Proposing a Design and Planning Method for Mine and Tunnel Drainages

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Abstract

Around the world, both mining and underground civil works require excavating tunnels or ramps, whether for access, ore mining, rail or road connectivity, ventilation, water supply, among other applications. During this process, it is common to intercept groundwater, which must be removed to achieve the final excavation objectives. If the tunnel slope or ramp is positive or zero, drainage can be done through a lateral channel or pipe without major impacts. However, when the slope of the ramp or tunnel is negative, the water must be removed as soon as possible to avoid accumulation due to gravity. It is common that when the underground works depth exceeds the hydraulic capacities of a simple pumping system, pumping stations are used to remove the water in stages to the surface or to the final accumulation or drainage site. This paper describes a methodology for the design, sizing and planning of pumping stations for underground drainage in mines with depths that require the use of pumping stations, due to the high hydraulic pressures above 10 bar. This methodology consists of determining the hydraulic design variables of the system from the initial project proposed setting up as the maximum depth reached, ramp slope and maximum expected infiltration flow. With the maximum depth and the total head losses estimated by the proposed design variables, the total head loss to overcome is determined. In this way, total losses can be subdivided according to the number of pumping stations proposed, based on the same height and flow to be overcome by each pumping station. This last allows the engineers to takes advantage of available resources, maintenance, geological conditions of the site and drainage needs in terms of flow and depth, considering potential anomalous situations and response capacities in the event of emergencies or faults. It also is aligned with the treatment and reuse of water to be used as "industrial water". Based on extensive field observations across various projects, this methodology provides a comprehensive solution for sustainable water management in mining, civil, and military operations, enabling water treatment and reuse while addressing both routine drainage and emergency scenarios.

Keywords: Pumping stations, groundwater, mine drainage, underground projects, ramp excavation, underground mining, piping

Introduction

Hard rock tunnel or ramp excavation often encounters groundwater that must be removed to meet project objectives and the maintain safe working conditions for the underground miners. Positive or zero slopes allow for straightforward drainage using a lateral channel or pipe. However, negative slopes necessitate pumping systems. Encountering one or more aquifers further increases the water volume requiring extraction. Therefore, a thorough hydrogeological study is essential to determine the anticipated inflow at depth. This involves established methods for testing and estimating parameters like permeability, transmissivity, and storage capacity (Dupuit, 1863; Thiem, 1906; Theis, 1935; Todd, 1959). Once these parameters are determined, steady-state groundwater inflows can be estimated using the Goodman *et al.* (1965) formulation.

When tunnel depth exceeds the capacity of simple pumping systems, pumping stations are required for staged drainage to the surface or a designated discharge point. Some authors discuss tunnel dewatering through articles and reports on underground pumping stations design (Cashman and Preene, 2013; Powers *et al.*, 2007), they offer useful but limited detail on pumping stations for ramps or mine tunnels.

The proposed methodology for drainage and water resource utilization involves a structured approach and an initial suggested pumping station design. This design aims to standardize hydraulic elements across all stations, including pump type and operating point, pipe dimensions, and fitting quantity. This work draws upon years of field observations at multiple mines and incorporates good practices from mining companies and their engineers, often based on practical experience (Palta Araya, 2015; Tapia Cid, 2018).

Proposed Drainage System Philosophy

Operational philosophy for excavating negatively sloped ramps considers a maximum vertical depth achievable with a generally consistent slope, often determined by the uphill grade capacity of the development equipment (excluding rest areas and curves). This defines the ramp length. As excavation progresses through aquifers or water-bearing geological structures, infiltration begins. This water, along with water from drilling equipment, must be removed from the excavation face. Submersible pumps designed for sludge or debris transport the water to a nearby mobile or temporary accumulation and pumping station for discharge to the surface or the nearest pumping station. As excavation deepens, permanent pumping and accumulation stations become necessary due to the hydraulic limitations of pumping systems. Furthermore, if properly designed, these stations could partially clean and treat the water for reuse as industrial water for drilling equipment. To achieve this, the stations require a minimum water accumulation volume to supply drilling operations and to accommodate downtime for pump system maintenance, mechanical or electrical failures, and unforeseen events. Additionally, from an operational point of view, the design is determined by the storage capacity required to manage the maximum number of stop-starts the pump system is designed to maintain. Too small volume results in excessive stop-starts and more likely system failure. At some Chilean underground mines, is observed at least one full day of accumulation capacity and the pumping system capacity should be sufficient to pump the entire accumulated volume within a fraction of a day. It can be operating less than 50% of the day, sometimes with multiple pumps in parallel. This redundancy allows for partial capacity pumping during maintenance, failures, or underestimating the total infiltration flow rate. Additionally, is frequently to find the maximum working hydraulic pressure not exceed 10 bar for operational feasibility and avoid leakages, because PVC Class 10 (10 bar) and HDEP (6–20 bar) are commonly used.

