Dewatering at Cove Mine, Nevada, USA

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ABSTRACT

The Cove Mine is located in north-central Nevada, part of the Basin and Range province of the western United States (USA). As is the case of many gold deposits currently being mined in the western USA, the Cove deposit is located at a lower elevation where the base of the mountains are covered by a veneer of alluvium. Water production data from reverse circulation (airlift), exploration drilling indicated that dewatering might be required to mine the deposit. Consequently a numerical ground-water flow model was developed to help estimate dewatering rates and optimize the dewatering system.

Mining of the Cove deposit started in 1988 as both an open pit and underground operation. The underground workings were located directly under the early stages of the open pit and were eventually mined through. Water was first encountered in the ramp of the underground decline in 1989. The underground was dewatered by a combination of sumps located in the workings and wells that were completed from the surface. Currently, the underground workings have been mined through; and the pit is being dewatered by a combination of in-pit wells, perimeter wells, and sumps. The pit floor is approximately 110 m (360 ft) below the pre-mining water level, and the current dewatering rate is 136,000 m^3/day (25,000 gpm). Mining will be completed in 1998, at which time the pit will be mined to a depth of approximately 240 m (790 ft) below the pre-mining water level; and the predicted dewatering will be approximately 191,000 m^3/day (35,000 gpm).

The dewatering of the Cove deposit presents a good case study of a dewatering program that was conceived prior to mining using the exploration drilling program to acquire hydrogeologic data to be incorporated into a numerical ground-water flow model. The numerical ground-water model was an effective tool for helping design the dewatering program and for predicting dewatering rates for permitting with state and federal regulators. The numerical model is updated with new hydrogeologic data and calibrated on an annual basis. A comparison of the actual dewatering rates to the predicted dewatering rates indicates that a good hydrogeologically-based model can be a reliable means of predicting dewatering rates for open pit mines.

INTRODUCTION

The Cove gold-silver deposit is located in Lander County, northeastern Nevada, USA, about 50 km (30 mi) southwest of the town of Battle Mountain (Figure 1). The deposit is situated in the north-central Fish Creek Mountains, 1.6 km (1 mi) northeast of the McCoy gold deposit.

Gold was discovered in the central Fish Creek Mountains in 1914 by Joseph H. McCoy [1]. Minor production from shallow underground workings continued from 1928 through the early 1930's. Total gold production from the McCoy mining district during this period is estimated to have been less than 311 kg (10,000 oz) [2]. The McCoy mining district remained inactive until the mid-1960's when the area underwent exploration for copper. During the late 1970's, the district had a resurgence of exploration for gold by various mining companies.

Tenneco Minerals Company acquired the property and placed the McCoy gold deposit into production in September 1985. Echo Bay Minerals Company (EBM) acquired Tenneco's precious metal properties in October 1986. District exploration, initiated by Tenneco and continued under EBM, resulted in the discovery of the Cove deposit in January 1987. Production from the Cove Mine began in February 1988. Pre-mining reserves at Cove totalled 48.7 mt with an average grade of 1.85 g/t Au (0.054 oz/st) and 87.1 g/t Ag (2.54 oz/st).

During exploration drilling, ground water presented several sampling problems; and it became apparent that ground water would cause economic, logistical, and permitting difficulties that would need to be addressed in order to mine the deposit. Initial hydrogeologic data were gathered from the exploration drilling and testing of a prototype dewatering well.

Mining of the Cove deposit started with both an underground decline and an open pit that would eventually mine through the underground workings. The pit was designed to an ultimate elevation of 1,170 m (3,850 ft). The original static water level at Cove was at an elevation of 1,420 m (4,650 ft). The Cove underground workings were abandoned in March 1993. The present pit floor is at an elevation of 1,280 m (4,180 ft), 140 m (470 ft) below the pre-mining water table.

DEWATERING OPERATIONS AND HISTORY

The dewatering infrastructure at Cove includes dewatering wells, underground and surface sumps, and horizontal drain holes. All water pumped from Cove is piped to a series of infiltration ponds located approximately 1.6 km (1 mi) northeast of the pit where the water passively returns to the alluvial aquifer (Figure 2).

There are currently 12 operating dewatering wells in and around the Cove Pit. Most of the wells extend below the bottom of the final pit to an elevation of approximately 1,070 m (3,500 ft) and are completed with nominal 50-cm (20-in) diameter casing and screen except where very high production is anticipated. Wells that are anticipated to have high production are completed with nominal 60-cm (24-in) diameter casing and screen. The annulus of the wells are filled with a quartz-rich, well-rounded stabilizer gravel (Figure 3). Test-pumping of each well is done after completion and development to select the most efficient pump. Typically, the wells are equipped with 350 to 1,250 horsepower (hp) submersible pumps set at depths ranging from 210 m (700 ft) to 365 m (1,200 ft). Production from individual wells ranges from approximately 5,450 m^3/day (1,000 gpm) up to 21,000 m^3/day (3,800 gpm). The dewatering capacity of the current system totals approximately 136,000 m^3/day (25,000 gpm).

Mining around in-pit wells has presented a unique challenge. Early efforts consisted of trying to carefully blast and excavate around the casing, cutting off the excess casing on each mining bench, and capping the open well. This technique usually resulted in the well casing filling with rock ranging from less than 1 cm (0.4 in) to more than 30 cm (12 in) in diameter. Some of the wells were successfully cleaned-out and put back into service using a cable tool drill rig; however, this was not always successful. More recently, wells have been filled with relatively fine-grain sand prior to being mined through. The sand can be removed easily with a cable-tool drilling rig. This procedure has protected the casing and allowed the wells to be recovered when they are located after several benches have been excavated.

During the initial phase of the mining at Cove, an underground mine was operating beneath the open pit. This underground operation served as a drainage gallery for the open pit portion of the mine and was successful in depressing water levels below the 1,350 m (4,415 ft) elevation on the west side of the Lighthouse Fault. *Flyght* pumps ranging from 58 to 88 hp were used in the headings to pump water up to a central sump. Three banks of two C-5 *Ash* pumps were used to pump as much as 24,500 m^3/day (4,500 gpm) from the main sump up to the surface. The underground portion of the mine was operational from 1988 until it was closed in March 1993. The open pit has since mined through the underground workings.

