions

The application of an integrated hydrogeological fieldwork campaign design has proven to be helpful to identify sources of infiltration associated with a TTSF deposit. In this case the campaign consisted in the construction of wells screened at different depths, combined with additional hydrochemistry and isotopic information obtained from the new wells which has been helpful to analyse, complement and validate previous assumptions about the site. Additional drillings are suggested to be built at the toe of the wall.

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