# Evaluation of Preferential Pathways for an Effective Dewatering and Depressurization of the Aitik Open-Pit, Norrbotten, Sweden

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## Abstract

Boliden's Aitik mine in northern Sweden has a mine plan which will deepen the pit to 850 mbgl by the end of mine life. The control on pit slope pore pressures becomes critical to ensure stable slopes and a safe operation. This often requires numerical groundwater modelling to support the geotechnical analysis. Following industry best practice, a multi-disciplinary approach has been adopted over different campaigns of characterisation to improve the understanding of source zones, pathways and magnitudes of water reaching the pit wall and floor. This enabled the construction of a detailed conceptual model, with a high level of confidence, that served as a basis for the construction of a 3D numerical groundwater flow model.

**Keywords:** Pore-Pressure, Depressurisation, Dewatering

## Introduction

The Aitik Main pit is excavated in metamorphosed Cu-Au-Ag porphyry rocks of the Kiruna-Ladoga shear zone. Mining has been ongoing at the site since 1968. The Life of Mine plan (LoM) has been revised to underpin continued ore production from the Main pit. The depth and geometry of the pit walls will evolve significantly over the projected mine life until 2043. The operating pit floor sump is currently at a depth of -470 mbgl (fig. 1). At the end of the LoM, the footprint of the Main pit will extend on both sides of the existing limit to reach a length of 3.6 km by 1.5 km of width. The pit floor in the Main pit is expected to reach a depth of -850 mbgl.

The conditions to ensure the stability of the pit wall will be increasingly challenging with a deeper pit. Existing pit walls are already subject to a close monitoring of slope movements and pore-pressure behind the pit walls from the pit crest to the pit floor. In addition, slope stability analysis is carried out on a regular basis to verify the conformity of the current and future slope design with local hydrogeological and geomechanical conditions. Slope stability analysis suggests that deepening the open pit results in a lower Factor of Safety (FoS). Although these results are highly sensitive to hydrogeological assumptions used. The analysis demonstrates that undrained conditions will produce a FoS of less than 1. Conversely, a drained condition, where the phreatic surface is greater than 100 m behind the pit wall, would produce a FoS that exceeds 1.5. Therefore, the effective depressurization of the pit walls is a central component of the pit slope stability.

Aitik has proactively installed horizontal drains in the pit walls and pumping wells in the pit floor to depressurize and dewater the current Main pit. To reach the depressurization objectives (to ensure that acceptance criteria are met) associated with the LOM pit expansion, this strategy must be further adapted and optimised. The evaluation of preferential groundwater pathways enables the efforts to be focused on sectors of the Main pit witnessing an excess of inflow from the pit wall and crest.

## General context

The mine topography is typically a low-gradient terrain. Pre-mining surface water comprised of small, shallow streams associated with, and connected to, numerous peat bogs with standing water and small lakes. The Sakajoki river flows from the south of the mine where its course changes to the northeast, cutting between the Main and Salmijärvi pits. An analysis of the pre-mining topography indicates that some tributaries of the Sakajoki river were covered by the Waste Rock Storage Facility (WRSF) and intercepted by the Main pit and Salmijärvi. (fig. 2). The drainage area upgradient of the hangingwall of the Main pit is about 7.8 km$^2$.

Aitik has a sub-arctic climate without dry seasons. Months of November to March have an average temperature below to -10°C. Over the period 1996-2020, the Mean Annual Precipitation (MAP) is equivalent to 610 mm/yr. There is an accumulation of snow over the freezing period, and it can reach 0.7 m depth at the end of the period of snow accumulation in March.

The geology at Aitik is divided into footwall, ore zone, and hangingwall, according to the structural contact and copper grades (fig. 3). The ore zone consists of biotite and muscovite schists and gneisses. Feldspar-biotite-amphibole gneiss with sub-economic Cu-grades occur in the footwall area. The hangingwall mainly comprises un-mineralised feldspar-biotite-amphibole gneiss, which is separated from the ore zone by a thrust fault. The dominant foliation within the ore zone dips 40–60° west and strikes approximately N–S, which is parallel to the footwall and hangingwall contacts. The major thrusting striking N–S and dipping 35–40°W (generated in the hangingwall) is highlighted by a zone of ductile deformation within the hangingwall of several hundreds of metres wide.

Quaternary deposits form an unconsolidated sediment cover of moraines and fluvio-glacial sediments. More recent sediments (Holocene) correspond to fluvial deposits and peats and are associated to phenomenon of continental erosion and accumulation of organic matter which leads to the surface accumulation of clay and which acts as barrier of the groundwater flow due to its low permeability. A refined analysis carried with an interpolation of available drill data and outcrops defined an average thickness of Quaternary deposits of 15 m around the Aitik mine.