Residual passive inflows into the Cove Pit are routed to a sump in the bottom of the pit that is equipped with a bank of 88 hp *Flyght* pumps. The water is then pumped in stages through several permanent sumping stations with approximately 80 m (250 ft) lifts, up to a pipeline on the outside of the pit. Both the temporary and permanent sump stations, located on the pit walls, consist of a 3,800 l (1,000 gallon) receiving tank and two 4,100 m^3/day (750 gpm) pumping tanks (one primary and one back-up), which are equipped with *Ash* pumps.

Horizontal drainholes, ranging from 90 m to 180 m (300 to 600 ft) in length, are used to depressurize portions of the pit highwall that contain excess pore pressure. Most of these drainholes are located on the east side of the pit, where water levels are higher. The drainholes are drilled conventionally using an *Aardvark* drill rig and cased with nominal 3.8 cm (1.5 in) diameter flush joint slotted PVC. Flexible pipe is used to carry water from the drainholes to the in-pit sumps.

Within the pit, nominal 30.5 cm (12 in) to 40.6 cm (16 in) diameter plastic *Drisco* pipe conveys water from the wells and sumps to a main sand and oil trap located outside of the pit. The water moves from the sand trap, through a nominal 152 cm (60 in) diameter steel culvert to an open ditch that leads to the infiltration pond system. The open ditch and the first few ponds act as settling ponds to remove any suspended solids. The water is then allowed to passively infiltrate into the alluvial fan and valley gravels.

Various infiltration pond designs have been tried at Cove, ranging from narrow, deep ponds with compacted fill-dams to shallow, broad ponds constructed below ground elevation. The preferred pond design consists of broad, shallow ponds with or without compacted fill dams, depending upon the slope of the ground surface. Costs have been relatively low for infiltration compared to other water disposal methods. Permitting of the infiltration ponds has generally focused on ground disturbance and construction methods and not on water quality issues, since the water pumped from the mine meets U.S. drinking water standards.

GEOLOGY OF COVE DEPOSIT

The Cove ore body is an epithermal-type precious metals deposit that is hosted by the Star Peak Group. The Star Peak Group consists of a sequence of carbonate and terrigenous clastic rocks ranging in age from early to late Triassic. Four formations comprise the Star Peak

Group, and include the Augusta Mountain and Faveret Formations at the Cove Mine (Figure 4). The Augusta Mountain Formation hosts the bulk of the mineralization at Cove. The Augusta Mountain Formation consists of three informal members that are, in ascending order, the Home Station, Panther Canyon and Smelser Pass members [3].

- The Home Station member consists of massively-bedded calcareous and dolomitic limestone. It commonly contains lenses and beds of sandstone or pebble conglomerate. The contact with the overlying Panther Canyon member is gradational.

- The Panther Canyon member consists of a lower massive dolomite bed overlain by an upwardly-coarsening sequence of terrigenous clastic rocks, including siltstone, greywacke, and chert pebble conglomerate. The Panther Canyon member hosts the bulk of the sulfide mineralization at Cove.

- The Smelser Pass limestone overlies the Panther Canyon member and consists of a massive, thickly-bedded limestone with minor, thin beds of shale. The Smelser Pass member hosts both oxide ore in the Cove ore body and skarn mineralization at the nearby McCoy deposit.

Numerous dioritic dikes and sills intrude the Triassic sediments in the mine area, mainly along northeast and northwest faults. These intrusives have been dated at 39.8 m.y.a., which is the approximate age of mineralization at Cove. An erosional contact at Cove divides the Triassic Smelser Pass member from the overlying post-mineral Caetano Tuff, which is Oligocene in age [4].

The main structural feature at Cove is the Lighthouse Fault, a normal fault which cuts through the middle of the deposit, trending almost due north and dipping 65 degrees east. The east side of the Lighthouse Fault is down-dropped about 120 m (400 ft) relative to the footwall. The displacement along the fault has offset an older northeast-trending set of faults which connect the Cove and McCoy deposits. Several of these older faults, including the Bay and Cay, are dike-filled (Figure 5).

Both oxide and sulfide ores occur at Cove. The Smelser Pass limestone hosts the oxide ores which occur in high-grade manganifeorous mantos. Lower-grade oxide ores and accompanying argillic alteration surround the mantos. The Panther Canyon member hosts the majority of sulfide ore. Sulfide ore occurs in a complex set of anastomosing veins that include 30 different sulfide and sulfosalt minerals with native gold and silver. The vein stockwork conforms to bedding and is locally associated with a diorite sill. Sericitic alteration is the dominant alteration type. The sulfide portion of the deposit shows characteristics of a Bolivian-type epithermal tin-silver deposit.

Approximately 20 percent of the area of the present Cove Pit was covered with Quaternary alluvium. The alluvium thickens to the east and ranges from 0 to 60 m (0 to 200 ft) thick in the pit area, and attains thicknesses of over 1,500 m (5,000 ft) in the center of the valley. The alluvium consists of moderately indurated sand, gravel, and silt-size material.

HYDROGEOLOGIC DATA

During the early stages of EBM's exploration of the Cove deposit, it became apparent that ground water would be a factor in developing the deposit into an economic mine. Hydrogeologic data collected to help delineate the hydrogeology of the Cove Mine included airlift production and temperature data from exploration boreholes, water-level data from exploration boreholes and piezometers, production logs of test and dewatering wells, dewatering pumping rates, and inflow to the decline [5]. The hydrogeologic data were used to develop a conceptual hydrogeologic model on which the dewatering operations and numerical flow model are based.

Airlift Production and Temperature Data

Airlift production data from exploration and development drillholes have been used to generate the "hydrostratigraphy" of the conceptual hydrogeologic model. Data were initially collected related to the amount, temperature and depth of the water being produced. These data were plotted for graphical analysis to help delineate the hydrostratigraphy and locate structures that could influence the hydrogeology (Figure 6).

