THE DECOMMISSIONING OF BUCHANS UNIT

ASSESSMENT OF HYDROLOGICAL MODIFICATIONS
AND
IMPLEMENTATION OF BIOLOGICAL POLISHING
(STAGE 1)

1993 FINAL REPORT

Prepared for

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ASARCO INC. - Abitibi-Price Inc.

December 22, 1993

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EXECUTIVE SUMMARY

Zinc loadings to the Buchans River must be reduced in order to meet the compliance schedule for the decommissioning of the Buchans Unit of ASARCO INC. Presently, discharge from the Tailings Ponds, the Oriental East Glory Hole and the Drainage Tunnel all contain elevated zinc concentrations and contribute to the zinc loading in the Buchans River.

Long-term water/effluent characteristics of the Drainage Tunnel, Lucky Strike Glory Hole, Oriental West Glory Hole, Oriental East Glory Hole and Tailings Ponds 1 and 2 are assessed in this report. Based on the long term zinc concentration trend in its discharge, the Drainage Tunnel will likely contain more than 1 mg.L^{-1} zinc for another ten years. To date, the 35' increase in the Lucky Strike Glory Hole water level, since resumption of force flooding in 1992, has not affected the rate of discharge from the Drainage Tunnel.

The zinc concentrations in Tailings Pond 1 discharge appear to have levelled off at 1 to 2 mg.L^{-1}, a predicted from bicarbonate-dominated geochemistry of the Tailings Ponds sediment-water systems. Zinc Concentrations in Tailings Pond 2 discharge are still diminishing, and are expected to fall to the 1 to 2 mg.L^{-1} equilibrium as well.

The zinc concentration in the Lucky Strike Glory Hole surface water is rapidly decreasing; in the event that the Lucky Strike Glory Hole begins contributing to the discharge from the Drainage Tunnel in 1994/1995, this water will, by then, contain a low zinc concentration relative to the Drainage Tunnel.

In spring, 1994, Drainage Tunnel Discharge will be pumped to the Oriental West Glory Hole. It is projected that, within a few months, the volume of the Oriental West Glory Hole pond will be comprised primarily of Drainage Tunnel Water. Since Drainage Tunnel water is amenable to algal growth, partial zinc removal from Drainage Tunnel water residing in the Oriental West Glory Hole via Biological Polishing would reduce the additional zinc loading to the Oriental East Glory Hole and the Biological Polishing system in the First Meadow.

Based on the long-term trend of decreasing zinc concentrations in the Oriental West Glory Hole, it is expected that acid generation in the pit walls is low, and little additional zinc will be contributed by the Oriental West Glory Hole to residing Drainage Tunnel water.

Excavation of a ditch and installation of a culvert joining the surface waters of the West and East Glory Holes was completed in 1993. The resulting low overland flow, observed during 1993, confirmed that the Oriental West Glory Hole has been contributing, in the past few years, only a small fraction of the flow from the Oriental East Glory Hole via old mine workings, and that most of the Oriental East discharge arises from groundwater entering from the bottom of the Glory Hole via old mine workings.

Detailed examination of the chemical profile of the Oriental East Glory Hole in 1993 confirmed earlier projections that ferrous iron and dissolved zinc enter from the bottom of the pit, that iron oxidizes and forms hydroxide/carbonate precipitates, and that zinc is coprecipitated with the iron hydroxide, which collectively settle in the pit. Directing oxygenated Drainage Tunnel water via the Oriental West Glory Hole into the Oriental East Glory Hole will increase iron oxidation, precipitation and zinc coprecipitation, as well as prolong these processes to year-round, especially if water is directed to the bottom of the Oriental East Glory Hole. The root mass underlying floating cattail mats, positioned at the outflow, may serve as a self-renewing filter cloth, improving retention of solids formed in the Oriental East Glory Hole prior to discharge.

Geochemical simulation and experimental mixing of various waters, which would possibly be mixed in the new hydrological setting, have been evaluation with respect to major problems which could be encountered. It was found that changes in iron precipitation rates may take place, which will influence zinc concentration in the system.

It is projected that further removal of remaining zinc borne in the Oriental East discharge can be achieved via Biological Polishing, mediated by the algal populations colonizing the new Polishing Ponds 10, 11, 12 and 13. Long-term performance data for the experimental Biological Polishing pools suggest zinc removal rates within the range of 2.2% to 5.2% of the inflow zinc concentrations per day of retention time.

Although seepages from the Oriental Waste Rock Pile contribute to Buchans River zinc loadings in addition to the other point discharges, the seepage pathways are diffuse. An evaluation of zinc and acidity removal as seepage water passes through the experimental ARUM cells indicates that application of the ARUM process should eliminate, or greatly reduce, this source of zinc to the Buchans River.

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1.0   INTRODUCTION

During mining operations of the Buchans Unit of Asarco in Central Newfoundland, three gloryholes - Oriental East Pit (OEP), Oriental West Pit (OWP), and Lucky Strike (LS) - were created and two tailings ponds - TP-1 and TP-2 - were constructed. In addition, a Drainage Tunnel (DT) underlying the town of Buchans was constructed, extending from the Lucky Strike gloryhole area to the Buchans River.

In 1985 the Oriental pits were force-flooded, along with the underground workings. A slight head established between the Oriental West and the East ponds. Thus, the Oriental West Pond contributes to the flow of water discharging from the Oriental East Pond. The Oriental East Pond overflows and the effluents drain via the First then Second Meadows to the Buchans River.

The Drainage Tunnel discharges directly to the Buchans River, while Tailings Ponds' effluents discharge to the Buchans River via Simms Brook. Presently, the Lucky Strike gloryhole is still filling, and whether it will eventually represent a discharge area remains to be seen. An overview of the various locations is given in Map 1.

The pH's of all effluents are neutral (1993 average pH's, 6.32 to 5.98), with the exception of the OWP (1993 average, pH 3.88[1]). However, all effluents contain elevated zinc concentrations; in 1992 the average zinc concentration in OEP effluent was 19.5 mg.L^{-1}, in OWP, 24.1 mg.L^{-1}, in LS, 10.7 mg.L^{-1}, in TP-1 effluent, 1.5 mg.L^{-1}, in TP-2 effluent, 2.0 mg.L^{-1} and in the Drainage Tunnel discharge, 17 mg.L^{-1}. Copper concentrations averaged less than 0.3 mg.L^{-1} in 1993 in all of the effluents from the waste management areas.

Waste water treatment for the discharges from the tailings and the gloryholes would require liming, likely in perpetuity. Associated with this treatment option is the generation of sludges which require disposal.

1   pH converted to hydrogen ion concentration before averaging. This value reconverted, reported as average pH.

REGIONAL
LOCATION MAP

BUCHANS PROJECT
Buchans, Newfoundland

Boojum Research Ltd.

Date: Dec./92   Map: 1

LEGEND

Major road	———
Secondary road	- - - -
Railway	—+—+—
Hydro line	—·—·—
Dam	▨▨▨

Metres

0   500   1000

N

Tailings Pond 2

TP2 Outflow

Simms Brook

Tailings Pond 1

Lake 3

Lake 1

Lucky Strike

River

2nd Meadow

1st Meadow

Oriental East Pit

Oriental West Pit

Buchans

Drainage Tunnel Outflow
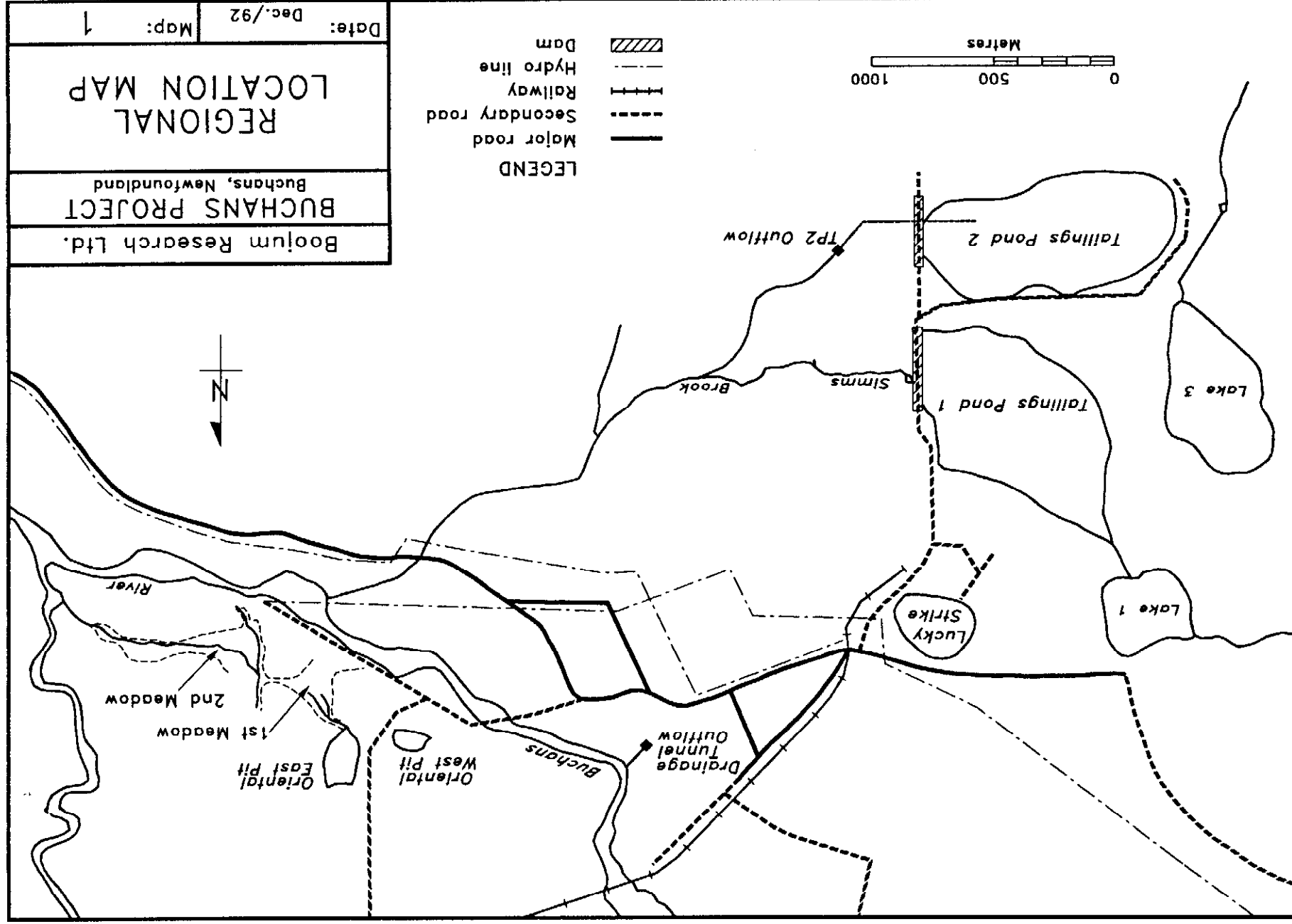
The geographical, hydrological and geochemical conditions of the site (remoteness; high precipitation; acid generation during operations generated in the presence of carbonate-rich groundwater during flooding sludges which serve as contaminant sources in the underground workings; difficult hydrology due to the mining activities) result in environmental problems which warrant consideration of novel, yet unproven approaches to decommissioning. Ecological Engineering - a soft technology based on natural water cleansing processes - was considered by the Joint Venture as a potential solution.

A commitment was made, after an initial site assessment by Boojum Research Limited in 1988, to carry out research and development on the natural processes, mainly focusing on the effluents of the Oriental East gloryhole.

Effluent treatment with natural processes requires the promotion of either oxidizing or reducing conditions, which facilitate chemical reactions leading to the formation of precipitates. Those precipitates are then collected by biological surfaces, such as algae, and relegated to the sediment in the polishing pond in which the algae grow. Acid Reduction Using Microbiology, abbreviated as ARUM, represents the creation of reducing conditions, through which sulphate is consumed and alkalinity is generated.

The implementation of ARUM is considered either as a sediment, for example in the Oriental West gloryhole, or as a seepage treatment system in low-flow seeps from the waste rock pile. Biological polishing can be utilized for the effluent of the Oriental East gloryhole, where iron hydroxide precipitates and co-precipitates zinc. The precipitates are collected by algal biomass and, through the selection of appropriate retention times, zinc is removed from the water as zinc carbonate captured by the algae.

In 1989 and 1990, experiments were carried out to test the applicability of these natural water cleansing processes. ARUM was tested in limnocorrals, 53 m^3 enclosures of

water where organic matter was used to create a sediment, in the Oriental East and West gloryholes. Methods were developed to create floating cattail islands, which would serve to reduce oxygen penetration and provide organic debris for the microbial processes. Floating rafts were installed in both gloryholes. Polishing ponds were constructed in series where algal growth was induced on cut brush and quantified, with and without slow-release fertilizer.

In 1991, the whole site, including tailings ponds and all gloryholes, was assessed with respect to hydrology and geochemistry. Nolan, Davis and Associates provided the framework for the assessment with a simple hydrological model. Existing groundwater wells were used to assess the groundwater conditions, and geochemical simulations assisted in reaching conclusions with respect to the final close-out configurations of the site. The force-flooding of Lucky Strike was resumed and the decision was made to bring the Drainage Tunnel effluent to the Oriental West Pond, which was to be connected to the Oriental East Pond.

An extensive study of the Buchans effluent chemistry in 1991 and 1992 concluded that, in general, the water chemistry in this area is dominated by a bicarbonate buffering system. The CO_2 solubility will determine the lower boundaries of the zinc concentration in these waters; zinc concentrations are predicted to be in the range of 1 to 2 $mg.L^{-1}$.

Biological polishing was considered to be the main treatment approach for the effluents from the Oriental East Pond, as it was concluded that the groundwater flow into the gloryhole would not allow the establishment of an ARUM sediment. Biological polishing provided promising zinc removal in test ponds 1 to 6. This process would also apply to the Drainage Tunnel effluent, as evident from good algal growth in the effluents from the Tunnel. However, space requirements cannot be met to utilize this treatment process at the outflow of the Tunnel.

The Oriental West gloryhole was originally targeted to be converted into a pond with floating cattails and an ARUM sediment. However, in light of the space problems with the Drainage Tunnel it was decided that the Oriental West Pond was to receive the Drainage Tunnel effluents.

The 1993, one objective was to confirm the proposed dilution, which takes place annually during spring run-off in the Oriental West gloryhole, by carrying out a winter and spring sampling program.

The proposed zinc removal mechanism in the Oriental East Pond, through co-precipitation of zinc with iron hydroxide, was to be quantified and confirmed in 1993 through further collection of precipitate, formed in the pond, with sedimentation traps.

The geochemical simulations carried out in 1990 on mixing water of the Drainage Tunnel, first with Oriental West Pond water and subsequently with Oriental East Pond water, were revisited using the additional data collected during the 1992/93 winter. The main objective of these geochemical simulations on mixing water is to anticipate potential problems which might be otherwise overlooked.

An additional row of floating cattail mats was added to the Oriental East Pond in 1993 to provide surface area to collect precipitate which formed in the OEP. It is the objective to contain as much of the iron hydroxide precipitate within the OEP, through providing root surface area of the cattail population for trapping the precipitates.

In 1992, an intermediate scale-up of the biological polishing ponds was provided through construction of pool 10. This pool was used in 1993 to confirm the scale-up parameters for the processes which were derived through the joint project on the biological polishing model with CANMET. In 1993, the model is being refined through continued joint project. Three more ponds, Polishing Ponds 11, 12 and 13 have been added in

the first meadow in fall, 1993.

This report will summarize the long-term effluent characteristics for all Buchans waste waters, discussing briefly long-term trends which will affect decommissioning decisions in Section 2. In Section 3, the zinc removal mechanisms are reviewed in light of the predictions made concerning the proposed removal mechanisms. These will either be confirmed or refuted, based on the data collected during the 1992/1993 winter and during spring run-off.

The geochemical implications of the proposed mixing of Drainage Tunnel discharge with the Oriental West Pond, and subsequently with the Oriental East Pond, are discussed in Section 4. In Section 5, the scale-up of the biological polishing system, comprised of Polishing Ponds 10 through 13, is discussed with respect to expected performance based on pools 1 to 6, and on pool 10 constructed in 1992.

The remedial measures which are envisaged to be implemented in 1994 when Drainage Tunnel water will enter the Oriental West Pond will be discussed in Section 6, whereupon conclusions and recommendations are made.

2.0 LONG-TERM TRENDS IN EFFLUENTS

Analysis of the long-term monitoring data indicates that zinc concentrations are decreasing in all Buchans effluents. These trends are examined in the sections below.

2.1 The Drainage Tunnel and Lucky Strike Glory Hole Pond

In 1991, available data were used to characterize the effluents discharged into the Buchans River. Through geochemical simulations, apparent changes in metal concentrations in the effluents with time were determined, and possible effects of mixing of waters and other potential treatment options were evaluated (Section 2.1 of 1991 report). It was concluded that there is only minor variation, with time, in the rate of Drainage Tunnel discharge, and in pH and [Cu]. Although [Zn] varied seasonally, no long-term trend (e.g. increase or decreasing [Zn]) was evident yet.

Since there is insufficient room for biological treatment of the Drainage Tunnel discharge between the tunnel portal and the Buchans River, water could be pumped to another area such as the Oriental East or Oriental West Ponds. Transferring the Drainage Tunnel discharge to one of the Oriental ponds would overall result in an improved water quality in the reach of the Buchans River between the Tunnel outfall and the Oriental mine road. Geochemical simulation was employed to estimate saturation degrees and sources of dissolved solids contents of the pond and tunnel waters, and to provide a preliminary evaluation of potential disposal options for the Drainage Tunnel discharge.

In Section 2.3 of the 1991 report, the topographic, hydrologic and water chemistry data for the Lucky Strike/Drainage Tunnel area were reviewed and interpreted. Preliminary modelling of the groundwater system provided by Nolan, Davis and Associates, was used to aid the interpretation, and to provide insight into the future of the flow regime.

From the results of these evaluations, it was concluded that, first, water from Lucky Strike and/or the mine workings can contribute only a portion of the Drainage Tunnel discharge. Discharge from the Drainage Tunnel is not "driven" by the water level in the Lucky Strike pond, but by the generally higher water levels in the surrounding ground.

Second, the results of the preliminary simplified model suggested that the water level of the Lucky Strike gloryhole would not be able to rise much above 900 ft a.s.l. Left unassisted, this final water level would be reached in the year 2005. The ultimate rise of the water level of Lucky Strike would increase the Drainage Tunnel discharge by less than 10 percent.

The Drainage Tunnel recorded discharge rate has varied between 6.5 and 8.9 L.s^{-1} in the period between January 30, 1990 and December 7, 1993 (Figure 1). There is only minor seasonal variation in discharge rates. More importantly, there is no long-term trend of increasing discharge rates for this period, despite the accelerated pond level increase in the Lucky Strike pond with time, due to siphoning of TP-2 water during the ice free-seasons of 1992 and 1993 (Figure 2). In fact, the average Drainage Tunnel discharge rate in 1993 was slightly lower than the 1991 and 1992 averages.

To date, these results confirm conclusions and projections made in 1991. At the present water level of Lucky Strike of 875 ft a.s.l., the Drainage Tunnel discharge rate is not driven by the Lucky Strike pond level, and discharge rates have not increased. The discharge rate is likely the result of higher water levels in the ground surrounding the Drainage Tunnel vicinity. Although the Drainage Tunnel discharge has not increased, despite the rapid increase in the Lucky Strike pond elevation, it remains to be seen whether Drainage Tunnel discharge will be increased when the Lucky Strike pond nears its maximum level of approximately 900 ft.a.s.l. Siphoning of TP-2 increased the Lucky Strike pond level by approximately 15'(1992) and 20' (1993) each year, and the level is now 875 ft. a.s.l (Plate 1). If summer siphoning is continued until

Fig.1:Drainage Tunnel Flow
Jan 13, 1990 - Dec. 7, 1993

Legend: —— 1990 —— 1991 ······ 1992 ▲ 1993
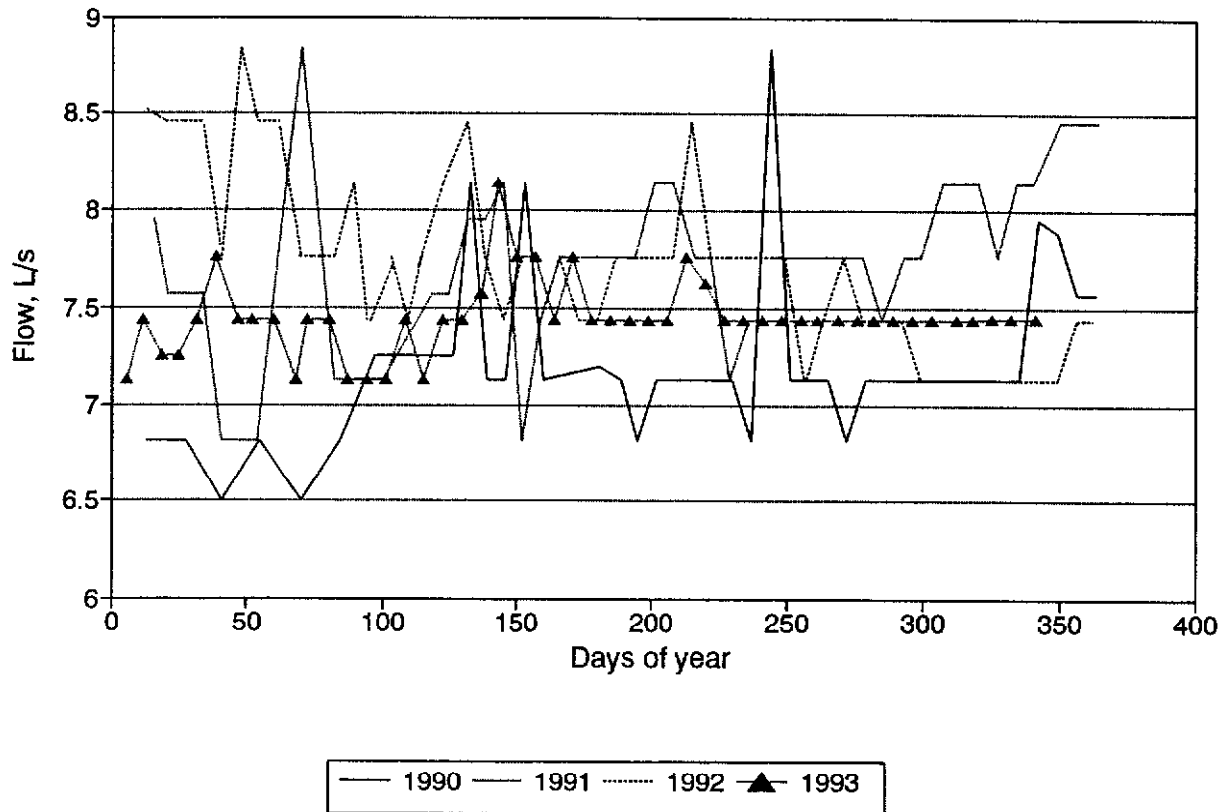
Fig. 2: Lucky Strike Pond Elevation
VS Drainage Tunnel Flow

Legend: —— L.S. Pond, 'ASL   —— Drainage Tunnel L/s
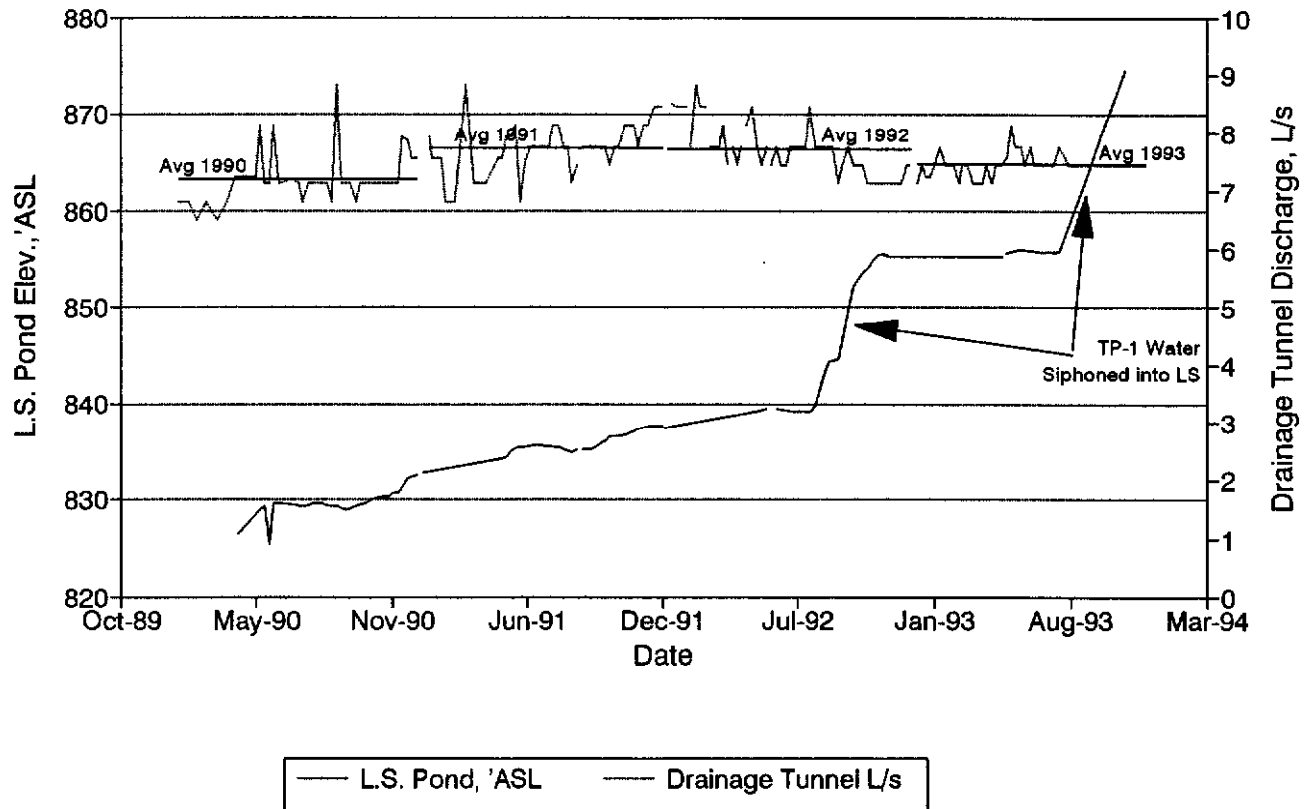
Fig.3: Drainage Tunnel Zn Concentration
Jan 13, 1990 - Dec. 7, 1993
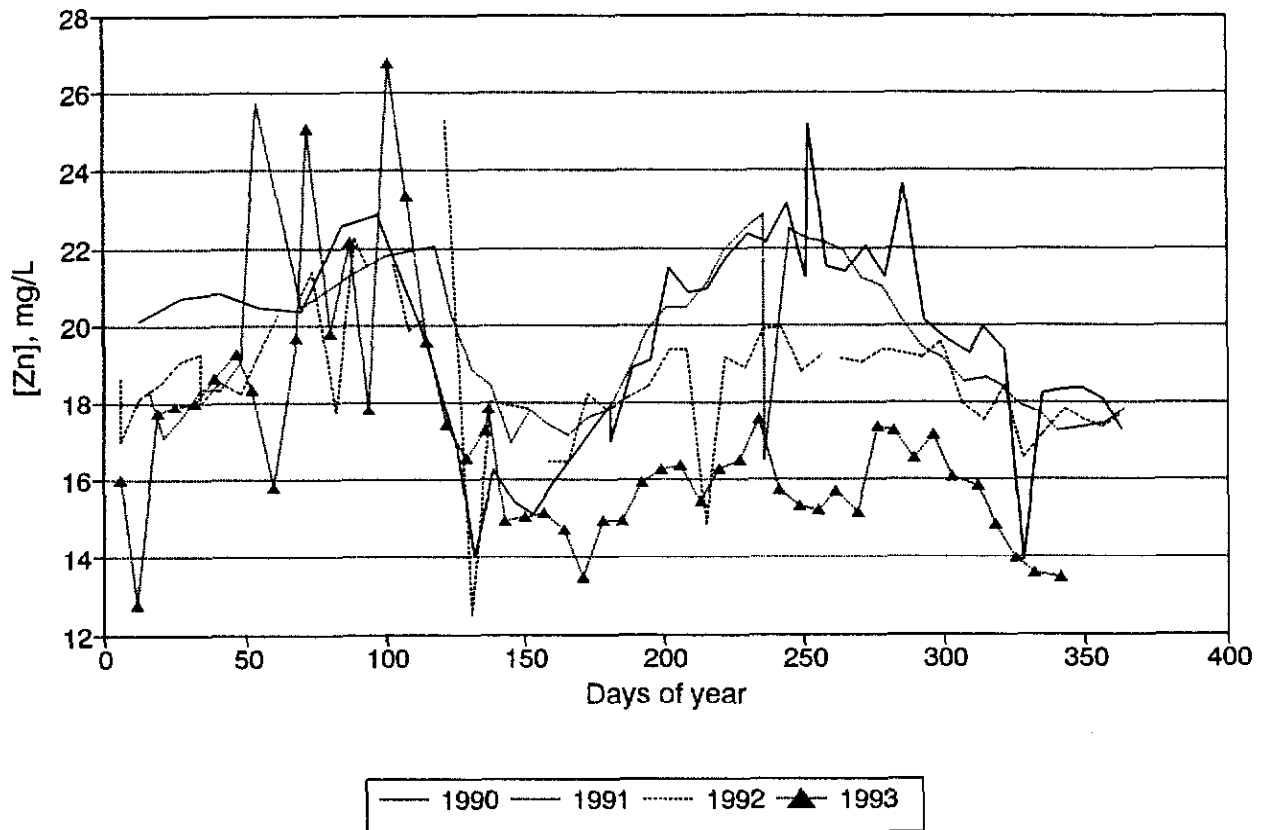
declined in the late winter and in spring to 12 to 18 mg.L^{-1}.

In 1990 and 1991, zinc concentrations increased over the summer months, reaching the previous winter's concentration. However, in the summer of 1991, the zinc increased to concentrations in the range of 17 to 20 mg.L^{-1}, less than the previous winter's concentrations, while in 1993, zinc concentrations remained at concentrations less than 18 mg.L^{-1}.

The relationship between the observed seasonal trend in zinc concentrations and seasonal variation in temperature, and/or seasonal variation in the amount of fresh water percolating into the Drainage Tunnel and diluting zinc concentrations in water through the Tunnel is discussed briefly below.

Plate 1:   Lucky Strike Gloryhole, November 16, 1993. Pond elevation 875.5' a.s.l.
            Headframe and mill in background.

fall, 1994, then the Lucky Strike pond water level may reach 900 ft. a.s.l., an elevation close to the maximum expected elevation (1991 report).

At this elevation, Lucky Strike surface water may begin joining the shallower groundwater in the area surrounding the Drainage Tunnel. Should this occur, the zinc concentration in the Lucky Strike pond at that time could then have direct bearing on the Drainage Tunnel discharge water quality.

The zinc concentrations in Drainage Tunnel discharge between January 13, 1990 and December 7, 1993 are summarized in Figure 3. While seasonal variation in the discharge rate is minor (Figures 1 and 2), there is a strong seasonal variation in zinc concentrations in the discharge. Zinc concentrations gradually increased over the winter months in 1990, 1991, 1992 and 1993 to similarly high concentrations by March and April, in the range of 20 to 26 mg.L^{-1}. Each year, the zinc concentration steeply

Higher temperatures could be expected to increase acid generation and leaching rates. However, there is very little variation in the Drainage Tunnel discharge water temperature (5° to 7° C; see 1992 report), and even so, high zinc concentrations coincide with the colder months. Overall, temperature variation cannot explain the pattern of seasonal zinc concentration variation.

If large volumes of water percolated into the Drainage Tunnel during spring and to a lesser degree in fall, diluting the zinc concentration, then the annual zinc concentration low observed each spring and concentration decreases in fall between 1990 and 1993 could easily be explained. However, there is only minor season variation in the discharge rate for 1990 and 1993, where slightly higher spring and fall flows were recorded. For 1991 and 1992, variation in discharge rate cannot be attributed to spring and fall run-off.

One explanation, although speculative, may be that zinc concentrations are, in fact, diluted in spring and fall, but that a structural or physical configuration (e.g. air-lock) exists in the Drainage Tunnel which maintains the relatively constant discharge rate despite seasonal variation in water level upstream. The tunnel and surrounding ground upstream from this structure or distal to the physical configuration operate as a reservoir throughout the year, diluted in spring and fall but draining at a relatively constant rate over the year.

From the long-term zinc concentration data, summarized in the 1991 for the period from 1987 to 1991, it appeared that the zinc concentrations were remaining relative constant from 1988 onwards (Section 2.1, 1991 report). However, the Drainage Tunnel zinc concentration data for 1990 through 1993 suggest a long-term decreasing trend in zinc concentrations with time and that this annual decrease may be accelerating (Figure 4). Even if the natural annual decrease in average zinc concentration was maintained at the 1992 - 1993 rate (1.72 $mg.L^{-1}.yr^{-1}$), by 1995 zinc concentrations may still be 14 $mg.L^{-1}$ and at least 9 to 10 years would be required before zinc concentrations would decline to the 1 - 2 $mg.L^{-1}$ range.