## Pit hydrogeology

The development of the mine modified the groundwater regime locally around the Main pit, with the development of a zone of drawdown. To the east of the Main pit

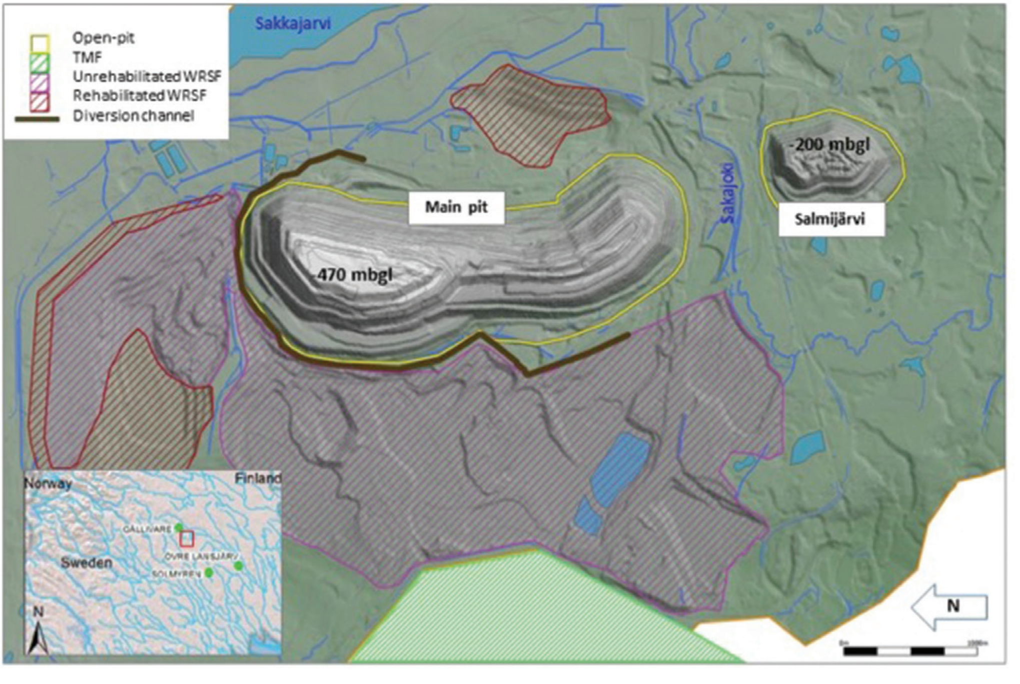


*__Figure 1__ Principal mine facilities and surface water hydrology (note that the mine coordinate system includes a rotation of ≈90°anticlockwise from north).*

