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POST CLOSURE MINE DEWATERING AND TREATMENT OF CONTAMINATED WATERS AT THE SULLIVAN MINE IN KIMBERLEY, B.C.

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ABSTRACT

The Sullivan Mine has been operated by Cominco Ltd. since 1909, and is scheduled for closure in December of 2001. The Sullivan ore body is acid generating but operated for many decades before the need to control acid rock drainage (ARD) was recognized. Presently, the generation of ARD can not be prevented, only mitigated. The main sources of ARD include drainage from the underground mine workings, run off and seepage from mining and milling wastes and discharges from the operating tailing ponds. The generation of ARD is expected to continue for an indefinite period after closure. While several projects have been undertaken to minimize the generation of ARD in the last 20 years of mine and concentrator operation, a plan to deal with the on-going generation of these contaminated waters after closure was required.

Components of the existing ARD mitigation system will continue to function with some modifications to account for the reduction in ARD volumes generated due to reclamation efforts and the cessation of mining and milling operations. The Drainage Water Treatment Plant (DWTP), which utilizes lime to increase pH and remove metals from ARD into a high-density chemically stable sludge, is the key to current and long-term treatment of contaminated waters. Collection and storage of ARD prior to treatment at the DWTP is another important aspect of ARD control.

The DWTP cannot operate continually at design capacity with the expected reductions in post closure ARD flows. For post closure operation, safe storage of contaminated waters is required until the volumes will allow the treatment plant to operate at design levels for a reasonable period of time. A two-reservoir system utilizing the under-ground mine and a surface pond has been designed for contaminated water storage. Three deep-well underground pump stations will be located within the mine. The mine will be allowed to fill to a predetermined level, after which, mine water will be pumped to the above-ground ARD reservoir and subsequently to the DWTP for treatment and discharge to the St Mary River. The DWTP will operate on a campaign basis during periods when the impact on the receiving water, the St Mary River, is minimized.

BACKGROUND

The Sullivan Mine and Concentrator are located within the city limits of Kimberley, British Columbia. In 1909, Cominco started mining the Sullivan ore-body with the Concentrator commencing operation in 1923 using a differential flotation process capable: of separating the complex ore into lead, zinc and iron concentrates. A site plan of the area around the Concentrator is shown in Figure 1. The surface mine site

is located 7 kilometers to the north of the Concentrator. At closure, 150 million tonnes of ore will have been removed from the mine and 149 million tonnes of ore will have been treated at the Concentrator. Nearly 14.5 million tonnes of waste rock and 93 million tonnes of tailings are stored on surface covering approximately 506 hectares of land within the Mine and Concentrator sites (1). The economic minerals, galena, sphalerite and marmatite, are enclosed in a siliceous host rock with abundant pyrrhotite. Since there are little accompanying alkaline gangue materials, the ore-body is "acidic" (2). Pyrrhotite, when exposed to air and water, generates an acidic run-off that leaches metals from the rock. This run-off and drainage is deleterious to natural watercourses and requires collection and treatment.

Prior to 1979 acidic drainage from the mine, tailing effluent and seepage from waste storage sites were discharged to local waterways without treatment. To comply with changing provincial environmental regulations and reduce the impact to the St Mary River, a high-density sludge water treatment plant was commissioned, to treat the contaminated waters prior to discharge. The plant removes metals from the influent and raises pH by the addition of slaked lime to the feed water. Metals are precipitated as metal hydroxides and removed from the water as a non-leaching sludge. The effluent is then discharged to the St Mary River.

Acid rock drainage (ARD) impacted water is collected from a network of ditches, sumps, aquifer de-watering wells and Sullivan Creek. This seepage collection system is operated year round and will be maintained after closure. Mine water is pumped from below the 2500 level to the 3900 level using a system of high head centrifugal pumps. The drainage flows out of the 3900 Portal into the lower mine yard (see Figure 1) grit chamber and seepage collection system. This combined flow is piped to the active tailing pond, which acts as a storage reservoir for the Drainage Water Treatment Plant (DWTP). Other inputs to the active tailing pond include seepage collected down gradient of all waste impoundments located at the Concentrator Plant and former Fertilizer Plant sites.