Proposed Methodology

The following outlines the proposed methodology, based on the philosophy described above:

Determine the tunnel or ramp design parameters, such as vertical depth and ramp slope, to calculate the total ramp length. These are typically defined by the project design.

Quantify maximum expected infiltration flow rate based on hydrogeological studies for flow and recharge estimations, that can be additionally influenced by different mining units like old mines and abandoned areas. The idea is to estimates a maximum capacity design for the pumping stations.

Estimate maximum accumulation period for the pumping stations, considering the maximum expected infiltration flow rate, and then calculate the maximum expected accumulation volume. Providing one full day of accumulation capacity is recommended to address potential failures, planned maintenance, or to avoid underestimating the total infiltration water flow rate.

Select a daily pump operating percentage, representing the pumps' daily operational time. A value below 50% is recommended, ensuring the pumps can drain the entire volume within a fraction of a day to cover underestimating the total infiltration water flow rate.

Select a pipe diameter based on the maximum pumping flow rate, daily pump operating percentage, and maximum expected infiltration flow rate, or the desired emptying time for the pumping station. An economical flow velocity range within the pipes is suggested to be between 0.5 and 2.5 m/s (Cengel & Cimbala, 2018) (Crane Co., 2018).

Estimate friction and minor losses as if the entire ramp were a single pipe, using the chosen diameter. This provides an initial approximation of total system losses.

Estimate the total head loss as the sum of the friction and minor losses for the entire ramp plus the total vertical lift.

Select the pump curve and operating point, based on the maximum working pressure per station established by engineering and operations (agreed-upon manageable pressure limit defined by the company experience and cost evaluation).

Determine the number of pumping stations vertically by dividing the total head loss by the head at the selected pump's operating point. This will likely result in a non-integer value. If the number is close to the lower integer, rounding down is recommended. For example, 4.05 or 4.1 could be approximated to 4. However, for larger non-integer values, assess the margin between the installation's required point and the chosen pump's operating point. Thea goal is to stay within the agreed-upon manageable pressure limit. Several design iterations may be necessary to optimize this value, as excavating and constructing a pumping station represents a significant investment. Once an acceptable value is reached, adjust the pump operating point according to the final number of stations.

Determine the recirculation volume for equipment water consumption, such as horizontal drilling jumbos, ground support equipment, hydraulic splitters, and radial and/or vertical drilling rigs. In the latter case, some equipment may require substantial water volumes for operation and may be supplied using the infiltration water, which can be partially recirculated to the nearest pumping station as an option. Optionally, the mine water may be cleaned of mud on surface to be introduced by gravity.

Design the pumping station, considering the accumulation volume, solids settling system, and water treatment for supplying industrial water to equipment.

Determine the operational parameters of the mobile pumping station based on the development characteristics to size its capacities, such as average and maximum flow rate, maximum lift, sludge removal, transportability, and rapid installation capability. This will determine the pump sizing, dimensions and design of the housing, and electrical power requirements. Commercial products are available, or they can be developed in-house.

Pumping System Design

The pumping system consists of three main parts: pumping at the working face to the mobile station, pumping from the mobile station to the nearest operational pumping station, and staged pumping to the tunnel exterior or final discharge point. The design of each stage is addressed below (see Fig. 1).

Pumping Station Design

The pumping station design comprises several components, detailed in Fig. 2. The

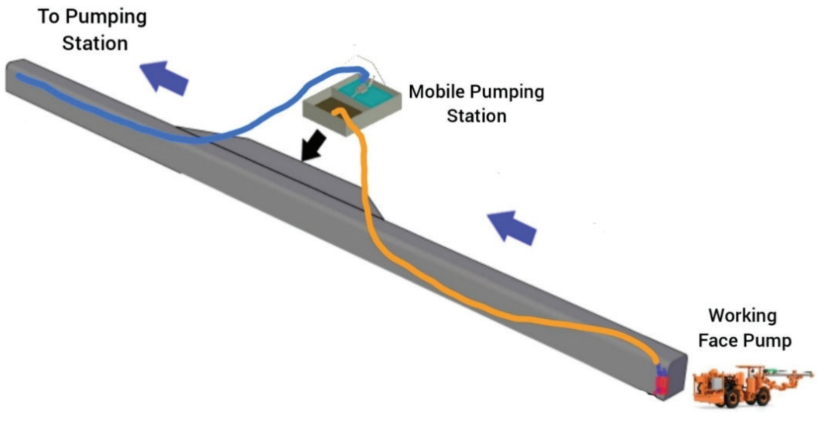

Figure 1 Pumping System Schematic.

station is located laterally to the main tunnel or ramp, with a slope to accommodate water accumulation. It includes a settling pond where dirty water from the face drains and solids settle. Cleaner water overflows the settling pond into the pumping area. A centrifugal pump located in the pumping area propels the water to the upper level or the next higher pumping station.