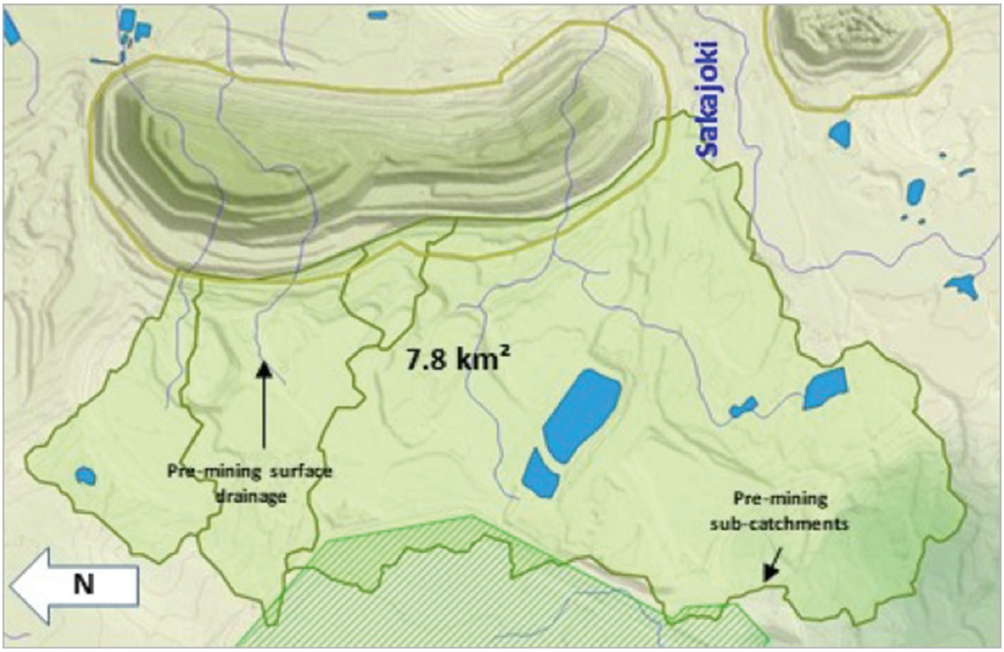


*Figure 2* *Pre-mining drainage system near the Main pit.*

in the footwall, groundwater levels show a clear seasonal fluctuation in monitoring boreholes. There is also an overlying trend of groundwater level decrease over the period 2005–2020.

The seasonal recharge fluctuation is not perceived at the crest of the hangingwall. This suggests that the WRSFs and natural superficial deposits to the west of Main pit (hangingwall side) have a significant storage capacity which subdues the seasonal recharge signature resulting from snowmelt. Bedrock groundwater levels in the area of the WRSF also remain relatively constant. The difference of seasonal fluctuation between the footwall and hangingwall is also observed in the Vibrating Wire Piezometers (VWPs) behind the pit wall (fig. 4).

A detailed review of pore-pressures measured along the lower hangingwall indicate that VWPs mostly record a water level similar to the pit floor. Mid-slope piezometers show a downward head gradient. This is a balance between: (i) downward drainage to the pit floor and to horizontal drain holes, and (ii) continuous recharge along the crest of the wall. Piezometers in the upper wall also show a downward head gradient, but pressures are higher. This reflects on-going recharge along the crest of the hangingwall. The piezometers are mostly in steady state which reflects the sustained and on-going

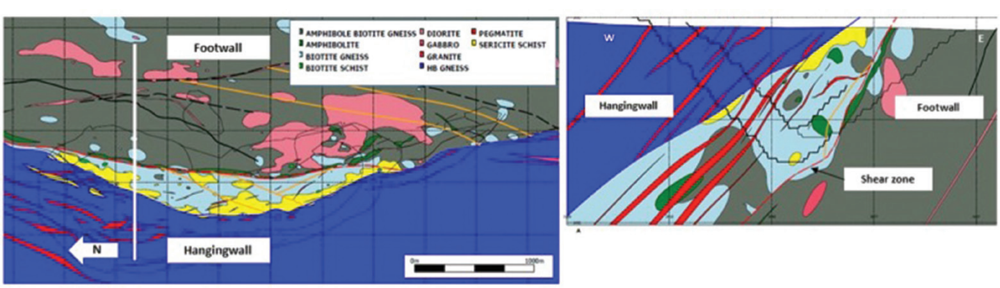


*Figure 3* *East-West section with the hangingwall and footwall separated by the shear zone. a) Picture taken from the south looking to the north. b) Geological model (Karlsson Peter).*