The DWTP operated, on average, 349 days a year and treated an average of 7.6 million m^3 of influent annually between 1995 and 1999 (3). The average plant operating rates over the same period were 15,100 litres per minute (lpm) with maximum and minimum flows 24,100 lpm and 10,000 lpm, respectively. The average plant outflow varies from 3.0% to *0.2%* of the flow in the St Mary River depending on the time

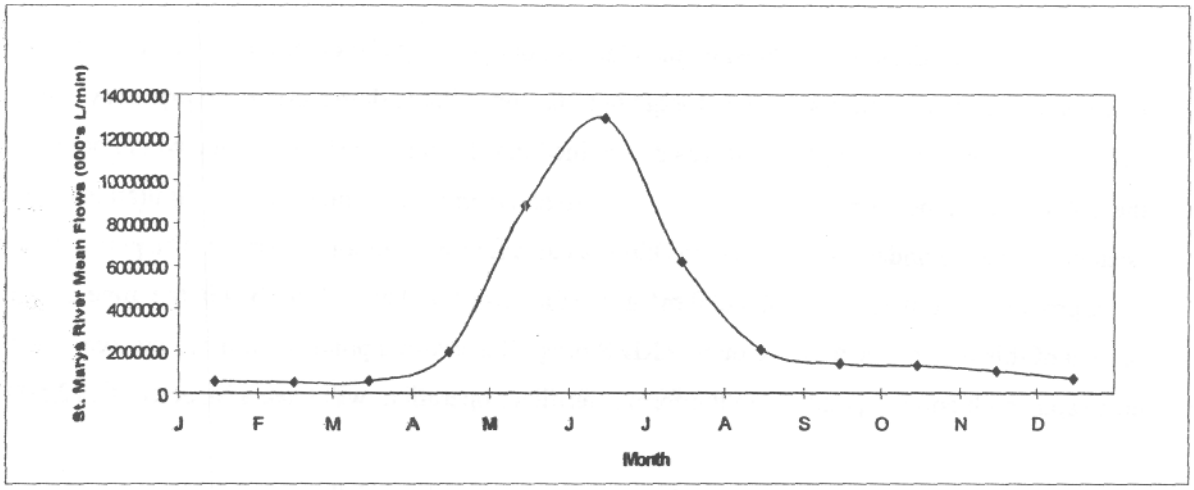

Figure 2: Average St Mary River Flow

of year. Figure 2 is a graphical representation of the long term average flow in the St Mary River for a one-year period. The plant has proven effective over the years, removing 96.43% to 99.99% of the influent dissolved metals (3) prior to discharge to the St Mary River. The treatment plant sludge is discharged to an impoundment located across the St Mary River from the DWTP. The average current sludge production is 20.8 tonnes per operating day (3).

In addition to the commissioning of the DWTP, several projects have been undertaken to minimize the quantity of acid impacted waters generated and improve collection. These projects include the diversion of Mark Creek through a protective channel, the installation of aquifer de-watering wells, the application of soil cover systems and the diversion of clean waters away from acid generating waste impacted areas.

The closure of the Sullivan Mine and Concentrator in December of 2001, will significantly reduce the quantity of influent to *be* treated by the DWTP by eliminating process water contributions. The most significant reduction in treatment volume will be *the* elimination of tailing effluent from the Concentrator operations. In 2000, the Concentrator generated 4,631,077 m^3 of effluent (4). Reclamation of all acid generating waste impoundments will be complete by 2005. It is expected that this work will further reduce the amount of seepage and mine drainage water requiring treatment.

Removal of tailing effluent and mine process water will result in a 65% reduction in quantity of contaminated water requiring treatment after closure. The current continuous operation of the DWTP cannot be maintained with this reduction in volume. The solution to this problem is to run the plant on a campaign basis. However, since ARD is generated continuously throughout the year, storage is required

for ARD collected during periods when the plant is not operating. To determine optimal operating times, required duration of operation, water storage options and suitable de-watering and piping systems, a water balance of the site was completed. It was determined that 1.2 million m^3 of storage would be required if the DWTP was to be operated twice yearly. Due to above ground storage capacity limitations, it was decided to use the under ground mine workings as an additional storage reservoir. The potential storage underground is estimated to be 625,000 m^3 given the operating levels described in the mine de-watering section of this paper. The above ground ARD Storage Reservoir, a pond constructed by combining the north and south cooling ponds from the former fertilizer operation, will have a capacity of 612,500 m^3 (5).

In addition to a review of the volumes of acid water generated, the following criteria for determining post-closure contaminated water storage and treatment were considered:

- minimizing capital and operating costs and maintenance requirements;
- minimizing the number of DWTP operating periods per year;
- avoiding winter DWTP operation; and
- operating the plant during the high flow periods of the receiving water (St Mary River).

