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THE EVOLUTION OF THE ISLAND COPPER MINE PIT LAKE

Mike J. Wilton
Gregory A. Lawrence, P.Eng.

Environmental Fluid Mechanics Group
Department of Civil Engineering
2324 Main Mall, University of British Columbia
Vancouver, BC V6T 1Z4

ABSTRACT

The seawater flooded open pit at the Island Copper Mine near Port Hardy is used as a passive treatment system for acid rock drainage (ARD). The pit lake has evolved into three distinct layers: a brackish upper layer; a well mixed intermediate layer extending down to the depth of the ARD discharge; and a quiescent lower layer. Temperature, salinity, and dissolved oxygen profiles have been measured and a layered model developed to predict the long term evolution of water quality in the pit lake and the wind speed required to cause upwelling of the intermediate layer.

INTRODUCTION

The Island Copper Mine, located near Port Hardy on Vancouver Island, British Columbia, is situated on the north shore of Rupert Inlet which is connected to the Pacific Ocean by Quatsino Sound. Mining operations, which began in October 1971 and ended in December 1995, produced 1.3 x 10^9 kg of copper, 31 x 10^6 kg of molybdenum, 0.34 x 10^6 kg of silver, and 32 x 10^3 kg of gold (BHP, 1996). Ore extraction resulted in an approximately 400 m deep open pit with a surface area of 215 hectares. Most of the excavated waste rock was dumped into Rupert Inlet forming approximately 260 hectares of land, while the remainder was dumped around the open pit. Tailings were discharged into Rupert Inlet through a submarine tailings disposal system.

During the 1980's, acid rock drainage (ARD) was detected from the on land waste rock dumps. ARD, which is caused by the chemical and biological oxidation of reactive sulphide minerals when exposed to air and water, contains high acidity and high metal concentrations. Soon after it was detected, the ARD was collected and treated before being discharged to the marine environment.

The mine closure plan proposed that the pit be flooded with seawater and used as a passive treatment system for ARD generated from the surrounding waste rock piles. The ARD is injected by static head into the pit at two locations at a depth of approximately 222 m. In addition to dilution due to the huge volume of water in the pit and neutralization from the natural alkalinity in the seawater, the plan is to treat the injected ARD by metal-sulphide precipitation. Since initial flooding in the summer of 1996, the pit lake has evolved into a three layer system due to the injection of the essentially fresh water ARD and surface inflow of fresh water. The three layers are: a brackish upper layer extending down to a depth of approximately 7 m; a well mixed intermediate layer extending down to the depth of the ARD discharge (approximately 222 m depth); and a quiescent lower layer extending to the bottom of the pit, see Figure 1. Extensive monitoring has been carried out to determine the water quality in the lake.

