Predicting Underground Mine Dewatering Requirements: A Case Study of a Precious Metal Mine in a Subtropical Environment

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Abstract Predicting underground mine dewatering rates is a difficult exercise for a mine in the planning and permitting stages of development. In this study, a comprehensive groundwater characterization program was conducted involving evaluation of existing exploration core, packer testing, multiple-well aquifer testing, and hydrodynamic down-hole flow logging. A groundwater model was developed using VADOSE/W (Krahn 2004) to intrinsically simulate the rapidly changing temporal and spatial dynamics of the operating underground mine. The results confirmed that the complexity of modern mining operations requires a rigorous approach to mine water predictions that integrates the site characterization data and the mining plan.

Key Words Underground mine dewatering, predictive modeling, site characterization

Introduction

Accurate predictions of mine dewatering rates are required for mine feasibility studies and environmental impact studies. Due to the uniqueness of each underground mine, comprehensive characterization, modeling, and analysis are required to accurately predict the dewatering requirements. Although empirical equations and analytical solutions have been published (Fawcett *et al.* 1984), they fail to capture the complexity of each individual mine and often correspond poorly to actual experience during operations.

In addition to the technical challenges mentioned above, additional challenges such as site heterogeneity, complexity of the mine development plans, and the potential impact to local water supplies require a tailored, multi-tiered approach to fully characterize and assess the future mine dewatering requirements. Here we suggest a methodology for a comprehensive approach to mine dewatering prediction at a mine with a complex hydrogeologic system that considers potential impacts on local water sources.

Site Description

The study area is a vein-type epithermal precious metal deposit hosted in andesitic and volcaniclastic host rock located in a subtropical valley. The hydrogeology of the site is characterized by two systems: the valley system and the mountain system. Both systems have the same basement rock— a heterogeneous volcaniclastic sedimentary sequence (VSS), which is overlain by alluvial deposits in the valley and a porphyritic andesite (Andesite) and lithic tuff in the mountains. The valley system contains both a shallow alluvial aquifer and deep fractured bedrock aquifer. The mountain system contains a fractured bedrock aquifer that is complicated by the existence of hydrogeologically significant structures. The planned underground mine workings at the project involve the development of tunnels, adits, down-ramps and stopes under the mountain that are significantly beneath the pre-mining potentiometric surface and will extend below the bottom of the adjacent valley. A cross-section of the mine workings, down the strike of the ore deposit, is shown below (fig. 1). The vein system is nearly vertical and 30 meters wide (into and out of the cross section presented).

It is clear from fig. 1 that the dewatering system is more complicated than a bottom-up or top-down development scheme.

The project area is heavily populated with the cultivation of coffee on the hillsides and irrigated crops in the valley. Due to existing stresses on the surface water resources and the shallow groundwater resources in the area, the mine must ascertain the impact that dewatering will have on the surface water and the alluvial aquifer in the valley.

Methods

In order to characterize the impact of dewatering, a comprehensive field program was conducted to determine the hydrogeological properties of the aquifers present, which included 11 slug tests (single-well recovery tests), 58 packer tests (fractured rock conductivity tests), and 3 multiple-well pumping tests.

Shallow Aquifer Characterization

Slug tests were performed on the shallow alluvial wells located in the valley and were used as an initial characterization of the shallow alluvial aquifer. Additionally, a long duration (24-hour) pumping test was performed in the alluvial valley to determine the aquifer properties in the alluvium. While the project has no interest in the alluvial aquifer