Given these criteria, it was determined that storage of contaminated waters would be necessary over the winter months. The duration and timing of the DWTP campaigns will vary depending on weather conditions, which influence the volume of contaminated water collected. Estimates for operating periods have been developed by reviewing historical seepage and drainage collection data.

MINE DEWATERING SYSTEM

Post-closure inflows to the mine are estimated to range from 1030 lpm to 5250 lpm (6). It is anticipated that it will take three to four years following the decommissioning of the existing de-watering system for the mine to fill to the 3700-foot level, at which point mine drainage would discharge to the environment through the 3700 Portal (Figure 3). Following closure, the mine will be allowed to fill to a maximum operating limit of 3650 feet. An allowance was made for freeboard between the 3650 elevation and the 3700 Level, providing 320,000 m^3 of emergency storage, which is equivalent to one month of the estimated peak inflow. When the maximum operating level is reached, the underground reservoir will be drawn down to its minimum-operating limit of 3550 feet. The estimated storage between the minimum and maximum operating limits is 625,000 m^3(7).

Alternatives

Alternatives for post-closure mine de-watering were assessed as part of detailed planning for the closure of the Sullivan Mine (7). The following alternatives were considered:

- de-water via a ventilation shaft by remote pumps;
- de-water via # 1 Shaft by semi-remote pumps
- de-water via 3700 Portal by submersible pumps;
- de-water through drilled bore holes intersecting # 1 Shaft by submersible pumps;
- install bulkhead at 3700 Portal and drain mine by gravity and pressure head; and
- de-water from 3700-foot level through 3900 Portal to existing Mine Line.

Figure 3 shows a cross section of the Sullivan Mine that can be used as a reference to compare these alternatives. The third alternative, to de-water the mine via the 3700 Portal using submersible pumps, was adopted as the preferred method to de-water the underground mine reservoir. The advantages to this option are:

- the 3700-foot level is a central collection point for water in the mine;
- pumps will be accessible and easily maintained;
- a number of pump stations can be constructed along the 3700 Drift to provide redundancy such that the mine can be de-watered from a number of locations;
- ground deterioration in the 3700 Drift is easily addressed;
- mine ventilation requirements can be easily met; and
- mine de-watering works can be located for convenient and safe installation and inspection.

System Overview

The chosen design consists of three deep-well underground pump stations located along the 3700 Level, intersecting the mine workings throughout the width of the mine. Figure 4 illustrates the general arrangement of each pump station. Each pump station will contain one pump that can be lowered to one of three pick-up elevations. Mine water will be pumped from these pump stations to an underground grit chamber/head tank, which will control the flow rate of discharge from the mine. From the grit chamber/head tank, water will be pumped 6 km to the ARD Storage Reservoir. A one-line diagram of the system is included as Figure 5. As a contingency measure, mine water may be routed directly to the

DWTP, or to an Emergency Storage Pond, located at the Active Tailing Pond (Figure 6). The system is designed to de-water the mine at a maximum rate of 10,000 lpm. The anticipated de-watering volumes range from 1,075,000 to 1,755,000 m^3/year.

TREATMENT OF CONTAMINATED WATERS

Two yearly operating periods will be required to safely store and treat collected ARD waters given the storage capacities offered by the underground mine workings and ARD Storage Reservoir. In the short term, the capacity of the ARD Storage Reservoir will be the trigger for DWTP start-up. It is estimated that it will take approximately three years for the water in the mine to reach the active de-watering level (7).

The St Mary River, the receiving water body for discharge from the DWTP, is a multi-species fisheries resource that is also used for seasonal water recreation. It is important to minimize any impact from the discharge of treated waters to the river to maintain this resource. The average flow in the St Mary River from 1914 to 1990 was 3,172,100 litres per minute (lpm) with average maximum and minimum flows of 12,900,000 lpm and 521,400 lpm, respectively (Figure 2). Peak flows generally occur between late April and early July with the lowest flows occurring in the winter months of December, January and February. Winter operation of the DWTP will be avoided to eliminate icing concerns as well as the low flow period for the St Mary River. Operating the plant on a campaign basis will allow the bulk of the plant discharge to occur during high flow periods in the river to maximize dilution and minimize impact on the river. Average outflows to the St Mary River are expected to be between 1.5%-0.2% of total river flow for the campaign periods chosen. This is approximately half the current average for full time operation.