Fig.4: Drainage Tunnel Average [Zn]
Annual: Jan 13, 1990 - Dec. 7, 1993
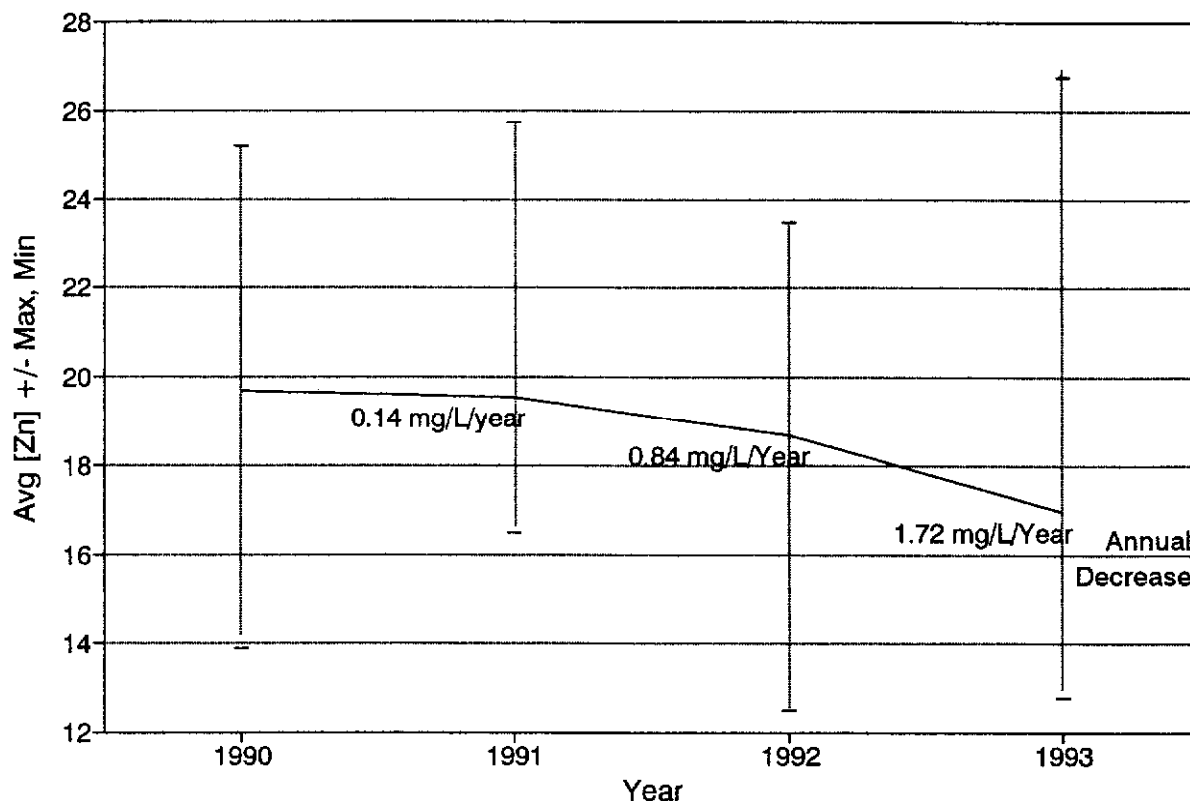
In the 1992 report it was suggested that the relatively stable zinc concentrations and pH in the Drainage Tunnel discharge are likely due to relatively constant leaching of zinc from the pyritic mine slimes still exposed to oxygen in the Drainage Tunnel. This was suggested in contrast with groundwater entering from the bottom of the Oriental East Pond, which has passed through the oxygen-free mine workings where acid generation has likely ceased.

Pumping Drainage Tunnel discharge into the Oriental West Pond would result in lower elemental concentrations in the pond water, but higher saturation with respect to most minerals (except gypsum); increased pH would tend to limit dissolution of metal-sulphides in the subsurface, but entrained oxygen may have the opposite effect.

Alternatively, pumping Drainage Tunnel discharge into the Oriental East Pond would result in lower [S], [Zn], [Al] and [Mn], and higher [Fe] and [Cu], in the pond water and lower saturation with respect to most minerals (except quartz).

It was projected in the 1991 report that the Lucky Strike pond zinc concentrations will likely decline to a minimum of 1 mg.L^{-1}, according to the same chemical considerations applicable to TP-1 and TP-2. Surface water zinc concentrations in Lucky Strike pond have, in fact, been declining since the summer of 1987 (64 mg.L^{-1} maximum; Section 2.3, Fig.2-3, 1991 report) to present (16 mg.L^{-1} maximum in 1993; Figure 5a). However, the zinc concentrations in mid-depth and bottom water samples collected in April in 1989, 1991, 1992 and 1993 indicate the zinc concentrations are consistently much higher in the lower half of the pond (Figure 5b).

The decrease in the annual average zinc concentration in Lucky Strike surface water between 1990 and 1991 (4.24 mg.L^{-1}.yr^{-1}; Figure 6) is in the same range as the decrease in annual zinc concentration for 1991 - 1992 (3.68 mg.L^{-1}.yr^{-1}), and 1992 - 1993 (2.44 mg.L^{-1}.yr^{-1}). The dilution effect of siphoning of TP-2 water into the Lucky Strike pond is not being reflected in the rate at which the average surface water zinc concentration is decreasing in Lucky Strike Pond each year. From this trend, and the pattern of higher zinc concentration with depth shown in Figure 5b, it appears that mixing of surface with bottom waters in the Lucky Strike pond, in the long term, is poor. A thermo/chemocline can be expected to be established in this gloryhole.

The average 1993 surface water zinc concentration in the Lucky Strike pond was only 11 mg.L^{-1} (Figure 6), compared to 17 mg.L^{-1} in Drainage Tunnel discharge (Figure 4). The annual average surface water zinc concentrations in the Lucky Strike pond have been declining at almost twice the rate as the Drainage Tunnel. If the annual decrease, in mg.L^{-1}.yr^{-1}, for Lucky Strike is averaged over the last four years (3.45 mg.L^{-1}.yr^{-1}), then the projected average zinc concentration in Lucky Strike pond surface water in 1995, when maximum pond elevation is expected, could be as low as 4.1 mg.L^{-1}. Therefore, surface water leaving Lucky Strike pond and joining the groundwater driving

Fig. 5a: Lucky Strike Zn Concentrations
Apr. 10, 1990 - Nov. 8, 1993
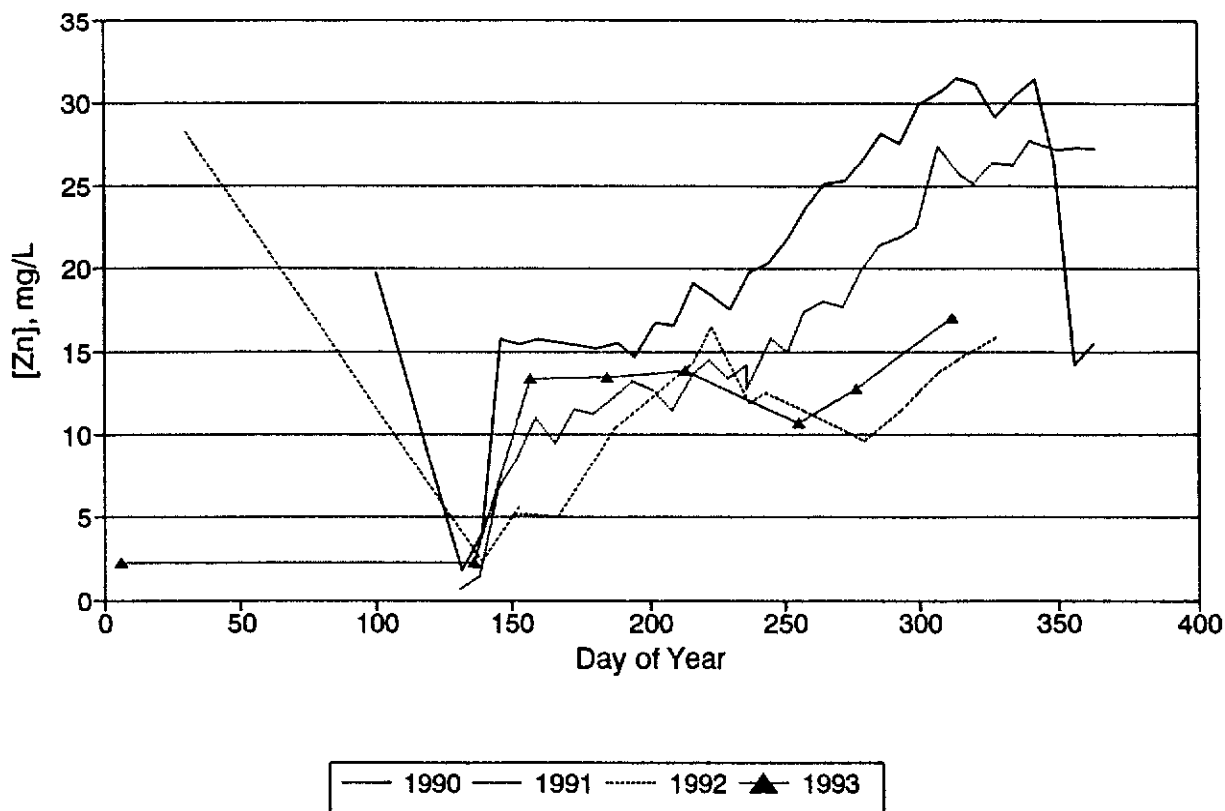
Fig. 5b:Lucky Strike Zinc Concentration
April, 1989, 1991, 1992, 1993
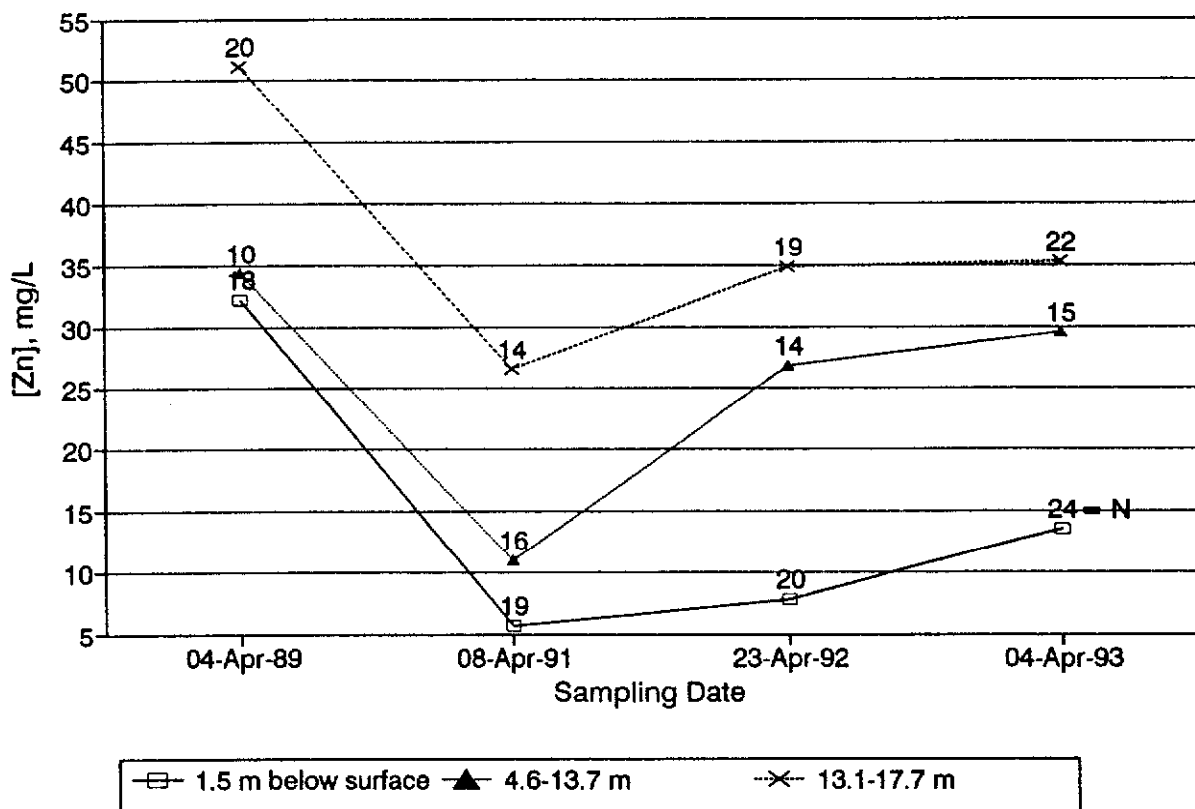
Fig. 6: Lucky Strike Average [Zn]
Annual: Apr. 10, 1990 - Nov. 8, 1993
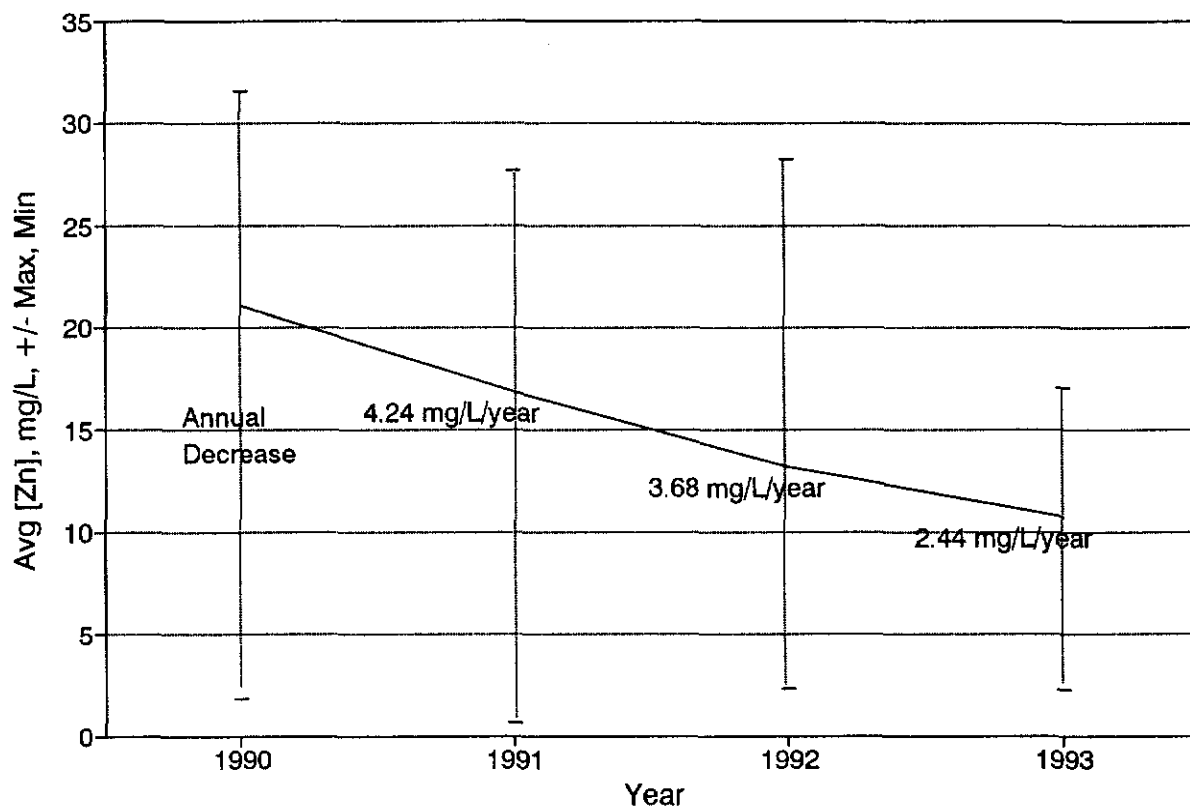
Drainage Tunnel flow will contain low concentrations of zinc, compared to the projected average *zinc concentration in Drainage Tunnel discharge water (14 mg.L^{-1} or higher;* see above).

2.2 Oriental West Pond

In the 1991 report, it was concluded, first, that the acidity in the OWP is mainly due to the hydrolysis of aluminum salts, and is not derived from acid generation in the exposed massive sulphide (Plate 2). Based on the declining OWP zinc concentrations, the source of zinc in OWP is likely a finite mass of precipitates, formed during flooding of the OWP, which are being depleted.

Second, it was concluded that the sources of zinc and copper in the OWP and OEP are independent, based on the very different water chemistry of the ponds, and the different rates of zinc concentration decline. Finally, it was concluded that the flow from the OWP only contributes a fraction of the flow discharging from the OEP.

Fig. 7: OWP Zinc Concentrations
Mar. 2, 1989 - Dec. 7, 1993
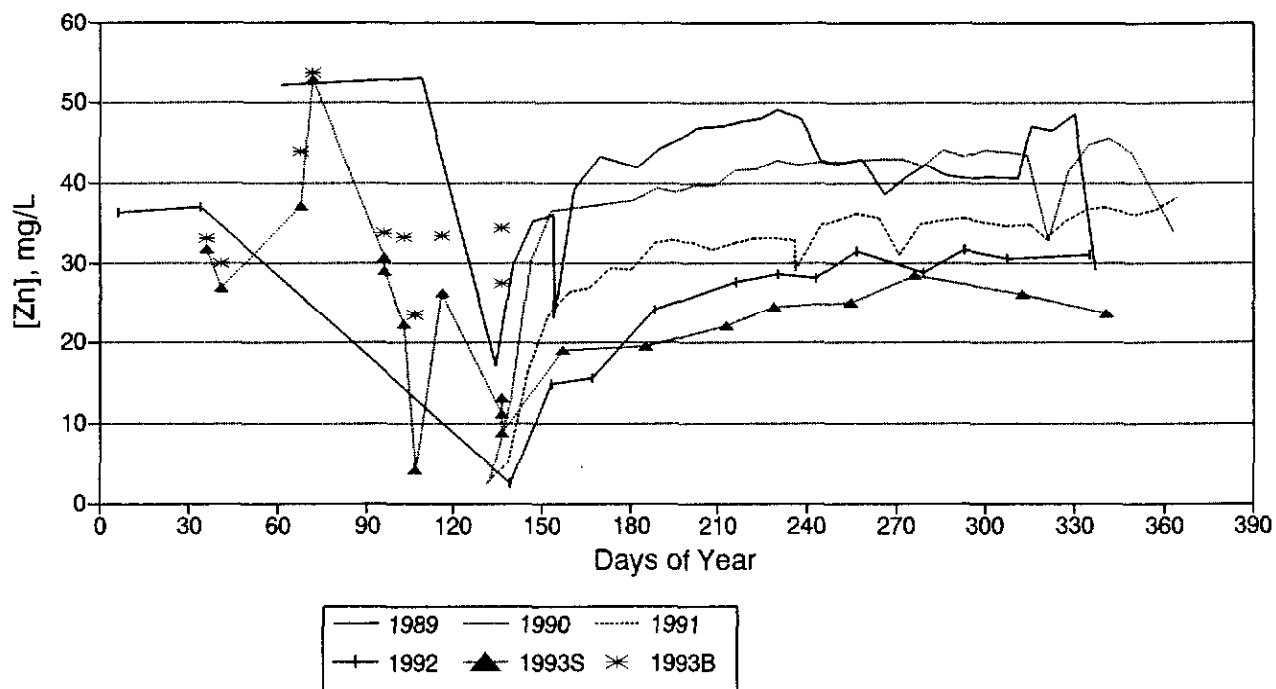
The seasonal pattern in OWP zinc concentrations was described in the 1992 report. Each spring, surface water zinc concentrations decline to about 2 $mg.L^{-1}$, but over the summer, rebound to concentrations about 5 $mg.L^{-1}$ lower than the previous year. Since the rate of surface water zinc concentration increase is similar each year, it was concluded that the similar amount of clean run-off and groundwater entering the pond each spring are causing the observed zinc concentration lows in spring.

During winter and spring 1992/1993, samples were collected more frequently, and included bottom and surface water samples. The results, plotted in Figure 7, indicate the same trends as in previous years for the surface water, with drastic decreases to 4 $mg.L^{-1}$ in the spring. The bottom water concentrations remained the same.

Plate 2:   Oriental West Pond, August 9, 1993.   1990-1991 Cattail rafts in
             foreground.   1992 Cattail rafts in background.   OWP-OEP culvert
             installation in centre background.

2.3   Oriental East Pit

With the exception of a short period during spring run-off, the discharge rate from the
Oriental East gloryhole is relatively constant (Figure 8). Over the last 8 years, the
discharge rate has averaged 10.7 $L.s^{-1}$. Prior to 1993, the contribution of the OWP to
the discharge of the OEP was unknown, but estimated to contribute a small fraction to
the discharge via the old mine workings.

Upon completion of the ditch connecting the OWP to the OEP, this assumption could
be verified. Approximately 1 to 2 $L.s^{-1}$ moved from the OWP to OEP via a groundwater
connection, and now likely moves to the OEP primarily via the new culvert. Therefore,
possibly 8.7 to 9.7 $L.s^{-1}$ discharged from the OEP enter the OEP from groundwater
sources other than the OWP. Given the relatively constant discharge rate from the
OEP over most of the year, the inflow is likely from deeper areas, where groundwater

Fig. 8: OEP Outflow, L/s
Jan. 13, 1990 to Dec. 7, 1993
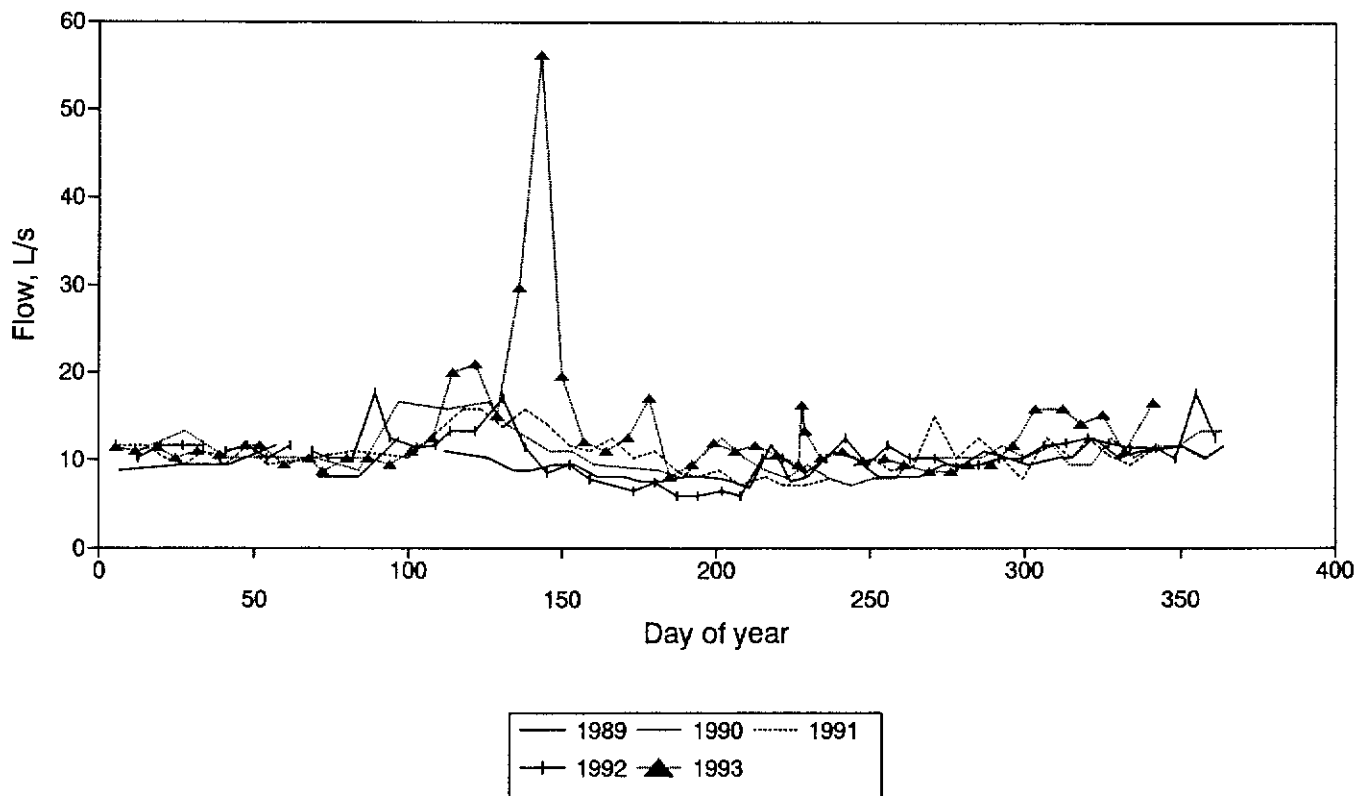
dynamics are not influenced by season variation in run-off, as would be the case for shallow groundwater.

Following spring run-off, during the period when the temperature gradient is minimal, the pond is likely mixed by wind-driven circulation for a time. However, measurements during summer months indicate that a temperature gradient establishes in the summer months, and a chemocline re-establishes at 4 m, such that the whole pond volume no longer mixes (Figure 9). Oxygen-free water groundwater enters the pond, and is oxygenated only once it has upwelled into the top 4 m of the pond above the chemocline. Mixing occurs in this top 4 m layer, and water is partially oxygenated prior to discharge.

It was suggested that zinc precipitates formed in the ore zone during flooding of the underground works. Groundwater passing through the underground workings is

Fig. 9: OEP Centre Profiles
Temperature
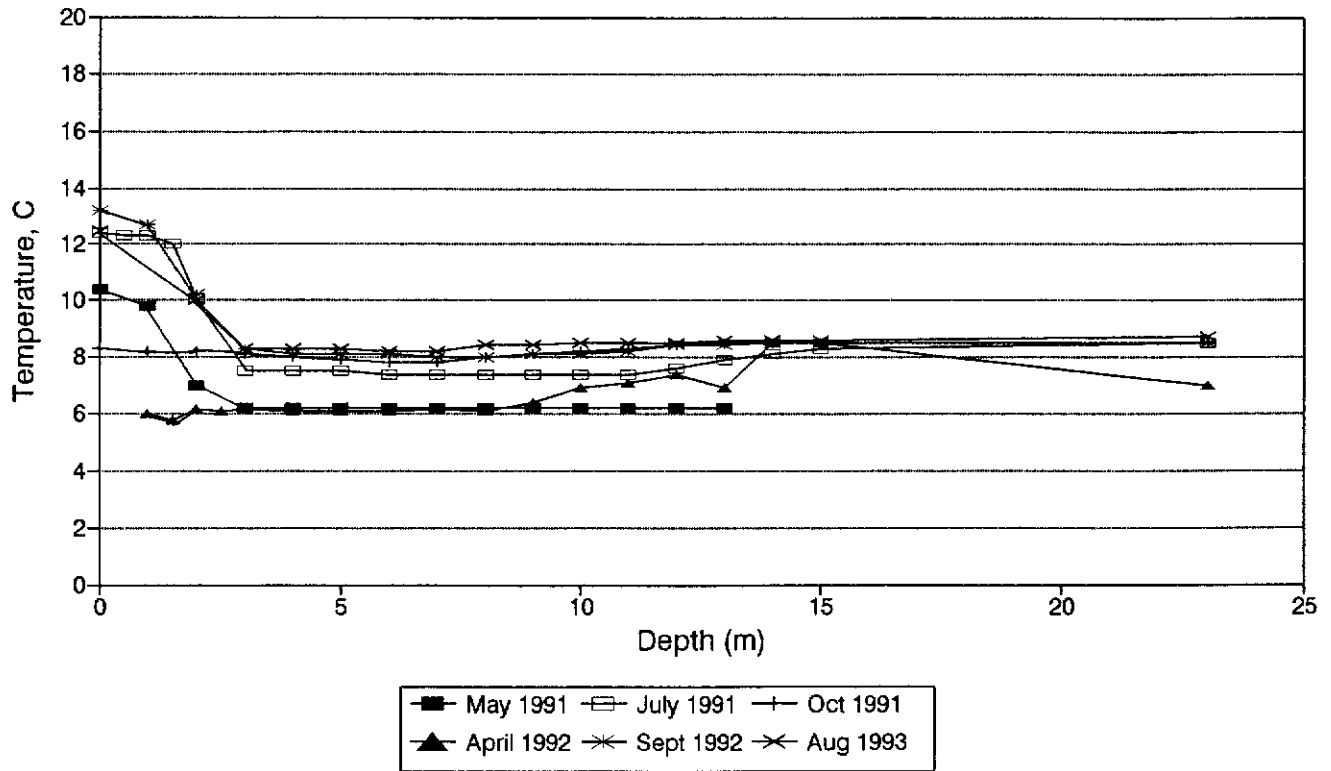
depleting the finite supply of zinc precipitates, which may account for the long-term trend of decreasing zinc concentrations in the OEP discharge (Figure 10). In 1989, zinc concentrations averaged 42 mg.L^{-1}, while in 1993 zinc concentrations averaged only 20 mg.L^{-1}, representing a 50 % decrease in four years (Figure 11). The rate at which the zinc concentrations are decreasing may be decelerating. If the annual zinc concentration decrease remains at 1.58 mg.L^{-1}.yr^{-1} (the 1992 - 1993 rate), and the system were left undisturbed (i.e., no Drainage Tunnel-OWP input), then the OEP discharge zinc concentration will still average above 10 mg.L^{-1} for another six years.

Fig.10: OEP Outflow Zinc Concentrations
Jan. 13, 1990 to Dec. 7, 1993
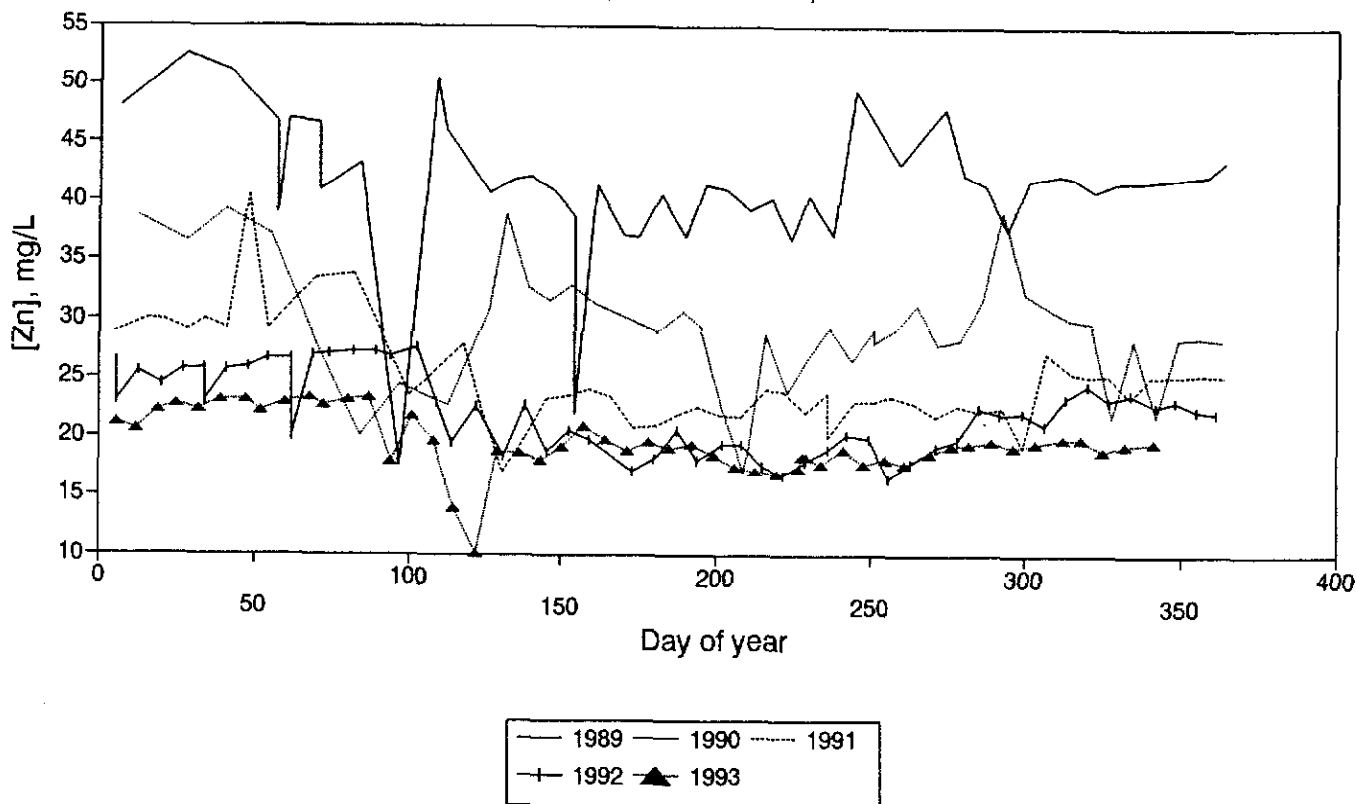
Fig. 11: OEP Average [Zn]
Annual: Jan. 13, 1990 to Dec. 7, 1993
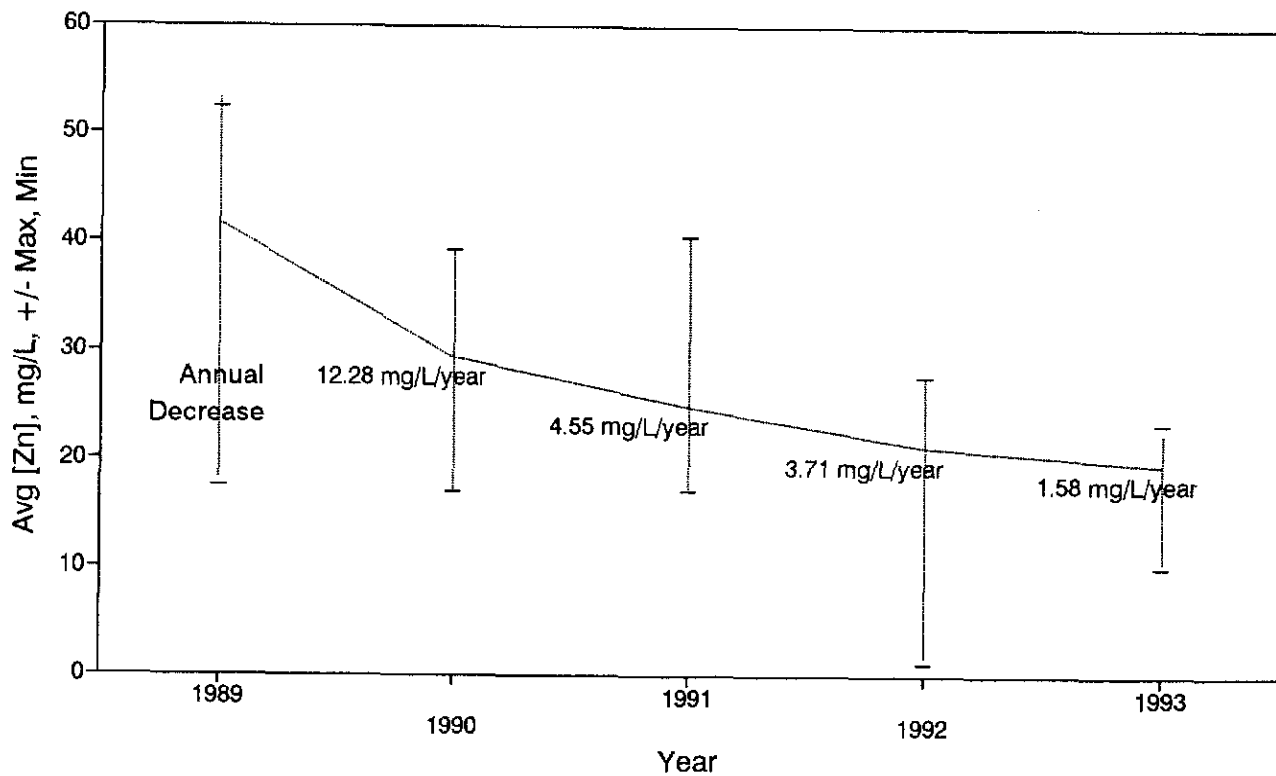
2.4 Tailings Pond 1 and 2

In Figure 12 the flows in TP-1 are presented since l990. Flows during the 1993 spring run-off were very high, compared to previous years, while run-off during fall was also somewhat higher than in previous years. The zinc concentrations during spring run-off were lower than ever previously recorded with 0.5 mg.L^{-1}, increasing following spring run-off to, on average, 1.5 mg.L^{-1} over the remainder of the year (Figure 13). The zinc concentrations are clearly around the equilibrium concentration expected for the effluents.