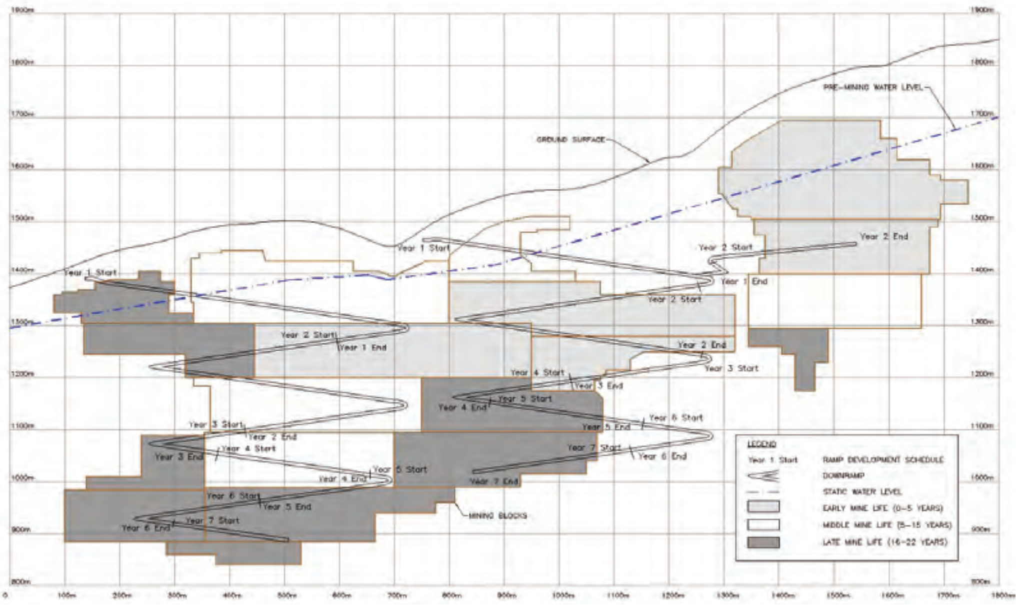

Figure 1 *Drawing of mining development blocks in cross section*

in terms of dewatering or mine water supply, understanding the shallow system was critical to protecting this resource from dewatering impacts.

Deep Valley Aquifer Characterization

A long duration pumping test was performed in order to characterize the deep aquifer that exists below the alluvium. Water levels were monitored in the pumping well (P-1) and three observation wells: two observation wells screened in the deep fractured rock aquifer and one well screened in the shallow alluvial aquifer. The goal of the test was to assess the ability of the deep aquifer to sustain a production well for the mine and to ensure that stress on the deep aquifer would not affect the shallow aquifer. In addition, the utilization of two observation wells in the deep aquifer allowed for the calculation of anisotropic conductivity.

Mountain System Characterization

A multiple-well aquifer tests and packer tests were utilized to characterize the hydrogeology of the mountain system. A long-term multiple-well pumping test was performed in the area of future underground workings. The aquifer test produced abundant groundwater (see Results) from a total screened interval of 224.8 meters. The screened interval covered several potential water bearing fractures in the Andesite and VSS Formations. Based on the aquifer test alone, it is impossible to determine which part of the interval was productive. As a result, a hydrodynamic flow test was performed by Colog Inc. The hydrodynamic flow test involved lowering a small sensitive spinner attached to a real-time data connection cable while the well was pumping. The spinner recorded the direction and velocity of flow within the well during pumping.

Packer tests were performed along several intervals in multiple core holes located around the site to assess the conductivity of major fractures and contacts.

Predictive Modeling

The data described above was integrated into a 2-D flow model constructed in VADOSE/W. VADOSE/W is a finite-element, variably saturated groundwater flow model often used in mining-related applications (Krahn 2004). In addition, other data was collected from the client and used as model inputs including the site geology, the mine development plan, and the mine closure plan. The model was constructed as a 2-D finite element model representing a geologic section across the deposit (fig. 1). The development of the mine was represented using open drains to simulate the tunnels and mine workings. It was assumed that all tunnels and workings will be free of backfill. Even though this is not true according to the mine plan, it offers a conservative estimate of potential mine dewatering needs.

A steady state model was constructed using data collected during the field campaign and was calibrated to the current, pre-mine, potentiometric surface. A transient model was then built to in-

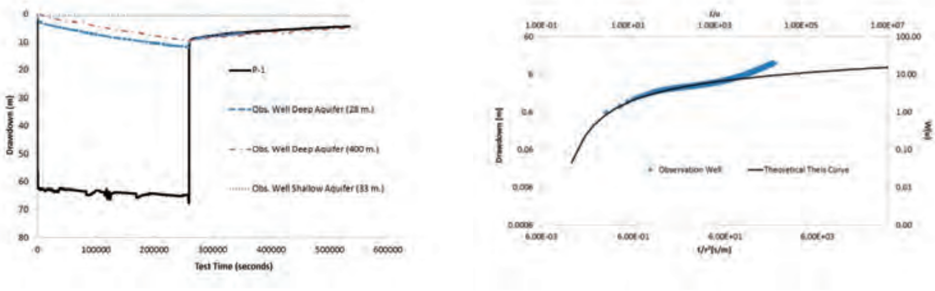

Figure 2 *Aquifer test results, P-1: drawdown and theis curve.*

corporate the seasonal dynamics that exist within the study area and the evolution of the mine plan (fig. 1).

Results

In addition to establishing the physical properties of the aquifers, the field campaign and model results revealed several important features of the groundwater system.

Valley Characterization Results

The pump test in the shallow alluvial aquifer confirmed that the shallow aquifer beneath the valley could be a significant and sustainable source of groundwater for the community

The response of the observation wells during the aquifer test of P-1, the deep well in the valley and planned production well for the mine, revealed that although the aquifer is capable of producing 350 gallons per minute (gpm); this production is not sustainable. The drawdown at the observation well deviated from the Theis Curve (Theis 1935) showing that the aquifer is constrained by geology and has insufficient recharge to replace the extracted groundwater (fig. 2). This does not demonstrate that the aquifer is not a suitable source of water for the mine, merely that P-1, as a single well, cannot sustainably produce 350 gpm.