Short Term DWTP Operating Campaigns

Water balances completed using the past seven years of seepage and drainage flow data indicate the underground mine storage can fill for three years after closure before de-watering is required. The ARD Storage Reservoir will require biannual draining during this period; the DWTP campaigns to drain the pond will be shorter than those required to de-water both the mine and the pond in later years. The DWTP will commence operation in mid April and run for approximately a month to drain the ARD Storage Reservoir. Plant flow during startup will be minimal, 10,000 lpm, but will step up to 20,000 lpm when the flow of the St Mary River increases. Exact start and stop dates for the plant will vary depending on spring run-off conditions in the St Mary River and the ARD Storage Reservoir level. A second shorter operating period (approximately 3 weeks) in October will be required to drain the pond prior to winter. The

estimated number of operating days for short-term operation is 53 days per year. During short term operation, the plant is expected to treat 1.4 million m^3 of acidic water.

Long Term DWTP Operating Campaigns

Long term operation of the DWTP will commence four years after closure. Two treatment campaigns will still be required for long-term plant operation, however, the length of operation will be extended to account for the additional flows from mine de-watering. De-watering of the ARD Storage Reservoir to the DWTP will begin in late April, with mine de-watering to ARD Storage Reservoir following in early May. The DWTP will operate until late June, with mine de-watering continuing for approximately two weeks after the DWTP shutdown. The second de-watering period will take place in October. In comparison to the short-term operation, the average number of DWTP operating days per year will increase by 41 days to 94 days. In total, during long term operation the plant is expected to treat 2.6 million m^3 of acidic water. A graphical representation of the de-watering periods is shown in Figure 6.

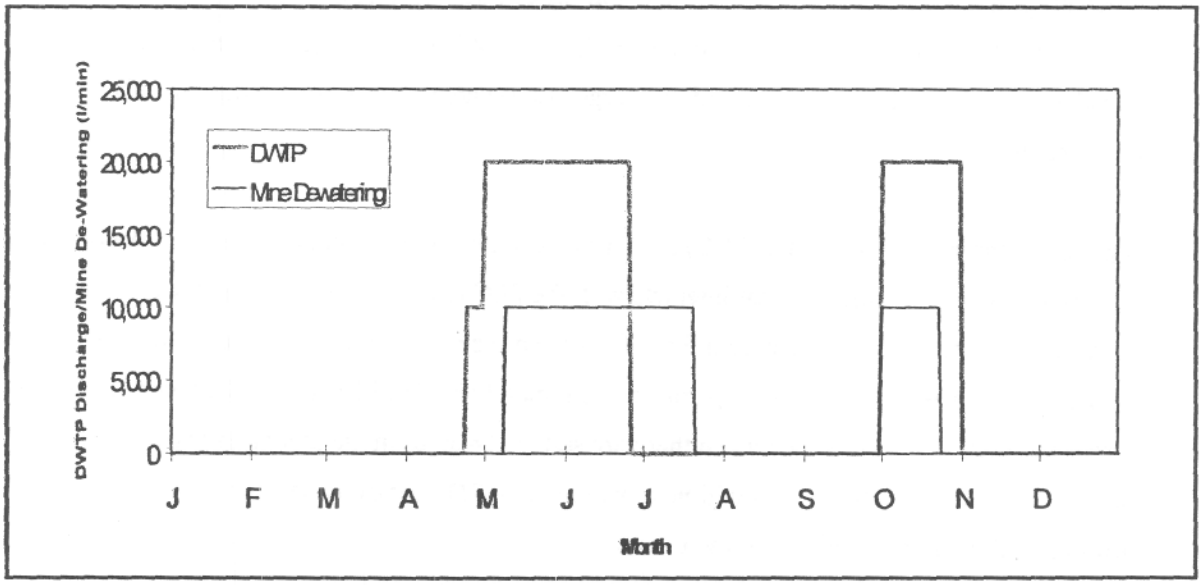

Figure 6: Long Term DWTP Discharge and Mine De-watering

Campaign Operation

The DWTP has run continuously since 11)79 treating the acid drainage impacted waters generated during the operation of the Mine and "Concentrator. The shutdown of the plant planned for the winter of 2001/2002 will be its first historical extended shutdown. To winterize the plant, all reaction vessels in the process will be drained. This will prevent process water and sludge from icing in the reaction vessels, which may damage equipment and complicate the plant's next start-up. To simplify the October start-up, the plant will idle with no discharge between the spring and fall operating campaigns.