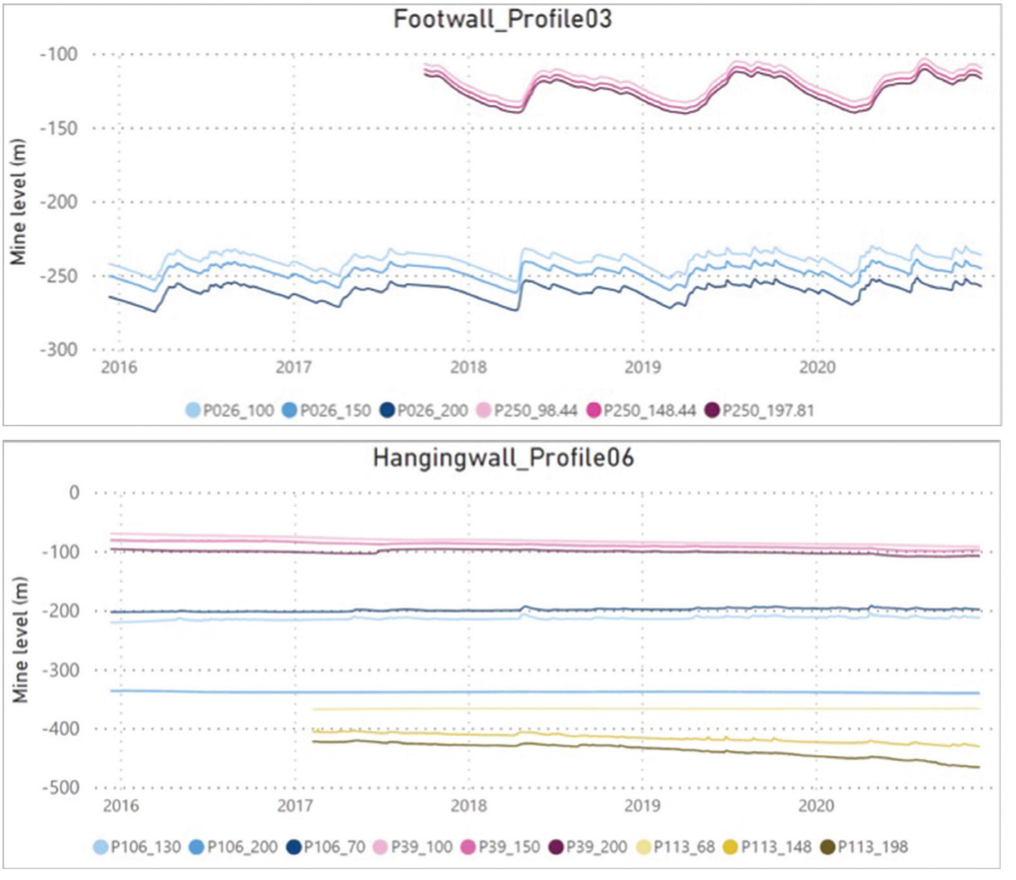


***Figure 4*** *Comparative response of footwall and hangingwall VWPs to seasonal recharge.*

nature of the recharge. There has been little change in pressure during the past 4 years, which reflects the relatively stable depth and areal extent of the pit over this time period.

A detailed analysis of the water balance components has been carried out to estimate groundwater inflows contributions to the Main pit. Groundwater inflows are estimated from pumping rate during the winter months, assuming that there is no surface water inflow during winter because of the low temperatures, which means the only source of inflow is groundwater. Estimated groundwater inflows range from 4,500 to 6,500 $m^3/d$ from historical observations.

## Artificial recharge and connectivity

Several campaigns of groundwater characterisation have been carried out to understand the interaction of the Main pit with the surrounding groundwater system and identify the predominant recharge components to the Main pit. A special focus has been given to the sector to the west of the Main pit with the diversion channel.

The ongoing artificial recharge from the Tailing Management Facility (TMF) and WRSFs to the west of the Main pit prevents the expansion of the area of drawdown from the pit to the west. The consulting company O'Kane (2018) estimated average annual percolation on the WRSFs (un-reclaimed, reclaimed top and reclaimed slope surfaces) through unsaturated flow modelling. It has been evaluated that WRSFs directly to the west of the main pit could receive between 55 and 60% of the mean annual precipitation (compared to 8.5% estimated from natural recharge above). The TMF is also likely to provide a substantial flow towards the Main pit. Literature review, flow rates in the collection channel, chemistry in the groundwater around the WRSF and TMF catchments indicate that an estimated 13,825 $m^3/d$ infiltrates from the TMF and flows towards the Main pit via the original drainage system which is a preferential pathway for the groundwater from the southwest of the mine area.

The runoff and groundwater flow in the moraine and is intercepted by a diversion channel along the pit crest of the hangingwall. The diversion channel has been constructed around the rim of the hangingwall and northern end wall. It is designed to collect seepage and runoff from the WRSF and TMF sector. However, it is identified as a feature potentially creating recharge to the underlying bedrock and to the pit crest. The flow rate gradually increases along its flow path although specific sectors lead to a local decrease in the surface flow rate, suggesting infiltration.

A detailed review of the water chemistry in different sectors of the Main pit and diversion channel has been carried (Amézquita Rico, 2019), and results are summarised as follow:

- The water quality of seepages in the upper hangingwall is very similar to water quality of the diversion channel water and the main tributary coming from beneath the dumps. Waters from the diversion channel and the seepages are acidic (pH 3.5 to 4.2). The dissolved elemental concentrations in drill holes near the pit wall and in seepages in the upper pit wall (particularly trace metal concentrations) indicate that the water in the hangingwall slope has a strong influence from the TMF.
- Samples from horizontal drains located in the lower pit wall of the western hangingwall have near-neutral pH (6.2 to 7.9) and a high alkalinity. The water quality does not indicate an influence of the diversion channel and TMF.
- A similar conclusion is obtained to the north of the Main pit in the shear zone and footwall where chemistry of seepages from horizontal drains in the lower pit wall differs significantly from the diversion channel.

The chemistry of seepages in the upper western hangingwall corresponds to a mixture of diversion channel water and waters are believed to be runoff from the dumps or infiltrated waters from the tailings.