These data defined two distinct hydrologic features that significantly affect inflows to the Cove Pit:

1) A zone of highly permeable rock bounded by the Lighthouse Fault on the west and an intrusive dike to the south. The nature of its northern and southern boundaries is unknown. The relatively high permeability in this zone is likely related to more intense fracturing in the area of the ore body.

2) Two relatively thin zones of high permeability within the Panther Canyon member. The upper zone coincides with conglomerates and the lower zone with a change in cementation from silica to carbonate in the Panther Canyon sandstone.

Inflows to Cove Decline

Inflow of ground water to the Cove decline has been influenced by the depth of mining below the original potentiometric surface, pumping of three dewatering wells, intersection of fracture zones and more permeable stratigraphic units, and local inrushes from exploration boreholes intercepted during drifting. Inflows to the Cove decline have ranged from 5,450 to 24,500 m^3/day (1,000 to 4,500 gpm).

The underground workings provided a unique opportunity to study the aquifer that will be dewatered during the mining of the Cove Pit. Specific events that have affected the inflow to the Cove decline and provided insight to the hydrogeology of the deposit included:

- Loss of a heading in a shear zone in April 1989. Upon entering the shear zone, inflows immediately increased by 5,450 m^3/day (1,000 gpm). These inflows could be typical of the structures that dominate flow in the aquifer and create the apparent north-south anisotropy in the aquifer.

- Increased inflows in the Panther Canyon conglomerates and its poor rock quality. These suggest that the conglomerates are a major conduit for flow.

Monitoring of Water Levels

Water levels are recorded for a network of piezometers completed in exploration boreholes. The piezometers are completed with nominal 2.5- to 5-cm (1- to 2-in) diameter, PVC pipe and are located and constructed to monitor specific intervals within the aquifer. The monitor-well network can be expanded as needed to provide information to help determine the extent of the change in water levels resulting from the dewatering operations. Water-level data are collected on a bi-monthly basis, and water level changes are reviewed monthly to better understand the effects of the dewatering.

Production Logging

Production logging was conducted in many of the wells in order to identify the specific water-producing intervals in the screened sections of the dewatering wells. An impeller logging tool was used and each well was pumped at a constant rate of 1,100 to 2,200 m^3/day (200 to 400 gpm). The relative inflow from each interval can be expressed as a percentage of total inflow and correlated to the stratigraphy of the screened section (Figure 7). The contact between the Smelser Pass limestone and the sandstones or conglomerates at the top of the Panther Canyon member provides a good marker in this hydrostratigraphic sequence.

The production logs indicate that two dominant water-producing intervals exist in the portion of the aquifer that will be mined. The primary interval includes the conglomeratic section at the top of the Panther Canyon member. In wells DW-2 and DW-3, this interval yielded the majority (up to 70 percent) of inflow. The second water-bearing interval in the Panther Canyon member is associated with the contact between silica and carbonate-cemented sandstones at a depth of approximately 110 m (350 ft) below the Smelser Pass/Panther Canyon contact. The enhanced production from this zone could be the result of increased primary porosity and/or fracturing.

Pumping Tests

Initially, long-term aquifer tests were conducted with each dewatering well. These pumping tests were designed to provide information on the aquifer characteristics of transmissivity, hydraulic conductivity, and storativity. All of the tests utilized a network of piezometers in the area of the pumping well to measure water levels. After the dewatering program was established, pumping tests were used primarily to size pumps for wells. Findings of a re-evaluation of these tests are consistent with the current conceptual hydrogeologic model. The important findings from the pumping tests include the following:

- The north-south elongation to the observed drawdowns could be the result of one or a combination of two factors, a) the Lighthouse Fault acting as a barrier to recharge from the east, and b) fracture-induced anisotropy.

- The intrusives form local barriers to ground-water flow.

- The transmissivity in the southern part of the Cove Pit is approximately 1,100 m^2/day (12,000 ft^2/day). This transmissivity value represents the entire section from the bottom of the Havallah Formation to the water table in the Smelser Pass member.

- Drawdowns propagate significantly further to the west, suggesting recharge from the saturated Reese River alluvium east of the pit.

CONCEPTUAL HYDROGEOLOGIC MODEL

The conceptual hydrogeologic model of the Cove Pit area has been updated on the basis of data that have been obtained from the exploration drilling program, dewatering operations, and recalibration of the numerical ground-water flow model of the Cove Pit. These data include water levels, pumping rates, aquifer test results and ground-water inflow data. The conceptual model is updated on a yearly basis or as new data are obtained. These data are used to recalibrate the numerical model as increased stresses are placed on the aquifer during dewatering.

The following are the most important components of the current conceptual hydrogeologic model that have been incorporated into the numerical model:

- The area within an approximate 2.5 km (1.5 mile) radius of the Cove Pit has an average hydraulic conductivity that is about two to four times greater than the surrounding country rock. This high hydraulic conductivity results from the same structural preparation that provided preferred pathways for ore-bearing fluids.

- Two zones of enhanced hydraulic conductivity occur in the mine area 1) a linear zone associated with the hanging wall of the Lighthouse Fault that extends from north of the pit to beyond the southern highwall, and 2) a zone on the eastern side of the pit.

- Although associated with the parallel zone of enhanced hydraulic conductivity, the eastern edge of the Lighthouse Fault also forms a barrier to ground-water flow from the east. The barrier is due to argillized rock in the footwall of the fault. It is very significant to mine dewatering because the largest potential source of inflow to the mine is ground water within the alluvium of the Reese River valley.

- The aquifer system is layered (Figures 4 and 6) and contains discrete units of relatively large hydraulic conductivity (e.g., the conglomeratic interval, and the base of the Panther Canyon Formation).

- The stratified nature of the aquifer system has created a horizontal to vertical anisotropy ratio of 10 to 1.

Since new data are incorporated into the conceptual model as they become available, the conceptual model will continue to be dynamic, and refined to more accurately represent the hydrogeology of the mine area until dewatering is complete.