Seed sludge harvested from the sludge disposal pond will be combined with fresh water in the lime/sludge mix tank of the DWTP to prepare for the spring campaign. Utilizing sludge from the storage pond will minimize the plant start-up time by providing a seed site for newly precipitated metal hydroxides. This reduces the settling rate in the clarifier and therefore improves plant performance. The sludge will be trucked from the sludge storage pond to the DWTP, screened and conveyed into the lime/sludge mix tank where it will be mixed with fresh water. Original plant start-up in 1979 required approximately 110 tonnes of sludge from a similar plant at Bunker Hill (2). Influent will be slowly introduced until the plant stabilizes and discharge criteria are met prior to discharging effluent to the St Mary River.

A programmable logic controller (PLC) regulates the addition of reagents in the plant. An operator at the plant will monitor the software that interacts with the PLC (RS View) during the day and remotely by Cominco Ltd. Trail Operations during the off-shift. The seepage collection system will be monitored in the same manner when the plant is operating and remotely by Trail Operations between campaigns. Plant upsets are generally experienced when there are sudden changes in the incoming water quality, therefor, the collected contaminated waters will be mixed in the ARD Storage Reservoir to produce an influent of uniform quality prior to delivery to the plant.

The Sludge Storage Pond, located across the St Mary River from the DWTP plant, has been in use since the original DWTP plant start-up in 1979. It is estimated that the pond will have an additional 30 years of storage available with predicted sludge generation rates. The pond capacity can be increased with a dyke lift to provide a further 17 years of sludge storage (8).

SUMMARY

While this paper represents the current plan and operating criteria for closure, there will be flexibility to alter it if unforeseen conditions are encountered. Flows of+/- 25% of the averages calculated in the water balance can be accommodated. Campaign start and stop dates can be altered depending on reservoir levels and both the mine and surface water storage sites have freeboard allowances for emergency storage. While there is experience with the operation of some of the post closure systems, such as, the seepage collection system and the continuous operation of the DWTP, it is likely that there will be new challenges in the years following the closure of the Sullivan Mine. The operation of the reservoir systems and the annual plant start-up from seed sludge will be first time experiences. The DWTP has been operating successfully for over 20 years producing effluent well within both provincial regulatory requirements and federal guidelines. Effluent quality will continue to be regulated and monitored during all campaigns to ensure standards are met.