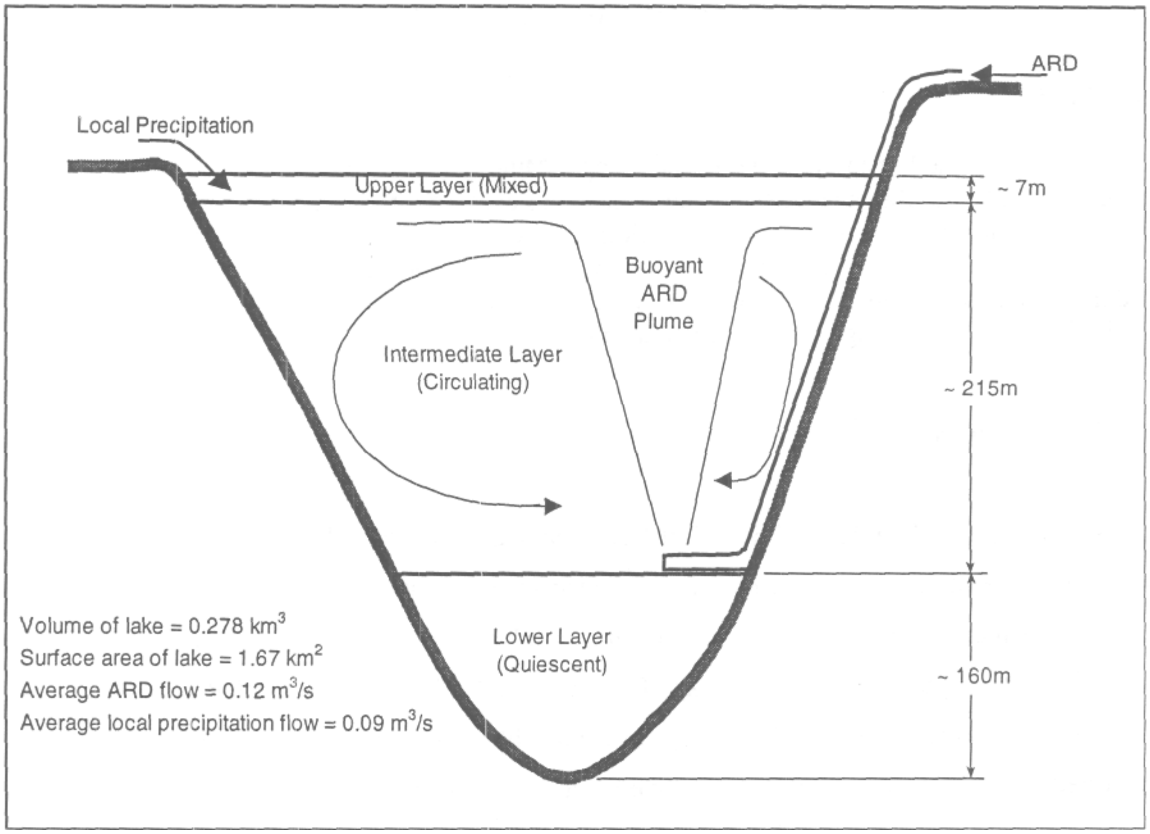

Figure 1: Cross section of the Island Copper pit lake (Data from Dunbar, 1995)

BACKGROUND

In the summer of 1996, the pit was flooded with sea water from Rupert Inlet through an excavated channel. The original proposal called for this channel to be left open to allow the pit to be connected with the marine environment. It was hoped that the pit would support marine organisms and could be used as a recreational area. Due to concerns raised by the Department of Fisheries and Oceans of metal contamination from the pit and the fact that the pit would not make good habitat for marine organisms, the channel was closed after flooding was complete.

Flooding was initiated on June 15, 1996 and continued until the water level reached approximately 15 m below sea level on July 23, 1996. The pit continues to fill due to the injected ARD as well as precipitation and surface water inflow. The ultimate water level in the pit is forecasted to be 2.4 m above sea level. This height is the top elevation of a concrete retaining wall built to enable additional mining to occur on the original shoreline. Upon reaching the ultimate water level in the second half of 1998, the discharge from the pit will flow through the waste rock dumped into Rupert Inlet, entering the marine environment as a broadly diffused flow.

An important component of the passive treatment system is the anticipated precipitation of metal-sulphides by sulphate-reducing bacteria. For anaerobic sulphate-reducing bacteria to multiply in the lake water and bottom sediments, the dissolved oxygen in the intermediate and lower layers must be below approximately 1 mg/L. To increase the rate at which oxygen is consumed in the water column, organic matter in the form of fish offal, wood chips, and fertilizer has been added to the lake.

The injected ARD is essentially fresh water (salinity is approximately 1 psu). Therefore, it behaves as a buoyant plume entraining the surrounding salt water as it rises. Upon impacting the chemocline between the intermediate and upper layers, the plume is forced to spread radially. This redirection of the plume may cause substantial mixing between the upper and intermediate layers. The combination of entrainment and radial spreading causes a circulation throughout the intermediate layer, see Figure 1.

FIELD MEASUREMENTS

Since flooding was complete in July 1996, monthly monitoring of the pit lake has been carried out by BCL Biotechnologies Ltd. Water samples obtained by Niskin samplers are analyzed for salinity, dissolved oxygen, dissolved heavy metals, pH, alkalinity, and turbidity. The salinity analysis is carried out by silver nitrate titration and dissolved oxygen is measured using the Winkler titration method. Temperatures are measured in-situ using reversing thermometers.