It was estimated that the retention time of Tailings Pond 2 (TP-2) was approximately 4.35 years. Outflow from TP-2 is driven by run-off from the surrounding drainage basin, which includes tailings beaches (Figure 14). In l993, spring run-off produced high flows, larger than in any previous years since l990. The average zinc concentration has been declining at a diminishing rate since l990 (Figure 15).

Fig. 12: TP-1 Outflow
May 12, 1990 - Dec. 7, 1993
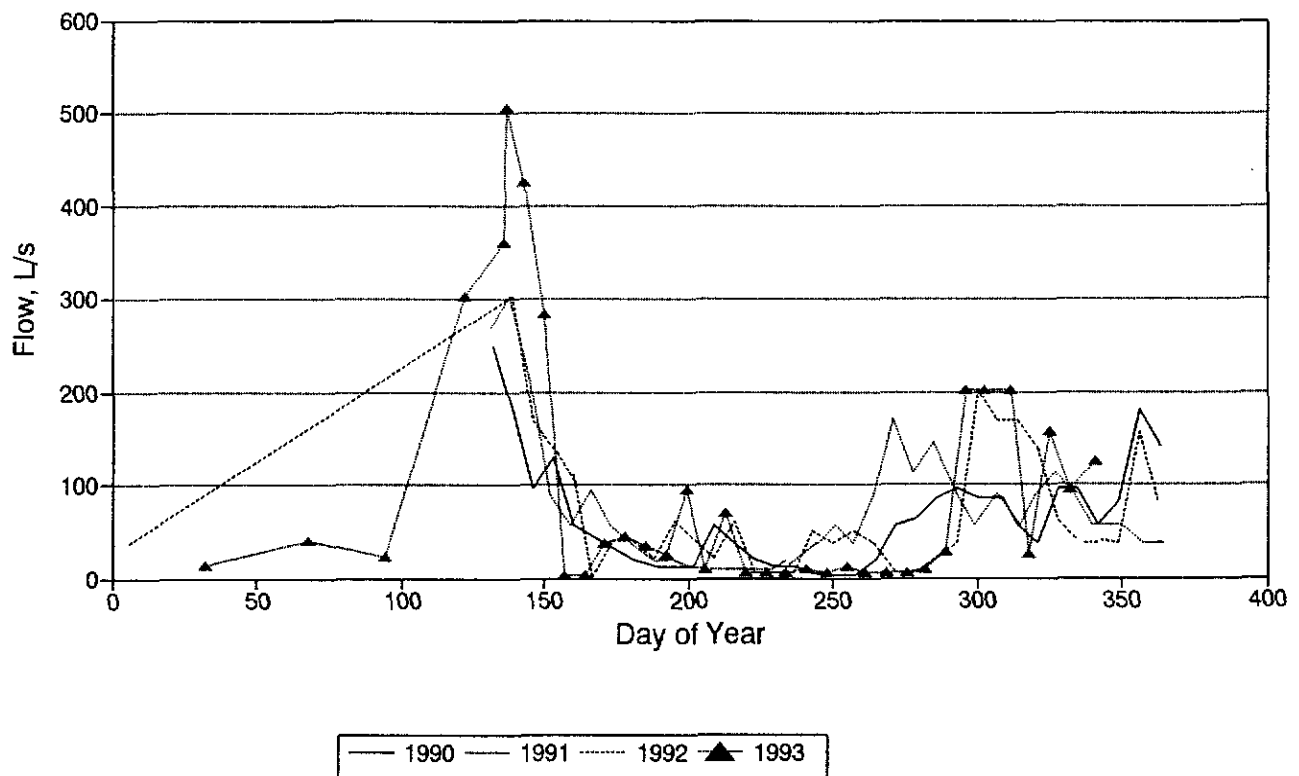
Fig. 13: TP-1 Zinc Concentrations
May 12, 1990 - Dec. 7, 1993

Legend: 1990, 1991, 1992, 1993
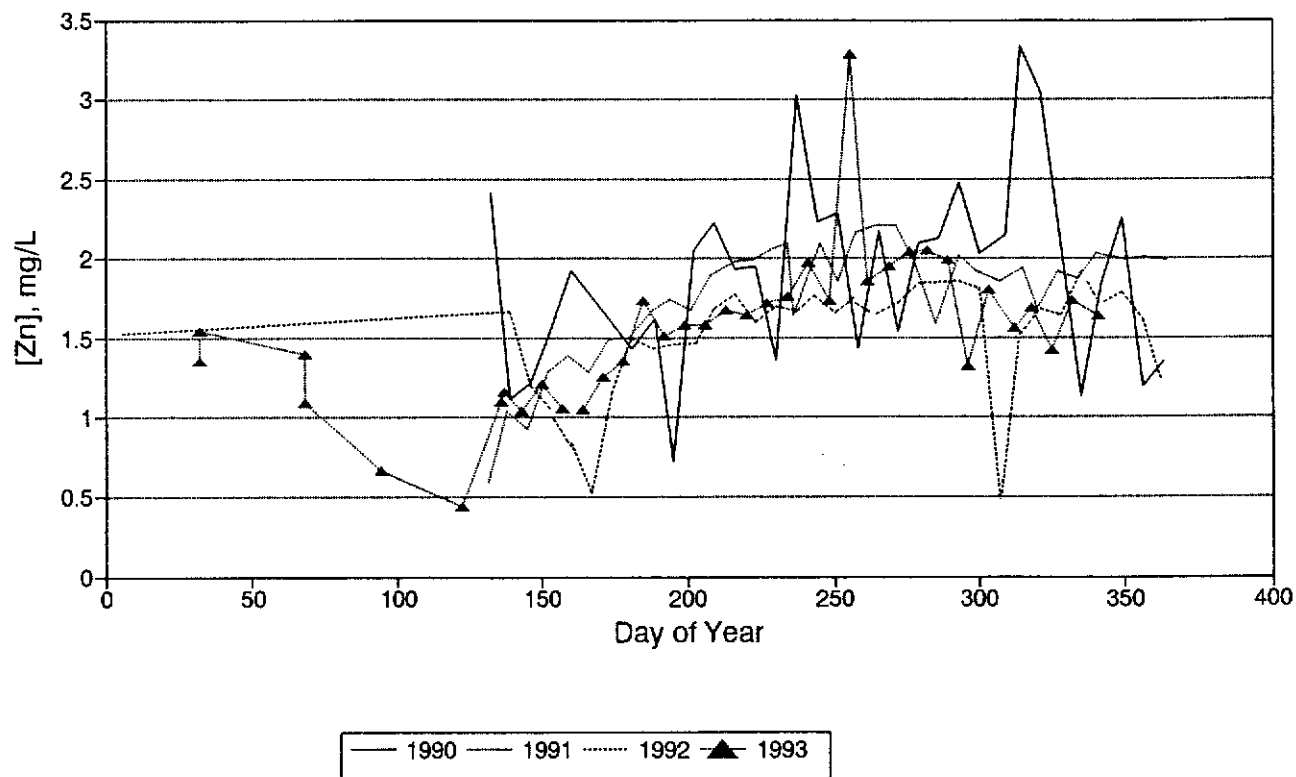
Fig. 14: TP-2 Outflow
May 12, 1990 - Dec. 7, 1993

Legend: 1990, 1991, 1992, 1993
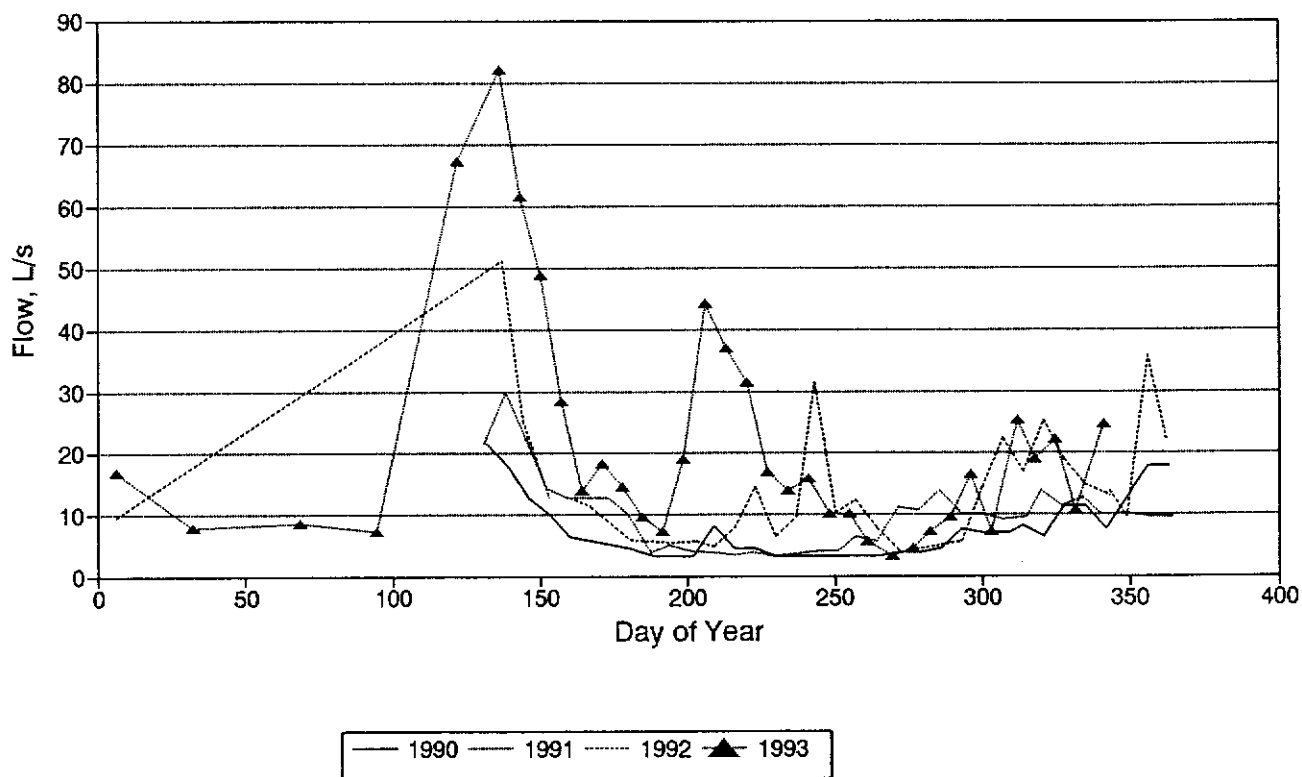
Fig. 15: TP-2 Outflow Average [Zn]
Annual: May 12, 1990 - Dec. 7, 1993
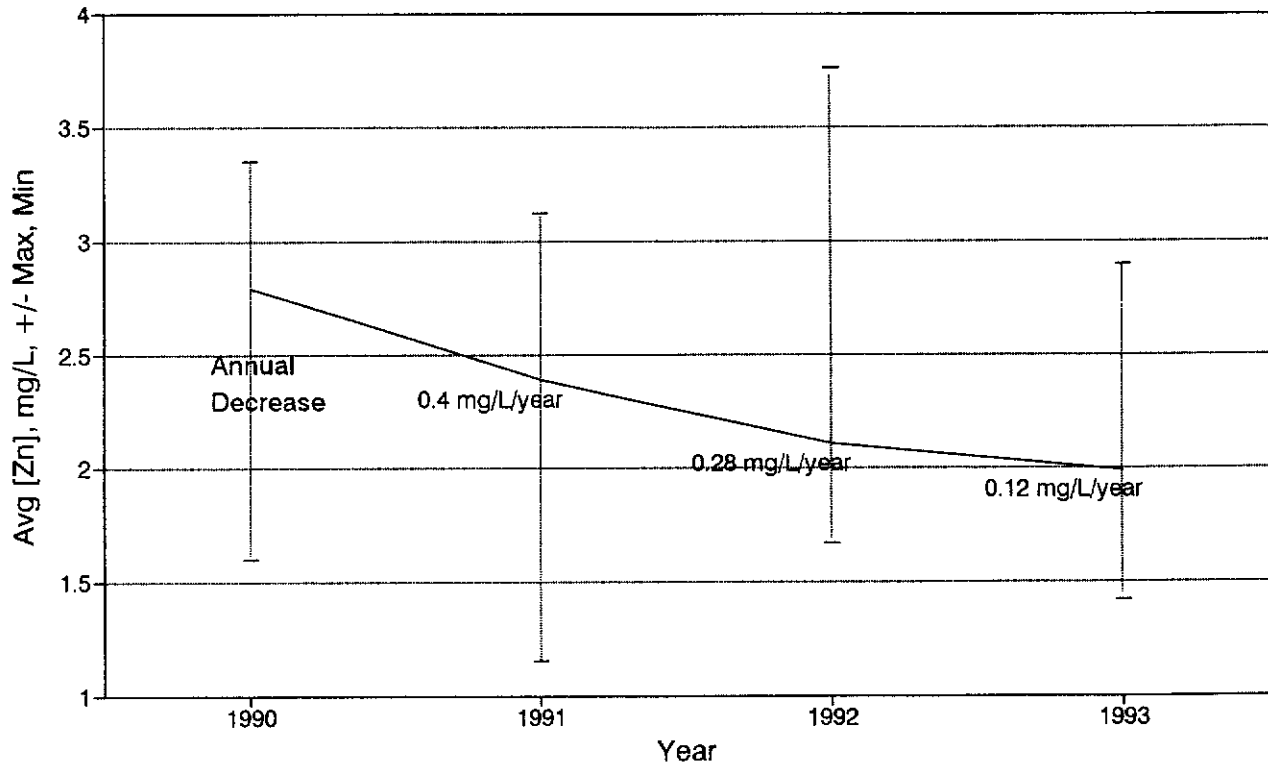
If the tailings beaches no longer add zinc to TP-2 water, then zinc concentrations should continue to decrease, ultimately dropping to about 1 mg.L^{-1} by 1994. The average rate of decrease of the zinc concentrations will be reduced as the concentrations get closer to the equilibrium concentrations of 1 mg.L^{-1}. The average decrease of about 0.12 mg.L^{-1} between 1992 and 1993 suggests that with the large run-off, potentially some of the zinc precipitated in the pond redissolved as the zinc concentrations approach equilibrium. The zinc concentrations for the entire year, plotted in Figure 16, suggest that, in the winter months, the concentrations increased above last year's average and that, during spring run-off, a drastic decrease occurred.

It may have been somewhat premature to preclude that additional zinc is being released from tailings Beach #1, which was studied intensively in 1992. However, the 1993 monitoring data are, overall, not deviating from the generally expected diminishing zinc concentrations trend.

Fig. 16: TP-2 Zinc Concentrations
May 12, 1990 - Dec. 7, 1993
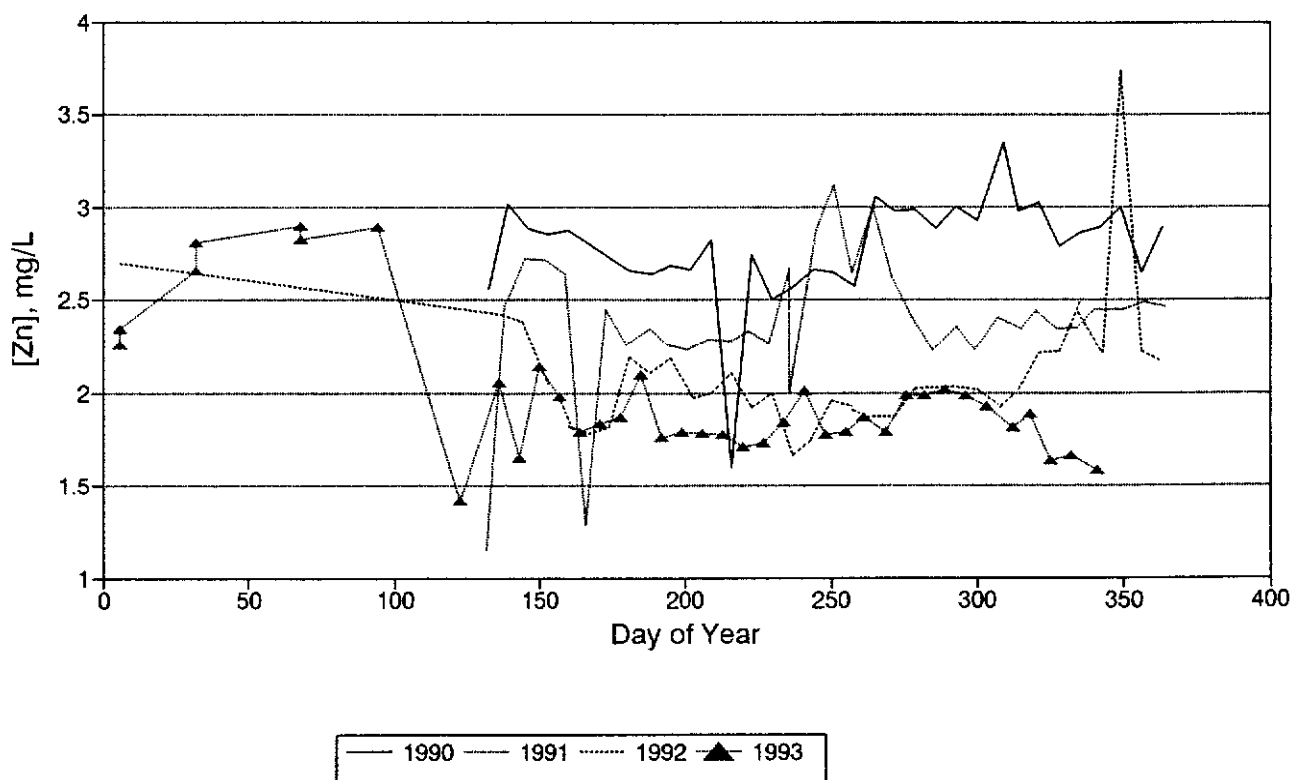
3.0   ZINC REMOVAL MECHANISMS

In the previous section, the monitoring data from all effluents were summarized with particular emphasis on long-term trends in zinc concentrations. Mechanisms which are driving the generally decreasing trends in zinc concentrations were proposed in the 1992 report.

The zinc concentrations from the Drainage Tunnel are expected to only slowly decrease in the long term, as the tunnel walls are generating acid, which presents, practically, an infinite source of zinc.

For the OEP, the major process in zinc removal was suggested as being the iron-hydroxide precipitation through which zinc is co-precipitated and remains in the OEP. Zinc concentrations are controlled by the dissolution of zinc from the sludges to the groundwater, which have formed during flooding of the underground workings. As the groundwater entering the OEP are depleted of oxygen, there is little reason to suspect that further acid generation is taking place.

Concerning Tailings Pond 2, it was proposed that the zinc concentration is a reflection of the dilution brought about by the drainage basin and, generally, no additional zinc is added to Tailings Pond 2 from the beaches.

In 1993, monitoring data were evaluated, specifically focusing on confirming or refuting the proposed zinc removal mechanisms. The evaluations are presented in this section.

3.1 Oriental West Pond

The overall pattern of water levels in the OWP suggested that, since the water level elevation varies by less than a 0.5 ft regardless of spring run-off, during periods of high run-off and groundwater input there is little resistance to water leaving OWP. Given that the zinc concentration is always lower, following spring turnover, than in the previous year, run-off and groundwater entering during spring must be displacing contaminated OWP water in this period.

OWP monitoring data was updated with 1993 zinc concentrations (Figure 7, Section 2.2). As seen in previous years, surface water zinc concentrations were lowest in spring, reaching the minimum concentration of 4 mg.L^{-1} for 1993. Therefore, 1993 was no exception in that run-off and clean groundwater was present at the surface of the pond in spring.

Meanwhile, bottom water zinc concentrations during winter and spring remained high (21 to 35 mg.L^{-1}), confirming that OWP bottom water remains unmixed with surface water during run-off (Table 1). Although surface water zinc concentrations rebounded over the summer, they reached a lower concentration (maximum 29 mg.L^{-1}) than in the previous summer. This suggests, again, that during run-off, water containing higher zinc concentrations in the range of bottom water concentrations was displaced from the pond, and explains why the overall OWP zinc concentration, following spring turn-over and mixing, is lower than the previous year.

In the 1991 report, an annual decrease of 5 mg.L^{-1} was calculated from OWP monitoring data to date. Between 1991 and 1992, the average surface water zinc concentration decreased by 4.7 mg.L^{-1}, but from 1992 to 1993, the average surface water concentration decreased by only 2.1 mg.L^{-1} (Figure 17). Whether the recurring annual decrease is diminishing, or whether the 1993 run-off conditions were anomalous, can only be determined after another year of monitoring.

Table 1: Concentrations of Elements in Oriental West Pit

Date	pH Bottom	Acidity,mg/L CaCO3 Surface	Bottom	Iron, mg/L Surface	Bottom	Aluminum, mg/L Surface	Bottom	Zinc, mg/L Surface	Bottom	Sulphur, mg/L Surface	Bottom
Jul-88				1.3	3.6	3.8	4.9	53	75	170	230
Jul-88				1.4	2.7	3.9	4.7	54	70	176	220
Dec-88					0.05		<0.01		55		195
Mar-89				0.1		3.6		48		169	
Jun-89				1.2		4.4		>10			
Aug-89					0.7		4.1		53		291
Sep-89				1.2		4.7		58		362	
Jul-90				1.2		3.8		39		120	
May-91	3.55	67	167	1.3	2.1	2.44	4.96	23.5	52.3	73.3	146
Aug-91	3.94	118	122	<1	1	7	6	33	33	107	107
Oct-91	3.72			1.5	1.3	7.4	7.2	39	37.3	119	105
May-92	3.55	38	138	0.9	3.2	1.6	4.2	15.4	50	52.4	144
May-92	3.7	37	110	0.8	1.4	1.45	6.35	12.4	35.1	47.3	114
Jul-92	4.13		57		<1		2.15		21.7		73.1
Jul-92	3.92	61.5	70	0.07	0.03	2.17	1.62	20.9	23.6	75.3	76.8
Sep-92	3.62		70.5	<1	<1	3	3	31.3	31.6	98	97
Feb-93	3.76	87.8	105	0.95	1.03			26.9	30		
Mar-93	3.77	97.9	110.7	0.95	1.1			34.6	33.8		
Apr-93	3.84	81.4	94.3	0.15	0.202	2.72	3.07	30.7	33.8	94.9	106
May-93	4.04	40.3	101.5	0.069	0.205	1.29	3.15	11.5	33.6	43.4	107

Long-term differences between bottom and surface water quality in the West Pond (Boojum and ICP data) are updated in Table 1. Since 1991, the concentrations of most elements have essentially remained unchanged, with the possible exception of iron. Underneath the ice of the 1992-93 winter, the overall concentrations in the pond remained the same as those measured in September 1992. The zinc removal mechanism in the OWP is therefore confirmed, as projected in 1992.

Fig. 17: OWP Average [Zn]
Annual: Mar. 2, 1989 - Dec. 7, 1993
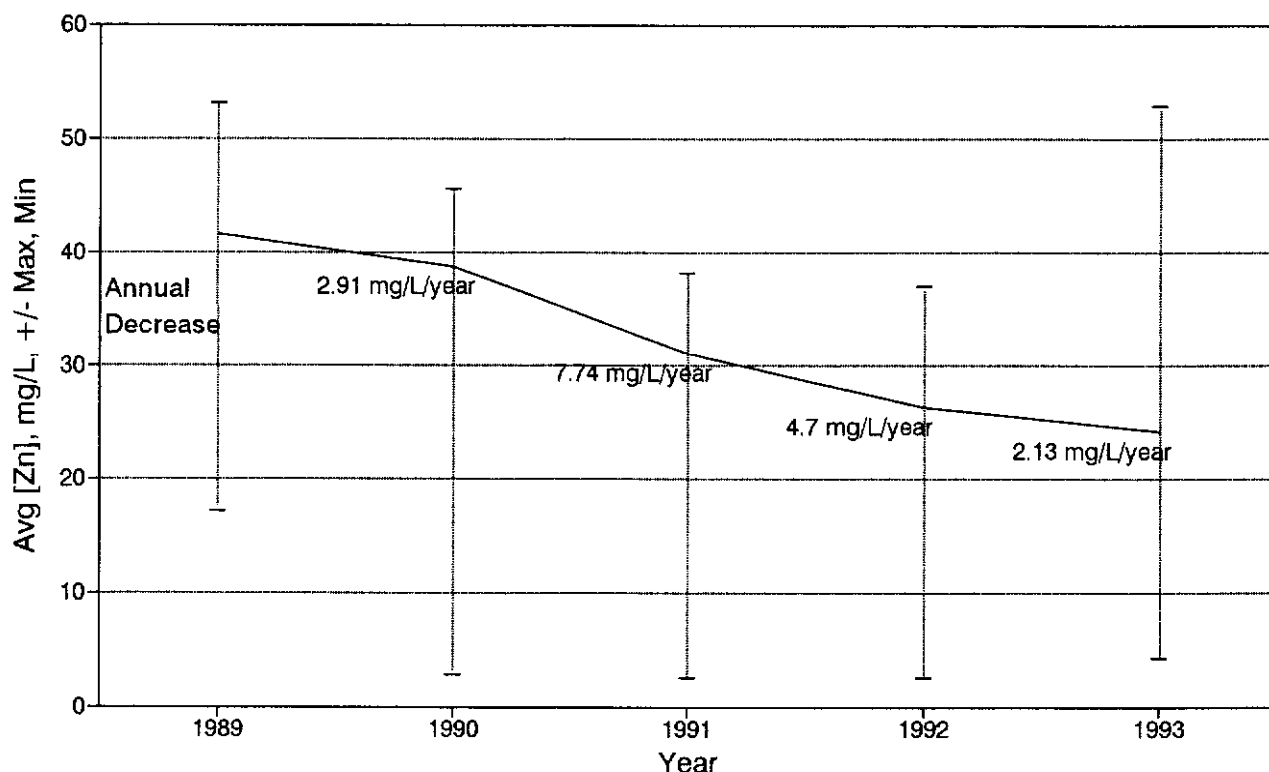
3.2 Oriental East Pond

The OEP temperature and oxygen concentration dynamics are very important, since the groundwater entering the OEP contains 50 mg.L^{-1} or more ferrous iron. It has been proposed that zinc co-precipitates with this iron following ferrous iron oxidation and precipitation as iron hydroxide. Ferrous iron is stable in water with a low dissolved oxygen concentration, as found in the pond in winter and below the chemo/thermocline in summer.

Complete oxygen depletion during the winter was confirmed during 1993, based on dissolved oxygen and Eh measurements made in the centre of the pond. The data, presented in Table 2, confirm that, between the 2 m depth and the weir overflow, some oxygenation takes place. This suggests that, during winter, iron precipitation will take place mainly in the polishing ponds, unless the OEP can be oxygenated during the winter months.

Table 2: Oxygen Concentrations and Eh in OEP Water Column.

Depth (m)	03-May-93 Diss. [O2], mg/L (2-3 days after melt)	17-Apr-93 Eh, mV (16" of ice)
At Weir	4.7	122
2 m	0.7	144
4 m	0.8	120
6 m	0.5	123
8 m	0.5	123
10 m	0.4	119
12 m	0.3	120
14 m	0.3	114
16 m	0.3	113
18 m	0.3	113
20 m		108

In April 1993, when ice was still covering the pond, a detailed profile was sampled to confirm the projected iron concentration reduction due to precipitation (Table 3). At the surface of the pond, above the chemocline, ferrous ions will oxidize to ferric ions, which then form ferric hydroxide and precipitate if the pH is above 6. This process is reflected in lower concentrations of dissolved iron at the surface, compared to the bottom of the pond. As expected, the zinc concentrations are lower at the surface of the pond than at the bottom.

It was suggested in the 1992 data summary that, if oxygen was introduced into the OEP, higher rates of iron oxidation could be expected. Higher oxygen concentrations, in turn, would increase iron precipitation and co-precipitation of zinc. During the winter of 1992, more frequent water sampling was carried out in the OEP to confirm the suggested chemical trends.

The TSS values for OEP (Table 4) suggest that there was a significant TSS increase, as was noted in OWP, during the months of April and May. The effluent monitoring data for April and the beginning of May (Figure 10), indicate that this is the period when zinc concentrations are at their lowest (10 mg $Zn.L^{-1}$). This suggests that adsorption of zinc onto particulate matter could also be a major process removing dissolved zinc from OEP water.

Table 3: Water Quality Data for OEP Profile Water Samples Collected April 17, 1993.

Sample	pH		Em		Cond.		T-C		Zn		Fe	Acidity	Alkalinit	TSS
Units			mV		umhos/cm				mg/L		mg/L	mg/L CaCO3 eq.		mg/L
Location	A	B	A	B	A	B	A	B	A	B				
weir	6.2	6.4	122	303	1195	2040	4.1	20.9	18.4	19.2	45.8	165	182	95
2m	6.2	6.4	144	253	1050	2050	3.3	20.7	18.3	17.6	41.0	186	194	53
4m	6.2	6.4	120	236	1380	2390	4.9	20.6	22.7	21.5	29.2	231	232	29
6m	6.2	6.4	123	217	1495	2480	5.6	20.6	23.8	22.3	53.6	257	254	86
8m	6.2	6.3	123	221	1495	2480	5.8	20.6	24.9	22.3	54.7	264	256	78
10m	6.2	6.4	119	228	1520	2560	5.8	20.6	25.7	23.0	49.0	272	256	82
12m	6.2	6.6	120	225	1680	2450	5.8	20.9	21.1	23.0	59.8	267	240	101
14m	6.2	6.5	114	207	1780	2710	7.0	20.9	24.8	23.8	56.2	299	281	79
16m	6.2	6.6	113	220	1810	2860	7.0	20.7	26.9	23.8	70.9	309	292	101
18m	6.2	6.5	113	215	1805	2900	7.0	20.3	27.7	25.3	76.4	305	304	96
20m	6.2	6.5	108	227	1790	2860	6.9	20.5	28.1	26.1	188.0	282	283	42

A = Buchans
B = Boojum

Table 4: Total Suspended Solids Concentrations in the OWP and OEP Sampled in 1993

	OWP		OEP	
Date	Surface TSS, mg/L	Bottom TSS, mg/L	Surface TSS, mg/L	Bottom TSS, mg/L
10-Feb-93	0.2	0.1	1.6	14.0
09-Mar-93	3.2	0.5	21.3	18.3
06-Apr-93	16.9	0.3	57.9	0.2
17-Apr-93			94.9	42.2
03-May-93			24.3	24.3
16-May-93	34.7	11.2		

A detailed sampling campaign with depth was carried out in April at the centre of the pond. Zinc, acidity, and alkalinity were determined in water samples from every 2 meters. The results, presented in Figures 18 and 19, indicate that acidity is closely related to iron and zinc concentrations.