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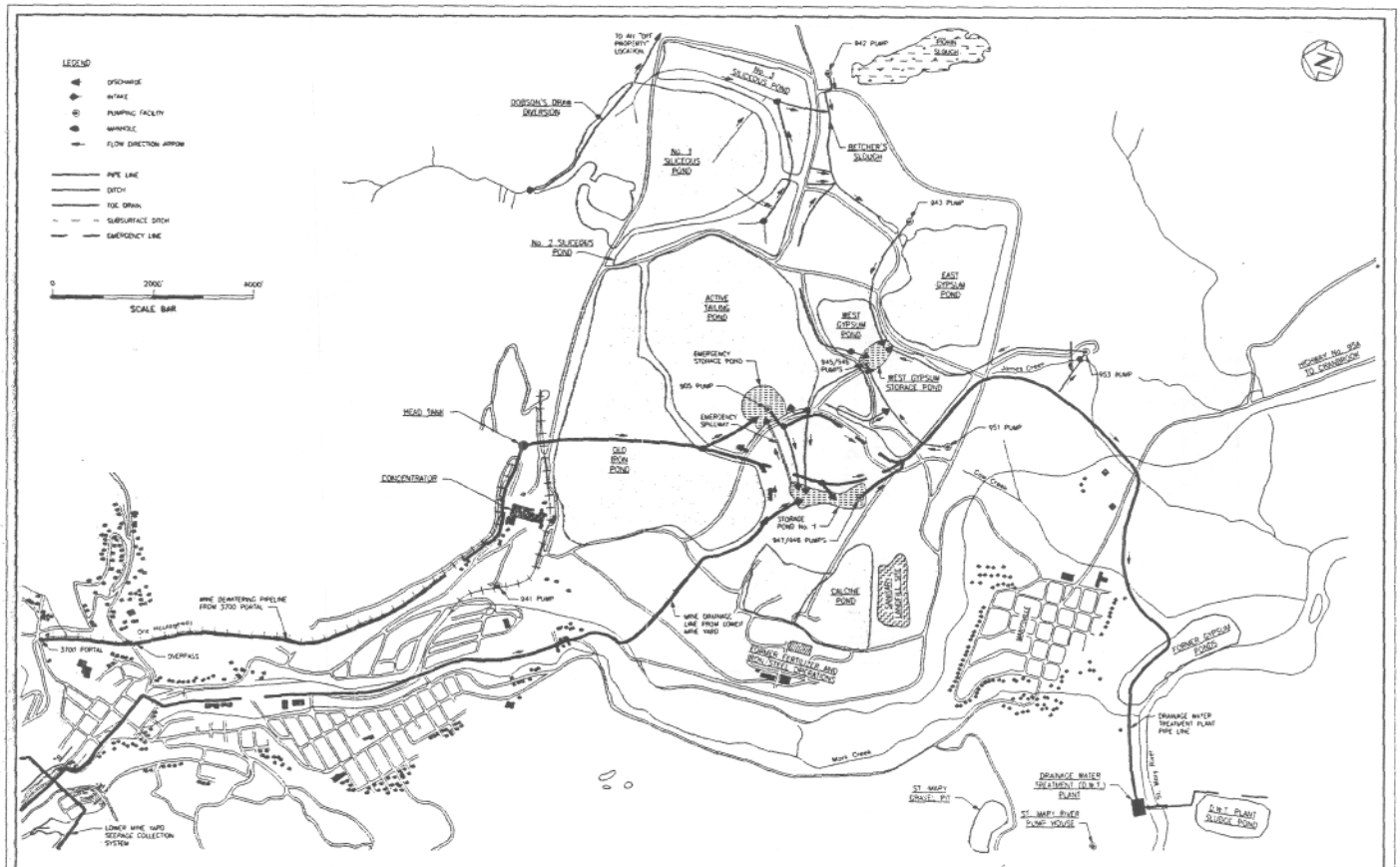