The Environmental Fluid Mechanics group at UBC has participated in field data collection and analysis. Five visits were made to the site (July, August, September, and November, 1997 and April, 1998) with an Ocean Sciences OS200 profiling conductivity-temperature-depth meter (CTD). The CTD yields a continuous high resolution profile of temperature and salinity through the water column that clearly shows the distinct three layer structure of the water column, see Figure 2. Dissolved oxygen profiles were obtained from a dissolved oxygen probe connected to the CTD.

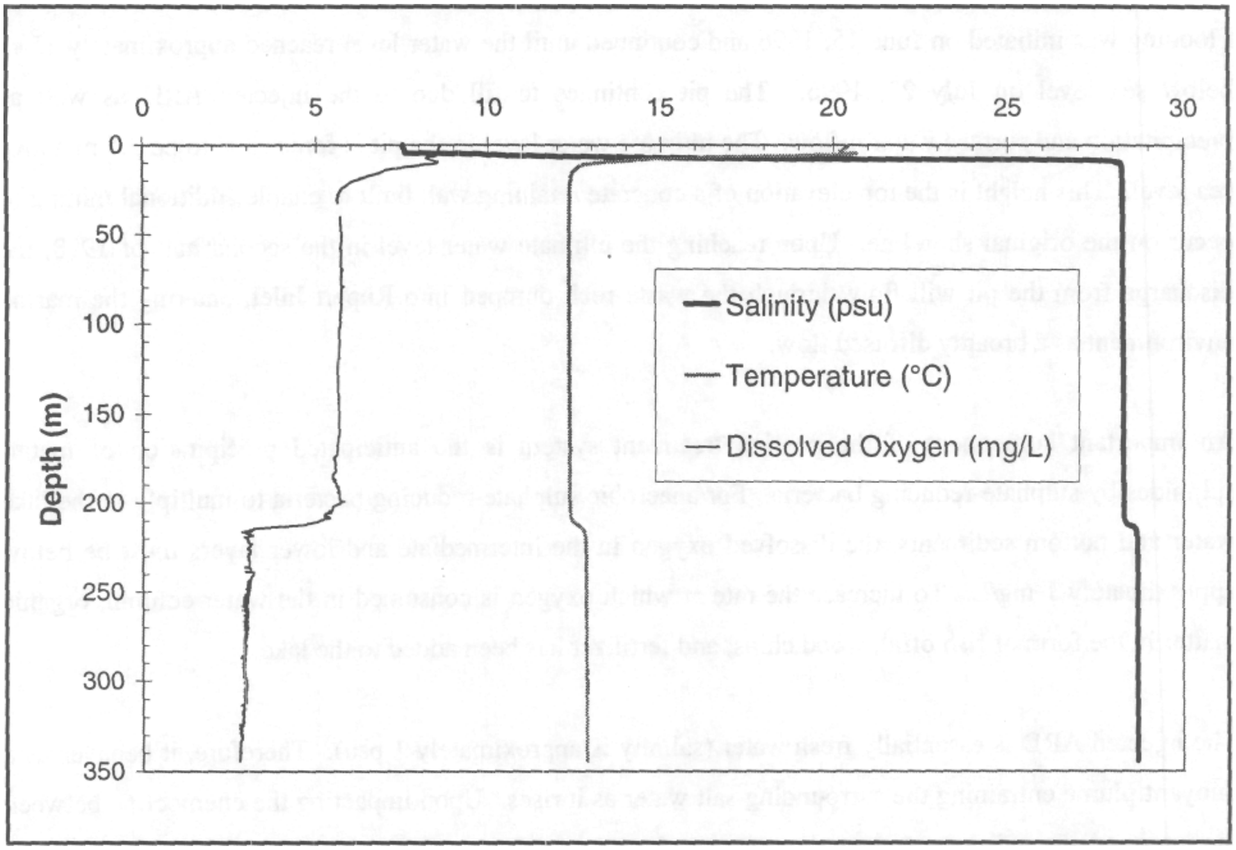

Figure 2: Profiles in the pit lake, August 28, 1997

<u>Temperature</u>

The first sampling in the pit lake was carried out on August 22, 1996, one month after the end of flooding. The surface water was at a temperature of approximately 17°C while the rest of the water column (from 40 m to 300 m) was at a temperature of 12.25 - 12.28°C. At this time a distinct lower layer had not formed. The temperature profiles obtained from subsequent sampling showed the development of a distinct lower layer below the ARD discharge: (see Figure 2). The increasing temperature difference between the intermediate and lower layers can be seen in Figure 3. The temperature in the lower layer is asymptotically rising to a temperature of approximately 12.85°C, presumably as a result of geothermal heating. The temperature of the intermediate layer is influenced by the upper layer, since there is some heat transfer between the two, and ranges between 12.3 and 12.4°C. The average temperature in the upper layer varies from, the 20°C in August: to 4°C in January with seasonal air temperature.