NUMERICAL MODEL

Description of Numerical Model

The numerical ground-water flow model is designed to estimate the amount of water to be managed during the proposed mining operation, assist in designing an effective dewatering system, and evaluate the effects of the proposed dewatering on the hydrologic system in the vicinity of the Cove Pit. The numerical model uses the flow code *FLOW3D* [6] to simulate the conceptual hydrogeologic model.

FLOW3D utilizes a deforming grid to solve for the position of the phreatic surface. It incorporates a variable flux boundary condition as an alternative to generating unnecessarily large model grids. Seepage faces in the pit are simulated using an analytical solution [7] to account for the height along the pit walls. Dewatering wells are simulated by using a feature of the model that allows the direct linking of nodes so that any node in the well can have a flux placed upon it and the flux from the simulated aquifer will be proportional to the hydraulic conductivity of the aquifer material into which the simulated well is completed.

The numerical model uses a grid of triangular shaped elements (Figure 8) to describe the domain in plan view. The grid in plan view has a finer discretization in the vicinity of the pit and becomes coarser with distance from the pit and infiltration ponds. In the vertical dimension, the model contains six layers in the area of the pit, pinching down to four layers regionally. The model grid contains 3,017 nodes and 5,070 elements.

Pumping data from dewatering wells, sumps and declines and historical water level data are used to calibrate the numerical model. As new data are collected, the hydrogeology is updated and the numerical model is recalibrated. The recalibration of the numerical model is accomplished by adjusting some of the hydraulic parameters of the ground-water system to replicate as closely as possible the observed water levels resulting from the dewatering. Water levels in all individual monitoring wells will not be matched exactly in the calibration process because of local heterogeneities in the aquifers system. However, by reasonably matching the trend of the water level changes through time over a relatively large area, hydraulic parameters can be incorporated into the numerical model to make it an effective tool for designing future dewatering operations.

Dewatering well locations are determined by selecting several possible sites based on logistical considerations. Using the numerical model, pumping wells are simulated at the sites, and the results are analyzed based on two criteria, 1) amount of water that can be sumped from the pit bottom, and 2) pumping costs.

History of Predictive Numerical Model Simulations

The best evaluation of the reliability of the predictive capabilities of a numerical model is to compare the predictive simulations that have been made each year with the actual dewatering rates. A number of factors need to be considered in order to evaluate the predictive capabilities of the model. These factors include changes in life of mine, rate of mining, and location of dewatering wells.

Predicted and actual dewatering rates for the Cove Pit were reviewed and graphed (Figure 9). Early predictions indicated that the dewatering rate would be 218,000 to 273,000 m^3/day (40,000 to 50,000 gpm). As the project progressed, the mine plans changed by accelerating the mining rate; however, the final depth of the pit remained approximately the same. The most recent dewatering estimates predict that the final dewatering rate will be approximately 191,000 m^3/day (35,000 gpm). The reduction in the predicted dewatering rate has been a function of reinterpretation based on additional data. It has been determined that the hydraulic conductivities obtained from early pumping tests from wells in the pit were larger than the regional aquifer characteristics that control the inflow rates during later time.

SUMMARY

The dewatering of the Cove Mine presents a study of a dewatering operation that has used exploration drilling to help gather hydrogeologic information and a numerical model as a successful predictive and management tool. Important airlift production data were used to locate and design the initial dewatering wells and direct the initial stage of the dewatering program. Data from the production testing and decline inflows allowed a better understanding of the important hydrologic features that are incorporated into the numerical model.

The numerical model has also helped reduce the total amount of water that has been pumped by evaluating available well locations based on pumping costs and the total amount of water that will have to be managed. Although the dewatering rates were initially over estimated, the conceptual model has not changed significantly enough to alter the location of the dewatering wells.

The numerical model has provided very reliable predictions of dewatering requirements in a complex hydrogeologic environment. Initial aquifer characteristic gathered from wells in the mine area tended to over-estimate dewatering rates in later time which are ultimately controlled by the regional hydrogeology.

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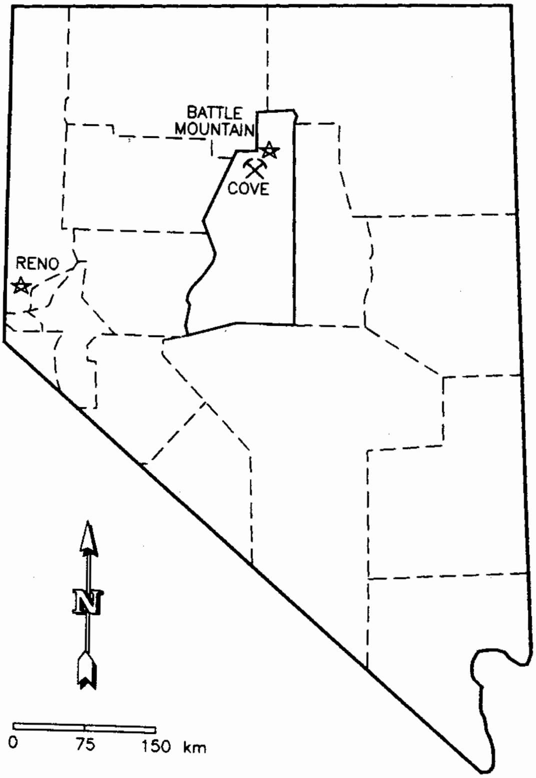

Figure 1: Location map of the Cove deposit, Lander County, Nevada, USA.