FIGURE 1 – TAILINGS PONDS ARD COLLECTION NTS

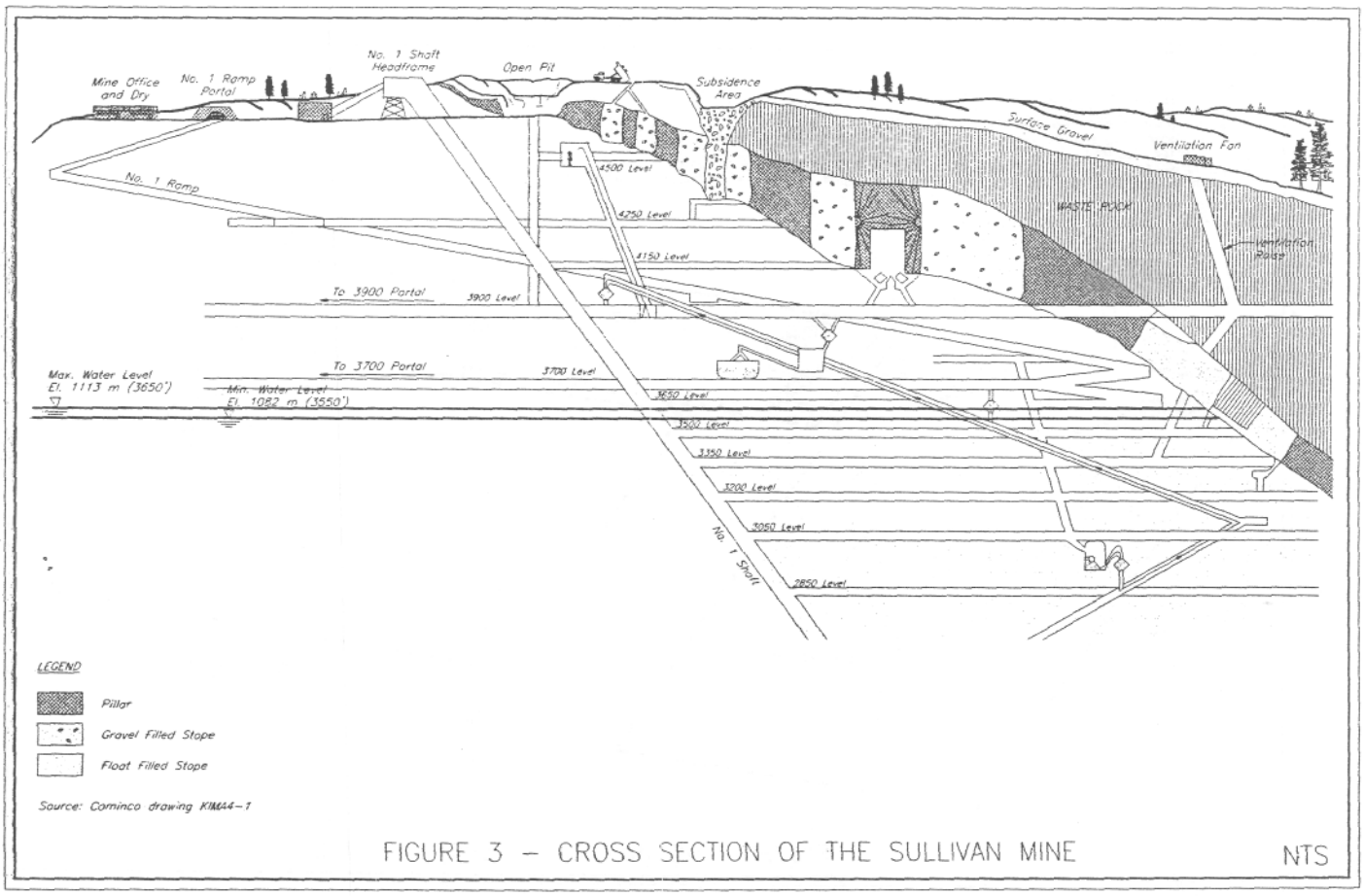

FIGURE 3 – CROSS SECTION OF THE SULLIVAN MINE NTS