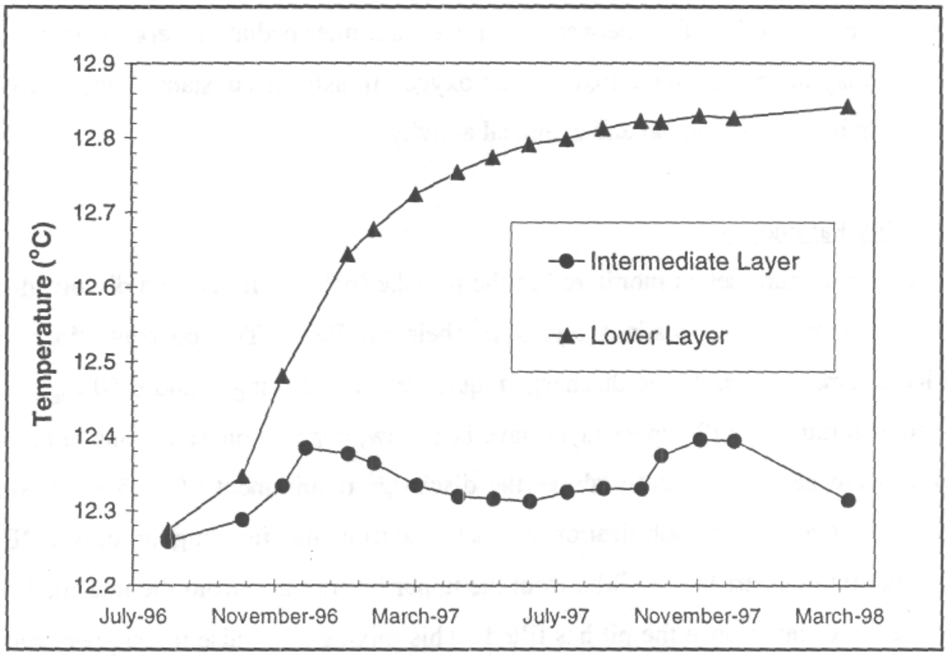

Figure 3: Average temperatures in intermediate and lower layers

Salinity

Initially the pit was filled with seawater from Rupert Inlet with a salinity of approximately 29 psu. A brackish upper layer formed soon after flooding was complete, decreasing in salinity to approximately 5 psu by April, 1998. As expected, the salinity of the intermediate layer has decreased with time due to the injection of the "fresh" water ARD and mixing with the upper layer, Figure 4. The laboratory titration results indicate that the salinity of the lower layer has decreased during the first year after flooding. This decrease is presumably due to mixing between the intermediate and lower layers while these layers were at a similar density. Since July, 1997, the salinity of the lower layer has been quite constant. The CTD yields slightly different salinities than the laboratory titration in the lower layer. The cause of this discrepancy is unknown.

Dissolved Oxygen (DO)

In the upper layer the DO concentration has remained near saturation, varying with the seasonal temperature, Figure 5. The average DO has decreased at a fairly constant rate of approximately 0.008 mg/L DO per day in the intermediate layer. Initially, the DO decrease in the lower layer appeared to be linear at a rate of approximately 0.015 mg/L DO per day, but as the data set grows it appears to be decreasing exponentially. Only 10 to 20% of the difference between these rates is attributable to the DO injected into the intermediate layer with the ARD. The remainder of the difference may be due to enhanced biological and chemical activity in the lower layer, and/or the mixing of DO into the intermediate layer across the interface between the upper and intermediate layers. It is possible that the intermediate layer may never become anoxic if this oxygen transfer is substantial and if consumption is not accelerated by enhanced biological and chemical activity.