Solids or Sludge Wall

The sludge wall, as mentioned, retains the coarse fraction of the drainage water, allowing cleaner water to overflow. This wall should be constructed of high-quality concrete to provide the necessary stability for sediment removal and withstand impacts from cleaning equipment buckets (see Fig. 3). A minimum concrete compressive strength of 17 MPa, or category G17, is recommended (Instituto Nacional de Normalización – Chile, 2016).

Pumping Station Sizing

Pumping station dimensions depend on the established accumulation volume, geomechanical stability requirements (height "y," width "b"), which typically do not exceed those of the main tunnel or ramp, and the station slope. This slope must allow development equipment access during construction. Fig. 4 illustrates the usable storage area within a pumping station, which can be divided into two volumes.

These volumes relate to the station's design geometry and quantify its capacity, with Vt, the total volume, being the sum of Volume 1 (V1) and Volume 2 (V2). In this schematic, Volume 1's length is directly related to the station slope, tunnel width, and height, but only half contributes to usable volume. This

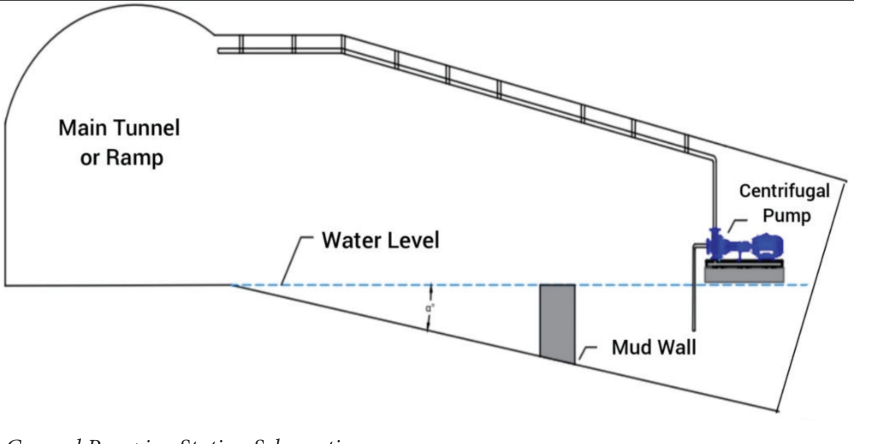

Figure 2 General Pumping Station Schematic.

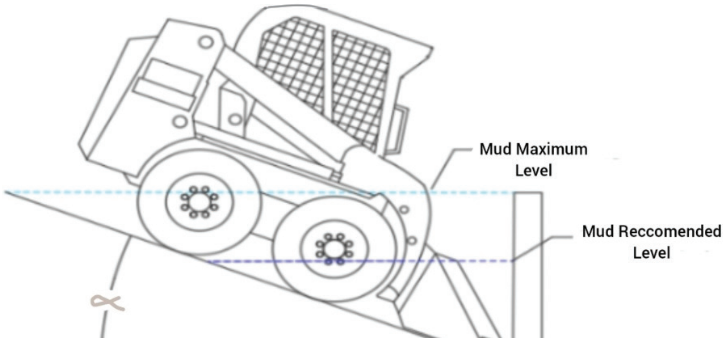

Figure 3 *Sediment cleaning equipment at the sludge wall.*

can be calculated directly using the slope and tunnel dimensions to estimate length L1:

Slope = y / L1 Then L1 = y / Slope

V1 = (y*L1*b) / 2

If Volume 1 is insufficient to accommodate the total accumulation volume, Volume 2 must be estimated. This can be considered a parallelepiped, with a volume given by:

V2 = (y*L2*b)

Length L2 is derived from V2 = Vt – V1.

Furthermore, before operations commence, waterproofing the tunnel walls exposed to water is recommended, especially near geological structures that could cause significant water infiltration. This is also crucial in areas with nearby mining activity or conditions that alter rock mass stresses, potentially activating geological structures and causing seepage to under levels.