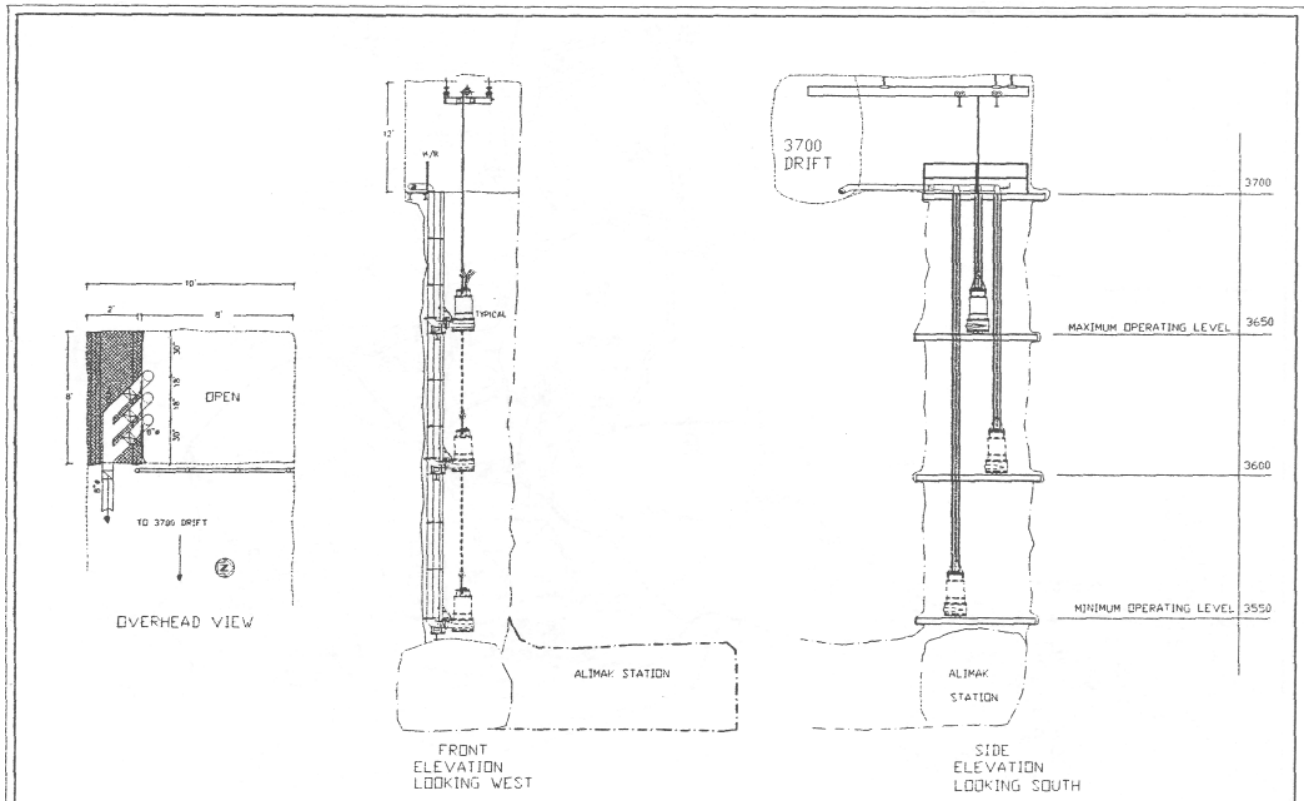

FIGURE 4 – MINE DEWATERING – PUMP STATION LAYOUT NTS

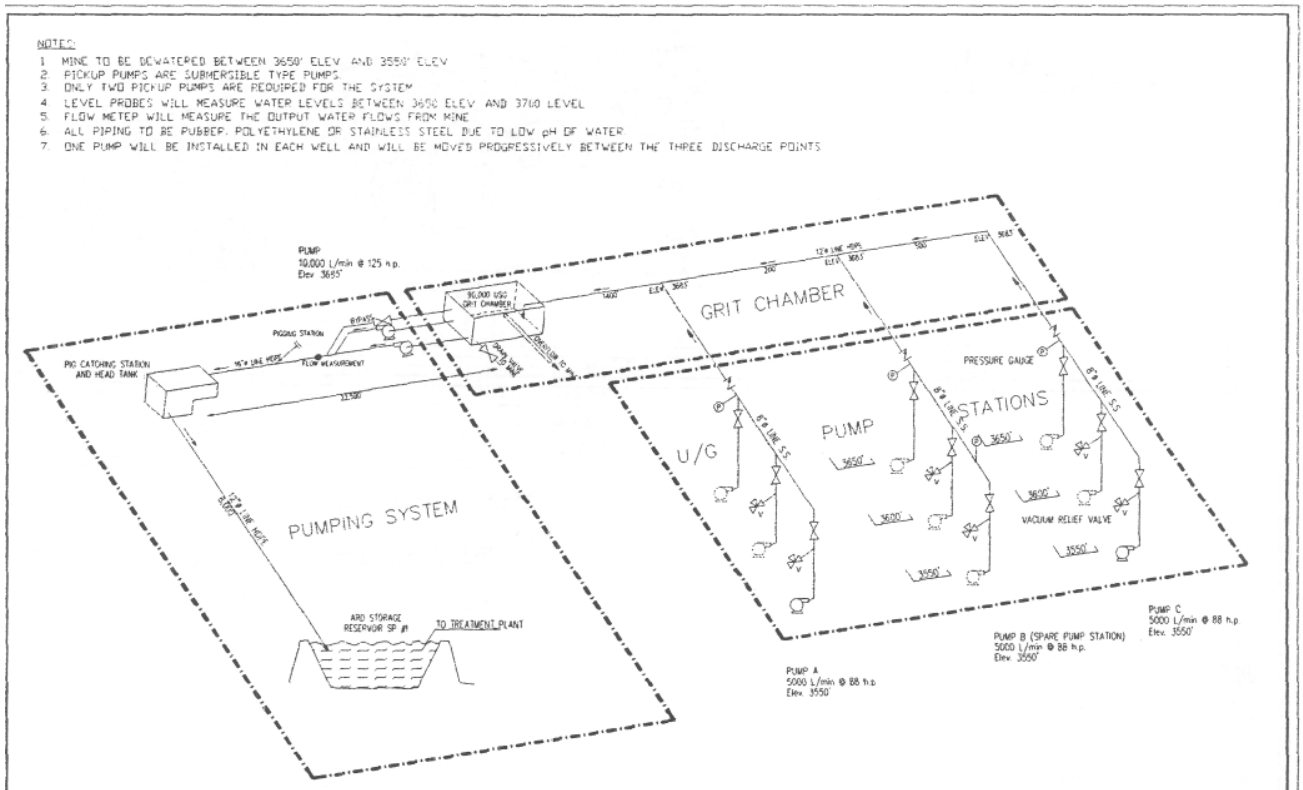

FIGURE 5 – MINE DEWATERING SYSTEM NTS