Other Water Quality Parameters

The additional chemical parameters monitored in the pit lake (pH, alkalinity, and dissolved metals) have for the most part shown three distinct layers in their profiles. The concentrations of zinc and molybdenum have remained below the discharge requirements of 1.0 mg/L and 0.50 mg/L respectively. While copper concentrations in the upper layer have been low, copper concentrations in the intermediate and lower layers have been consistently above the discharge requirement of 0.05 mg/L since the first sampling (Figure 6) due to the mobilization of metals during the flooding process (MEND, 1995). Although discharge into Rupert Inlet will be from the upper layer, water from the intermediate layer will be mixed into the upper layer once the pit has filled. This mixing may raise the copper concentration in the upper layer as shown in the next section.

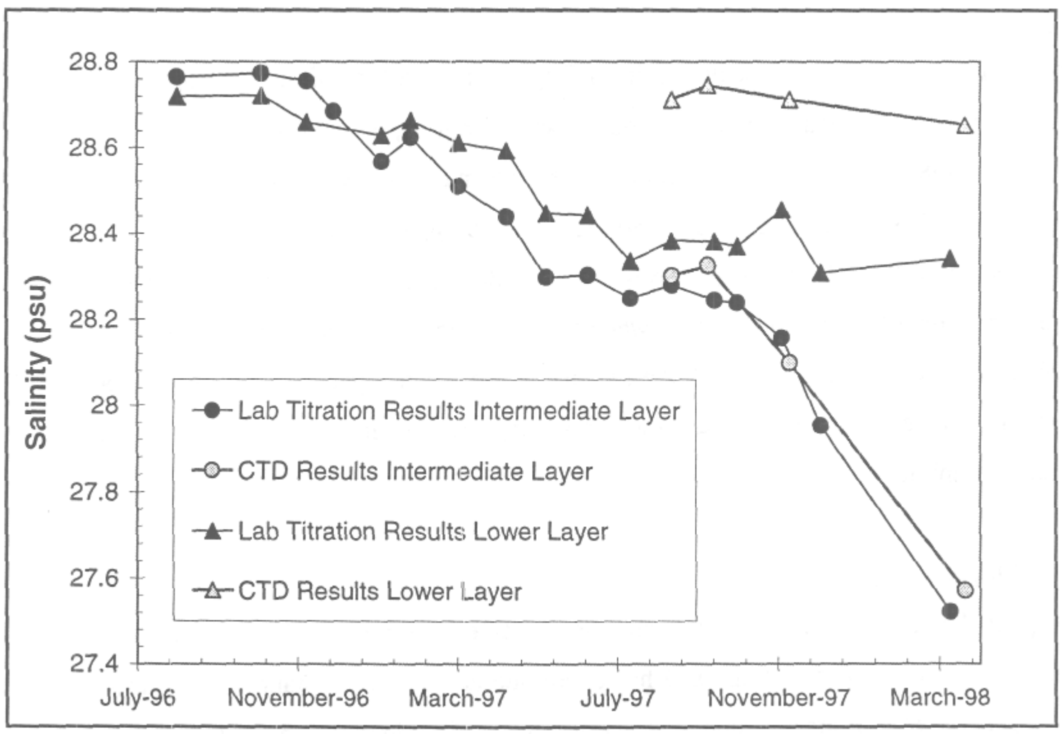

Figure 4: Average salinity in intermediate and lower layers

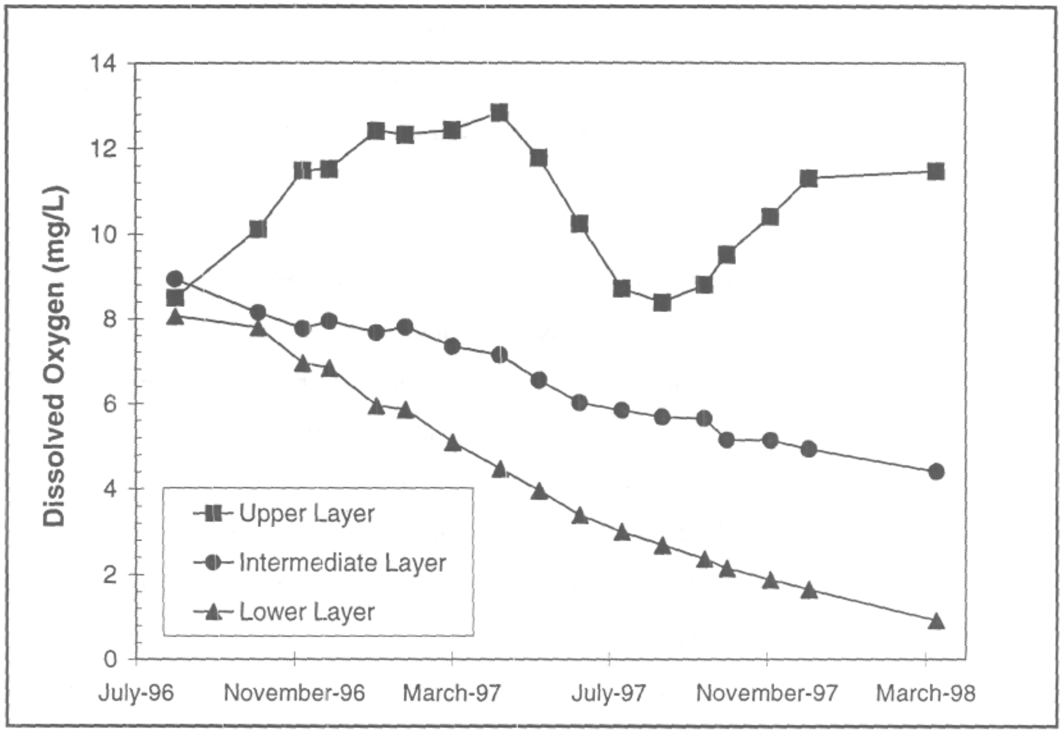

Figure 5: Average dissolved oxygen in upper, intermediate, and lower layers

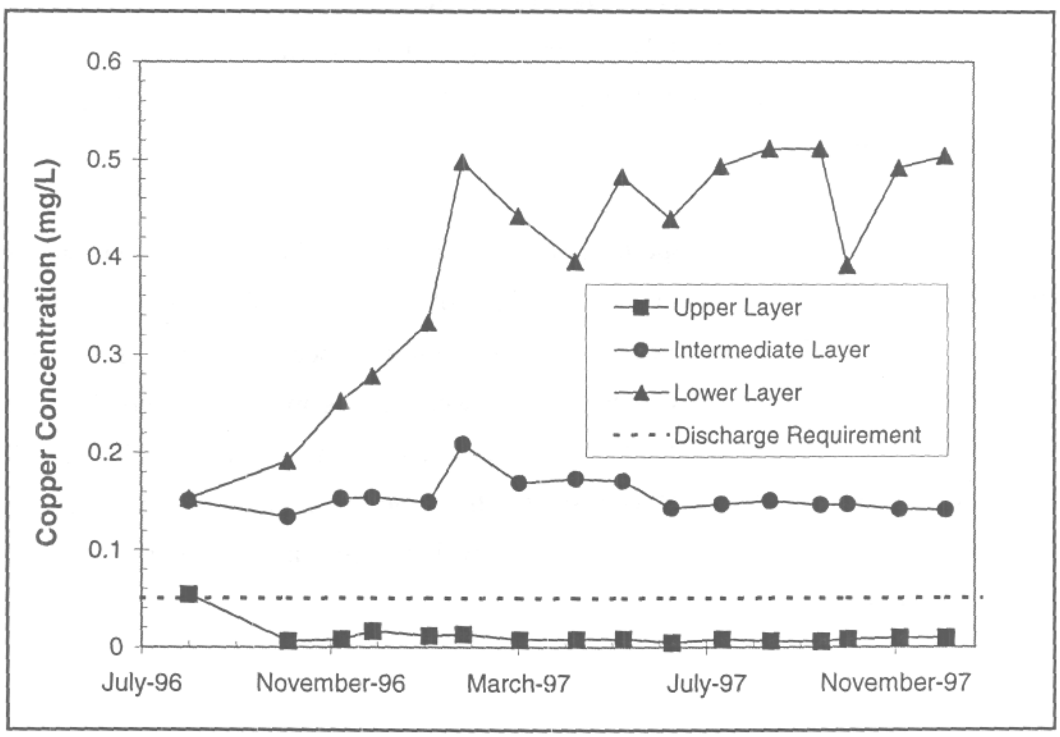

Figure 6: Average copper concentrations in upper, intermediate, and lower layers

MODEL FORMULATION AND RESULTS

The Environmental Fluid Mechanics Group at UBC is developing a two layer box model of the system with the objective of examining the long term evolution of water quality in the pit lake. This model, which incorporates features of previous models presented in BHP (1996), does not, as yet, incorporate the possibility of metal-sulphide precipitation.