The P-1 test also proved that pumping the production well will not impact the upper aquifer. The nearby shallow well exhibited no drawdown during the pumping test (fig. 2). This result is important because the deep fractured rock aquifer in the mountain system may be connected to the deep fractures in P-1. The shallow monitoring

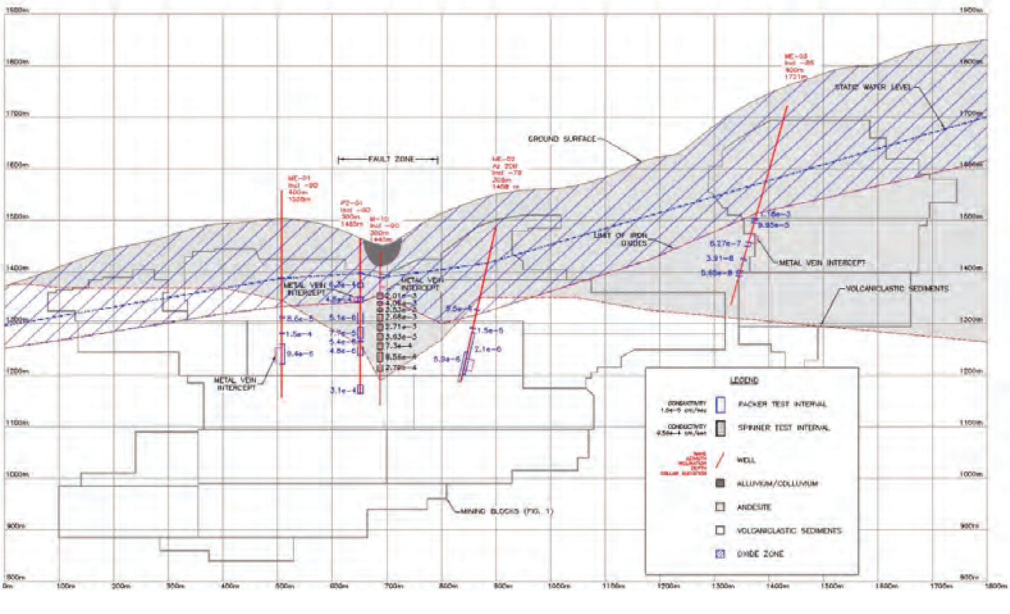

Figure 3 *Packer and spinner test results in cross-section.*

wells showed no response to pumping thus showing that mine impacts will have minimal impact on precious community water resources.

Mountain System Results

Similarly, based on the drawdown results from the fractured rock aquifer test, it is clear that the fractured rock aquifer in the ore zone has a finite extent and that a no-flow boundary was encountered by the cone of depression during the pumping test. This is the most significant observation from the aquifer test and greatly influences the dewatering predictions because it demonstrates that dewatering will deplete storage, and the fractured rock aquifer is not connected to prolific fracture zones or to sources of surface water.

The hydrodynamic flow test showed conclusively that the upper weathered andesite is a high yield aquifer and was the source of nearly all of the flow extracted in the ore zone pump test. However, the pumping test results suggest that this discharge may not be sustainable. It is a compartmentalized system of limited extent that is constrained by the hydrostructure of the post-mineral faulting in the ore zone (a fault located along a major site drainage).

Packer testing further confirmed these conclusions. Testing revealed that rock outside the primary post-mineralized structure had very low conductivity. Within the fractured zone, the uppermost andesite layer that was fractured with iron oxide staining was the most conductive unit, and the VSS formation was the least conductive unit. Conductivity generally decreased with depth, and deeper fractures were not hydrogeologically significant due to the presence of fault gouge. Packer testing confirmed that most of the water flowed down the structural axis, and flow transverse to the main fault was minimal (fig. 3).

Predictive Modeling Results

The predictive model produced time-variant dewatering requirements for the mine and predictions of the dewatering requirements over time. Below is a view of the model from mine year 18 (fig. 4).

Fig. 4 demonstrates that some unmined blocks retain their moisture in spite of deeper open workings which is a result of the irregular mine plan.

A graph of the model predicted dewatering requirements for the mine is shown below (fig. 5). In the first years, the mine must pump a large volume of groundwater because storage is being depleted and the tunneling is encountering the fractured portion of the andesite which contains the most water. For the rest of mine life, the level of pumping is a function of the rate of mine development. For example, in year 15, large blocks are opened in the mine zone and the simulation predicts an increase in the necessary pumping rate as a result.