NEV-CNTY.DWG
NEV-CNTY.PLT

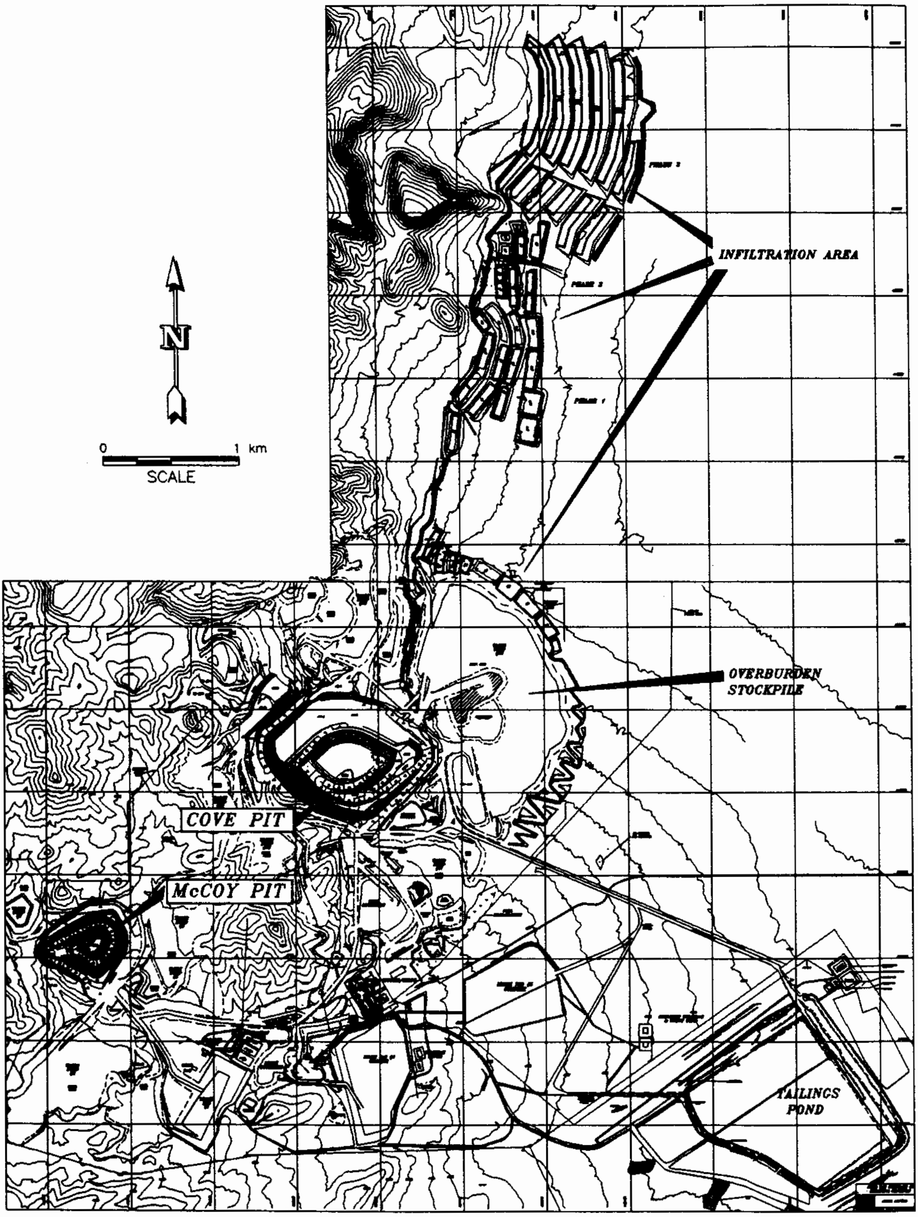

Figure 2: Site map of Cove Pit area.

SITEMAP.DWG
SITEMAP.PLT

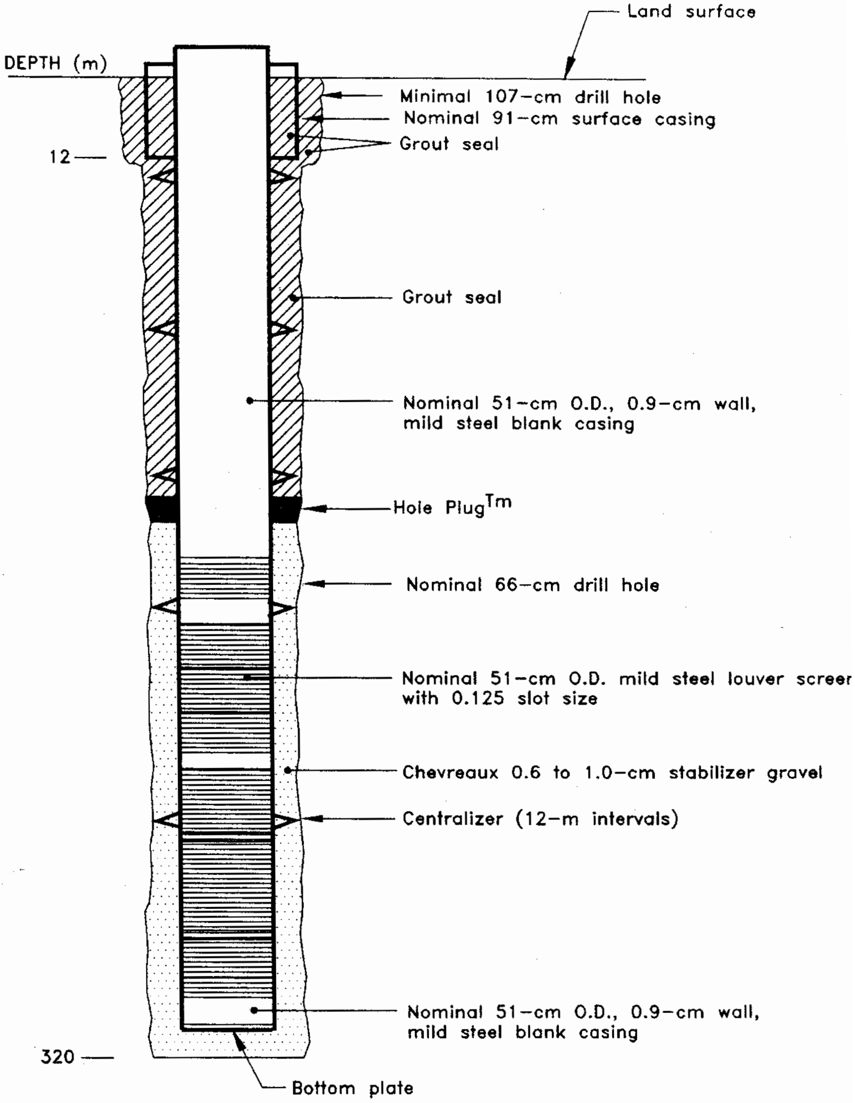

Figure 3: Schematic diagram of typical dewatering well.