The upper and intermediate layers are modeled as "continuously stirred reactors" with an exchange of fluid from the intermediate to the upper layer. This exchange is due to the fact that once the pit fills, the inflow of ARD will tend to cause the interface between the upper and intermediate layers to rise. However, during penetrative convection and wind events, water from the intermediate layer will be mixed into the upper layer, maintaining the interface at an almost constant depth. On average, the amount of fluid mixed from the intermediate layer into the upper layer will equal the amount of ARD inflow. This mixing of intermediate layer water into the upper layer will cause the initial increase in salinity and copper concentrations in the upper layer shown in Figures 7 and 8. The only inputs into the system, ARD into the intermediate layer and fresh surface inflow into the upper layer, are quantified from the estimates reported by Dunbar (1995).

The "continuously stirred reactor" model predicts the evolution of salinity in the upper and intermediate layers as shown in Figure 7. At present the copper concentration in the upper layer is very low, but in the absence of precipitation it will rise to slightly exceed the discharge requirement approximately two years after the pit fills, Figure 8.

The model also predicts the wind speed required to cause upwelling, the phenomena where the intermediate layer comes to the surface at the upwind end of the lake and mixes into the upper layer. The results presented in Figure 7 are calculated assuming that upwelling occurs at a Wedderburn number (see Stevens and Lawrence, 1997) equal to one. Lower wind speeds may cause partial upwelling, see Monismith (1986). Upwelling is of importance as it can lead to complete mixing of intermediate layer water into the upper layer, which is a concern since without the action of the sulphate-reducing bacteria the copper concentration in the intermediate layer will remain substantially above the discharge requirement, see Figure 8.