Fig. 18: OEP [Acidity] and [Fe]
April 17, 1993 Samples
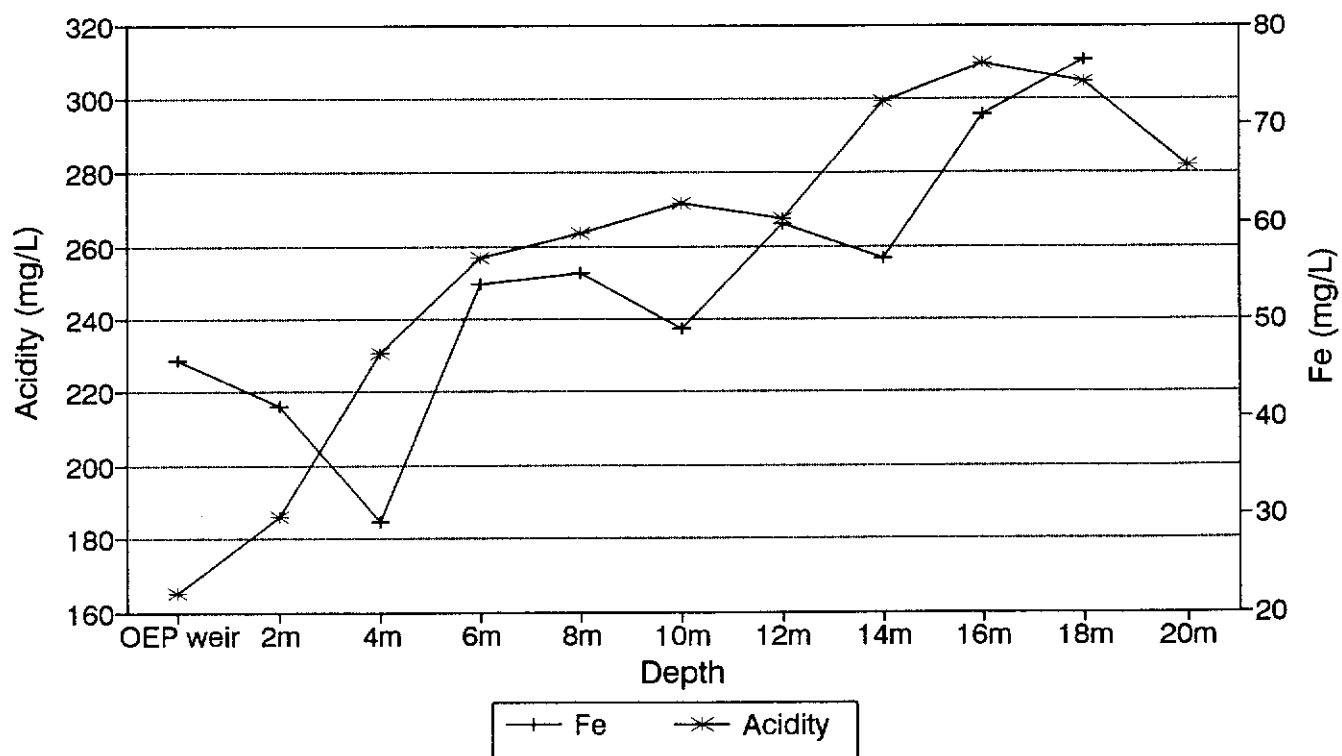
Fig. 19: OEP [Acidity] and [Zn]
April 17,1993 Samples
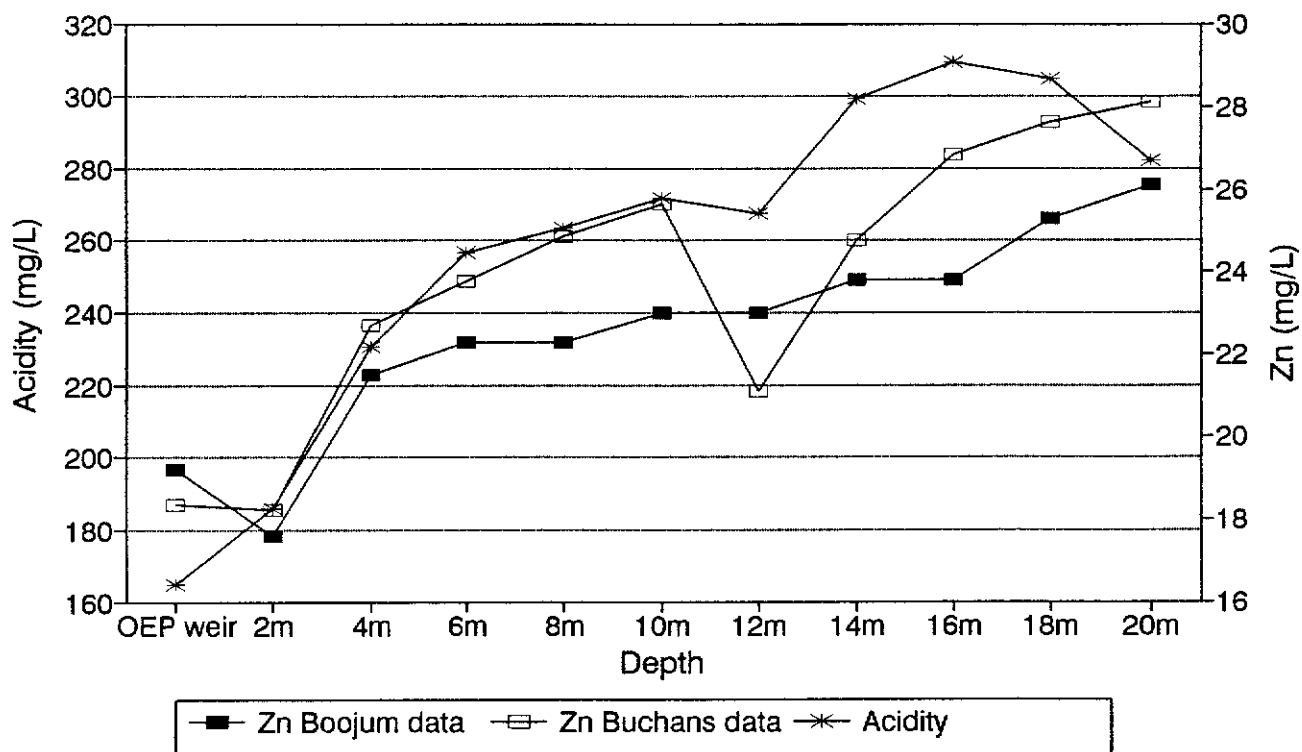
The changes in zinc and iron concentrations with depth are very similar to those noted for acidity with depth. The zinc concentrations determined by Boojum and Asarco are in relatively good agreement, given that zinc precipitation during shipment is expected; generally, 2 to 4 $mg.L^{-1}$ zinc have been removed as precipitate.

The concentrations of iron, zinc and acidity in the weir sample deviate from the relationships noted for the deeper samples. This can be expected, since iron oxidation is taking place between the last measurement at 2 m depth and the outflow water at the weir.

These relationships between acidity and metal concentrations are dictated by the chemical characteristics of the water. Water acidity consists of both proton ions and metal ions (Fe, Al, Cu, Mn, Zn, etc.). When minerals dissolve in acidic water, the acid radicals will form weak acids and consume proton ions, as follows:

$$MeS + H^+ = Me^{+2} + HS^-, \qquad MeS + 2H^+ = Me^{+2} + H_2S$$
$$MeCO_3 + H^+ = Me^{+2} + HCO_3^-, \quad MeS + 2H^+ = Me^{+2} + H_2CO_3$$
$$MeSiO_3 + H^+ = Me^{+2} + HSiO_3^-, \quad MeS + 2H^+ = Me^{+2} + H_2SiO_3$$
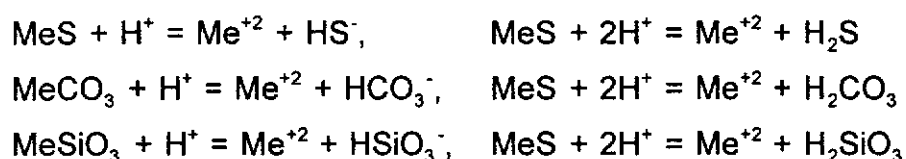
Hence, when these reactions occur, acidity and alkalinity concentrations can be expected to shift. Both acidity and alkalinity consistently decrease from the pond bottom to the surface (Table 3). The acidity or alkalinity values for a sample from a particular depth were subtracted from the corresponding value for the sample taken 2 m below. These changes in acidity and alkalinity with depth are plotted (Figure 20). When the acidity increased from a lower stratum to a higher one, the difference is positive. In this graph, changes in acidity and alkalinity are directly related. The co-relatedness of the metal concentration, acidity and alkalinity changes indicates that concentrations of these parameters are dictated by metal-bicarbonate precipitation processes.

Fig.20: OEP Acidity, Alkalinity Changes
April 17,1993 0 - 20 m Samples
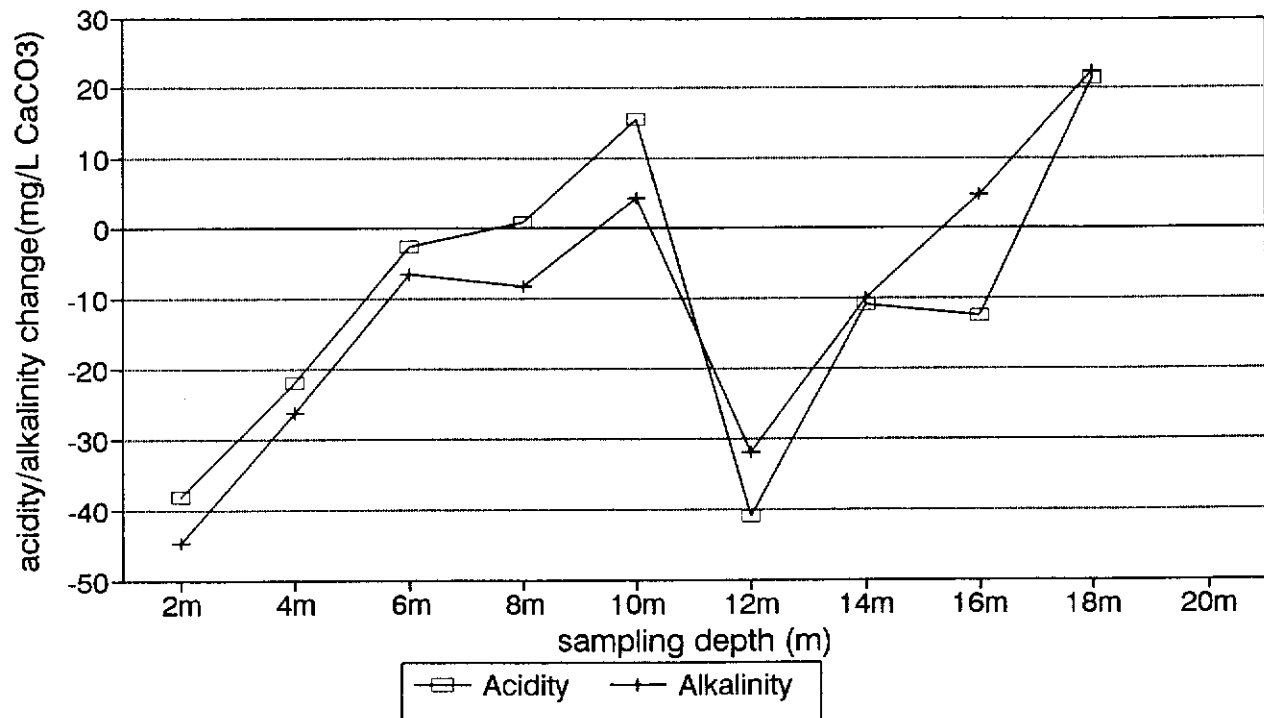
At a depth of 18 to 20 m, both acidity and alkalinity increased, indicative of incoming high carbonate water, and high iron and zinc concentrations. The concentrations of these parameters decreased as the water upwelled to shallower strata. Between 12 and 14 m, a large shift was noted, whereupon both acidity and alkalinity continued to consistently decrease with decreasing depth. At the 12 m depth, oxygen concentrations were also at their lowest value (0.3 mg.L^{-1}; Table 2), and the field Eh also slightly decreased at that depth. An oxygen concentration just above 0.3 mg.L^{-1} might represent the critical concentration at which iron hydroxide precipitation commences, proceeding all the way up to the surface.

The average zinc concentration change in the OEP with time and depth is plotted in Figure 21. Zinc concentrations in the whole pond have dropped consistently from 1988 to 1993. There is a zinc concentration gradient increasing from the bottom to the surface. The slopes of the gradient are very similar for years 1989, 1992 and 1993. The similarity in the slopes is probably due to similar iron precipitation rates (and

Fig.21: OEP Surface,Middle,Bottom [Zn]
1988-1993 Asarco Data
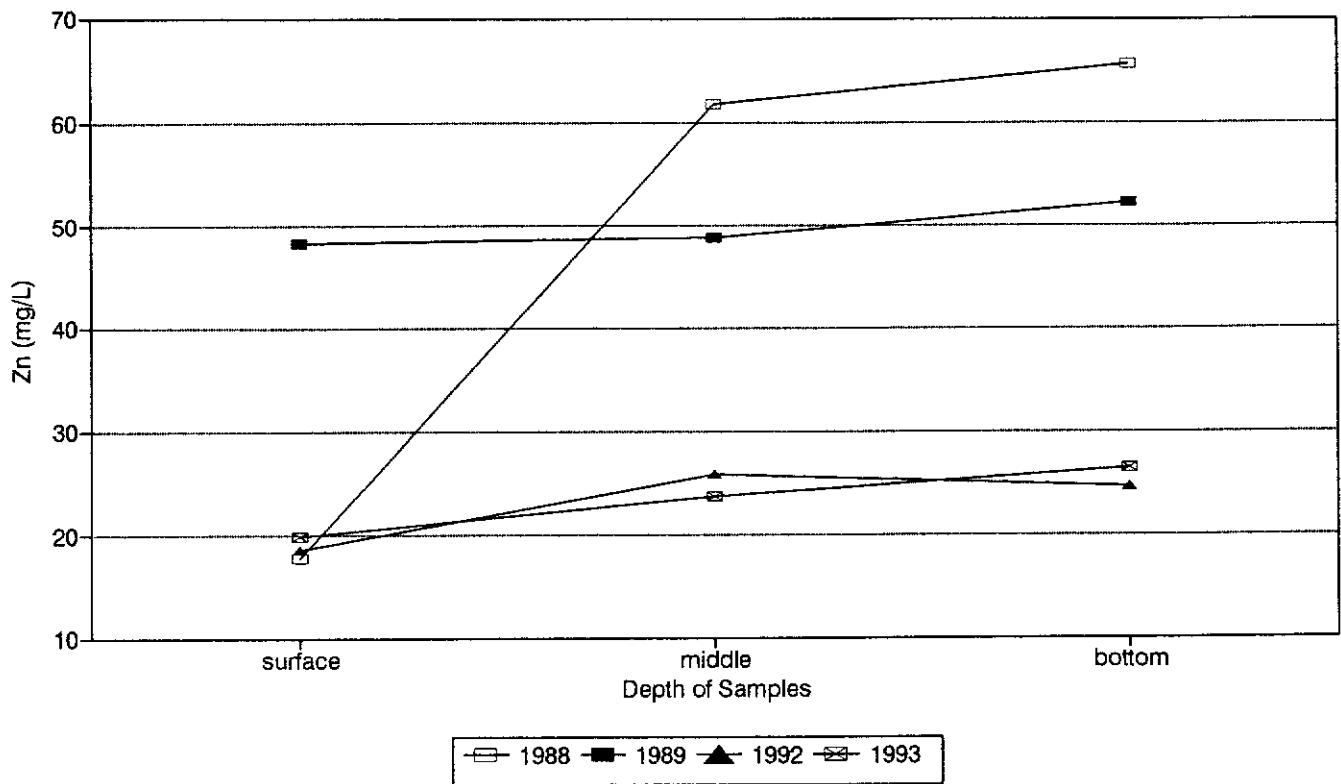
concomitantly similar zinc co-precipitation rates). The steeper slope in 1988 was likely due better oxygenation of the water as the pit was filling. This was followed by establishment of an annually recurring summer and winter thermocline, which controls, to a significant degree, the oxygenation of the pond. This thermocline breaks down in spring and fall, whereupon wind-driven mixing can occur (Figure 19, pg.20).

Sedimentation traps, positioned at 4 m and 11 m below the pond surface, collected the equivalent of 115 to 193 kg precipitate over the entire pond area per day between June 14 and August 30 in 1993 (Figure 22). In 1993, the amount of material which collected in bottom trap indicated sedimentation rates which exceed, by an order of magnitude, the rate suggested by the other two traps or any of the previous data. It is suspected that these high rates were caused by the construction activities which took place during

Fig. 22: Sedimentation Rates in OEP
For Periods Between Sep 20,90-Aug 30,93

High rate may have
been due to OWP-OEP
ditch construction

Legend:
- OEP 20 m A
- OEP 20 m B
- OEP Outflow 3m A
- OEP Outflow 3m B
- OEP 11 m
- OEP 4 m
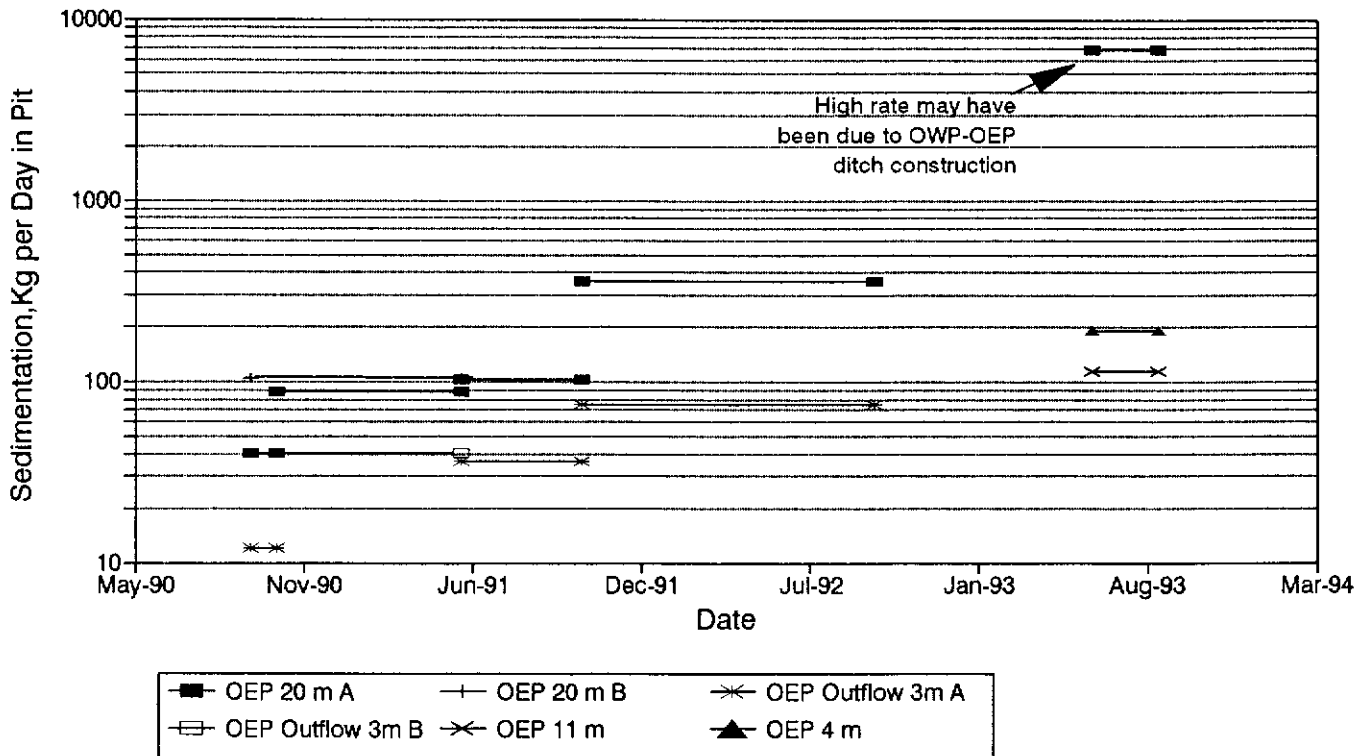
I993. As both gloryholes were connected, some debris may have been dislodged from the sides of the OEP filling the sedimentation trap at the bottom. Therefore, the data from the bottom trap are ignored.

Co-precipitation of zinc with iron hydroxide is evident from the elemental composition of precipitate which collects in sedimentation traps. The I991, zinc concentrations in the precipitates ranged from 2.7 % zinc (20 m trap depth) and 5.0 % zinc (3 m trap depth) in two OEP precipitate samples, which also containing 45 and 29 % iron, respectively. In I993, the concentrations of both elements are in the same range, with the exception that the bottom trap, which has received debris during construction activities, contained lower concentration of zinc (1.6 %).

Given these ranges of zinc and iron contents in sedimentation trap solids, and the measured sedimentation rates, 33 to 87 kg of iron, and 2.1 to 9.7 kg of zinc, are retained in the pond each day as settled precipitates.

The observed dissolved iron and zinc concentration decrease observed between the bottom and the outflow of OEP (for instance April 17, 1993; Table 3) can be used as another approach to estimating the amount of iron and zinc which precipitate and settle to the pond bottom. These estimates can then be compared with measured sedimentation rates. The results from these estimates, comparing water concentrations differences and the expected sedimentation rates are summarized in Table 5, and were calculated as follows.

The volume of the OEP is 188,500 m^3. On April 17, 1993, the bottom water contained 188 $mg.L^{-1}$ dissolved iron, and 28 $mg.L^{-1}$ dissolved zinc. On that same day, only 46 $mg.L^{-1}$ iron and 18 $mg.L^{-1}$ zinc were leaving in discharge water. Therefore, about 131 kg of iron and 9 kg of zinc were remaining in the pond as precipitates, settling to the bottom.

The settling rate, derived from the sedimentation trap data, compares well with estimates made by comparing bottom and outflow iron and zinc concentrations measured in the water on April 17, 1993. In summary, the proposed zinc removal mechanism through zinc co-precipitation of iron can be considered as confirmed.

Table 5: Measured concentration changes in Fe and Zn between OEP bottom and outflow April 17, 1993), estimated Fe and Zn sedimentation and measured sedimentation according to to Sedimentation Trap data.

Pit Volume	188,500	m^3
Outflow	10.7	L/sec (9 yr avg.)

	Iron	Precipitate	Zinc	
Bottom Diss. [ ]	188		28	mg/L (Apr. 17, 1993)
Outflow diss. [ ]	46		18	mg/L (Apr. 17, 1993)
Load from Groundwater	174		26	kg/day
Loss before Outflow	131		9	kg/day
Sed Trap Data		115 - 193		kg Precipitate/day (Jun 14-Aug 30/93)
Sedimentation	33 - 87*		1.8-9.7**	kg/day

* Iron in precipitate	1991 29 to 45 %	** Zinc in precipitate	1991 2.7 to 5.0 %
	1993 31 to 41 %		1993 2.3 to 1.6 %

4.0   HYDROLOGICAL MODIFICATIONS AND WATER MIXING EVALUATION

According to the compliance schedule, zinc loadings to the Buchans River must be reduced. Presently, zinc loadings arise from the Drainage Tunnel, from the Oriental East Pond via the First and Second Meadows, and from Tailings Ponds 1 and 2 via Simms Brook. During 1993, three major modifications have been completed or are under construction as part of addressing the reduction of zinc loadings from Drainage Tunnel and OEP discharge to the Buchans River.

Diversion of Drainage Tunnel Discharge to OWP: A pump has been installed at the portal, and a pipeline has been installed between the Drainage Tunnel Discharge and the Oriental West Pond (Plate 3). When pumping commences in spring 1994, zinc loadings from the original point of discharge in the Old Buchans area will be redirected to the OWP at a flow rate likely averaging 7.7 L.s^{-1} annually.

Plate 3:   Drainage Tunnel pipeline, Old Buchans, November 9, 1993.

Excavation of Ditch Between OWP and OEP: Excavation of the ditch and installation of a culvert was completed in 1993. OWP surface water can now freely flow overland, joining OEP surface waters. The first measurements during summer 1993 indicate that, to date, the flow rate is low $(1 - 2 \text{ L.s}^{-1})$.

Construction of Polishing Ponds: In fall 1992, construction of Polishing Pond 10 and addition of alder brush as substrate for algae was completed. In 1993, construction of Polishing Ponds 11, 12 and 13 were completed and addition of alder brush was recently completed (Plate 4).

Plate 4: Polishing Ponds 10 (foreground), 11, 12 and 13 (background), First Meadow, October 31, 1993.

Prior to the 1993 modifications, inadequate conditions, including insufficient residence times, were available for natural zinc removal mechanisms to reduce zinc concentrations in the Drainage Tunnel Discharge, OEP and the Meadows before discharge to the Buchans River.

While the residence time for Drainage Tunnel discharge will be increased, residence times for OWP and OEP will be reduced. In this new configuration, where Drainage Tunnel discharges passes through the OWP-OEP Polishing Pond system, the residence time of water in OWP will decrease from an estimated 202 days to 33 days, while the residence time of water in the OEP will decrease from 204 days to 119 days (Table 6). If the cumulative flow of Drainage Tunnel, OWP and OEP water were diverted through Polishing Ponds 10 through 13, the residence time of water in these ponds will be 1.7 days or less.

Table 6: Current and Projected Flows and Retention Times.

	Volume (m^3)	Current Avg Flow (L/s)	Current Retention Time (days)	Projected Cumulative Flow (L/s)	Projected Retention Time (days)
Drainage Tunnel		7.7		7.7	
OWP	26,200	1.5	202	9.2	33
OEP *	188,500	10.7	204	18.4	119
Polishing Pond 10	320	10.7	0.3	18.4	0.2
Polishing Pond 11	1,140	10.7	1.2	18.4	0.7
Polishing Pond 12	1,850	10.7	2.0	18.4	1.2
Polishing Pond 13	2,700	10.7	2.9	18.4	1.7

* 8 year average

With these changes, some considerations was given in 1993 to potential chemical changes which might be brought about due to the mixing of waters. These are discussed in the section below.

4.1   Mixing of OWP with OEP

Both experimental mixing, and geochemical simulations, suggest that there is sufficient buffering capacity in the OEP to maintain the pH of the OEP upon entry of OWP water (Figures 23a to Figure 23d).

Alkalinities and acidities of the mixtures are given in Table 7. If all of the OWP water (26,200 m^3) were displaced to the 1.3 m deep stratum of the OEP above the thermocline of the same volume (top 1.3 m, 26,200 m^3), then the mixing ratio would be 1:1 OWP:OEP. Changing the ratio between 1:1 and 1.5:1 produces only a very slight shift in acidity and alkalinity. After connection of the ponds, a flow of 1.5 L.s^{-1} between the OWP and the OEP has been reported. The effects of the mixing will, therefore, be slight.

The geochemical simulations suggest a decrease in the saturation indices for Al, Cu and Zn. This means that these metals are less likely to precipitate. The same simulations predict an increase in the likelihood that iron, magnesium and sulphate will precipitate (Appendix A). The mixing of the two water bodies is not likely to have a significant effect on zinc concentrations of the OEP effluent.   Increased iron precipitation will increase the amount of zinc which is removed by co-precipitation.

Table 7: Acidity and Alkalinity of OEP and OWP Waters and Mixtures

Mixing Ratio		Surface Acidity Surface Alkalinity mg/L CaCO3 equiv.		Mixing Ratio	Bottom Acidity Bottom Alkalinity mg/L CaCO3 equiv.	
OWP		85			85	
OEP		400	301		134	199
OWP : OEP	0.5 : 1	181	179	0.5 : 1	97	127
	1 : 1	127	116	1 : 1	89	87
	1.5 : 1	144	101	1.5 : 1	81	66
	2 : 1	123	71	2 : 1	85	50

Fig. 23a: OEP-OWP Mixtures, Acidity
March 9, 1993

Fig. 23a: OEP-OWP Mixtures, Acidity, March 9, 1993

Fig. 23b: OEP-OWP Mixtures, Alkalinity
March 9, 1993
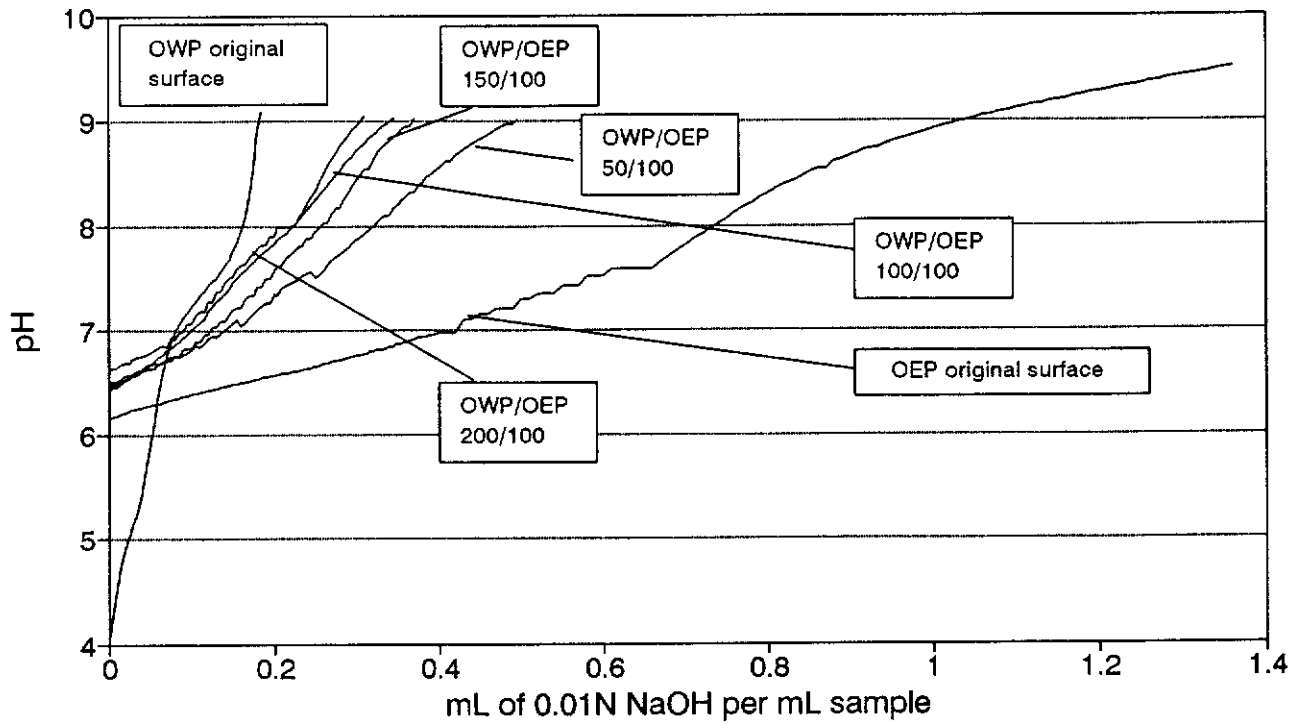
Fig. 23b: OEP-OWP Mixtures, Alkalinity, March 9, 1993
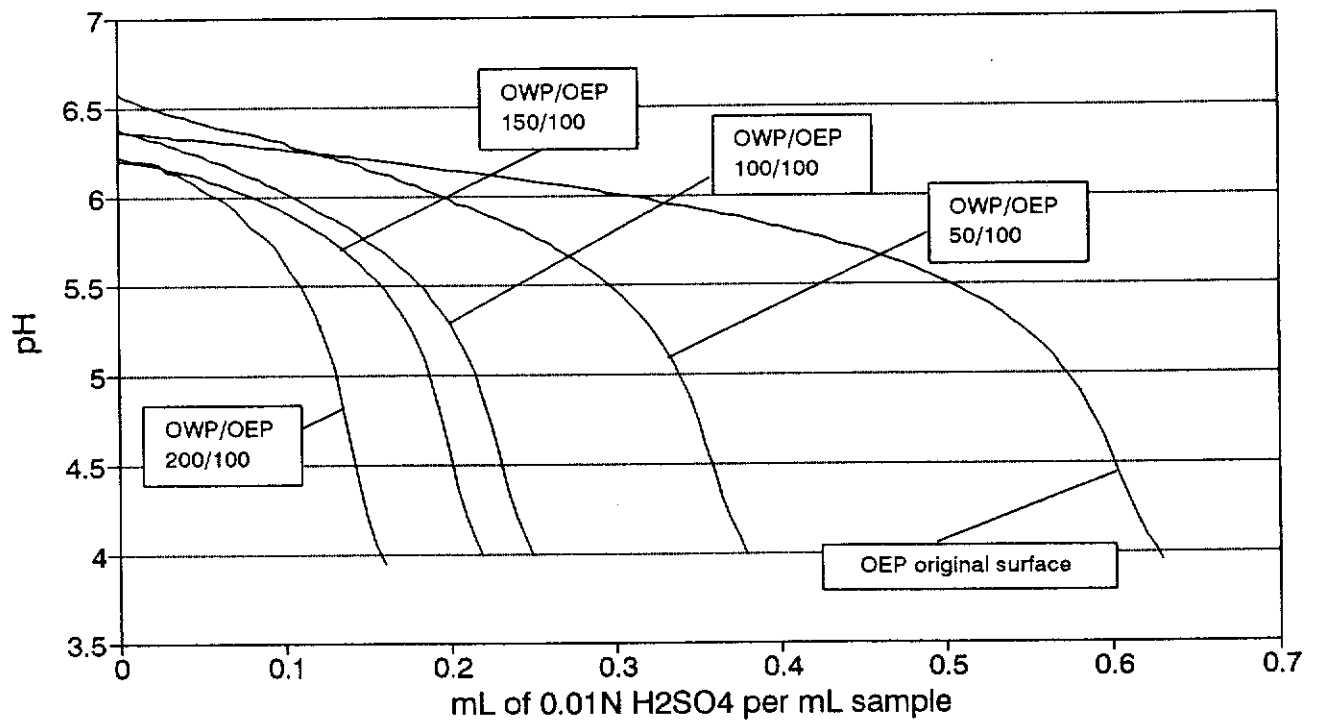
Fig. 23c: OEP-OWP Mixtures, Acidity
bottom water sampled on Mar.9,1993

OWP/OEP
150/100

OWP/OEP
200/100

OEP original

OWP/OEP
50/100

OWP/OEP
100/100

pH

mL of 0.01N NaOH per mL sample
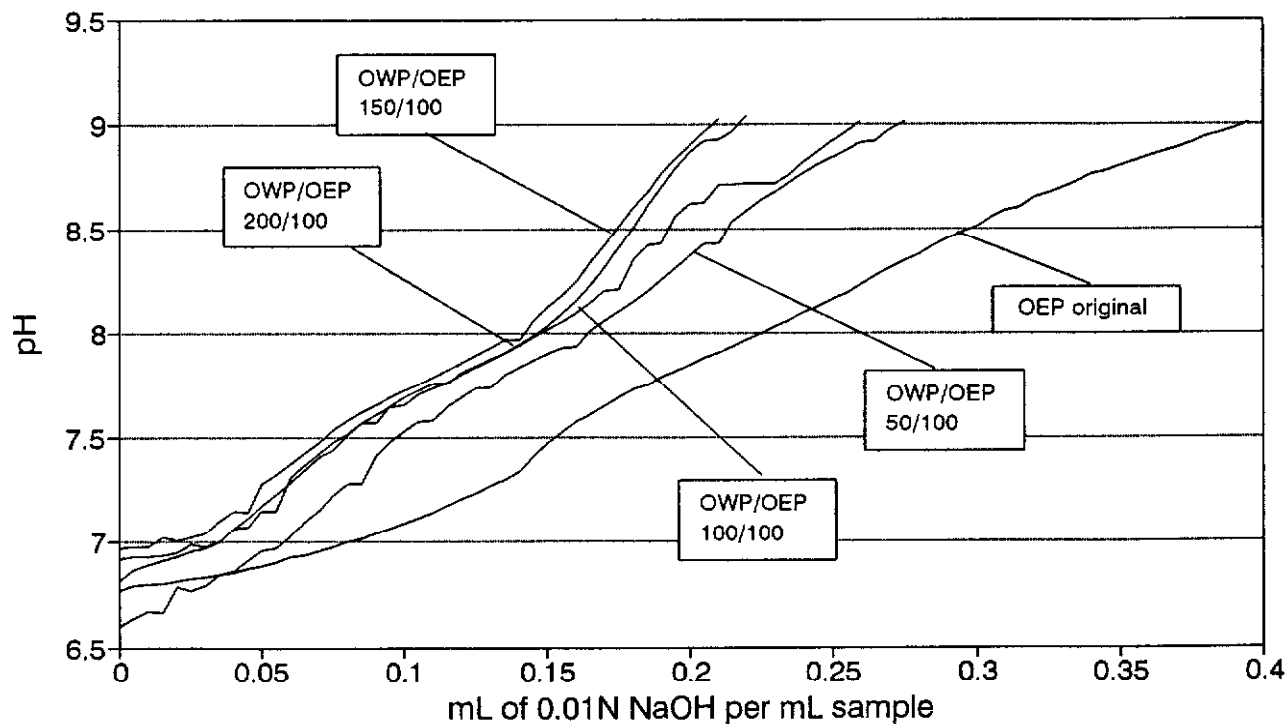
Fig. 23d: OEP-OWP Mixtures, Alkalinity
bottom water sampled on Mar.9,1993

OWP/OEP
100/100

OEP original

OWP/OEP
50/100

OWP/OEP
150/100

OWP/OEP
200/100

pH

mL of 0.01N H2SO4 per mL sample
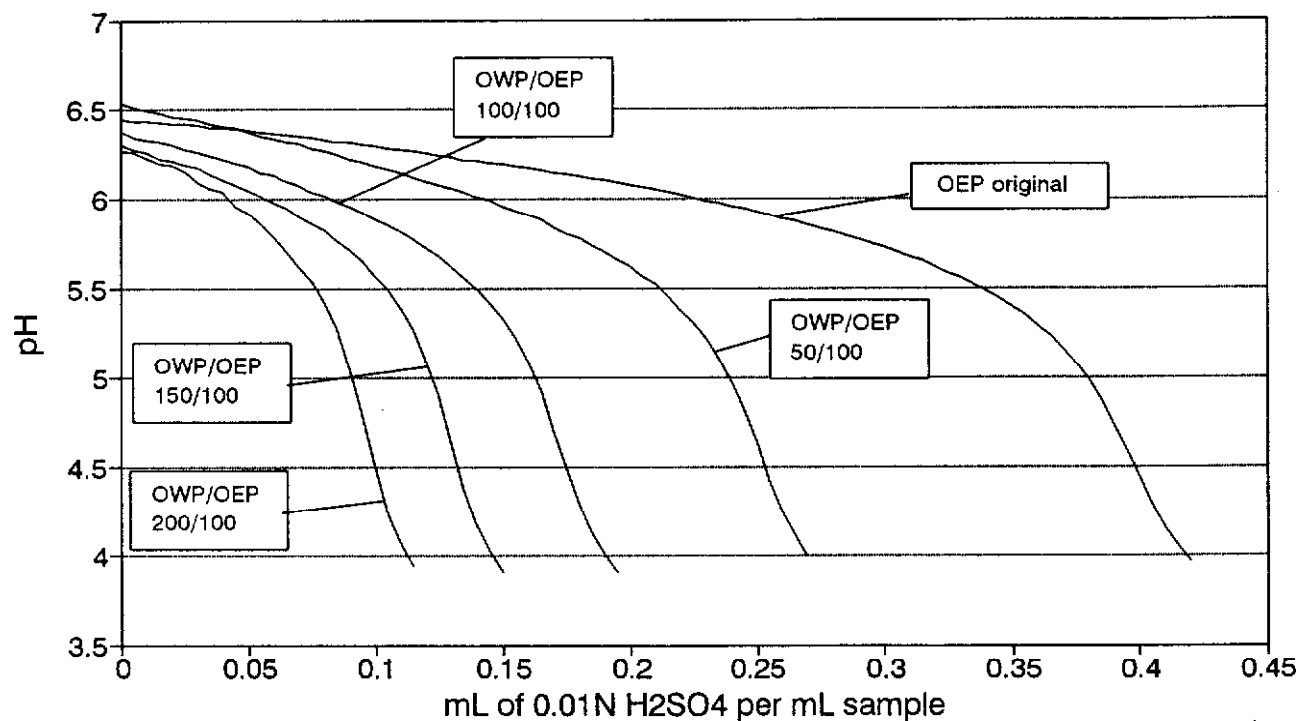
4.2   Mixing Drainage Tunnel with OWP

The bottom water of the OWP could be disturbed by the introduction of the Drainage Tunnel water. Therefore, it might be useful to consider the installation of a bottom sediment or, at least, to treat specific locations with higher metal concentrations, such as around Stn 22, with organic amendments. The installation of a sediment might be needed if the pit generated acid.