NOT TO SCALE

TYPDWELL.DWG
TYPDWELL.PLT

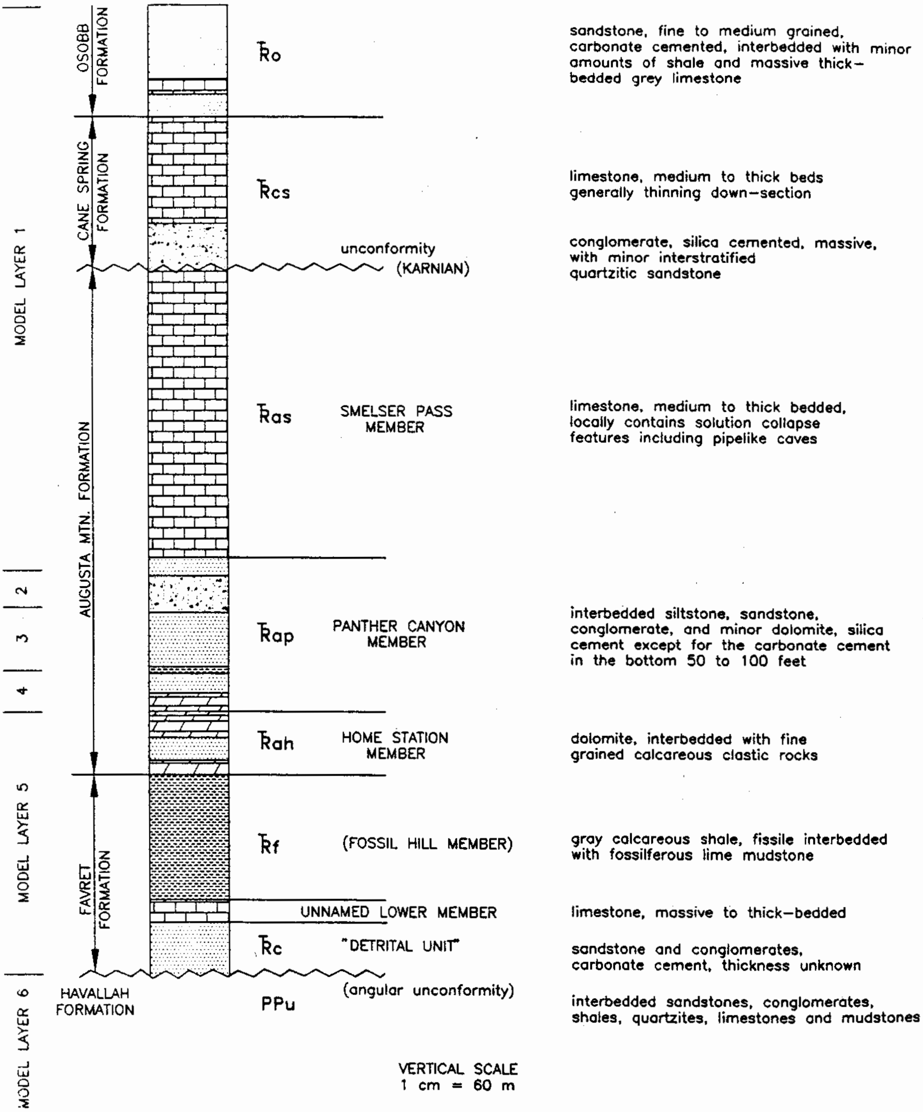

Figure 4: Triassic stratigraph section and related layers in numerical model of Cove Pit.

STRTIGRF.DWG
STRTIGRF.PLT

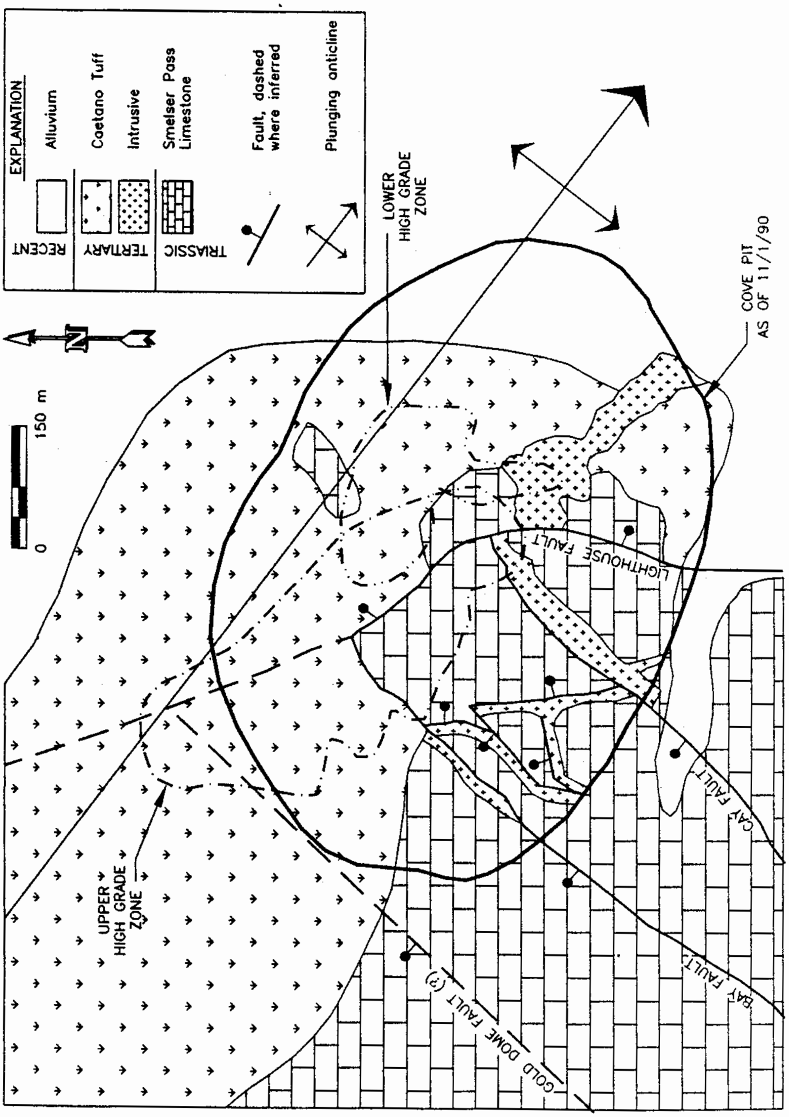

Figure 5: Geologic map of the Cove deposit showing outline of sulfide mineralization projected to surface.