Water Treatment and Utilization

The water recovered and stored in the pumping area can be treated for use as industrial water, supplying drilling equipment and other operations. Treatment occurs in the accumulation area. The first step is pH neutralization. Low pH acidity can corrode equipment materials, pipes, valves, and fittings. Acidic water is common in sulfide mines due to the presence and degradation of pyrite. Conversely, high pH or alkaline conditions are also corrosive and tend to precipitate Mg and Ca salts in pipes, valves, and fittings, potentially causing complete blockage through internal accretion by scaling. After pH neutralization, suspended solids must be settled to prevent their circulation through the system, which can cause blockages or accretion. While the sludge wall retains a significant portion of solids, some (primarily fines) enter the accumulation area due to flow turbulence in the sludge zone.

Pump and Staged Pumping

The pump lifts water from the accumulation area to the next station. It should be easily accessible for maintenance; a platform

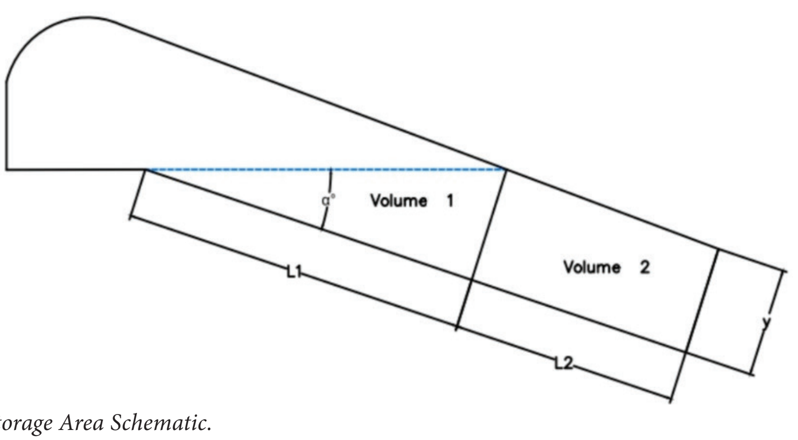

Figure 4 *Storage Area Schematic.*

above the flooded area can facilitate this. A centrifugal pump is suggested, standby operating in parallel with another for redundancy during repairs or maintenance. The station length may be determined by the pump's NPSH (Net Positive Suction Head) requirements. In this case, a floating pump on a raft or a submersible backup pump can be installed. Using a primary submersible pump is not recommended due to their lower hydraulic pressure output, which would limit the distance between pumping stations.

Staged pumping conveys drainage water to the exterior. This can be manual, semi-automated, or fully automated, depending on the implemented sensors, PLC (Programmable Logic Controller), and communication system available in the tunnel. It's crucial to consider that the stations operate in series; failure at one station halts drainage until the issue is resolved. Therefore, the accumulation volume should account for potential failure scenarios, providing time for intervention and solve them.

Sump pumping at the working face

When ramp is developing at the lower level, working face requires one or more submersible sludge pumps operating continuously to manage infiltration. These pumps must be designed for abrasive solids; otherwise, their lifespan will be significantly shortened by drilling debris. Submersible sludge pumps typically have a limited hydraulic lift capacity, so their role is to transfer water from the face to a nearby pumping station. Hydraulic lift calculations must account for head losses and vertical elevation.

Mobile Pumping Station

The mobile pumping station is crucial in this drainage system. It should be located as close as possible to the working face to receive water and convey it to the nearest pumping station. Positioning it in an auxiliary drift prevents obstructing tunnel traffic. Careful consideration should be given to matching the hydraulic pressure of the face pumps with the maximum distance to the mobile pumping station to facilitate planning during tunnel development. The station design should include a receiving tank and a booster pump. For solids separation, the tank should be divided by a settling wall, allowing cleaner water to overflow for pumping. The pump must handle abrasive solids, have a flow rate exceeding the infiltration rate to accommodate various scenarios, and a hydraulic lift capacity greater than the separation between pumping stations. This is because when the design distance between stations is reached, the next station may not yet be constructed or operational, requiring additional time beyond the main tunnel or ramp development (at least one week).

Final Discussion and Conclusions

This document has outlined the key design elements for drainage in descending tunnels or ramps. The methodology and design enable drainage water utilization through accumulation and treatment. Variations and alternative designs may be necessary depending on site-specific characteristics, such as complex spatial layouts often found in mines. This method can be combined with other techniques like vertical drainage wells from the surface or the horizontal directional drilling (HDD) method to support drainage in more complex areas. Similarly, aquifer waterproofing where the tunnel intersects is an option for reducing infiltration rates.

If high accumulation volumes lead to excessively long pumping stations, shorter parallel stations in a "Y" or cross configuration, or even bilaterally on both sides of the ramp, can be considered. Adequate geomechanical and hydrogeological studies are also essential, as high-quality information enables proper system sizing to meet requirements and ensure tunnel stability. The entire project requires economic evaluation, considering excavation, equipment, instrumentation, operation, and maintenance costs, which could be the subject of a separate, in-depth article.

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