Measurements in the winter of 1993 indicate that the OWP pond is, for the most part, well oxygenated, with some oxygen depletion at a depth of 8 to 9 m. With the addition of Drainage Tunnel water, very little change in oxygenation is expected. However, as cautioned in the geochemical considerations provided in Appendix A, oxygen entrainment might enhance sulphide oxidation in the submerged pit walls and sediments, resulting in acid generation.

When the flow of Drainage Tunnel discharge into OWP commences, the flow rate from OWP to OEP will increase. It is estimated that the OWP water will be displaced within 33 days, assuming a flow from the Drainage Tunnel of 7.7 L.s^{-1}.

Once OWP water has been displaced with Drainage Tunnel water, it is unlikely that high metal concentrations currently found at the bottom of the pond will remain in place. At 9.2 L.s^{-1} (7.7 L.s^{-1} from Drainage Tunnel, + 1.5 L.s^{-1} OWP base flow), the pond water will be exchanged eleven times per year. However, it will be important to monitor the bottom metal concentrations trends carefully.

In order to assess what might be expected from the OWP sediments and the bottom water, the available information from the grid sampling in the OWP carried out for 4 winters is summarized in Schematics 1a, 1b and 1c. In Schematic 1a, the zinc concentrations are given for each sampling station. Stn 22 appears to have the highest concentrations at the bottom. Unfortunately, no data are available to determine the effects of the ARUM sediment behind the curtains.

Schematic 1a: Oriental West Pit Zinc Concentrations (mg/L), 1988 - 1993

N6400 · E11000 · E10900 · E10800 · E10700 · N6300 · N6200

BOOM # 2

BOOM #2

1
5.9 8.0 3.3 7.2
· · · ·

13

14
30.1 53.9 7.1 -
45.6 53.4 10.6 -

2

12
10.7 58.4 5.9 14.7
- 53.9 - -
26.5 59.0 13.9 30.0

15

18

3
15.1 53.8 3.3 29.0
- 55.6 - -
27.9 54.5 15.1 31.8

11

16
29.8 54.2 8.3 15.0
- 53.9 - -
35.0 53.5 12.3 36.9

19
28.4 51.2 5.1 17.4
- - - -
33.4 54.5 10.1 31.9

4

10
13.4 52.9 4.3 22.4 27.0
29.0 53.4 14.8 29.2 -
52.9 53.8 23.6 33.2 29.0

17

Surface
Middle
Bottom
Apr 13,1993

Surface
Middle
Bottom
Apr 6,03

20

5
0.2 54.3 13.6 -
27.3 59.4 16.4 -
58.7 67.2 17.7 -

9

22
39.1 52.6 13.1 21.5
- 53.7 12.6 42.7
59.1 63.1 19.2 60.0

Surface
Middle
Bottom
Apr 17,1991

21
30.5 58.7 5.2 12.2
40.5 53.5 11.2 30.4

6

8
11.4 53.3 9.0 25.2
- 53.5 - -
31.6 61.2 20.1 34.2

Surface
Middle
Bottom
Mar 13,1989

7
29.6 58.4 6.5 20.7
33.0 54.3 7.9 36.1

Mar 18,1988
Surface
Middle
Bottom

Schematic 1b: Oriental West Pit Copper Concentrations (ug/L), 1988 - 1993

N6400 E11000 N6300 E10900 N6200 E10800 E10700

BOOM # 2

BOOM #2

1   900 95 140

13

14   940 1595 430 / 1390 1950 370

12   368 1430 310 / - 1530 - / 780 1835 435

15

2

3   550 1535 160 / - 1560 - / 910 1510 450

11

16   895 1530 875 / - 1495 - / 1030 1545 490

18

19   1035 1550 170 / - - - / 1270 1680 280

4

10   470 1530 990 / 880 1530 490 / 1570 1435 665

17

20

5   370 1590 330 / 870 1535 415 / 1215 1565 460

9

22   1405 1565 350 / - 1580 480 / 1605 1530 585

21   1090 1565 295 / 1305 1565 270

6

8   590 1500 250 / - 1485 - / 1080 1595 535

7   1100 2145 990 / - - - / 1980 1630 880

Mar 18,1988   Mar 13,1989   Apr 17,1991

Surface   Surface   Surface
Middle   Middle   Middle
Bottom   Bottom   Bottom

N6400 N6300 N6200

E11000 E10900 E10800 E10700

1
555 600

13

14
804 · 692

BOOM # 2

2

12
1518 683
1500 683

15

18

3
1121 681
1807 713

11

16
804 681
814 769

19
1161 684
1807 696

4

10
764 687
797 696
517 993

17

20

5
804 691
848 703
847 1008

9

22
750 693
793 719
797 1195

21
1111 698
1164 683

6

8
938 697
948 742

7
1000 ·
1094 ·

BOOM #2

Apr 17,1991
Surface
Middle
Bottom

Apr 13, 1993
Surface
Middle
Bottom

While differences in zinc concentrations were noted for Stn 22, this was not the case for copper concentrations (Schematic 1b). Copper concentrations were generally higher at the bottom but, by 1991, all locations showed concentrations in the range of 500 μg.L^{-1}, with the exception of some stations around the edge of the pit, where copper concentrations were lower (Stns 21, 19, 1 and 7). The conductivity measurements available for the grid are summarized for completeness (Schematic 1c), but differences between bottom and top are not pronounced. The zinc and copper concentration distributions and conductivities support the suggestion that no additional contaminants are generated in the OWP. Through annual dilution, the pond concentrations drop by about 5 mg.L^{-1} per year.

In 1993, TSS values were determined for both the OEP and the OWP (Table 4). The large increase in TSS in the surface samples from both ponds collected in April and May suggest a second mechanism of zinc removal, namely adsorption onto the surfaces of suspended solid particles. The upper half of the OWP volume had a TSS loading of about 0.56 t in April, which had likely settled to the pond bottom by May. In mid-May, the upper half of the pond had received an additional tonne of TSS. These quantities could have provided a significant surface area for zinc adsorption.

4.2.1 Potential acid generation of OWP sediments

Sediment and water samples were collected in August 1993 from Oriental West Pond at Stns 8, 9, 11, 12 and 18. Bottom water samples were collected from Stns 23 and 13. The bottom water and sediment supernatant water samples were titrated for their acidity. The titration curves are shown in Figure 24a and 24b. The pH, conductivity and Em values were measured for all these samples. A comparison of the field data and lab data, collected three days later, are listed in Table 8a.

The sediment samples were covered by the original supernatant water and sealed in bottles in the lab at room temperature. In October, pH was measured again for both

Fig. 24a: OWP Sed. H2O Titration Curve
August 29, 1993
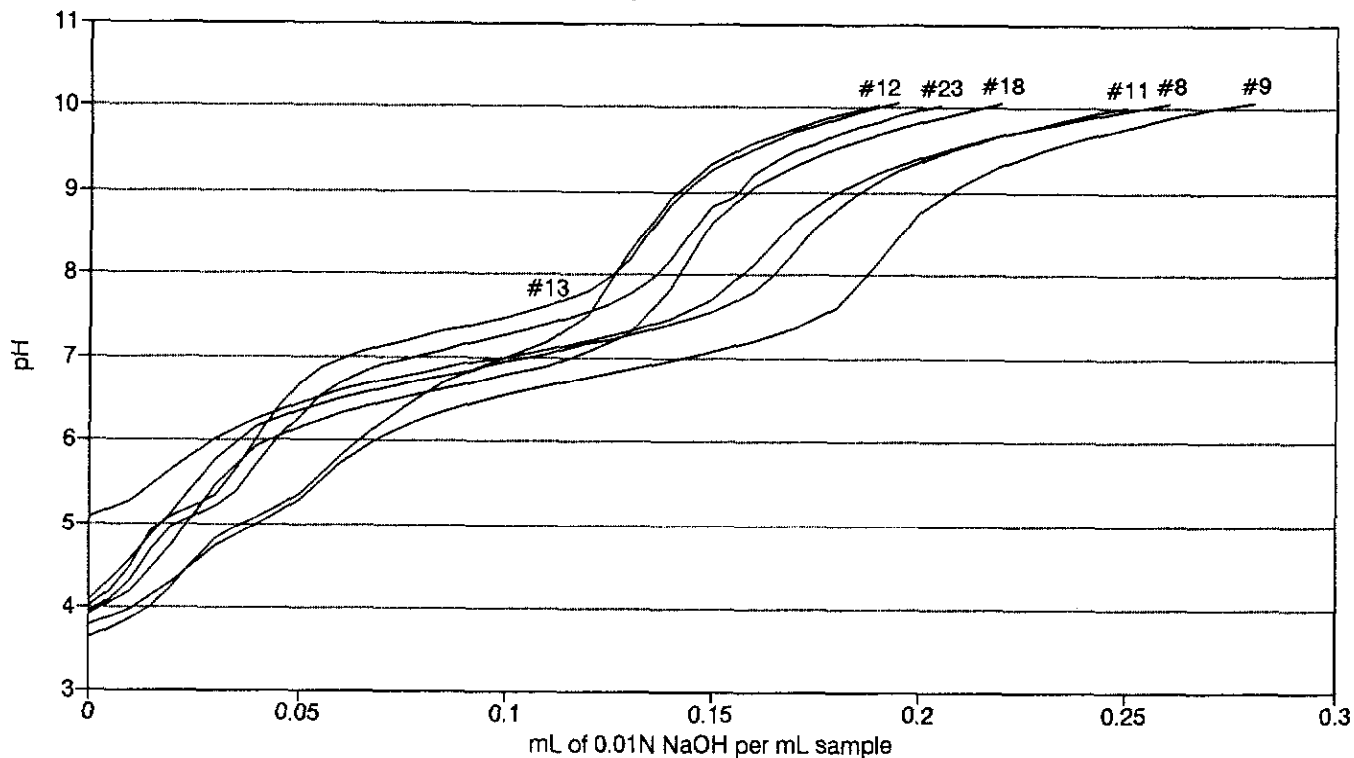
Fig. 24b: OWP Sed. H2O Titration Curve
December 6, 1993
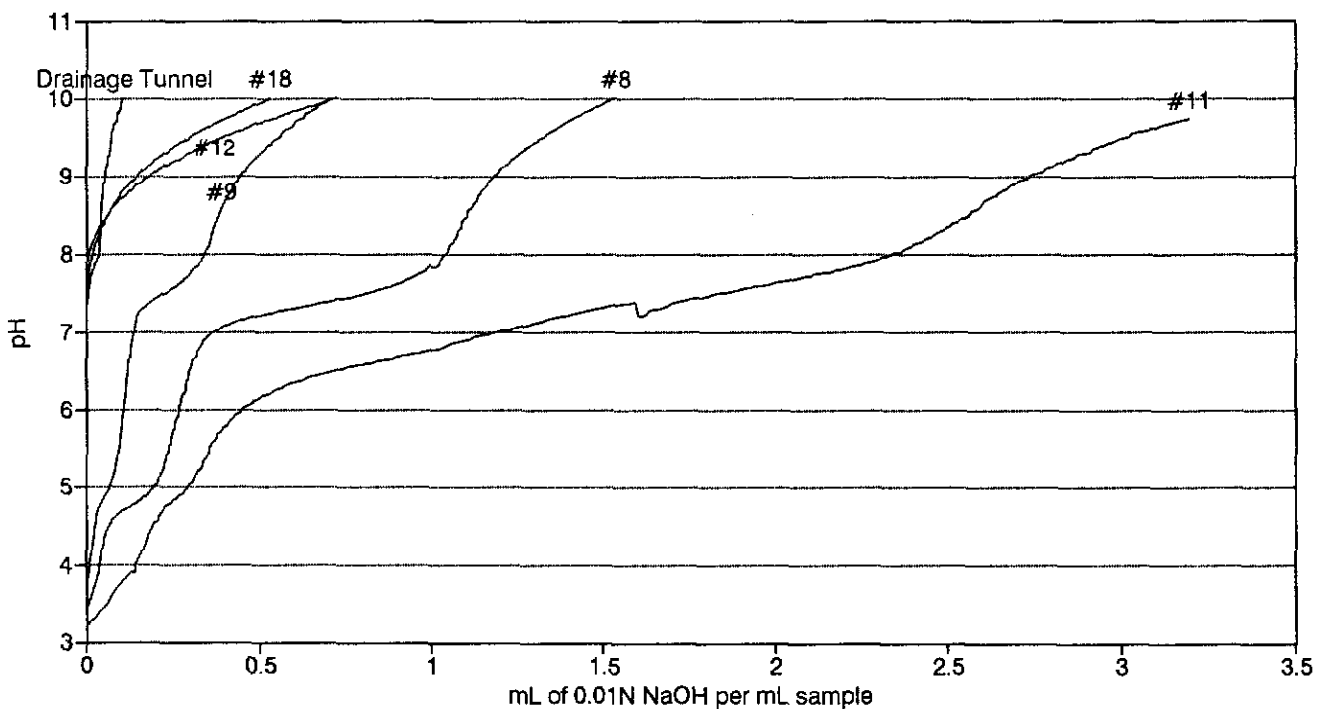
Table 8a: OWP sediment and water chemistry in the field and in the lab.

Sampling Grid Number and Stratum (see Schem. 1 for Locations)	Field Data				Laboratory Data			
	Aug-30-93				Sep-02-93			
	pH	Cond. (uS/cm)	Em (mV)	Temp. (C)	pH	Cond. (uS/cm)	Em (mV)	Acidity mg/L
#8 Water + Sediment	3.80	520	250	19.7	3.75	520	394	81.8
#9 Water + Sediment	4.08	520	183	19.6	3.76	520	424	96.2
#11 Water + Sediment	3.98	456	255	19.6	3.71	456	443	85.2
#12 Water + Sediment	4.20	418	221	19.8	4.25	418	371	65.2
#18 Water + Sediment	5.10	433	209	19.4	3.81	433	351	73
#23 Bottom Water Only	3.85	440	332	19.4	3.87	440	417	70.9
#13 Bottom Water Only	4.00	423	288	19.5	3.97	423	405	65.9

Table 8b: OWP sediment with Drainage Tunnel water

Sampling Grid Number and Stratum (see Schem. 1 for Locations)	Sediment with Original Water								Sediment with Drainage Tunnel Water					
	Oct-22-93		Dec-06-93						Dec-10-93			Dec-14-93		
	pH Sed	pH Water	pH	Cond. (uS/cm)	Em (mV)	[Fe] mg/L	[Zn] mg/L	Acidity mg/L	pH	Cond. (uS/cm)	Em (mV)	pH	[Fe] mg/L	[Zn] mg/L
#8 Water + Sediment	3.98	3.91	3.42	1745	312	0.09	457	538	3.54	748	295	3.59	0.11	199
#9 Water + Sediment	3.85	4.01	3.59	1064	267	1.03	37.9	181	3.76	492	312	3.84	0.03	37.9
#11 Water + Sediment	3.68	3.58	3.27	2570	315	499	53.8	1240	3.06	909	433	3.04	16.8	28
#12 Water + Sediment	5.85	5.56	6.74	700	-196	7.2	0.53	15.9	6.17	451	127	6.65	0.16	0.47
#18 Water + Sediment	6.05	5.87	6.67	463	-135	34.9	0.11	19.9	6.11	358	41	6.64	1.93	1.05
Drainage Tunnel Water			5.73	337	48	<D.L.	21.7	19.9						

the supernatant and the sediments. On December 6, the supernatant of sediments were measured again. The supernatant was then decanted out. Drainage Tunnel water (200 mL for Stns 8, 9 and 18; 150 mL for Stns 11 and 12) was transferred to the bottles without disturbing the sediments. Four days later, assuming new equilibrium of the systems were achieved, some measurements were made. All data are shown in Table 8b.

Comparing the measurements of the supernatant, before it was replaced with Drainage Tunnel water (Table 8a and Table 8b), pH values for Stns 8, 9 and 11 sediments were essentially the same, while Em values had decreased slightly. However, the conductivities had substantially increased. This indicates that some minerals had been dissolved from the solid sediments to the supernatant during the three month period at laboratory temperature in sealed (not exposed to oxygen) bottles. The increased acidities are mainly due to iron and zinc, as can be derived from the Figure 24b.

For Stns 12 and 18 sediments, the water pH had increased to about pH 6. Em values had dropped to below zero. Although the conductivities slightly increased, the acidities fell to about 20 mg.L^{-1}. The acidity decreases were likely caused by microbial reducing activities.

Two days following exchange of the supernatant with Drainage Tunnel water, the water pH had only slightly changed, while Em had slightly increased. Conductivities were generally lower than the old supernatant but higher than the Drainage Tunnel water. This indicated that minerals in the sediments dissolved into water to build up a new equilibrium system. However, the individual Fe and Zn measurements indicated that, in both samples, iron and zinc concentrations had decreased with the addition of Drainage Tunnel water (Figure 25a and 25b). It can be concluded that, although acid generation potential exists in some of the material from the OWP sediments, this source is not of major concern in the long term.

Fig 25a: Iron Concentration in Supernatant over OWP Sediment
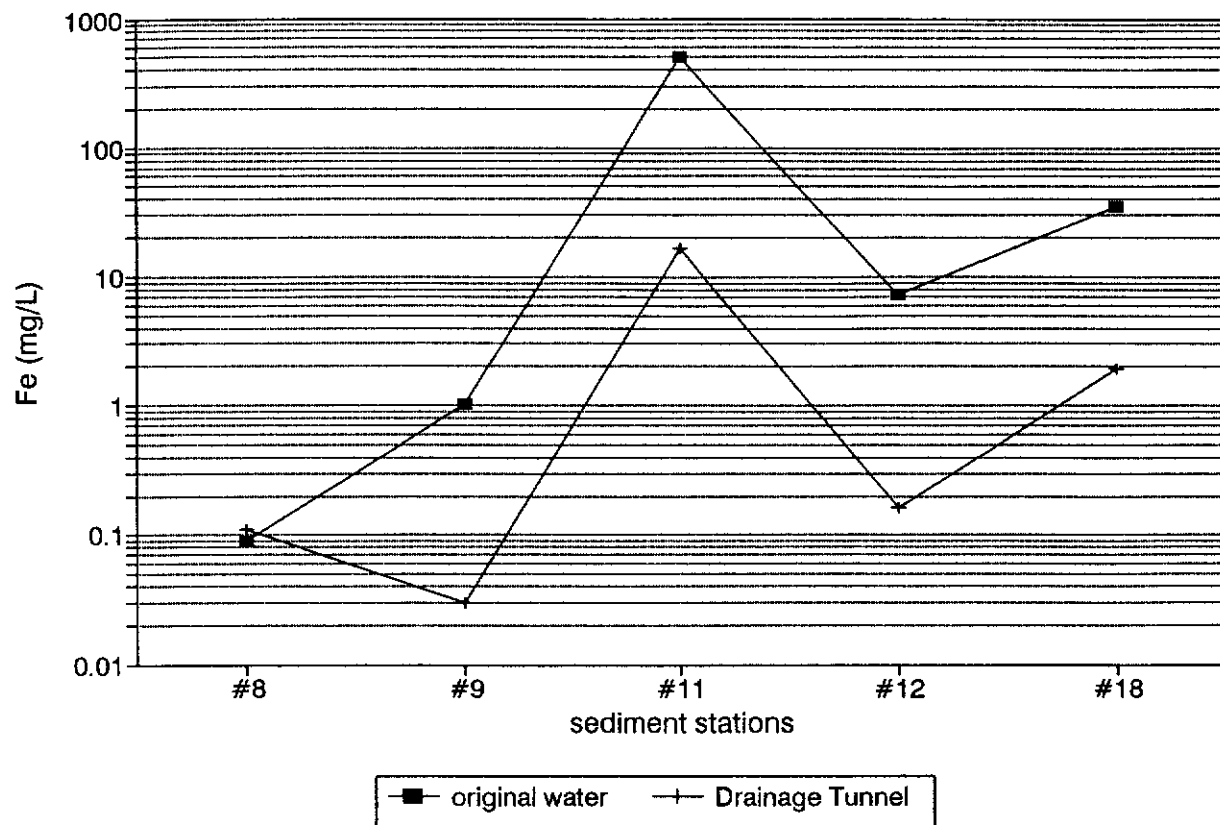
Fig. 25b: Zinc Concentration in Supernatant over OWP Sediment
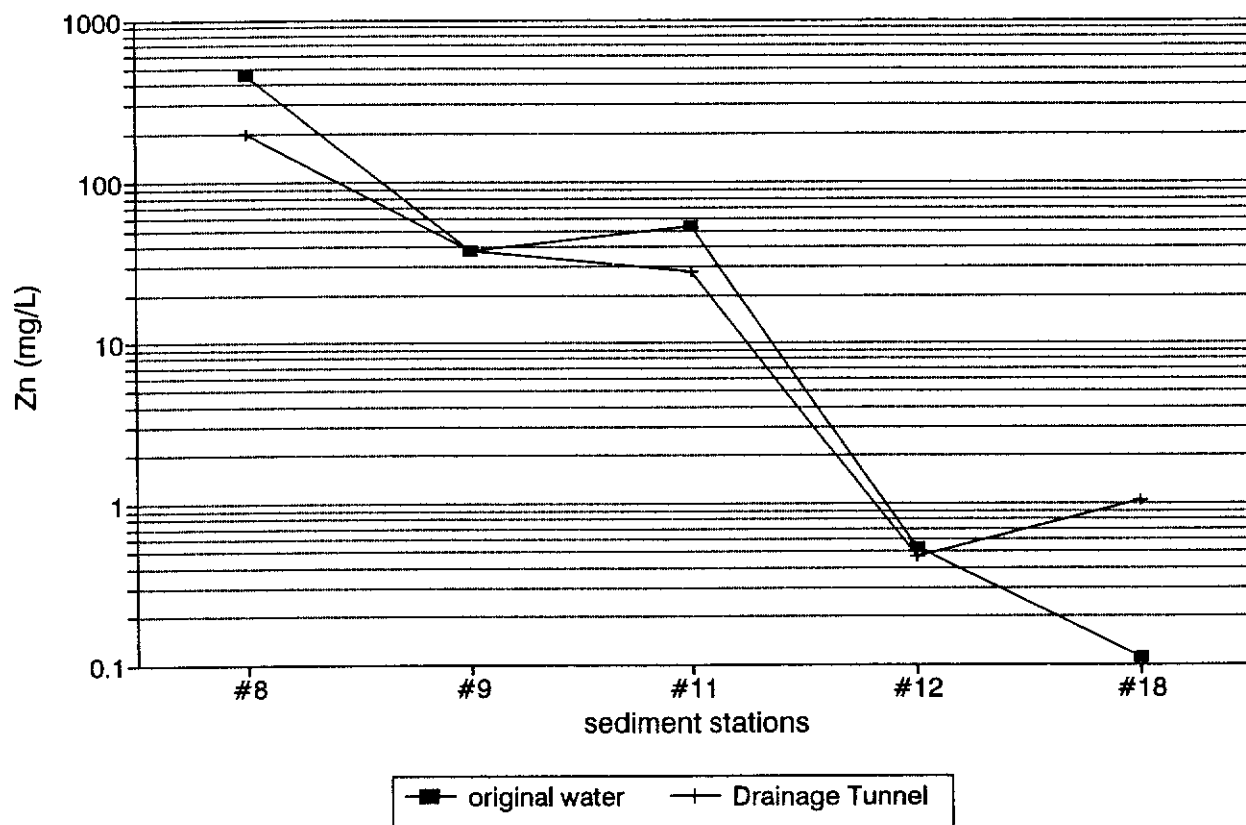
Considering all the information, the most appropriate location to introduce Drainage Tunnel water to the Orientals is in the OWP. Within a period of 3 to 4 months, the OWP water chemistry will be primarily that of the Drainage Tunnel water, if acid generation is not, in fact, occurring within the pit. The specific discharge point to the OWP is probably dictated by construction limitations. If it is assumed that no acid generation is occurring in the pit, then there is no preferred location for Drainage Tunnel water discharge. However, in order to remain on the cautious side, Drainage Tunnel water should be introduced at a depth of about 3 to 4 m, as far away as possible from the connection between OWP and OEP. This should minimize short-circuiting, maximizing the retention time of Drainage Tunnel water in the OWP.

In principle, once the OWP volume has be replaced with Drainage Tunnel water, its water characteristics will be that of the Drainage Tunnel water, a solution amenable to supporting biological polishing by algae. Substrate for algal growth should be installed, since the contaminant concentrations in Drainage Tunnel water are not likely to greatly diminish in the long term.

4.3 Mixing Drainage Tunnel with OEP

The data summarized above suggest that if Drainage Tunnel water is introduced to the OEP, it should be diverted to the bottom of the OEP water column, in order to introduce oxygen, and initiate precipitation reactions as deep in water column as possible. Expansion of the precipitation zone throughout a much larger volume of the OEP is particularly important, since the added flow volume from the Drainage Tunnel will significantly shorten the retention time of water in the OEP, the time when these precipitation reactions must occur in the OEP.

Should Drainage Tunnel water be discharged into the bottom of OEP via a pipe, then a brief review of the distribution of the zinc concentrations in the pond is warranted. In Schematic 2, the results of the grid samples collected in 1988, 1989, 1992 and 1993 are summarized for surface, middle and bottom samples. While the bottom zinc

N6700 18   19   20
8.1 48.1 16.0 22.8
60.6 87.4 24.0 25.9

N6600 17   16   15   14
7.4 47.8 17.5 15.8   4.9 47.5 19.6 17.9
- 48.2 25.0 21.7   55.4 48.3 19.9 20.6
59.1 47.9 11.1 25.0

N6500 10   11   12   13
5.5 48.0 21.9 15.3   4.3 47.8 13.7 24.3 17.4 18.95   4.6 48.5 15.1 24.1
57.3 48.3 25.3 26.2   57.5 48.4 26.6 - 22.9 25.7   - 47.2 22.0 23.3
60.5 49.6 25.8 27.7   71.6 53.6 29.9 29.8 27.8 28.1   71.3 47.3 26.7 22.2

N6400 9   8   7   6
6.2 47.6 19.7 19.2   7.5 47.9 21.3 22.1
64.2 46.9 26.7 24.7   60.1 49.4 26.5 21.4
71.0 56.8 26.4 30.4   75.0 57.8 26.2 30.2

N6300 3   4   5
6.0 49.2 24.0 21.8   27.8 49.4 16.8 20.3
59.9 50.3 27.7 24.8   66.2 50.6 27.0 24.3
65.2 57.9 30.6 30.3   75.0 57.8 26.6 30.2

N6200 2   1
16.1   18.8
-       24.2
25.1   24.7

Mar 16,88 Mar 10, 89 Apr 16,92 Apr 6, 93 Apr 12,93 Apr 17,93
Surface Surface Surface Surface Surface Surface
Middle   Middle   Middle   Middle   Middle   Middle
Bottom   Bottom   Bottom   Bottom   Bottom   Bottom

N6100

E11600 E11700 E11800 E11900 E12000

concentrations have decreased over the years, bottom samples have typically contained higher concentrations of zinc than surface water samples.

The zinc concentration distribution in the OEP on April 12, 1993 is plotted in Figure 26. Lower zinc concentrations at the bottom are noted at Stns 8, 13 and 14. This may have been due either to groundwater input (Stn 8), or the shallow nature of Stns 13 and 14. At all other locations in the pit, bottom water samples contained higher zinc concentrations than the corresponding surface water samples.

Fig. 26: OEP [Zn] with Depth
Asarco data (April 12,1993)
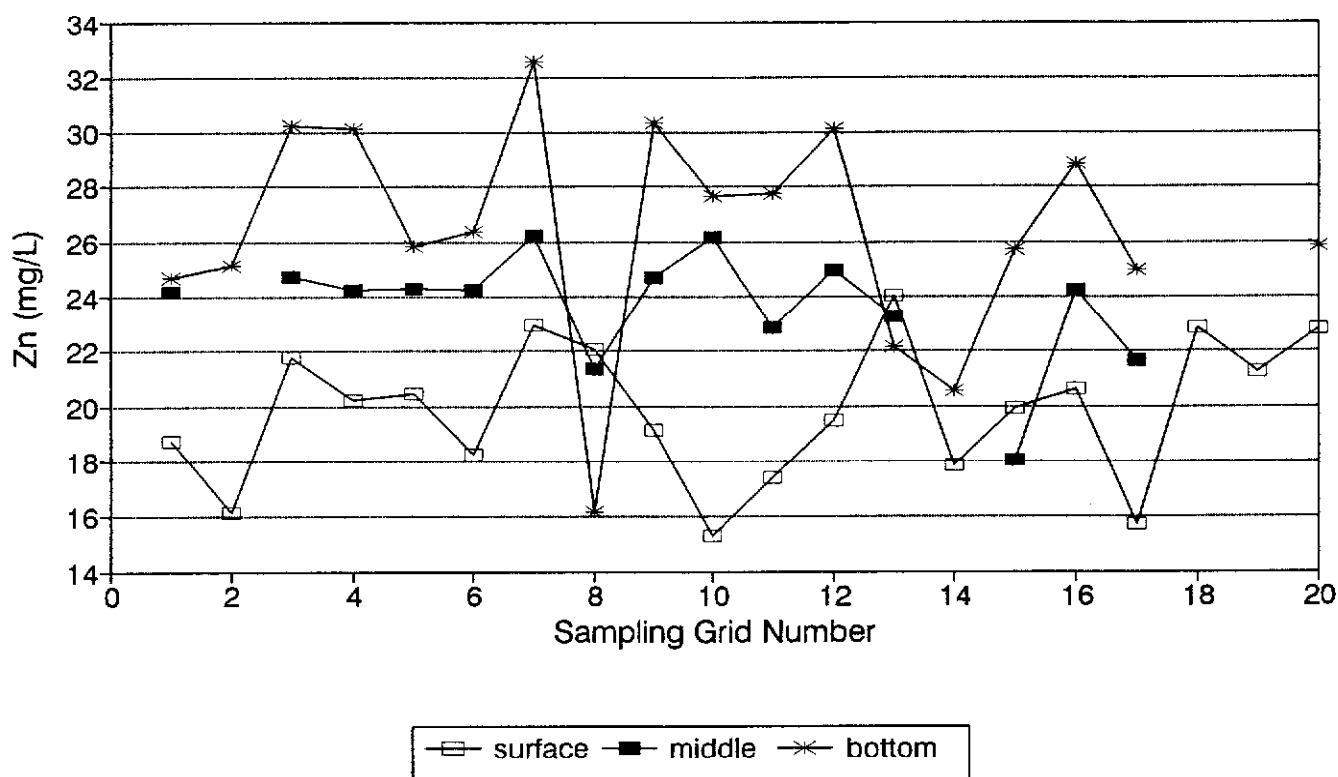
Because the Drainage Tunnel water contains very little iron, it will serve to dilute the iron content in the OEP (Appendix A). This expected decrease in iron concentration in the OEP could have an overall effect on zinc concentrations, but this effect is difficult to estimate. However, it can be projected with some confidence that dilution by the Drainage Tunnel, combined with increased oxygen input carried by Drainage Tunnel water to the bottom of OEP, will lower iron concentrations at OEP outflow.