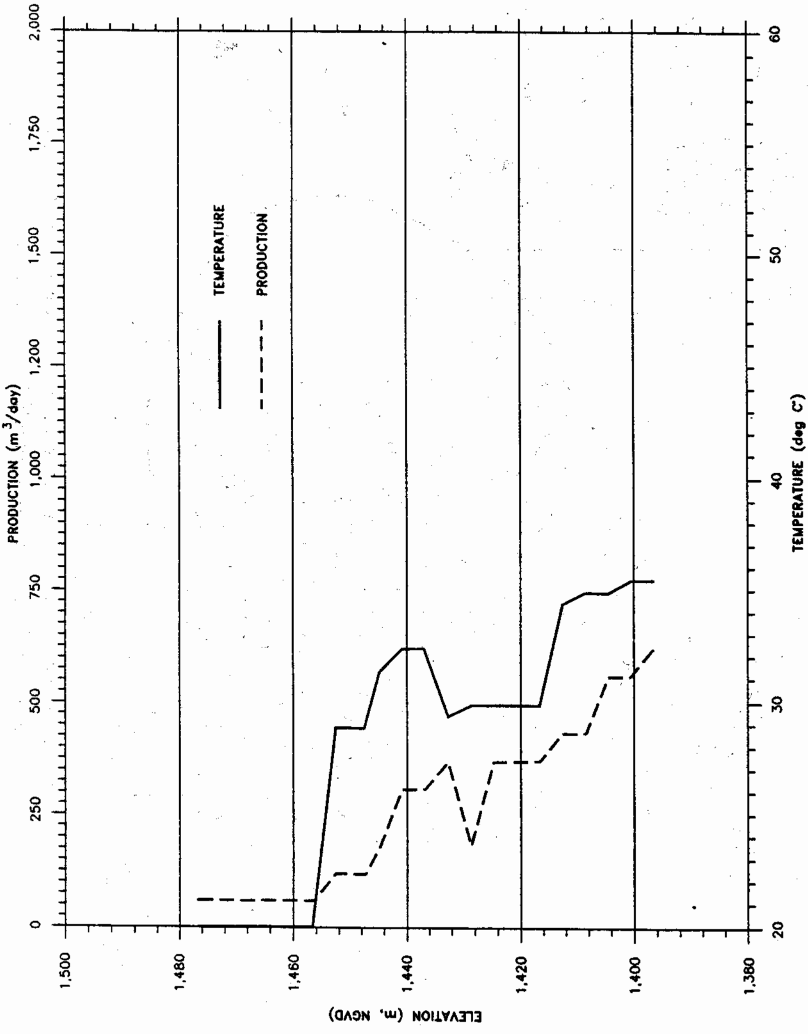

Figure 6: Typical airlift production log.

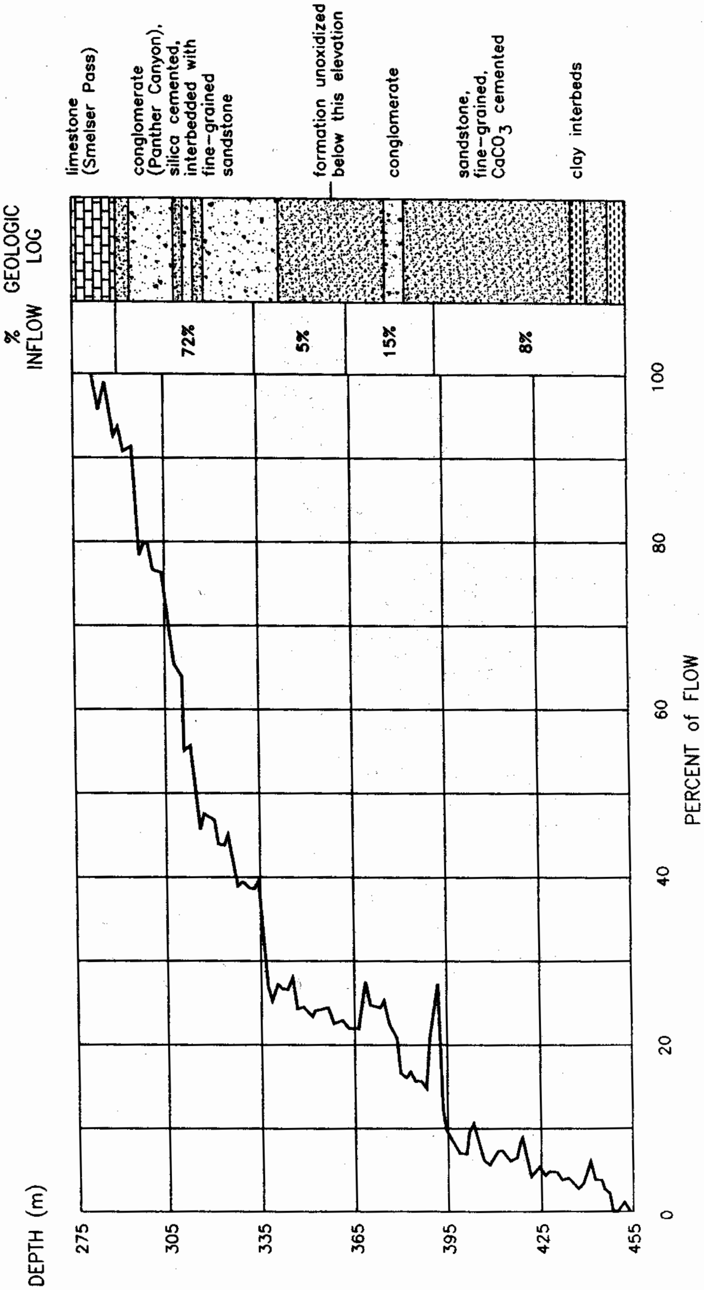

Figure 7: Production log for well DW-3.