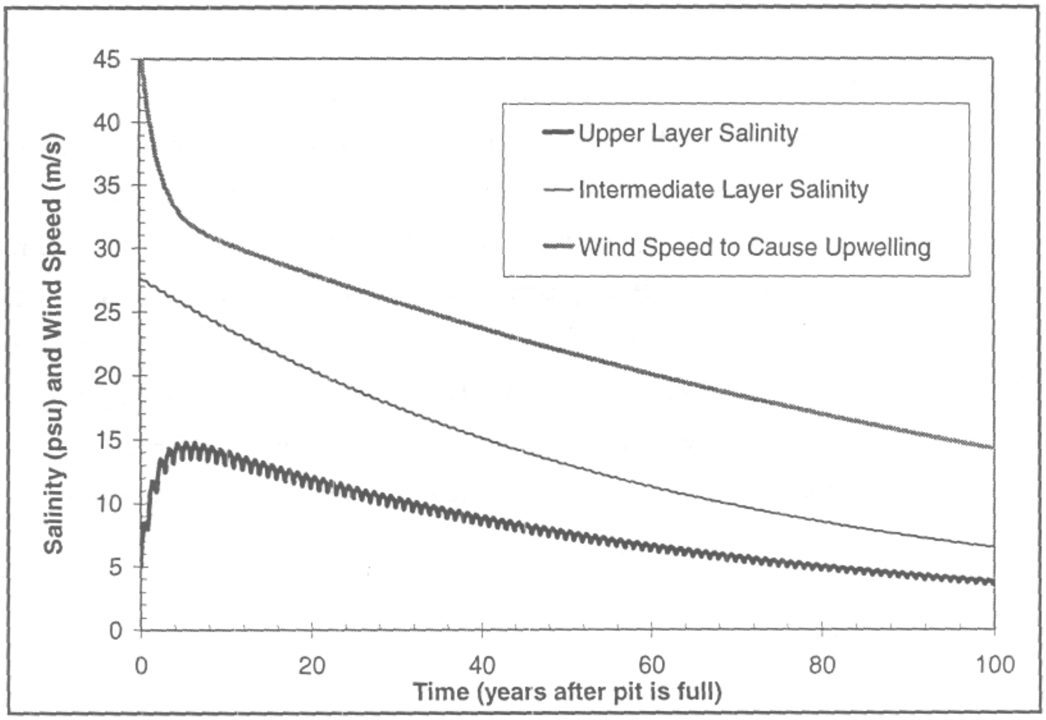

Figure 7: "Continuously stirred reactor" model results: Upper layer initial salinity = 5 psu, Intermediate layer initial salinity = 27.7 psu, Upper layer depth = 7 m, Inflows from Dunbar (1995)

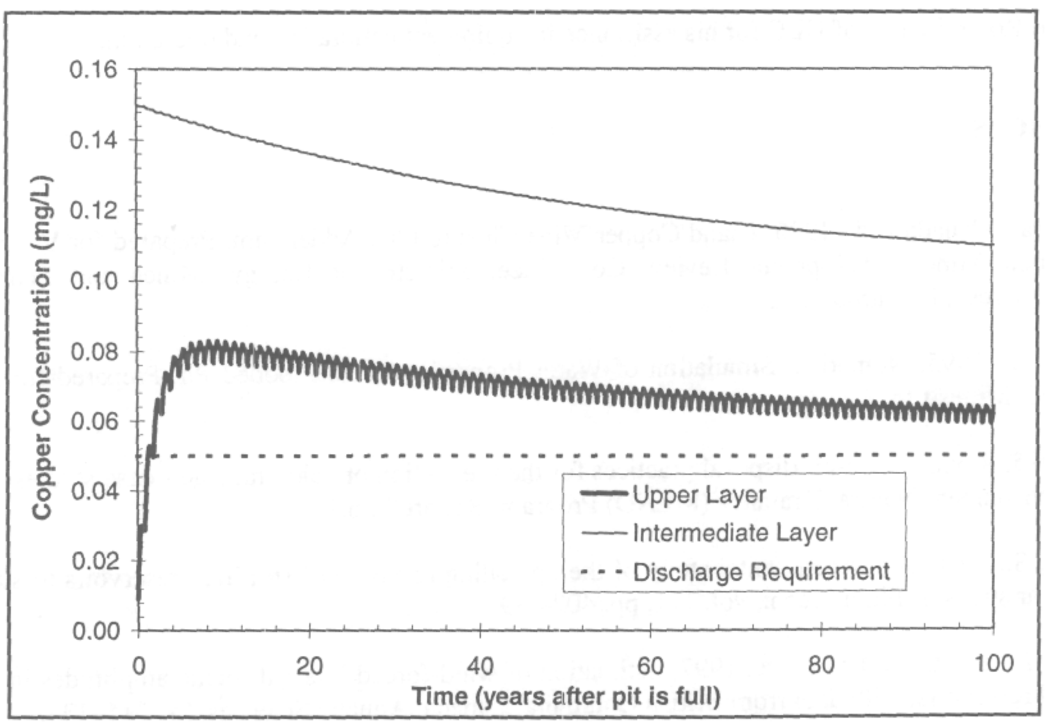

Figure 8: "Continuously stin-ed reactor" model results: Upper layer initial Cu = 0.009 mg/L, Intermediate layer initial Cu = 0.15 mg/L, ARD Cu = 0.1 mg/L, Metal-sulphide precipitation not taken into account.

CONCLUSIONS

As predicted (BHP, 1996) the pit lake has stratified into three distinct layers. A layered model predicts that in the absence of a sulphate-reducing bacteria population to precipitate metals, copper concentrations in the upper layer will rise from their very low value at present to slightly exceed the discharge requirement approximately two years after the pit is full. The establishment of a sulphate-reducing bacteria population is contingent on the development of anoxia in the intermediate layer. The DO concentration in the intermediate layer has decreased much less rapidly than in the lower layer. This difference suggests that there may be an oxygen input into the intermediate layer caused by mixing across the interface between the intermediate and upper layers. This oxygen transfer could hinder the development of anoxia in the intermediate layer. Further study is required before the long term behaviour of the pit lake can be predicted accurately.

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