The ultimate goal of this project is to reduce the zinc concentrations leaving the OEP. Thus, it is recommended that the introduction of Drainage Tunnel water to the OEP be implemented in stages. First, the introduction of OWP water to the OEP must be assessed. Then, before the Drainage Tunnel water is introduced to the bottom of the OEP, its introduction to the OWP and the surface of the OEP must be assessed.

5.0 BIOLOGICAL POLISHING OF OEP EFFLUENT

In 1989, six ponds were constructed in series through which a fraction of the OEP discharge was directed. Brush was placed as a growth substrate for the algae, and performance (% zinc removal per day retention time) of the system was derived. Fertilizer was found to increase growth and hence, improve the zinc removal.

The summer season of 1993 represented the fourth year when samples could be collected so to describe the biological polishing capacity of the system. The biological processes which are playing a role in the treatment system have been elucidated through joint research projects over the last three years with CANMET Biotechnology.

The mechanisms responsible for the observed zinc removal have been identified to involve: 1) settling of zinc-bearing suspended solids in OEP discharge; 2) adhesion of suspended solids onto algal biomass surfaces; 3) adsorption of dissolved zinc onto algal cell walls; and 4) photosynthetically induced pH increases, with subsequent precipitation of zinc carbonates.

Given these different mechanisms which all take place at the same time, the evaluation of process performance of the polishing pools is very complex. Numerous physical, chemical and biological variables are involved. Two approaches have been selected in order to arrive at the key operating parameters.

The first approach examined the overall performance of experimental pools 1 through 6, in terms of zinc removal according to flow rates and residence times. Assuming that the same physical, chemical and biological processes will operate in a scaled-up Biological Polishing system, the required dimensions and the expected performance can be estimated.

The second approach used to determine the performance assessed the algal growth rate data and biomass zinc concentration data. These values can be used to estimate

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removal rates by the algal population for comparison with zinc loadings.

The two approaches assume that performance of the process is either purely a function of retention time (First Approach), or only biological in nature (Second Approach), neither of which being exclusively the case. Thus, it is not surprising, when percent zinc removal is calculated for the newly constructed scaled-up ponds, to find some zinc removal is taking place, despite extremely low retention time of 1 to 2 days and low algal biomass to date. The model considerations indicated a minimum retention time required was 14 days for 68 % zinc removal (CANMET Model I992). As shown in Table 9, the data of the new scaled-up Polishing Ponds report, in some cases, as much as a 27 % zinc decrease even though the retention time was less than 3 days.

Table 9: Polishing Ponds 11, 12 and 13 1993 (preliminary) performance.

Date	Polishing Pond	Flow USGPM	Flow L/s	Inflow [Zn]	[Zn], mg/L In outflow	[Zn], mg/L decrease	% [Zn] Decrease	Volume (m3)	Retention Time, days
23-Oct-93	11	180	11.36	19.15	17.3	1.85	9.7%	1138	1.16
	12	180	11.36	17.3	15.45	1.85	10.7%	1848	1.88
	13	180	11.36	15.45	11.25	4.2	27.2%	2693	2.74
30-Oct-93	11	220	13.88	22.85	18.855	3.995	17.5%	1138	0.95
	12	220	13.88	18.86	17.25	1.605	8.5%	1848	1.54
	13	220	13.88	17.25	12.6	4.65	27.0%	2693	2.25
08-Nov-93	11	230	14.51	19.5	18.95	0.55	2.8%	1138	0.91
	12	230	14.51	18.95	17	1.95	10.3%	1848	1.47
	13	230	14.51	17	15.45	1.55	9.1%	2693	2.15
14-Nov-93	11	200	12.62	19.65	18.8	0.85	4.3%	1138	1.04
	12	200	12.62	18.8	18.05	0.75	4.0%	1848	1.70
	13	200	12.62	18.05	16.95	1.1	6.1%	2693	2.47
21-Nov-93	11	225	14.20	18.45	16.355	2.095	11.4%	1138	0.93
	12	225	14.20	16.36	17.3	-0.945	-5.8%	1848	1.51
	13	225	14.20	17.32	17.65	-0.33	-1.9%	2693	2.20
28-Nov-93	11	150	9.46	20.25	19.8	0.45	2.2%	1138	1.39
	12	150	9.46	19.8	20.15	-0.35	-1.8%	1848	2.26
	13	150	9.46	20.15	19.25	0.9	4.5%	2693	3.29

Construction of Polishing Ponds 11, 12 and 13 was completed only in late fall, 1993. Alder brush, provided as a substrate for algal growth, was then placed on top of the ice cover in November, 1993. Since all of the OEP discharge has been passing through Polishing Ponds 10 through 13 (9.5 to 14.5 L.s^{-1}), retention times are very low in each cell, ranging from 0.91 to 3.29 days (Table 9). Adsorption of zinc onto any organics in the ponds is certainly an additional process which assists in the zinc decreases, independent of the biological polishing.

5.1 Overall Performance of Polishing Ponds 1 Through 6

Zinc removal from water upon passage through the experimental pools 1 through 6 has been observed almost without fail since 1989, the year in which the pools were constructed (Figure 27). Using all data collected to date, the percentage zinc removal in the pools plotted against residence time (in days) of water passing through the system reveals one of the design criteria used during scale-up of Polishing Pond 10.

From a regression analysis using all data, a zinc concentration decrease of 2.2 % with each additional day of residence time can be expected. To achieve 100 % zinc removal, a projected residence time of 45 days would be required. For this series of small experimental pools, this retention time is achieved if the inflow is maintained at 0.06 L.s^{-1}. Scaling-up to Polishing Pond 10, using retention time as an operating parameter, one would expect 100 % zinc removal with a flow of 0.08 L.s^{-1}.

In Figure 27, each data point is differentiated according to year and month (e.g. Jn = June). Data for 1989, the first year of test system operation, are included in the calculation of the regression line, the year when zinc removal was due, essentially, to only those non-biological processes limited by retention time. Virtually no algal growth was noted in this year, as algal growth had not been induced by addition of fertilizer. Therefore, it can be argued that percent zinc concentration decreases very close to the regression line reflect those periods when non-biological processes alone were responsible for zinc removal.

However, many data points in the years following 1989 fall well above the regression line. These periods of exceptionally good performance typically occur in the summer months, when the algal population was actively growing. In contrast, the many data points below the regression line are mostly November and December data, when temperature is close to 0° C and algal growth rates are very low. If the observations of peak summer performance are attributed to algal growth and uptake, a second regression line using the top 8 performance period data can be proposed, given in Figure 27. The slope of this new regression line is such that, for every day of retention time, zinc concentrations decrease by 5.2 %.

Fig. 27: % [Zn] Decrease between PP1
and PP6, Versus Retention Time in Days

Top 8 Performance Dates; % [Zn]
Decrease = 5.2 %*R.T. in days, p<0.01

All Data, 1989 - 1993; % [Zn]
Decrease=2.2%*R.T. in days,p<0.01

| ■ | 1989 | + | 1990 | ✳ | 1991 |
| ☐ | 1992 | × | 1993 | | |

Relating process performance of the ponds to scale-up, it can be concluded that winter performance will likely be a function of the 2.2 % regression line, where zinc removal is due primarily to non-biological processes limited by retention time. Summer performance will likely be a function of the 5.2% regression line, where zinc removal is enhanced by algal growth and zinc uptake.

Polishing Pond 10 performance data are plotted in Figure 28, and the 2.2% and 5.2% regression lines, derived from Ponds 1 through 6 data, are included for comparison..

Fig.28:% [Zn] Decrease between Inflow & PP10 Outflow VS R.T. Oct 6,92-Nov 28,93

Since construction of Polishing Pond 10 was completed in late 1992, good performance was expected in 1993. Very little performance data was collected in late 1992, the period before algae had colonized substrate and also the period when flow rates were high. From the 1993 performance data, it can be seen that there were periods in July

when performance started to increase, likely when the algal population had grown substantially. The performance was not as high as could be expected, which is likely due to the early colonisation stage of the algal population.

Since construction in 1989, data collected for the experimental pools 1 through 6 (PP1 - PP6) have demonstrated that zinc concentrations can be effectively reduced in OEP discharge water, and that algal populations colonizing these pools is likely important components of the zinc removal process. It is very likely that Polishing Pond 10, constructed in 1992, and Polishing Ponds 11 through 13, constructed in 1993, will provide similar conditions for Biological Polishing of zinc present in OEP discharge water.

Direct removal of zinc by algal biomass via filtration and adsorption are only two of four main mechanisms which are likely operating, and contribute to zinc removal. As suggested in the 1992 report, perhaps 70 % of zinc removal in the biological polishing may occur through sedimentation, and capture of zinc-bearing suspended solids by the massive algal population in a mature polishing system. Some zinc removal is directly mediated by algal growth which facilitates precipitation of zinc carbonates with increased pH due to photosynthesis.

The decrease in both acidity and alkalinity in water passing through the experimental pools, observe in both 1992 and 1993, is evidence of photosynthetically-induced pH increases, and precipitation of mainly zinc carbonate, takes place as the water flows through the ponds (Figures 29a to d). The titration curves of Pond 10 (not shown) indicate that similar chemical conditions exist in this pond, compared with Pond 6, where fertilizer was also added.

Fig.29a: Polishing Ponds Acidities
May 28, 1992
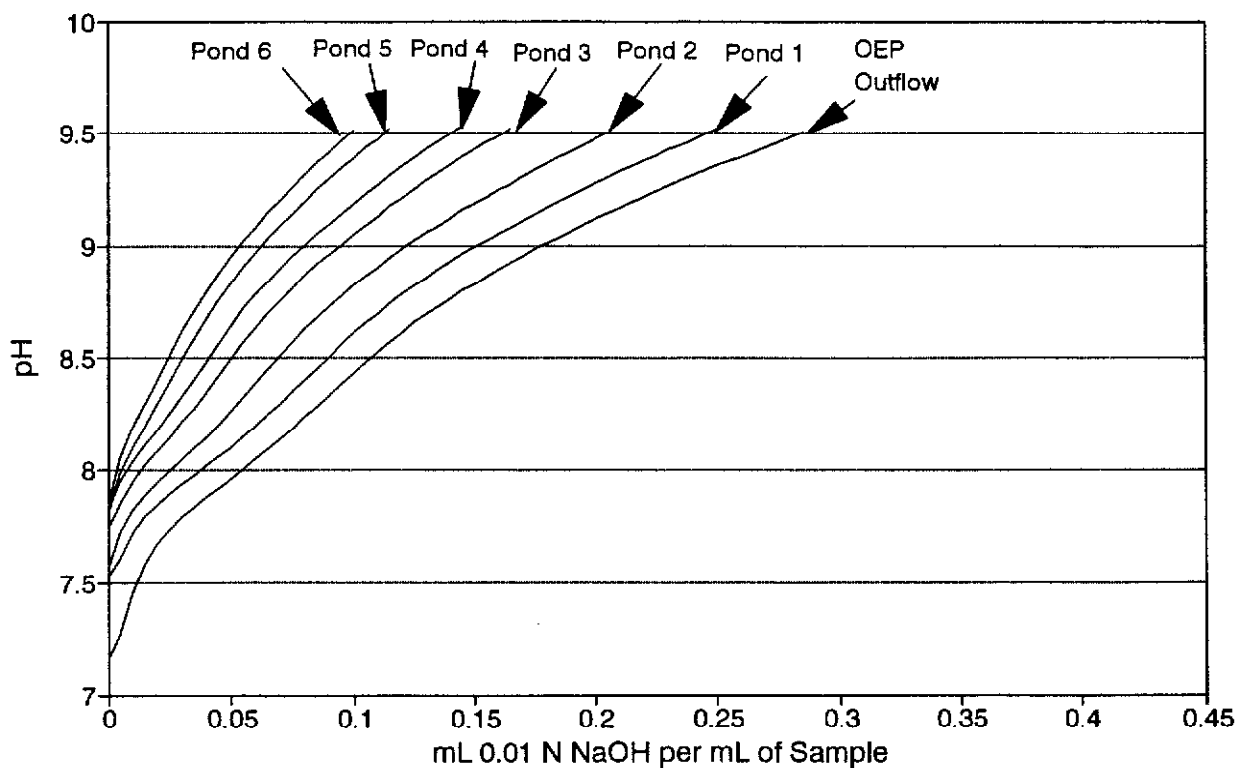
Fig. 29b: Polishing Ponds Acidities
August 29, 1993
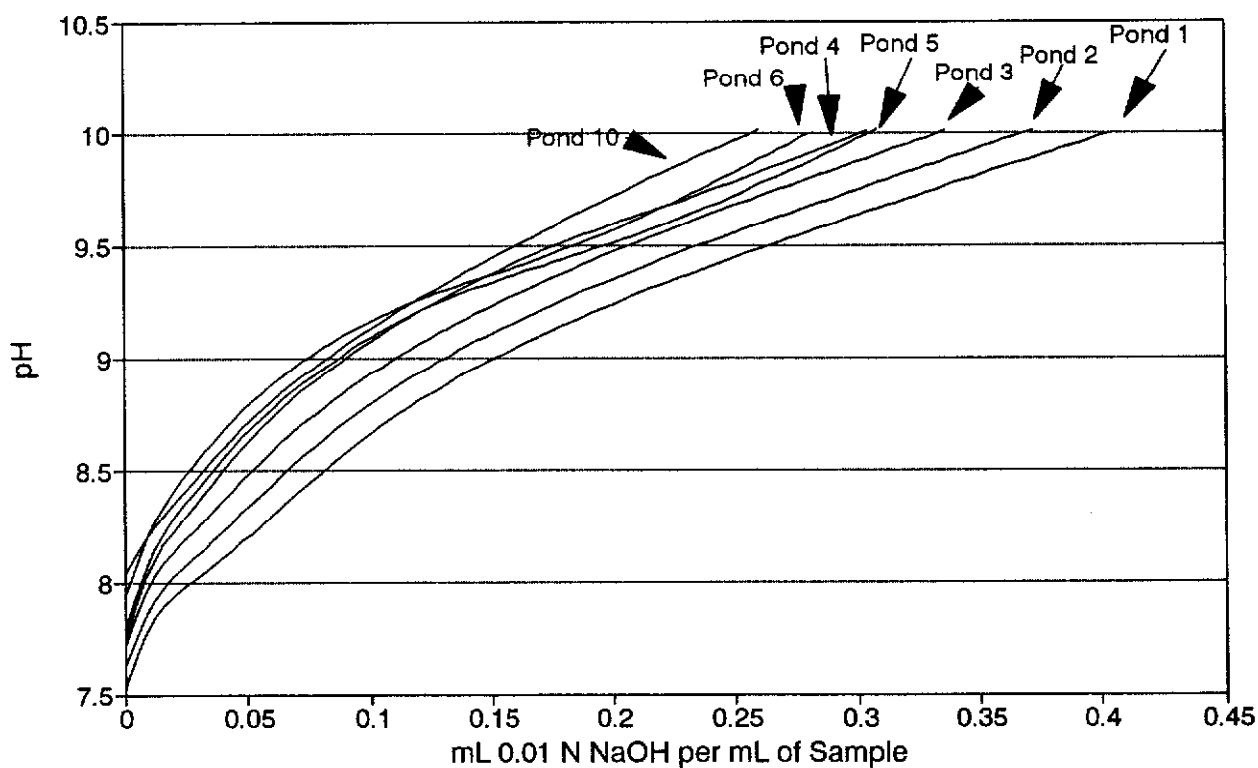
Fig. 29c: Polishing Ponds Alkalinities
May 28, 1992
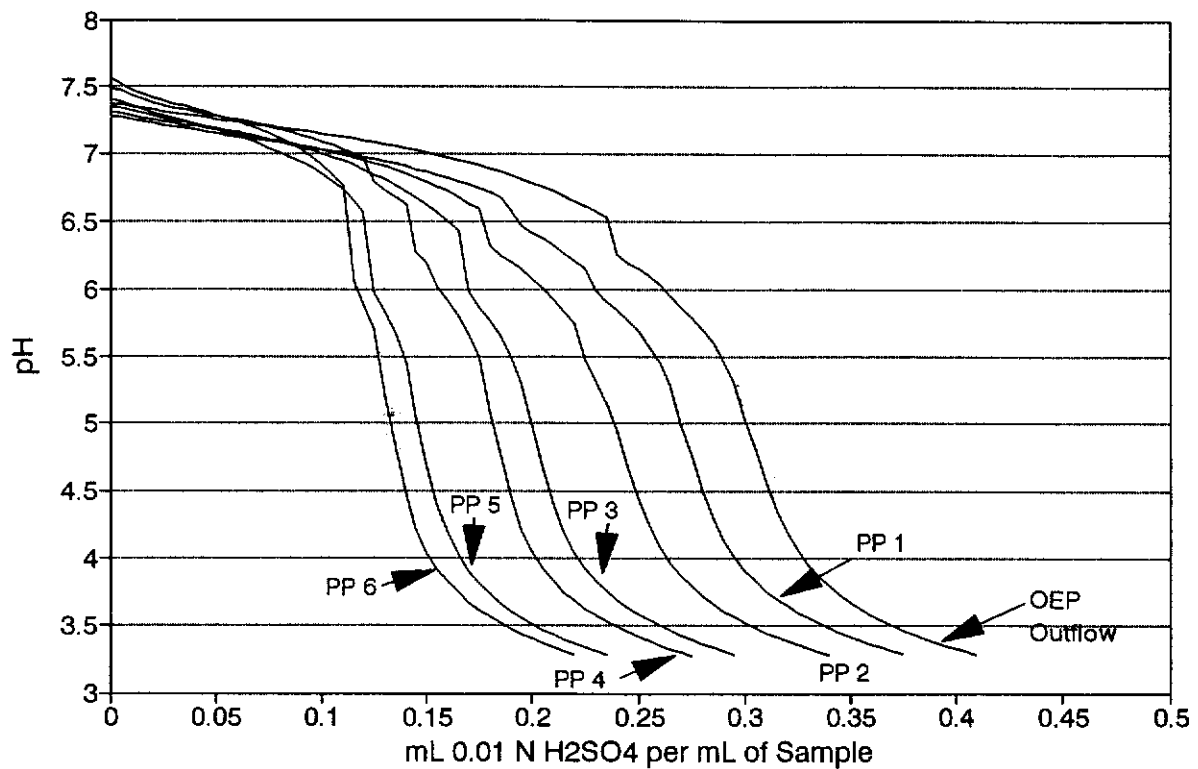
Fig. 29d: Polishing Ponds Alkalinities
August 29, 1993
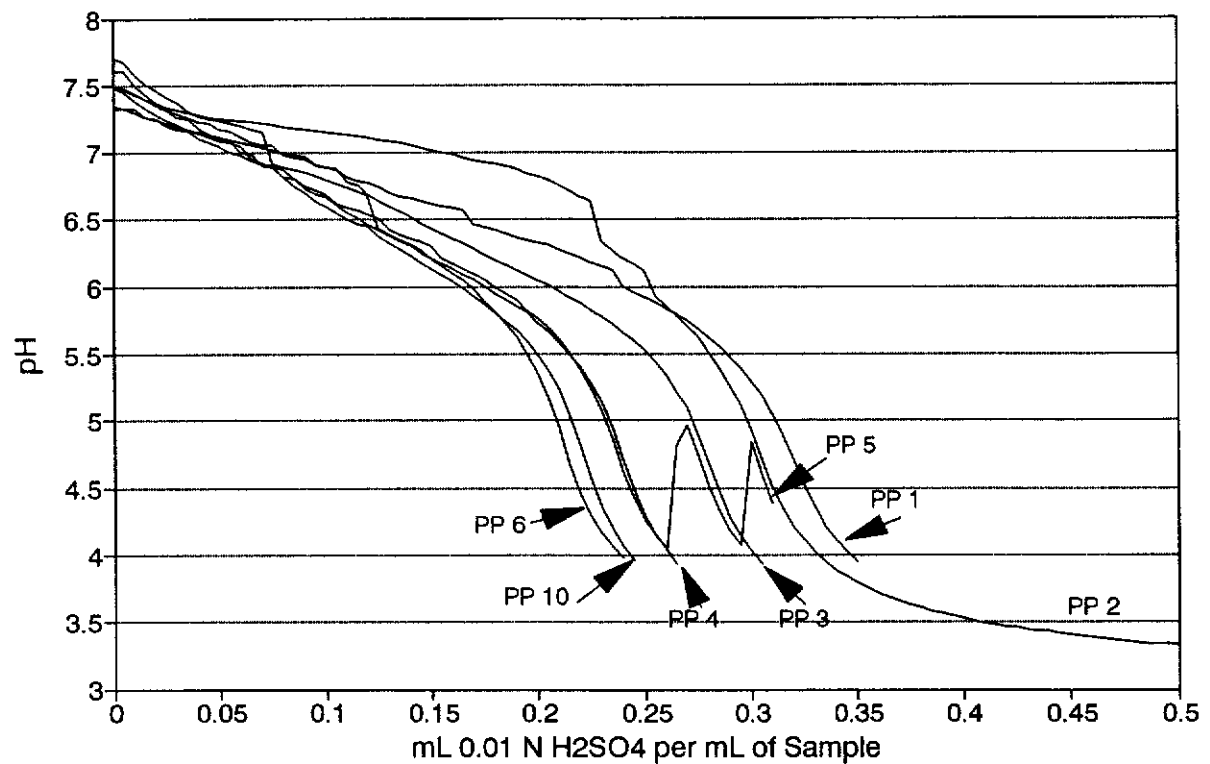
5.2 Projected Performance of Polishing Ponds

Using the two regression lines estimated in the section above, the projected performance of Polishing Ponds 10 through 13 can be estimated according to the first approach, based on the examination of the overall performance of experimental pools 1 through 6, in terms of zinc removal according to flow rates and residence times. Based on 2.2% zinc removal with each day of retention time (winter), 99 % zinc removal is estimated for the scaled-up Polishing Ponds, if the inflow is set at 1.55 $L.s^{-1}$, which translates to a retention time of 45 days (Table 10a). Based on 5.2 % zinc removal per day (summer), 98% zinc removal is estimated at an inflow of 3.7 $L.s^{-1}$ (19 day retention time). The overall relationship between percent zinc removal, flow and retention time, estimated by the two regression lines, is shown in Figure 30a.

The second approach to projecting performance of the scaled-up Polishing Ponds is based strictly on algal growth rates and algal zinc content, which collectively determine the amount of new algal biomass, and subsequently the amount of zinc which can be removed, in a polishing system of a given volume per day.

Using 1992 algal growth rate data and zinc concentrations in algal biomass, it was projected in the 1992 report that algal biomass growing on alder trees could remove 115 g Zn per tree per year, or in alternative units, 121 g Zn per m^2 of tree per year (1 tree = 0.95 m^2).

In 1993, some effort was expended to develop a more standard method of quantifying algal growth, rather than the presently used unit of growth per surface are of tree branch. Netting of a known surface area was suspended in polishing ponds and algal biomass was quantified after a known period of time. Using the data for the amount of biomass which grew on squares of netting, and biomass accumulated on alder branches placed in Polishing Pond 10 in late 1992, the average 1993 growth rate in Polishing Pond 10 is estimated at 0.745 g per m^2 of substrate per day (Table 10b).

Table 10: Projected performance of Polishing Ponds 10, 11, 12 and 13.

10 A: PROJECTED PERFORMANCE ACCORDING TO PP1 - PP1 DATA			
	All Performance Data	Performance of Top 8 Dates	Units
Inflow set at	1.55	3.7	L/s
Total Pond System Volume	5998	5998	m^3
Residence time in system	45	19	days
Percent Zn removal, accordng to PP1-PP6 data	99	98	Percen

10 B: PROJECTED PERFORMANCE: PP10 ALGAL GROWTH AND ZN CONTENT			
	1992 Projection	1993 Projection	
Growth rate (Avg 1993 Netting,Branch data)		0.745	g/m^2/day (100 d growing season)
	0.5 - 1.0	0.204	g/m^2/day over 1 year (no growth in winter)
Zinc content in PP10 algae ((1993 data)	62	115	g/kg dry wt
Alder surface area in ponds (2.8 trees/m^3)	900	17130	m^2 of trees
Zinc removed per day in polishing pond	0.007 (PP10,320 m3)	0.40 (PP10-13,5998 m3)	kg/day
1993 Avg [Zn] in OEP discharge	20	20	mg/L

Fig. 30a: Projected Zn Removal Performance Data to Date

Top 8 data, 5.2 % Decrease per Day R.T
Retention Time, Days
All data, 2.2 % Decrease per Day R.T.

— Percent Removal —☐— Retention Time(d)
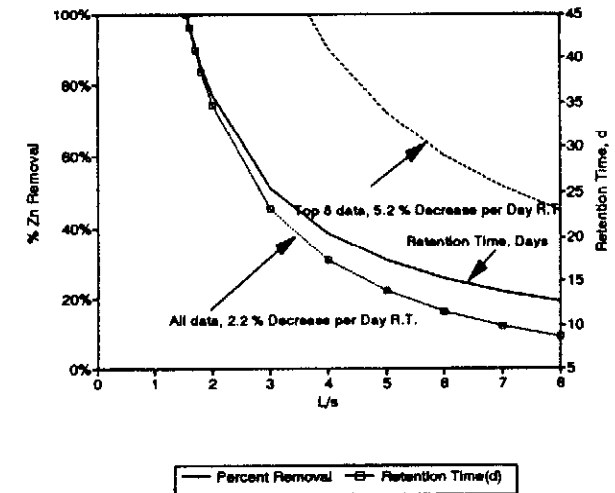
Fig. 30b: Projected Zinc Removal Algal Growth and Zinc Content to Date

45 Day Retention Time at 1.55 L/s
15 % Removal at 1.55 L/s

— Percent Removal —☐— Retention Time (d)
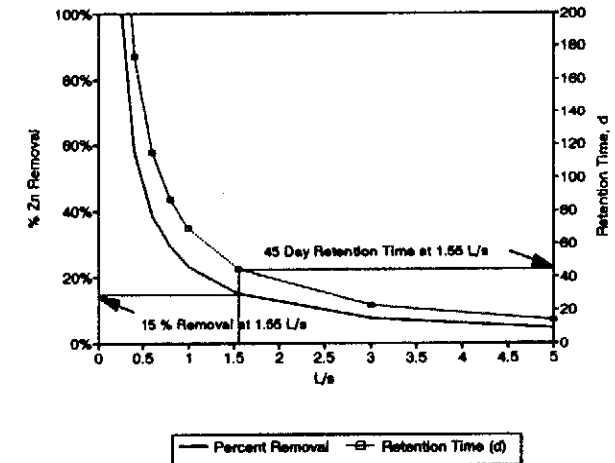
The algae biomass grew on the netting in the summer months, while the biomass on trees likely grew mostly in this period as well. Assuming a growing season of 100 days, this average growth rate is more likely 0.204 g per m^2 of substrate per day (*.745 $g.m^2.d^{-1}$ ÷ [100 d ÷ 365 d]) over an entire year.

These growth rates fall within the range of growth rates determined in the period October 1991 through July 1992 for the experimental pools, where growth rates ranged from 0.1 to 3.1 g per m^2 of substrate per day (1992 report, Figure 12). However, in 1993, fertilizer (Plant Prod 10-52-10) was regularly added to Polishing Pond 10 between June 25 and July 12, and higher growth rates were anticipated, given the high growth rates in the experimental pools in September 1992 (1.5 to 4.7 $g.m^2.d^{-1}$), the period when fertilizer was added to that system.

Phosphate, released from the fertilizer, was in fact being accumulated in algal biomass, as samples of this algae contained 1.5 % phosphorus. (Table 11). It is possible that, since 1993 represents the first growing season available for algae in Polishing Pond 10, colonization of the pond by algae was incomplete, and the effect of fertilizer addition upon zinc removal in this period was less apparent.

Table 11: Elemental concentrations in 1993 Polishing Pond algae.

% Dry wt.	PP 6 Algae on Netting	PP 6 Alga Jelly on branches	PP 10 Algae on Netting
Al	0.28	0.78	1.65
Ca	19.3	7.65	4.26
Fe	2.07	9.52	3.51
Mn	1.34	3.52	1.7
P	0.63	2.49	1.51
Zn	2.73	4.76	11.5
% L.O.I.	34	31	31

In Table 10b, the adjusted algal growth rate (0.204 $g.m^2.d^{-1}$) is used, in combination with, second, the 1993 zinc content in Polishing Pond 10 algae (115 kg.kg dry wt of algae^{-1}), and third, the number of trees in Polishing Ponds 10 through 13 required to achieve an average density of 2.8 trees per m^3 of pond (17,130 trees), to estimate zinc

removal in the system per day. Using these values, 0.40 kg of zinc would be captured by the algal biomass growing each day in the scaled-up Polishing Pond system. Using 20 mg.L^{-1} zinc as the average zinc concentration in OEP discharge, it can be seen in Figure 30b that this Polishing Pond system could remove only 15 % of the zinc if the inflow was kept at 1.55 L.s^{-1}, or effectively, a retention time of 45 days. Using this approach of assessing performance, using growth rates and zinc content in algae, results in a much poorer performance assessment, compared to the results shown in Table 10a and Figure 30a, where all zinc removal processes are operating.

From the assessment of the expected performance of the biological polishing process, it is evident that a retention time of 10 to 14 days will result is a good reduction in zinc concentrations, especially in summer. Polishing Ponds 10 through 13 are, however, not large enough to effectively treat all of the current discharge from OEP (20 mg.L^{-1} Zn in 10.7 L.s^{-1} flow). Higher flows anticipated when the Drainage Tunnel is diverted to the OWP commencing in spring, 1994. Should the performance of the system exceed expectations, and/or zinc concentrations in OEP discharge decline upon increased zinc removal due to the new geochemical conditions upon mixing and/or biological polishing upstream, then system throughput can be increased.

In retrospect, construction of experimental pools in parallel would have generated a better setting to determine key operating parameters for the system, as the relative roles of the various zinc removal mechanisms could be differentiated. However, the two components used for design are likely relatively representative but conservative, and only better performance than predicted could be anticipated.

6.0 SUMMARY OF REMEDIAL MEASURES

In Section 5, the assessment of the zinc removal capacity of the scaled-up Biological Polishing system indicated that, without partial zinc removal in water bodies upstream, the Polishing Pond system in the First Meadow is projected to treat only part of the loading presently discharging from the OEP.

Given that the contents of the OWP will be exchanged with Drainage Tunnel water, some biological polishing could be promoted in the OWP. This could reduce the loading to the polishing system constructed to date in the First Meadow. Although, intuitively, it could be expected that the performance of the process improves with lower zinc loadings, the empirical relations derived to evaluate performance (retention time or algal growth) have not taken into account different concentrations in, and chemistries of, the water to be treated.

In Section 4, the geochemical implications of combining Drainage Tunnel discharge with OWP water, which ultimately results in a combining of Drainage Tunnel water with OEP water, were discussed. While it is anticipated that the high dissolved oxygen content of Drainage Tunnel will promote iron oxidation and, subsequently, zinc precipitation in the OEP (especially if directed to the bottom of OEP), diversion of Drainage Tunnel water in the OWP-OEP system will also dilute iron concentrations and increase flow in, and zinc loadings to, the system. Although no deterioration of the conditions for biological polishing are anticipated, there remains a significant level of uncertainty as to the overall change in geochemistry, and subsequent zinc concentrations, in OEP discharge following the hydrological modifications. Overall, a "wait and see" stance must be taken at this time.

Although somewhat optimistic, it is projected that a substantial improvement in treatment performance will occur when all suggested measures have been implemented. These measures include, first, zinc removal via Biological Polishing in the OWP; second, improved iron oxidation with subsequent increased zinc

coprecipitation; and third, improved retention of iron hydroxide precipitates on the floating cattail curtains. These measures should all reduce zinc loadings reporting to the Biological Polishing system.

6.1 Biological Polishing in OWP

There is good indication that some biological polishing of Drainage Tunnel water could be achieved in the OWP, since a filamentous algal population already thrives in Drainage Tunnel water between the discharge point and the Buchans River. The Drainage Tunnel water's present composition in the high flow conditions is apparently suitable for algal growth. As this algal community contains between 0.46 to 0.96 % zinc, its zinc removal potential capacity, on a biomass basis, is comparable with algae in the First Meadow Biological Polishing System.

While the overall chemical composition of Drainage Tunnel discharge water will be similar, after a few replacements of OWP's volume, to that water presently discharging from the tunnel, the physical conditions which the algae in the Drainage Tunnel currently enjoy will be different, and possibly less optimal for growth in the OWP volume. Presently, over the Drainage Tunnel effluent flow path, there is some surface area available for anchorage by the algae. Flow from the Drainage Tunnel over the algae is laminar, providing constant replenishment with new water, whereas in the OWP, the surface area to water volume is lower. Minor water movement in the OWP will allow build-up of nutrient concentration gradients between bulk water and algae.

While field and laboratory experiments examining algal growth in Drainage Tunnel water in large open pond conditions could not performed to date, small-scale experiments of this kind in 1994 would identify whether Biological Polishing of Drainage Tunnel water residing in OWP is possible. The technical challenge will likely lie in the design of appropriate structures which will serve both as good growth substrates, and possibly, direct water so as to circulate around the algal biomass, increasing growth rates.

6.2   Sedimentation in OEP

With more thorough oxidation, larger amounts of precipitates will form in the OEP, which should reduce the zinc loading at the same time. To retain as much precipitate as possible in the OEP, the previously installed cattail floats, intended for ARUM, can be used to collect precipitate. The dense root and rhizome matrix underlying floating cattail mats near the outflow (Plate 5) will serve as a filter cloth for these suspended solids. Sloughing of the older, dead biomass and growth of new biomass will prevent this matrix from becoming blocked, and curtail short-circuiting of water around the matrix.