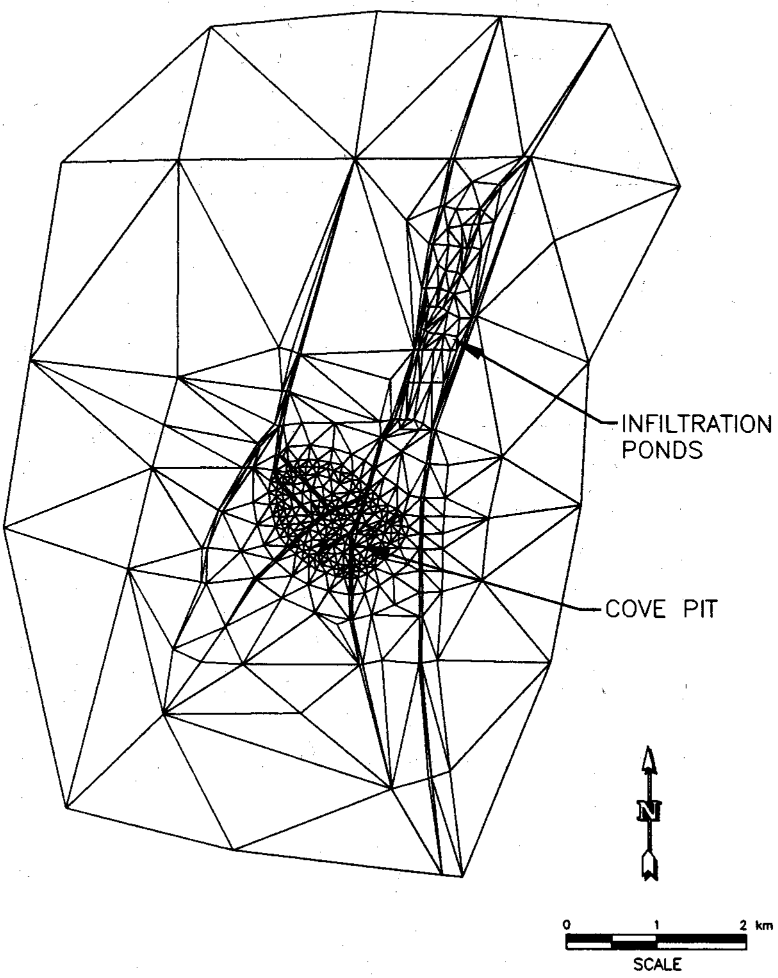

Figure 8: Finite–element grid used for simulating the hydrogeologic system in vicinity of Cove Pit.

GRID_94.DWG
GRID_94.PLT

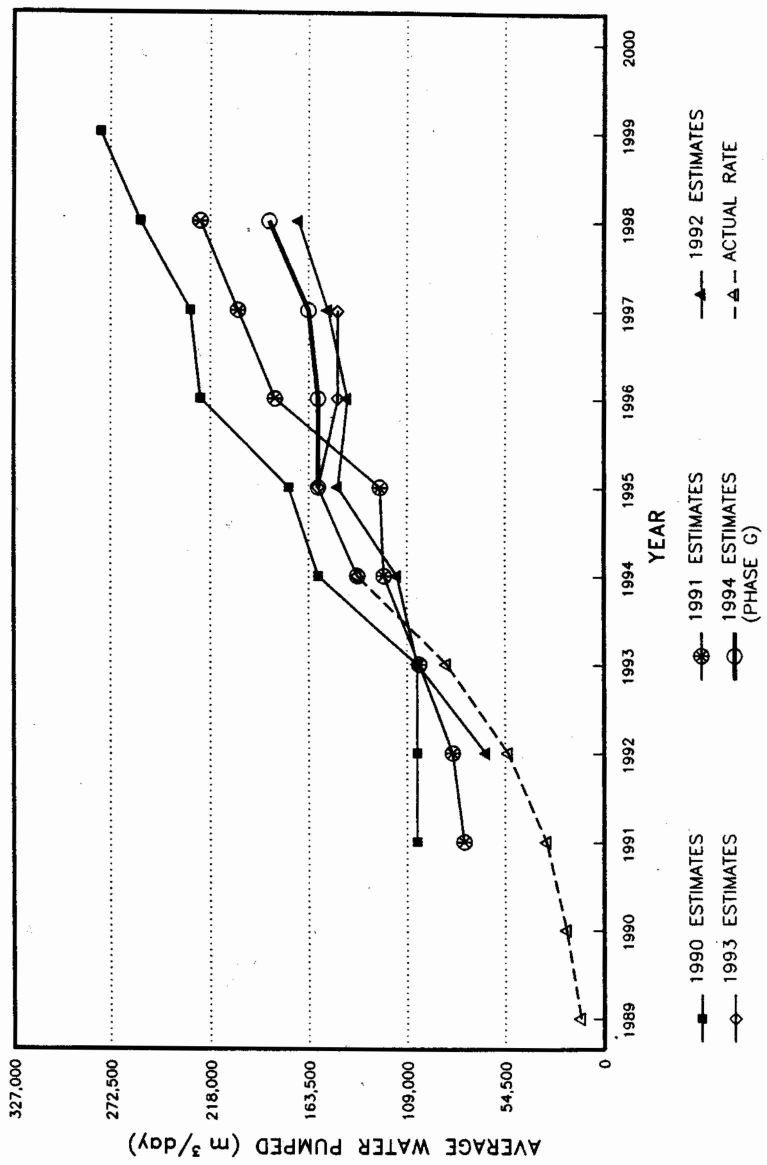

Figure 9: Historical estimates of total amount of water to be handled during dewatering of Cove Pit.