## Implications on the dewatering and depressurisation strategy

The volume of water reaching the Main pit is essentially coming from the crest of

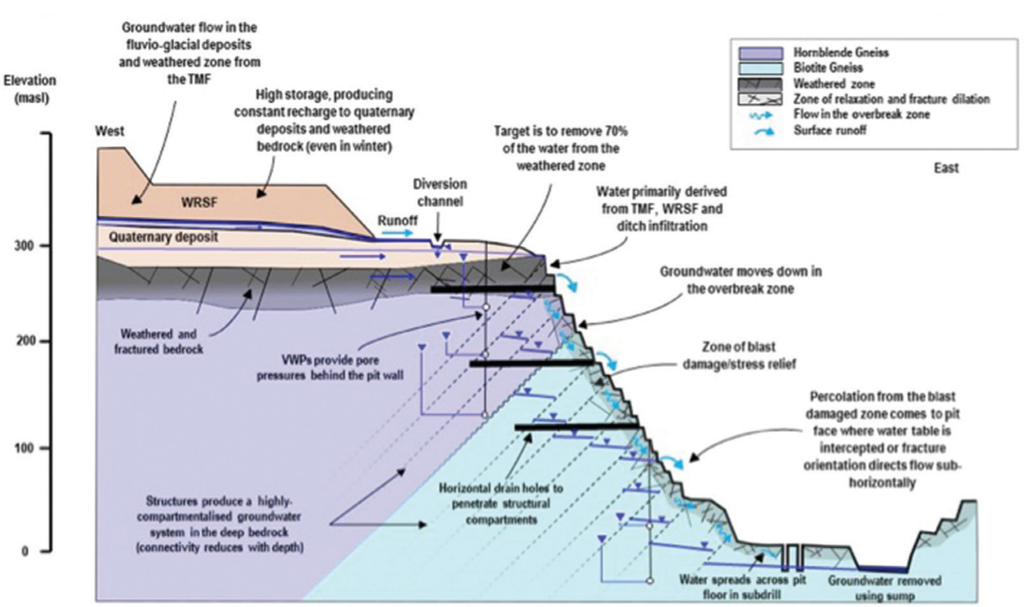


***Figure 5** Conceptual section for the hangingwall.*

the hangingwall. Groundwater inflow to the open-pit is not expected to increase significantly over time because the LoM plan considers mainly the excavation in a hydrogeological unit associated to a very low hydraulic conductivity.

The lower fractured and compartmentalized bedrock has shown an effective depressurisation with horizontal drains. Nevertheless, the partial interception of sub-superficial flows in the quaternary deposits and weathered bedrock by the diversion channel creates a constant recharge to the underlying units and overbreak zone at the level of the pit crest (fig. 5). The location of this recharge component at the top of the pit wall impacts the ability to achieve depressurization objectives.

A numerical model has been developed as a tool to evaluate the pore pressure distribution, and alternative dewatering and depressurisation strategies. It is used to optimize the configuration and number of horizontal drains. One of the modelling objectives is also to assess water management above the pit crest to help develop alternate strategies to intercept water before it ingresses to the open-pit. Going forward, dewatering of the pit crest and control of recharge sources to the west of the Main pit should form a key part of the future dewatering strategy.

## Conclusions

The pore-pressure distribution has a major effect on the slope stability of open-pit walls. An evaluation and control of the pore-pressure distribution is only possible with a precise characterization of the groundwater system. Consequently, any field program involving water level and quality monitoring can be used to quantify source zones, pathways behind the pit-wall and magnitudes of water reaching the pit wall and floor. At Aitik, it has been found that fluvio-glacial deposits play a major role in the conveyance of water to the pit and streams have been diverted around the crest of the hangingwall and end walls and these provide on-going (year round) recharge to glacial sands and gravels around the pit area, together with seepage losses from water storage ponds, waste rock areas and other mine facilities. Water from the glacial deposits infiltrates into the bedrock particularly in areas of faulted rock and where the zone of weathering of the underlying bedrock is thinner. Much of the water moves into the overbreak (blast damaged) zone within the pit, and then allows movement of water behind the pit wall to reach the pit floor and increase the total dewatering requirements and pore pressures behind some of the slopes. Horizontal drains are installed to reduce pore pressure in the pit slopes. The effectiveness of the drains is partially reduced by the on-going flow down the over-break zone. Strategies to capture the fluvio-glacial groundwater outside of the pit, or before it can migrate through the overbreak zone, are seen to produce more tangible benefits regarding both dewatering and depressurisation objectives.

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