Plate 5:   Planting of the 1993 cattail rafts in OEP (left). 1992 cattail mats (right) and 1991 cattail mats (far right). August 9, 1993.

If these solids are not retained in the OEP, the solids loading to the Polishing Pond system will result in greater light blockage to the algal populations through reducing light penetration in the ponds, and increasing accumulation of solids over the algal biomass.

Currently, oxidation of ferrous iron, precipitation of ferric hydroxide and coprecipitation of zinc occur, at best (summer), strictly in the upper 4 m stratum of the Oriental East pond. While a fraction of the precipitates do settle to the bottom of the OEP, more of the precipitates are exported in the discharge. With entry of Drainage Tunnel water projected in 1994, the stratum where ferrous iron oxidation will occur can be expected to increase below the current depth of the chemocline. Furthermore, if water discharging from OWP is directed to the bottom of OEP, ferrous iron oxidation and iron hydroxide precipitation may occur throughout the water column over the entire year.

6.3 ARUM in Waste Rock Pile Seepage Pools

Seepage from the Orientals Waste Rock Pile (WRP) remains a source of acidity and zinc to the Buchans River, apart from the Drainage Tunnel, OEP and Tailings Ponds. The potential of an ARUM (Acid Reduction Using Microbiology) system for treatment of the WRP seepage needs to be evaluated.

In 1989, three small pools were excavated at the base of the Oriental Waste Rock Pile (WRP), such that seepage water would collected in the first pool (ARUM Cell 7) and flow to Cell 8 then Cell 9. Low pH water with elevated acidity collects in this system (Table 12). Organic amendment in the form of hay bales was added to these pools in 1989 to induce the sediment bound ARUM process. The same process was developed for the OWP and tested in the Limnocorrals. Microbial consumption of oxygen, followed by microbial reduction of iron and sulphate and alkalinity generation was proven possible in the Limnocorrals study. Improvement in the quality of water passing through test Cells 7 to 9 would provide evidence that application of ARUM in this area has potential, especially since the seepage from the WRP is very slow and diffuse.

Table 12 : Chemistry of Waste Rock Pile seepage and ARUM pools.

	28-May-92		19-Aug-92		30-Aug-93	
	pH	Acidity	pH	Acidity	pH	Acidity
Seepage	3.32	240			3.82	420
Cell 7 In	3.73	153	3.36	234	3.23	473
Cell 7 Out	3.57	143			3.29	430
Cell 8 Out	3.69	98			4.67	215
Cell 9	3.74	80	3.77	108	4.08	145

The zinc concentration in seepage water consistently decreases as it passes through the experimental ARUM pools 7, 8 and 9, providing some indication that ARUM processes are operating in these cells (Figure 31). On average, over the 1989 - 1992 period, zinc concentrations decreased from 63 mg.L^{-1} in Cell 7, to 27 mg.L^{-1} in Cell 9.

Fig. 31: WRP ARUM Cells 7 and 9
Zinc Concentrations, 1989 - 1993
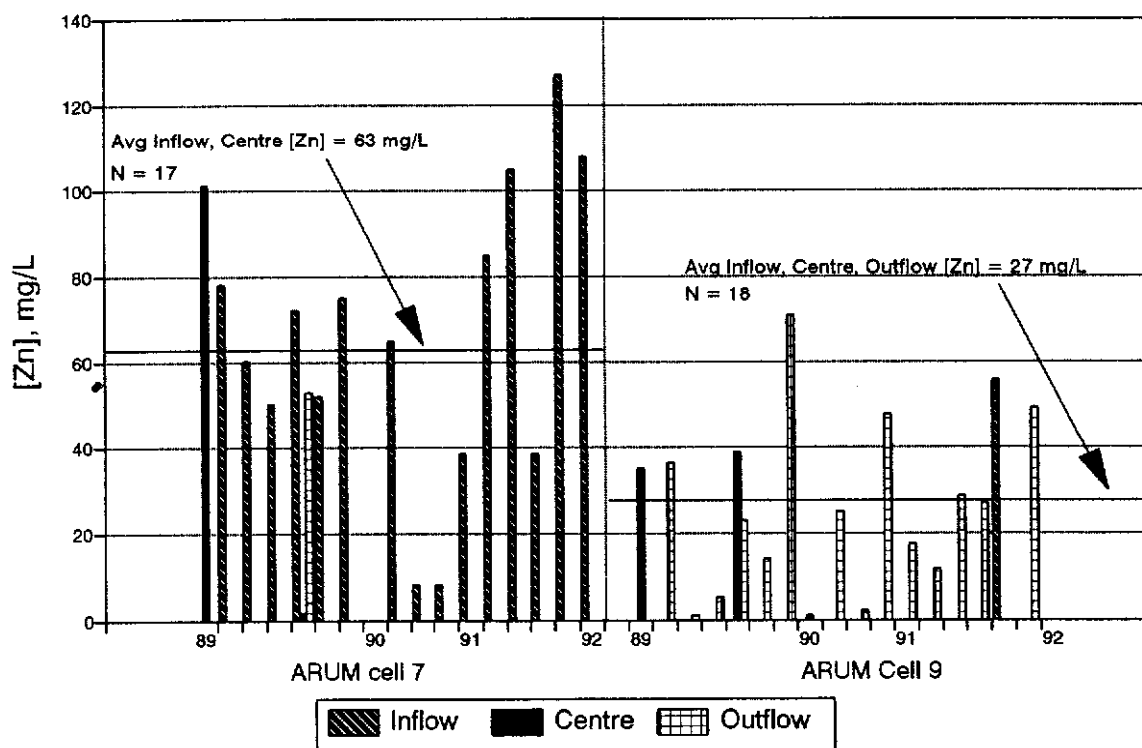
The titration curve data for each of the cells in both May, 1992 and August 1993 indicate that acidity is reduced in seepage water as it passes through the cells (Figure 32a and b). The acidity of the seepage was much higher in August 1993, compared to May, 1992, when the seepage was likely diluted by spring run-off water. As water passes through the cells, the amount of NaOH required to raise the pH during the titration to pH 4.5 is much lower downstream, in Cells 8 and 9, than in the seepage upstream. This is especially evident in 1993 data. Because ferric iron is precipitated between the original pH and pH 4.5, the cells appear to be removing this form of dissolved iron.

In the titration curves for the seepage and the inflow to Cell 7, there is a second pH range, between pH 6 and 7.5, where an exceptionally large amount of NaOH is required to increase the pH each 0.1 pH unit. This region of each curve has, therefore, a lower slope. This pH range represents the period during the titration when zinc was being precipitated upon addition of NaOH. Since the slopes of the curves in this pH range of the samples taken downstream are steeper, these samples likely contained less zinc. Therefore, some zinc removal takes place as water flows through the cells. With scale-up of the ARUM process an in situ remedial process, this source of zinc and acidity to the Buchans River could be eliminated.

Fig. 32a: WPR ARUM Cells Acidities
May 28, 1992
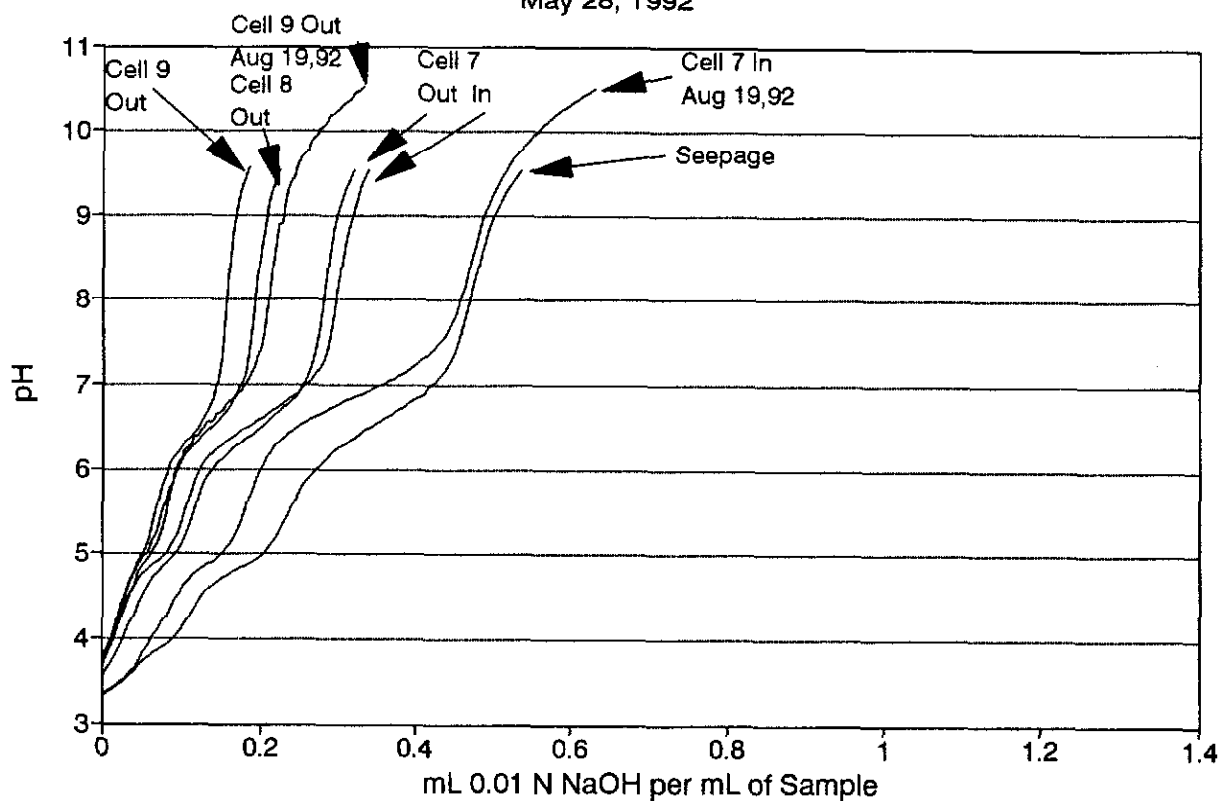
Fig. 32b: WPR ARUM Cells Acidities
August 29, 1993
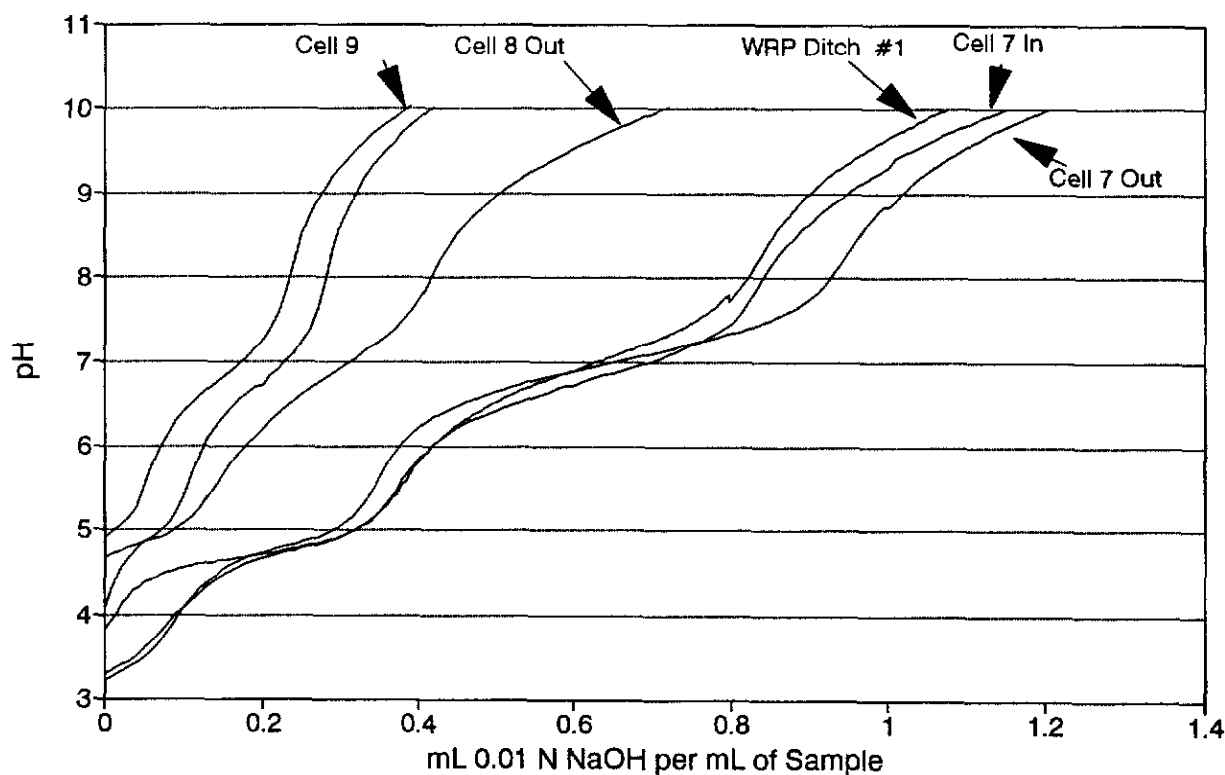
7.0 CONCLUSIONS AND RECOMMENDATIONS

A significant part of the 1993 work centred around problem anticipation, in light of the hydrological alterations made between the OWP and OEP, and the introduction of the Drainage Tunnel flow to the OWP/OEP, commencing in spring 1994. Both experimental data were generated, and geochemical simulations were used, to predict potential problems with the water mixtures. Essentially, no drastic changes in water chemistry are predicted, but is it relatively certain that the rate of iron and zinc precipitation in the Oriental East Glory Hole will change. It is, at this stage, not possible to predict to what degree the change will affect the zinc concentrations, since the rate at which oxygen will be introduced, increasing the rate of precipitation, is not presently known.

The other major focus of the 1993 work was to confirm the zinc removal mechanisms for the different effluents draining to the Buchans River. A winter sampling program was performed in both the OWP and OEP. It can be concluded that the proposed natural mechanisms which result in zinc reductions are actually occurring in the effluents. The zinc removal mechanisms are those fundamental to the Ecological Engineering treatment strategies developed for the Buchans site. As these processes are confirmed, the site's long-term liability with respect to effluent treatment is significantly reduced because, ultimately, the zinc concentrations will reach low (1 to 2 mg.L^{-1}) equilibrium values.

The Biological Polishing system, built to treat OEP/Drainage Tunnel effluent, is not, at present, able to deal with the entire anticipated zinc loading. However, from the evaluations of the first year of performance data for the scaled-up Pond 10, compared to the last few years of Pools 1 to 6 data, it can be concluded that the same processes will operate in pool 10, and scale-up of the process is prudent. Based on the chemical analysis of Pond 10 algal biomass, fertilization of the Polishing Ponds will not be required on a continuous basis.

As joint funding with CANMET was again obtained, facilitating refinement of the biological polishing model and address of the phosphorus/iron cycling in sediments in polishing ponds, firmer predictions with respect of the long-term fate of the treatment ponds, and expected performance, will be reported at the conclusion of this work. Recommendations for 1994 with respect to the Biological Polishing process have to await the findings of the joint study.

It is concluded that, in 1994, Biological Polishing should be considered for the Oriental West Glory Hole, as this might result in a lower treatment performance requirement for the Polishing Ponds constructed in the First Meadow.

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APPENDIX A

GEOCHEMICAL SIMULATION
OF THE
DISPOSAL OF DRAINAGE TUNNEL DISCHARGE
INTO
THE ORIENTAL PITS

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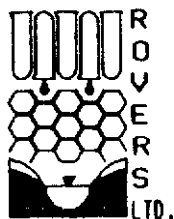
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ASARCO - BUCHANS UNIT

GEOCHEMICAL SIMULATION
of the
DISPOSAL OF DRAINAGE TUNNEL DISCHARGE
into
THE ORIENTAL PITS

JUNE 1993

GEOCHEMICAL SIMULATION
of the
DISPOSAL OF DRAINAGE TUNNEL DISCHARGE
into
THE ORIENTAL PITS

INTRODUCTION

It has been suggested that the Oriental West Pit be connected to the Oriental East Pit by a surface channel, and that the discharge from the Drainage Tunnel (DT) be pumped to one of the Oriental pits, where the water would eventually flow through the biological-treatment system for discharge from the Oriental East Pit, currently being tested.

To test the possible geochemical consequences of these suggestions, several aspects had to be evaluated, in addition to the hydraulic engineering challenge. These aspects include:

(1)   the mixing ratio of DT discharge with Oriental West Pit and Oriental East Pit waters; potential mixing ratios between the DT discharge and OWP or OEP waters have been estimated earlier, on the basis of the volume and assumed turnover rates of the two pits (see report on "The Drainage Tunnel and the Lucky Strike Pit", November 1991);

(2)   the potential for dissolution or precipitation of minerals by the various mixtures; for the preliminary geochemical simulations reported in the November 1991 report, Eh (or pE) values were not available;

(3)   the introduction of additional oxygen into the Oriental system.

In this report, geochemical simulation is employed to estimate elemental concentrations and mineral saturation degrees for ranges of mixtures of DT water with West Pit surface water (WPS), West Pit bottom water (WPB), East Pit surface water (EPS), and East Pit bottom water (EPB), on the basis of the analyses of a set of water samples collected on 6 April 1993.

A similar simulation was carried out to test the potential geochemical consequences of the mixing of WPS and EPS waters that would result from the proposed connection of the West Pit to the East Pit via a surface channel.

Every effort has been made to insure that the data used in the simulations and predictions presented in this report are the best available. Any errors found, and significant new information that could affect the interpretation and predictions, should be brought to the attention of the author to enable correction and, where necessary re-interpretation.

CHEMICAL ANALYSES

The results of the chemical analyses for the April 1993 samples from the Drainage Tunnel discharge (DT), the Oriental East Pit surface and bottom (EPS and EPB), and the Oriental West Pit surface and bottom (WPS and WPB) are listed in Table 1.

of the tables (and the B parts of the illustrations) present the calculated saturation indices. A positive SI value for a particular mineral indicates saturation (or the potential for precipitation of the mineral in question), and a negative SI value indicates undersaturation (or the potential for dissolution of the mineral, if present).

Increased SI values in the mixtures indicate that precipitation of the minerals from the mixtures would be more likely than it is for the unaffected water. Decreased SI values would make precipitation of the minerals from the mixtures slightly less likely than it is for the unaffected water.

DT into WPS (Table 2 and Figures 1-A and 1-B)
Discharge of diverted Drainage-Tunnel water to the surface of the Oriental West pit would result in lower metal and sulfur concentrations in the pit water, for all mixing ratios. Saturation indices with respect to the potential precipitate minerals, except gypsum and Fe hydroxide, would be increased. At low mixing ratios, the low pH in the WP water would depress the SI value for Fe-hydroxide imported with the DT water. At higher mixing ratios, increased pH would tend to limit potential dissolution of metal-sulfides, and increase the SI for Fe-hydroxide, promoting formation of some Fe-precipitate.

DT into WPB (Table 3 and Figures 2-A and 2-B)
Discharge of diverted Drainage-Tunnel water into the bottom of the Oriental West pit would also result in lower metal and sulfur concentrations in the pit water, for all mixing ratios. Saturation indices with respect to the potential precipitate minerals, except gypsum and Fe-hydroxide, would be increased. At intermediate mixing ratios, the lower pH in the WP water would depress the SI value for Fe-hydroxide imported with the DT water. At high mixing ratios the SI for Fe-hydroxide would be somewhat higher, possibly promoting formation of some Fe-precipitate. Increased pH would tend to limit dissolution of metal-sulfides but, particularly at higher mixing ratios, entrainment of oxygen in the DT discharge could encourage sulfide oxidation. Further simulation tests, using analyses of samples collected at various times through the year would be required to evaluate the effects of pH change and oxygen entrainment in more detail.

DT into EPS (Table 4 and Figures 3-A and 3-B)
Discharge of diverted Drainage-Tunnel water to the surface of the Oriental East pit would result in somewhat higher [Al], [Cu] and [Zn] values, and lower [S], [Fe], and [Mn] values in the pit water, for all mixing ratios. Saturation indices with respect to the potential precipitate minerals (except gypsum) would increase somewhat, particularly at high mixing ratios. Actual precipitation is not likely to increase for mixing ratios of 1.25:1 or less.

DT into EPB (Table 5 and Figures 4-A and 4-B)
Discharge of diverted Drainage-Tunnel water into the bottom of the Oriental East pit would result in somewhat higher [Al] and [Cu] values, and lower [S], [Fe], and [Mn] values in the pit water, for all mixing ratios. Saturation indices with respect to the potential precipitate minerals (except gypsum) would increase somewhat. Actual precipitation is not likely to increase for mixing ratios of 1.25:1 or less.

WPS into EPS (Table 6 and Figures 5-A and 5-B)
Mixing of the surface waters of the Oriental West and East Pits, as a result of the establishment of a surface channel connecting the two pits, would cause higher [Al], [Cu] and [Zn] values, and lower [Fe], [Mn] and [S] values in the East Pit

outflow. Saturation indices with respect to Al and Cu minerals would increase somewhat at low and intermediate mixing ratios, but saturation indices for all selected minerals would decrease at higher mixing ratios. Some precipitation of CuFerrite may take place.

In any of the above cases, the increased rate of discharge from the Oriental system would have to be accommodated in the treatment area in the Meadows. This increased discharge rate would tend to increase flow velocities and reduce residence times, which may be detrimental to the stability and treatment efficiency of the system, respectively. The higher flow rates could also result in changes in the ice buildup in the Meadows during the winter.

It should be kept in mind that, depending on the temperatures of the diverted DT water and the receiving water, the DT water may have a tendency to float, or sink or rise in the receiving pit. This would affect the extent of mixing, as well as the degree of re-suspension of precipitates. The actual behaviour is likely to vary throughout the year as the waters undergo different degrees of heating and cooling. This aspect can only be analysed in detail if year-round temperature data are available, not only for the surface and bottom waters in both pits, but also for the summer-heated and winter-cooled DT water delivered to the pits.

The proposed channeling of acidic West Pit water (or mixed DT+WP water) into the East Pit could have some detrimental effect on the biological treatment systems established in the East Pit and in the Meadows.

CONCLUSIONS

a.   Discharge of diverted Drainage-Tunnel water to the surface of the Oriental West pit would result in lower metal and sulfur concentrations in the pit water, for all mixing ratios. Saturation indices with respect to the potential precipitate minerals, except gypsum and Fe hydroxide, would increase. At high mixing ratios, increased pH would tend to limit dissolution of metal-sulfides, and increase the SI for Fe-hydroxide, promoting formation of some Fe-precipitate.

b.   Discharge of diverted Drainage-Tunnel water into the bottom of the Oriental West pit would also result in lower metal and sulfur concentrations in the pit water, for all mixing ratios, and increased saturation with respect to the potential precipitate minerals, except gypsum and Fe-hydroxide. At high mixing ratios, increased pH would tend to limit dissolution of metal-sulfides and increase the SI for Fe-hydroxide, promoting formation of some Fe-precipitate, but entrained oxygen may encourage sulfide oxidation.

c.   Discharge of diverted Drainage-Tunnel water to the surface of the Oriental East pit would result in somewhat higher [Al], [Cu] and [Zn] values, and lower [S], [Fe], and [Mn] values in the pit water, for all mixing ratios. Saturation indices with respect to the potential precipitate minerals (except gypsum) would increase somewhat, particularly at high mixing ratios, but actual precipitation is not likely to increase for mixing ratios of 1.25:1 or less.

d.   Discharge of diverted Drainage-Tunnel water into the bottom of the Oriental East pit would result in somewhat higher [Al] and [Cu] values, and lower

[S], [Fe], and [Mn] values in the pit water, for all mixing ratios. Saturation indices with respect to the potential precipitate minerals (except gypsum) would increase somewhat, but actual precipitation is not likely to increase for mixing ratios of 1.25:1 or less.

e. Mixing of the surface waters of the Oriental West and East Pits, as a result of the establishment of a surface channel connecting the two pits, would cause higher [Al], [Cu] and [Zn] values, and lower [Fe], [Mn] and [S] values in the East Pit outflow. Saturation with respect to Al and Cu minerals would increase somewhat at low and intermediate mixing ratios, but saturation for all selected minerals would decrease at higher mixing ratios.

RECOMMENDATIONS

Further refinement of the predictions regarding the potential chemical effects of disposal of the Drainage Tunnel discharge into either of the Oriental pits would require field data and laboratory analyses for representative samples collected from the various sample stations at several times throughout the year.

If it is decided to put the Drainage Tunnel water into the West Pit, and if the approximate mixing ratio becomes better defined, then it may be useful to carry out an additional simulation, in which DT and WP water are mixed in the most probable ratio, followed by mixing of the DT+WP mixture into EP water in the most likely ratio.

The potential effects of temperature differences between the Drainage Tunnel water and the receiving water, on mixing and on re-suspension of precipitates, should be evaluated.

The proposed channeling of acidic West Pit water (or mixed DT+WP water) into the East Pit could have detrimental effects on the biological treatment systems established in the East Pit and in the Meadows. The likelyhood and possible severity of such effects should be evaluated.

The potential effects of increased flow velocities and decreased residence times on the stability and efficiency of the Oriental discharge-treatment system in the Meadows also remain to be evaluated.

Removal of the Drainage Tunnel discharge to the Oriental Pits should lead to improved water quality in Buchans River upstream of the Oriental road bridge. It will also increase the total discharge into the river from the Meadows. Careful monitoring should determine if the total metal loading to Buchans River is decreased by this arrangement.

R.O. van Everdingen
6 June 1993

TABLE 1.

	AT.WGHT	1	2	3	4	5	6	7	8
ANALYSIS DATE		06-Apr	06-Apr	06-Apr	06-Apr	06-Apr	16-May	06-Apr	16-May
SAMPLING LOCATION		BUCHANS DT	BUCHANS DT	BUCHANS OEP	BUCHANS OEP	BUCHANS OWP	BUCHANS OWP	BUCHANS OWP	BUCHANS OWP
		replicate bottom	bottom	surface	surface	bottom	bottom	surface	surface
** F I E L D **									
Temp. (C)		5.5	5.5	6.5	4.8	4.5		1.1	
pH		6.1	6.1	6.3	6.2	3.6		3.8	
Cond. (umhos/cm)		242	242	1715	1280	378		332	
Em, mV		196	196	-70	-55	474		421	
Eh, mV		450	450	183	199	729		678	
pE		7.5992	7.5992	3.0948	3.3671	12.3063		11.4489	
Alkalinity									
Acidity									
** L A B . **									
pH		6.50	6.51	6.22	6.22	3.51	3.45	3.65	4.01
Temp. (C)									
Cond. (umhos/cm)		399	401	2820	2040	674	671	600	310
Em (mV)									
Alkalinity (mg/l)		23	23	220	170				
ELEMENTS, AT.WGHT									
Ag	107.8680								
Al	26.9815					3.07	3.15	2.72	1.29
As	74.9216								
B	10.8100			0.09	0.07	0.07			
Ba	137.3300	0.026	0.024	0.017	0.02	0.034	0.041	0.036	0.049
Be	9.0122								
Bi	208.9804								
C	12.0110								
Ca	40.0800	43.2	42.9	508	332	79	75.8	71.1	32
Cd	112.4100	0.07	0.069	0.004	0.003	0.078	0.084	0.071	0.035
Ce	140.1200								
Co	58.9332			0.031	0.022	0.012	0.016	0.014	0.006
Cr	51.9960			0.009					
Cu	63.5460	0.065	0.067						
Fe	55.8470	0.006		3.97	0.788	0.603	0.703	0.581	0.41
Hg	200.5900							0.15	0.069
K	39.0983	1.9	1.5	4.6	3.7	1.8	1.9	1.8	1.7
La	138.9055								
Mg	24.3050	5.76	4.86	45.9	32.6	10.2	9.86	9.61	4.16
Mn	54.9380	0.267	0.259	14.6	10.3	2.22	2.14	2	0.834
Mo	95.9400								
Na	22.9898	12.6	12.3	127	88.5	2.86	2.78	2.86	1.36
Nb	92.9064								
Ni	58.7000	0.21	0.2			0.02	0.02	0.01	
P	30.9738			0.09		0.02	0.02		
Pb	207.2000					1.17	1.2	1.09	0.576
S	32.0600	43.1	43.8	383	273	106	107	94.9	43.4
Sb	121.7500								
Se	78.9600								
SiO2	28.0855	19.8	19.8	18.9	16.3	13.8	13.6	12.8	6.21
Sn	118.6900			0.23	0.16				
Sr	87.6200	0.128	0.12	2.83	2	0.249	0.239	0.231	0.106
Te	127.6000								
Ti	47.9000								

TABLE 1.		1	2	3	4	5	6	7	8
ANALYSIS DATE		06-Apr	06-Apr	06-Apr	06-Apr	06-Apr	16-May	06-Apr	16-May
SAMPLING LOCATION		BUCHANS	BUCHANS	BUCHANS	BUCHANS	BUCHANS	BUCHANS	BUCHANS	BUCHANS
		DT	DT	OEP	OEP	OWP	OWP	OWP	OWP
			replicate	bottom	surface	bottom	bottom	surface	surface
U	238.0290								
V	50.9415								
W	183.8500								
Y	88.9059								
Zn	65.3800	23.9	22.8	24.2	17.2	33.8	34.4	29	13.2
Zr	91.2200								
Bromide				4.51	3.13				
Chloride		20.9	20.4	196	129	1.54	1.48	1.54	0.83
Fluoride		0.19	0.18	0.61	0.34	0.14	0.12	0.14	0.06
Phosphate									
Carbonate									
Bicarbonate		23	23.2	220	170				
Sulphate		122	122	1260	861	310	316	267	125
Nitrate		1.06	1.04						0.14
Nitrite									
Ammonium									
Turbidity, NTU				5	5		1		

TABLE 2. Mixtures of Drainage Tunnel Water
and Oriental West Pit Surface Water

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	WEST PIT SURFACE WATER	0.25 DT in 1 WPS	0.5 DT in 1 WPS	1.0 DT in 1 WPS	2.0 DT in 1 WPS	2.5 DT in 1 WPS	DRAINAGE TUNNEL WATER
S needed	1.904E-04						3.571E-04

| Fraction | 0.000 | 0.200 | 0.333 | 0.500 | 0.667 | 0.714 | 1.000 |

Temp.	1.10	1.98	2.57	3.30	4.03	4.24	5.50
pH	3.80	3.96	4.12	4.45	5.04	5.22	6.10
pE	11.00	7.25	6.79	6.53	6.37	6.34	7.60

Al	1.01E-04	8.07E-05	6.73E-05	5.04E-05	3.36E-05	2.88E-05	
Ba	2.62E-07	2.48E-07	2.38E-07	2.26E-07	2.14E-07	2.10E-07	1.89E-07
C		7.67E-05	1.28E-04	1.92E-04	2.54E-04	2.74E-04	3.83E-04
Ca	1.77E-03	1.64E-03	1.54E-03	1.43E-03	1.31E-03	1.28E-03	1.08E-03
Cl	4.35E-05	1.53E-04	2.25E-04	3.17E-04	4.08E-04	4.33E-04	5.90E-04
Cu	9.15E-06	7.52E-06	6.44E-06	5.08E-06	3.73E-06	3.35E-06	1.02E-06
F	7.37E-06	7.90E-06	8.25E-06	8.69E-06	9.13E-06	9.25E-06	1.00E-05
Fe	2.69E-06	2.17E-06	1.83E-06	1.40E-06	9.66E-07	8.45E-07	1.07E-07
K	4.61E-05	4.66E-05	4.69E-05	4.73E-05	4.78E-05	4.79E-05	4.86E-05
Mg	3.95E-04	3.64E-04	3.43E-04	3.16E-04	2.90E-04	2.82E-04	2.37E-04
Mn	3.64E-05	3.01E-05	2.59E-05	2.06E-05	1.54E-05	1.39E-05	4.86E-06
Na	1.24E-04	2.09E-04	2.66E-04	3.36E-04	4.07E-04	4.27E-04	5.48E-04
S	2.78E-03	2.48E-03	2.28E-03	2.03E-03	1.77E-03	1.70E-03	1.27E-03
Si	2.13E-04	2.37E-04	2.52E-04	2.72E-04	2.91E-04	2.97E-04	3.30E-04
Sr	2.64E-06	2.40E-06	2.25E-06	2.05E-06	1.85E-06	1.80E-06	1.46E-06
Zn	4.44E-04	4.28E-04	4.17E-04	4.04E-04	3.91E-04	3.87E-04	3.64E-04

Saturation Indices LOG[IAP/Kt]							
Alunite	0.5420	1.1700	1.8165	3.2781	5.6778	6.0150	--
Barite	0.8231	0.7474	0.6935	0.6208	0.5415	0.5176	0.3475
Diaspore	-1.6640	-1.2014	-0.7670	0.1294	1.6083	1.9221	--
Fe(OH)2.7	3.5026	0.3172	0.2732	0.8556	2.2060	2.6106	5.3076
Goethite	1.4996	-1.7644	-1.7881	-1.1214	0.4043	0.8624	3.8344
Gypsum	-0.9220	-0.9890	-1.0379	-1.1053	-1.1807	-1.2037	-1.3717
Quartz	0.7371	0.7663	0.7834	0.8025	0.8196	0.8240	0.8481
Cuprousferrite	1.7352	2.2828	2.8066	3.9512	6.0855	6.7015	8.7397
Cupricferrite	-0.1834	-6.4366	-6.2143	-7.1949	-0.1607	1.0704	8.2910
ZnSiO3	-3.7723	-3.3608	-2.9922	-2.2682	-1.0139	-0.6424	1.2260
Kaolinite	-1.7656	-0.7858	0.1146	1.9425	4.9311	5.5667	--
Pyrophyllite	0.4775	1.4574	2.3535	4.1717	7.1464	7.7775	--
Lepidocrocite	1.5545	-1.7464	-1.7945	-1.1583	0.3370	0.7867	3.7071
Ca-nontronite	16.2683	10.0131	10.1964	11.9703	15.7340	16.8187	--
Chlorite	-3.5496	-1.6355	0.5595	5.3475	13.8205	15.9464	--

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Temp. in degree C; pH and pE in units; concentrations as MOLALITY