From these results, an area-by-area prediction of mine dewatering requirements was calculated that will be used by the client’s engineering staff to purchase the necessary equipment to dewater workings prior to their excavation.

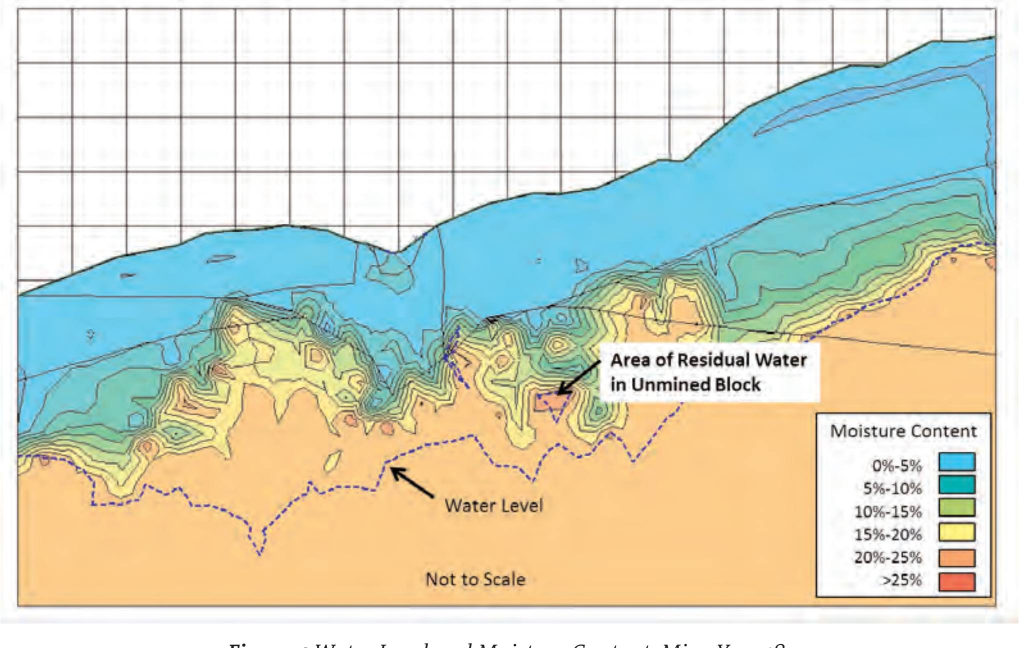

Figure 4 *Water Level and Moisture Content, Mine Year 18.*

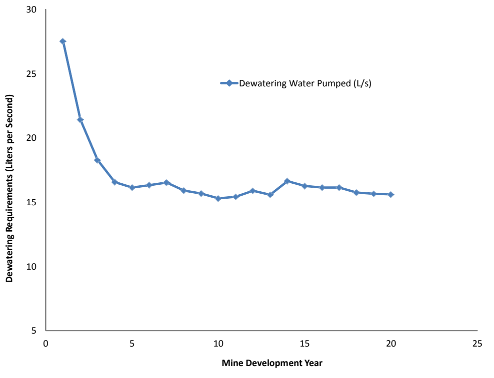

Figure 5 *Mine Pumping Requirements.*

Conclusions

The results of the field assessment and model simulations indicate that the mine will have a significant dewatering burden early in mine life as the fractured and weathered andesite aquifer is dewatered. This burden will diminish as the mine life continues but will still respond strongly to the irregular mine development pattern. Long-term aquifer tests in the fractured rock systems (Andesite and VSS) showed that it is unlikely that the dewatering of the mine will impact the shallow aquifer.

It does not appear from model results that the required pumping rate for dewatering will change significantly as a result of seasonal fluctuations in rainfall. Even though packer testing did not encounter large conductive fractures at depth, high-yield fracture zones are possible in all underground operations below the phreatic surface. The mine plans to seal these fractures, and if they are similar to other fractures encountered, they are expected to dewater quickly.

This study clearly demonstrated that despite daunting challenges in characterization and prediction, a rigorous approach to mine dewatering can produce reasonable predictions of mine dewatering needs. A flexible work plan is the best method to respond to challenges as they appear, such as the addition of the hydrodynamic modeling in response to higher than expected well yield in the ore zone aquifer tests.

This study proved critical to the mine's environmental impact statement by proving with empirical evidence and groundwater simulations, demonstrating mine dewatering is not likely to impact critical local water resource. Although expensive, the deep multiple-well aquifer tests were powerful evidence for the regulatory community because they showed with concrete data that the shallow and deep systems were separate. This mine is currently driving down-ramps (in Year 1, fig. 1) and in the coming years, the model results will be verified to ascertain the accuracy of the predictions and to improve the model results.

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