TABLE 3. Mixtures of Drainage Tunnel Water and Oriental West Pit Bottom Water

	WEST PIT BOTTOM WATER	0.25 DT in 1 WPB	0.5 DT in 1 WPB	1.0 DT in 1 WPB	2.0 DT in 1 WPB	2.5 DT in 1 WPB	DRAINAGE TUNNEL WATER
S needed	1.195E-04						3.571E-04
Fraction	0.000	0.200	0.333	0.500	0.667	0.714	1.000
Temp.	4.50	4.70	4.83	5.00	5.17	5.21	5.50
pH	3.60	3.73	3.85	4.08	4.56	4.81	6.10
pE	11.75	11.49	11.16	9.25	6.64	6.53	7.60
Al	1.14E-04	9.11E-05	7.59E-05	5.69E-05	3.79E-05	3.26E-05	
Ba	2.48E-07	2.36E-07	2.28E-07	2.19E-07	2.09E-07	2.06E-07	1.89E-07
C		7.67E-05	1.28E-04	1.92E-04	2.56E-04	2.74E-04	3.83E-04
Ca	1.97E-03	1.79E-03	1.67E-03	1.53E-03	1.38E-03	1.33E-03	1.08E-03
Cl	4.35E-05	1.53E-04	2.25E-04	3.17E-04	4.08E-04	4.33E-04	5.90E-04
Cu	9.49E-06	7.80E-06	6.67E-06	5.26E-06	3.84E-06	3.45E-06	1.02E-06
F	7.37E-06	7.90E-06	8.25E-06	8.69E-06	9.13E-06	9.25E-06	1.00E-05
Fe	3.62E-06	2.92E-06	2.45E-06	1.86E-06	1.28E-06	1.11E-06	1.07E-07
K	4.61E-05	4.66E-05	4.69E-05	4.73E-05	4.78E-05	4.79E-05	4.86E-05
Mg	4.20E-04	3.83E-04	3.59E-04	3.28E-04	2.98E-04	2.89E-04	2.37E-04
Mn	4.04E-05	3.33E-05	2.86E-05	2.26E-05	1.67E-05	1.50E-05	4.86E-06
Na	1.24E-04	2.09E-04	2.66E-04	3.36E-04	4.07E-04	4.27E-04	5.48E-04
S	3.23E-03	2.84E-03	2.58E-03	2.25E-03	1.92E-03	1.83E-03	1.27E-03
Si	2.30E-04	2.50E-04	2.63E-04	2.80E-04	2.97E-04	3.01E-04	3.30E-04
Sr	2.84E-06	2.57E-06	2.38E-06	2.15E-06	1.92E-06	1.86E-06	1.46E-06
Zn	5.17E-04	4.87E-04	4.66E-04	4.41E-04	4.15E-04	4.08E-04	3.64E-04

Saturation Indices LOG[IAP/Kt]

Alunite	-0.5615	-0.0818	0.3726	1.2869	3.4122	4.4792	
Barite	0.7754	0.7139	0.6688	0.6063	0.5351	0.5132	0.3475
Diaspore	-2.0097	-1.6749	-1.3721	-0.7973	0.4385	1.0542	
Fe(OH)2.7	3.8433	4.0531	4.0664	2.7577	1.3246	1.8326	5.3076
Goethite	1.9223	2.0159	2.0198	0.7417	-0.5742	-0.0012	3.8344
Gypsum	-0.8478	-0.9211	-0.9755	-1.0518	-1.1396	-1.1668	-1.3718
Quartz	0.7092	0.7418	0.7620	0.7857	0.8079	0.8138	0.8481
Cuprousferrite	1.1186	1.5315	1.9188	2.6835	4.3366	5.2205	8.7397
Cupricferrite	0.3557	0.7423	0.9370	-1.2494	-3.0393	-1.4400	8.2910
ZnSiO3	-3.9136	-3.6134	-3.3508	-2.8704	-1.8881	-1.3911	1.2260
Kaolinite	-2.5277	-1.7936	-1.1485	0.0479	2.5630	3.8063	
Pyrophyllite	-0.5632	0.2232	0.9000	2.1330	4.6817	5.9339	
Lepidocrocite	1.8360	1.9214	1.9198	0.6348	-0.6879	-0.1144	3.7071
Ca-nontronite	16.6970	17.1456	17.3582	15.1424	13.1463	14.5998	
Chlorite	-6.5357	-4.6637	-2.9718	0.1093	6.7733	10.3368	

Temp. in degree C; pH and pE in units; concentrations as MOLALITY

TABLE 4. Mixtures of Drainage Tunnel Water
and Oriental East Pit Surface Water

	EAST PIT SURFACE WATER	0.25 DT in 1 EPS	0.5 DT in 1 EPS	0.75 DT in 1 EPS	1.0 DT in 1 EPS	1.25 DT in 1 EPS	DRAINAGE TUNNEL WATER
S needed	7.493E-04						3.571E-04
Fraction	0.000	0.200	0.333	0.429	0.500	0.555	1.000
Temp.	4.80	4.94	5.03	5.10	5.15	5.19	5.50
pH	6.20	6.20	6.20	6.20	6.20	6.20	6.10
pE	3.70	3.80	3.88	3.95	4.00	4.05	7.60
Ba	1.46E-07	1.55E-07	1.60E-07	1.65E-07	1.68E-07	1.70E-07	1.89E-07
Br	3.92E-05	3.14E-05	2.62E-05	2.24E-05	1.96E-05	1.75E-05	
C	2.84E-03	2.35E-03	2.02E-03	1.78E-03	1.61E-03	1.48E-03	3.83E-04
Ca	8.30E-03	6.85E-03	5.89E-03	5.20E-03	4.69E-03	4.29E-03	1.08E-03
Cl	3.64E-03	3.03E-03	2.63E-03	2.33E-03	2.12E-03	1.95E-03	5.90E-04
F	1.79E-05	1.63E-05	1.53E-05	1.45E-05	1.40E-05	1.35E-05	1.00E-05
Fe	1.41E-05	1.13E-05	9.46E-06	8.12E-06	7.12E-06	6.35E-06	1.07E-07
K	9.48E-05	8.55E-05	7.94E-05	7.50E-05	7.17E-05	6.92E-05	4.86E-05
Mg	1.34E-03	1.12E-03	9.78E-04	8.69E-04	7.90E-04	7.29E-04	2.37E-04
Mn	1.88E-04	1.51E-04	1.27E-04	1.09E-04	9.63E-05	8.63E-05	4.86E-06
Na	3.86E-03	3.19E-03	2.75E-03	2.44E-03	2.20E-03	2.02E-03	5.48E-04
S	8.98E-03	7.44E-03	6.41E-03	5.67E-03	5.12E-03	4.70E-03	1.27E-03
Si	2.71E-04	2.83E-04	2.91E-04	2.96E-04	3.00E-04	3.04E-04	3.30E-04
Sr	2.29E-05	1.86E-05	1.57E-05	1.37E-05	1.22E-05	1.10E-05	1.46E-06
Zn	2.64E-04	2.84E-04	2.97E-04	3.07E-04	3.14E-04	3.19E-04	3.64E-04

Saturation Indices LOG[IAP/Kt]

Barite	0.7185	0.7058	0.6908	0.6756	0.6612	0.6479	0.3476
Fe(OH)2.7	3.9466	3.9544	3.9578	3.9584	3.9574	3.9554	5.3076
Goethite	2.2497	2.2857	2.3103	2.3279	2.3405	2.3498	3.8344
Gypsum	-0.0714	-0.1839	-0.2741	-0.3497	-0.4131	-0.4676	-1.3717
Quartz	0.7779	0.7934	0.8032	0.8101	0.8151	0.8190	0.8481
ZnSiO3	0.9328	1.0186	1.0752	1.1158	1.1456	1.1682	1.2260
Lepidocrocite	2.1510	2.1813	2.2020	2.2169	2.2275	2.2352	3.7071

Temp. in degree C; pH and pE in units; concentrations as MOLALITY

TABLE 5. Mixtures of Drainage Tunnel Water
and Oriental East Pit Bottom Water

	EAST PIT BOTTOM WATER	0.25 DT in 1 EPB	0.5 DT in 1 EPB	0.75 DT in 1 EPB	1.0 DT in 1 EPB	1.25 DT in 1 EPB	DRAINAGE TUNNEL WATER
S needed	1.383E-04						3.571E-04
Fraction	0.000	0.200	0.333	0.429	0.500	0.555	1.000
Temp.	6.50	6.30	6.17	6.07	6.00	5.95	5.50
pH	6.30	6.30	6.30	6.30	6.30	6.30	6.10
pE	4.01	4.11	4.19	4.26	4.32	4.37	7.60
Ba	1.24E-07	1.37E-07	1.46E-07	1.52E-07	1.57E-07	1.60E-07	1.89E-07
Br	5.66E-05	4.53E-05	3.77E-05	3.23E-05	2.83E-05	2.52E-05	
C	3.68E-03	3.02E-03	2.58E-03	2.26E-03	2.03E-03	1.85E-03	3.83E-04
Ca	1.27E-02	1.04E-02	8.83E-03	7.72E-03	6.89E-03	6.25E-03	1.08E-03
Cl	5.54E-03	4.55E-03	3.89E-03	3.42E-03	3.07E-03	2.79E-03	5.90E-04
F	3.22E-05	2.78E-05	2.48E-05	2.27E-05	2.11E-05	1.99E-05	1.00E-05
Fe	7.13E-05	5.70E-05	4.76E-05	4.07E-05	3.57E-05	3.18E-05	1.07E-07
K	1.18E-04	1.04E-04	9.48E-05	8.82E-05	8.33E-05	7.95E-05	4.86E-05
Mg	1.89E-03	1.56E-03	1.34E-03	1.18E-03	1.06E-03	9.74E-04	2.37E-04
Mn	2.66E-04	2.14E-04	1.79E-04	1.54E-04	1.36E-04	1.21E-04	4.86E-06
Na	5.54E-03	4.54E-03	3.88E-03	3.40E-03	3.04E-03	2.77E-03	5.48E-04
S	1.31E-02	1.08E-02	9.19E-03	8.05E-03	7.21E-03	6.56E-03	1.27E-03
Si	3.15E-04	3.18E-04	3.20E-04	3.22E-04	3.23E-04	3.23E-04	3.30E-04
Sr	3.24E-05	2.62E-05	2.21E-05	1.91E-05	1.69E-05	1.52E-05	1.46E-06
Zn	3.71E-04	3.70E-04	3.69E-04	3.68E-04	3.68E-04	3.67E-04	3.64E-04
Saturation Indices LOG[IAP/Kt]							
Barite	0.679	0.686	0.688	0.684	0.678	0.671	0.348
Fe(OH)2.7	5.274	5.284	5.288	5.288	5.285	5.281	5.308
Goethite	3.626	3.653	3.670	3.682	3.689	3.694	3.834
Gypsum	0.155	0.041	-0.051	-0.129	-0.195	-0.253	-1.372
Quartz	0.816	0.822	0.827	0.830	0.832	0.834	0.848
ZnSiO3	1.375	1.405	1.426	1.441	1.452	1.460	1.226
Lepidocrocite	3.458	3.493	3.516	3.531	3.542	3.548	3.707

Temp. in degree C; pH and pE in units; concentrations as MOLALITY

TABLE 6. Mixtures of Oriental West Pit and
Oriental East Pit Surface Waters

	EAST PIT SURFACE WATER	0.25 WPS in 1 EPS	0.5 WPS in 1 EPS	0.75 WPS in 1 EPS	1.0 WPS in 1 EPS	1.25 WPS in 1 EPS	WEST PIT SURFACE WATER
Fraction	0.000	0.200	0.333	0.429	0.500	0.555	1.000
Temp.	4.80	4.06	3.57	3.21	2.95	2.75	1.10
pH	6.20	6.15	6.09	6.03	5.96	5.89	3.80
pE	3.37	3.46	3.54	3.61	3.67	3.72	11.45
Al		2.02E-05	3.36E-05	4.33E-05	5.04E-05	5.60E-05	1.01E-04
Ba	1.46E-07	1.69E-07	1.85E-07	1.96E-07	2.04E-07	2.10E-07	2.62E-07
Br	3.92E-05	3.14E-05	2.62E-05	2.24E-05	1.96E-05	1.75E-05	
C	2.84E-03	2.27E-03	1.89E-03	1.62E-03	1.42E-03	1.26E-03	
Ca	8.30E-03	6.99E-03	6.13E-03	5.50E-03	5.04E-03	4.68E-03	1.77E-03
Cl	3.64E-03	2.92E-03	2.45E-03	2.10E-03	1.84E-03	1.65E-03	4.35E-05
Cu		1.83E-06	3.05E-06	3.92E-06	4.57E-06	5.08E-06	9.15E-06
F	1.79E-05	1.58E-05	1.44E-05	1.34E-05	1.26E-05	1.21E-05	7.37E-06
Fe	1.41E-05	1.18E-05	1.03E-05	9.22E-06	8.41E-06	7.78E-06	2.69E-06
K	9.48E-05	8.50E-05	7.86E-05	7.39E-05	7.04E-05	6.77E-05	4.61E-05
Mg	1.34E-03	1.15E-03	1.03E-03	9.37E-04	8.69E-04	8.17E-04	3.95E-04
Mn	1.88E-04	1.58E-04	1.37E-04	1.23E-04	1.21E-04	1.04E-04	3.64E-05
Na	3.86E-03	3.11E-03	2.61E-03	2.26E-03	1.99E-03	1.79E-03	1.24E-04
S	8.98E-03	7.74E-03	6.91E-03	6.32E-03	5.88E-03	5.54E-03	2.78E-03
Si	2.71E-04	2.59E-04	2.52E-04	2.46E-04	2.42E-04	2.39E-04	2.13E-04
Sr	2.29E-05	1.88E-05	1.61E-05	1.42E-05	1.28E-05	1.16E-05	2.64E-06
Zn	2.64E-04	3.00E-04	3.24E-04	3.41E-04	3.54E-04	3.64E-04	4.44E-04

Saturation Indices LOG[IAP/Kt]

Alunite		6.7588	7.5174	7.9098	8.1636	8.3474	0.5420
Barite	0.7185	0.7741	0.8036	0.8212	0.8320	0.8391	0.8231
Diaspore		2.7064	2.8939	2.9570	2.9721	2.9607	-1.6640
Fe(OH)2.7	3.6137	3.3753	3.3150	3.1407	2.9574	2.7639	3.9216
Goethite	1.9168	1.7607	1.5848	1.3953	1.1966	0.9870	1.9186
Gypsum	-0.0714	-0.1628	-0.2342	-0.2927	-0.3406	-0.3809	-0.9220
Quartz	0.7779	0.7715	0.7668	0.7632	0.7604	0.7581	0.7371
Cuprite		0.0128	0.2890	0.3219	0.2586	0.1453	-18.6823
Cuprousferrite		10.8308	10.8035	10.6382	10.4135	10.1516	1.7053
Cupricferrite		4.1484	3.9390	3.5674	3.1183	2.6129	0.6545
ZnSiO3	0.9328	0.8570	0.7516	0.6295	0.4971	0.3550	-3.7723
Kaolinite		7.0308	7.3986	7.5193	7.5451	7.5186	-1.7656
Pyrophyllite		9.1486	9.5390	9.6757	9.7129	9.6953	0.4775
Lepidocrocite	1.8181	1.6924	1.5368	1.3620	1.1742	0.9730	1.9735
Ca-nontronite		19.0911	18.7775	18.3934	17.9739	17.5227	17.1062
Chlorite		28.3464	28.3358	27.9235	27.3503	26.6755	-3.5774

Temp. in degree C; pH and pE in units; concentrations as MOLALITY
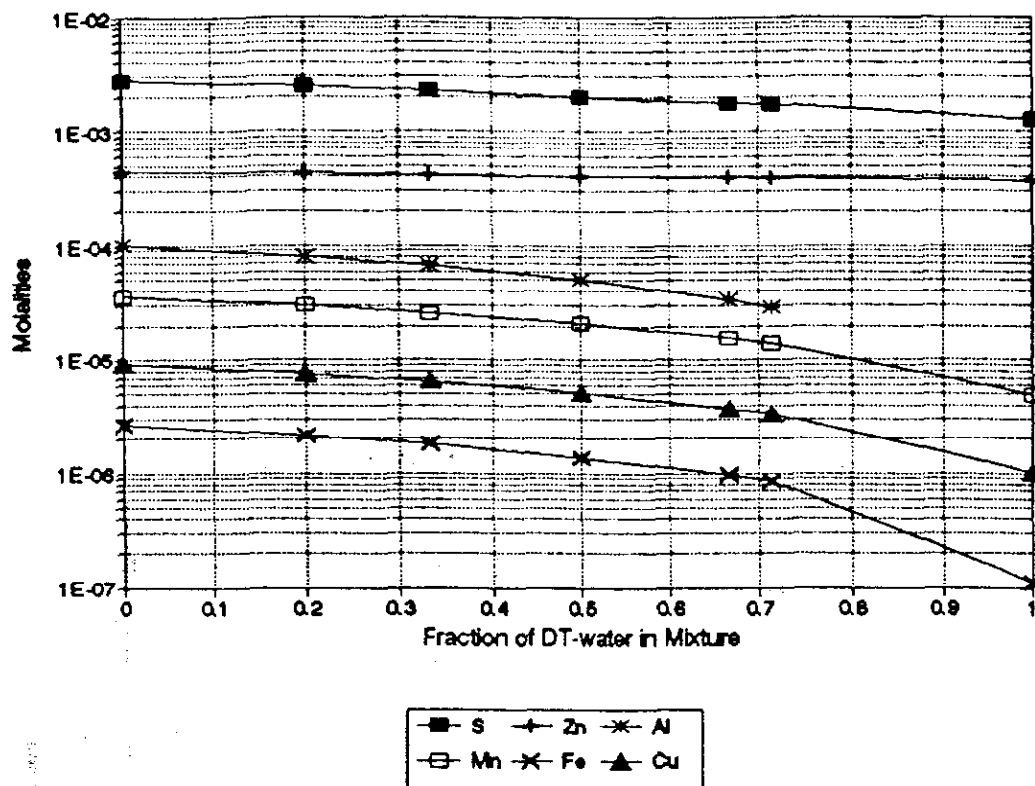
Figure 1-A. Mixtures: DT and WPS waters

Legend:
- ■ S
- + Zn
- ✳ Al
- ☐ Mn
- ✕ Fe
- ▲ Cu

Figure 1-B. Mixtures: DT and WPS waters

Legend:
- ■ Diaspore
- + Fe(OH)2.7
- ✳ Gypsum
- ☐ Quartz
- ✕ CuFerrite
- ▲ ZnSiO3

Figure 2-A. Mixtures: DT and WPB waters

Legend: ■ S + Zn ✳ Al ⊟ Mn ✕ Fe ▲ Cu

Figure 2-B. Mixtures: DT and WPB waters

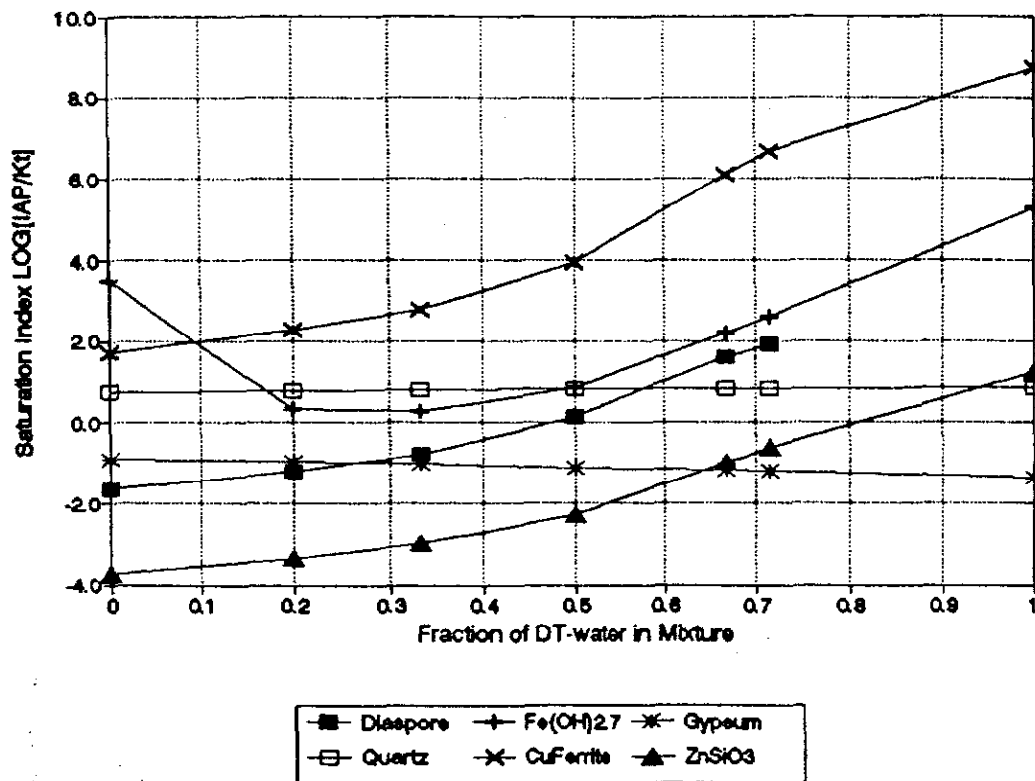Legend: ■ Diaspore + Fe(OH)2.7 ✳ Gypsum ⊟ Quartz ✕ CuFerrite ▲ ZnSiO3
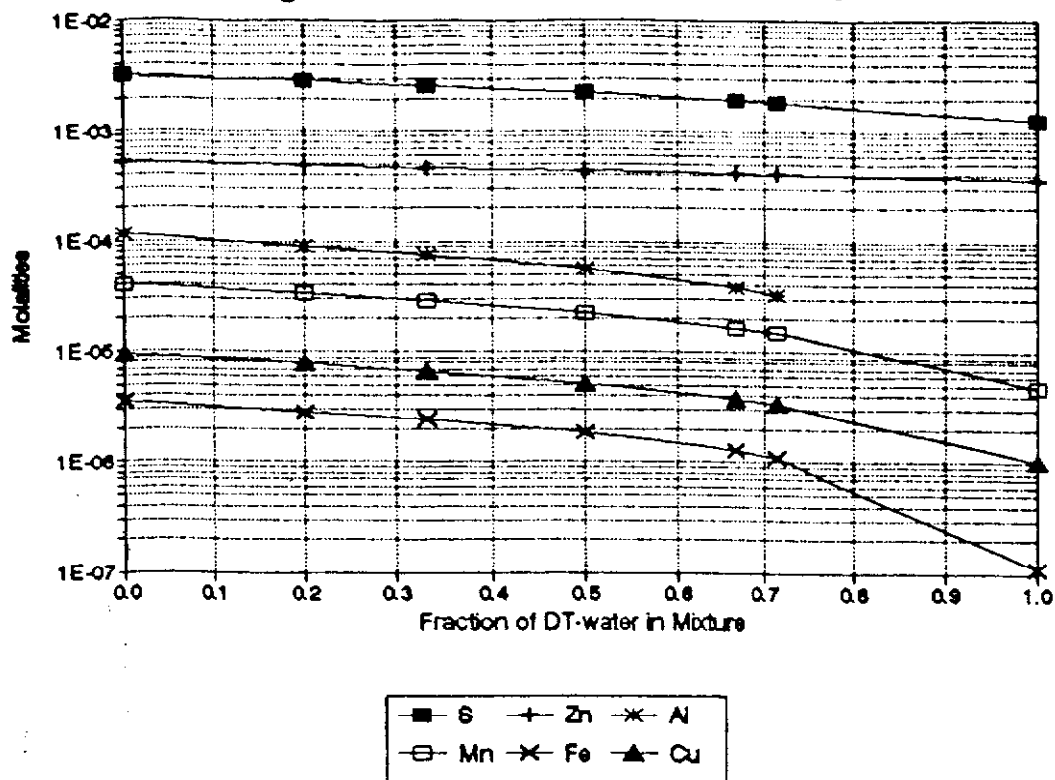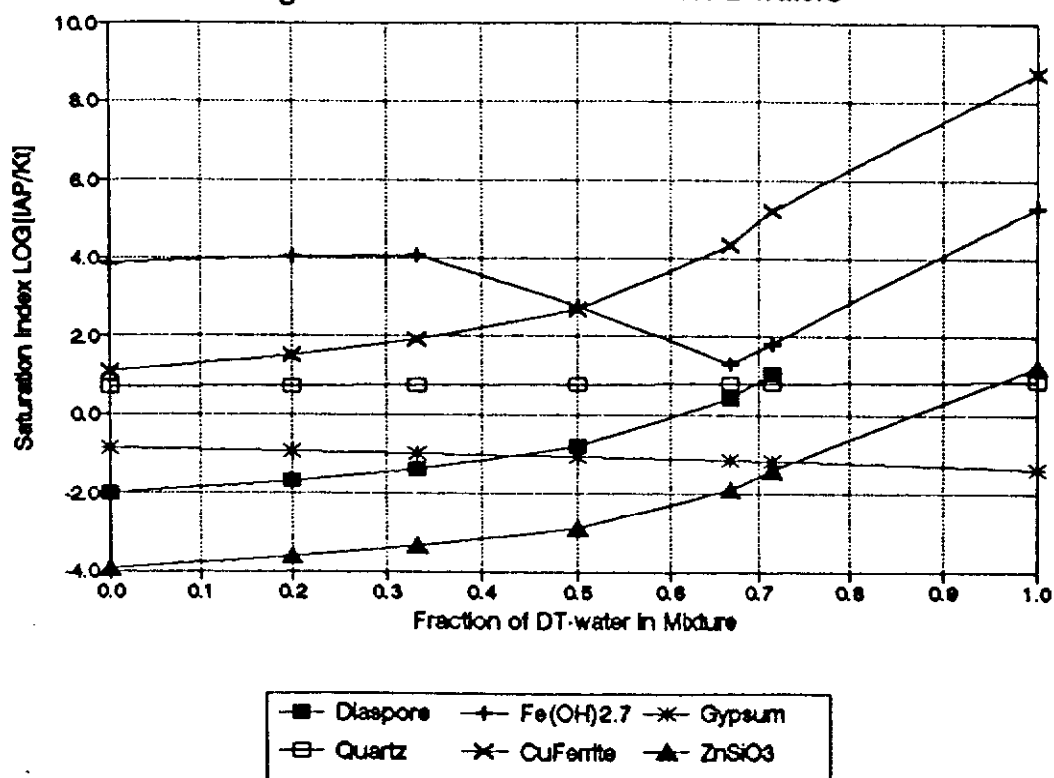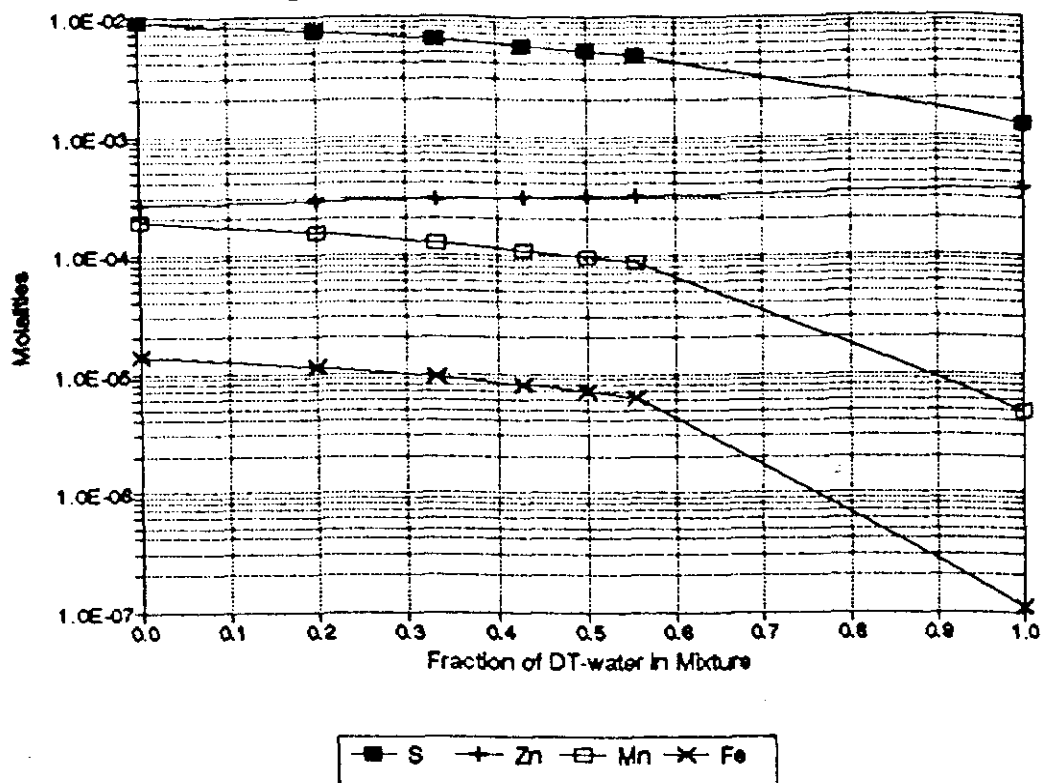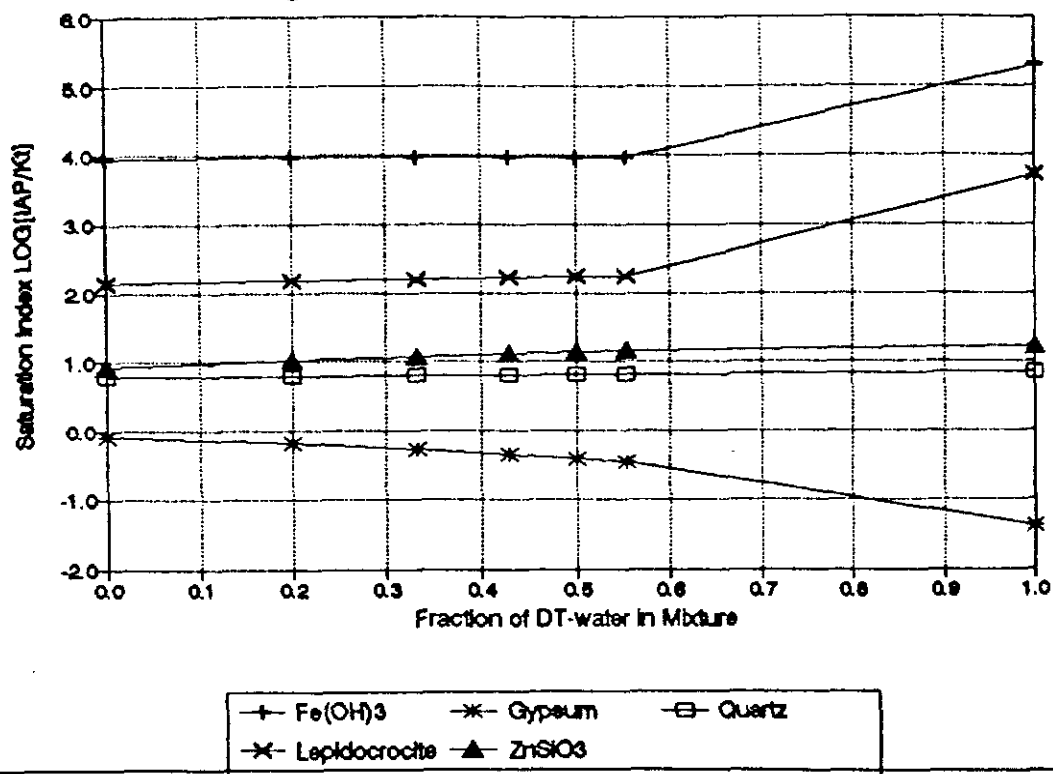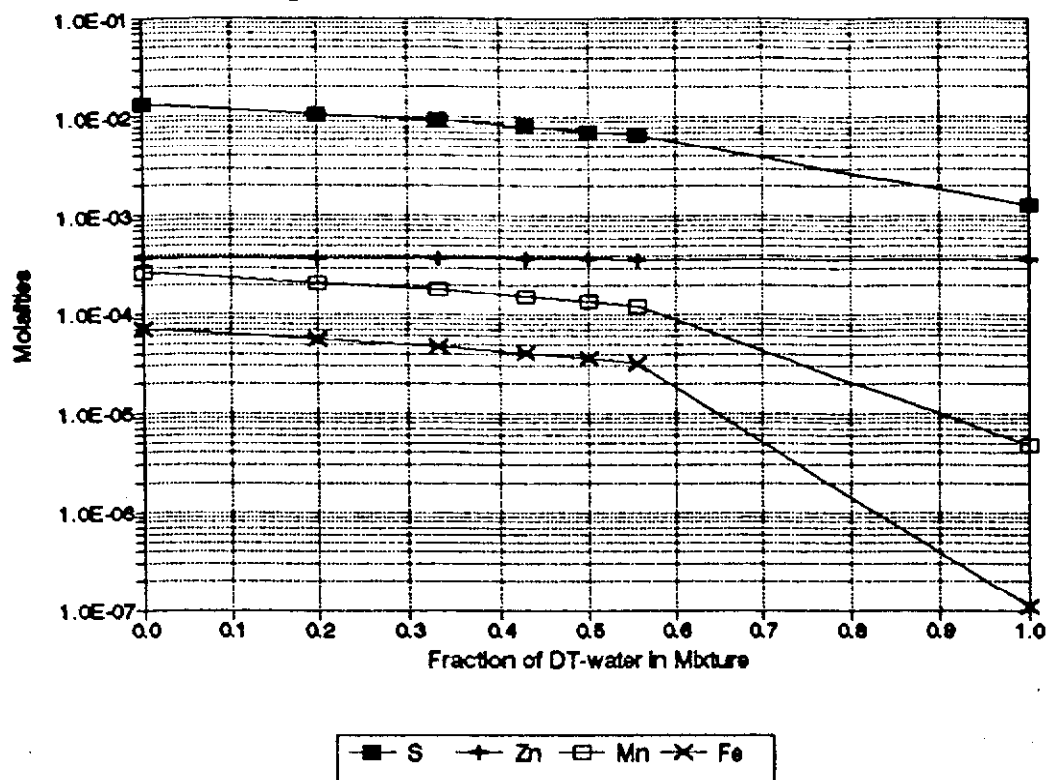
Figure 3-A. Mixtures: DT and EPS waters

Figure 3-B. Mixtures: DT and EPS waters

Figure 4-A. Mixtures: DT and EPB waters

Legend: —■— S   —+— Zn   —□— Mn   —✕— Fe

Figure 4-B. Mixtures: DT and EPB waters

Legend: —+— Fe(OH)2.7   —✳— Gypsum   —□— Quartz   —✕— Lepidocrocite   —▲— ZnSiO3
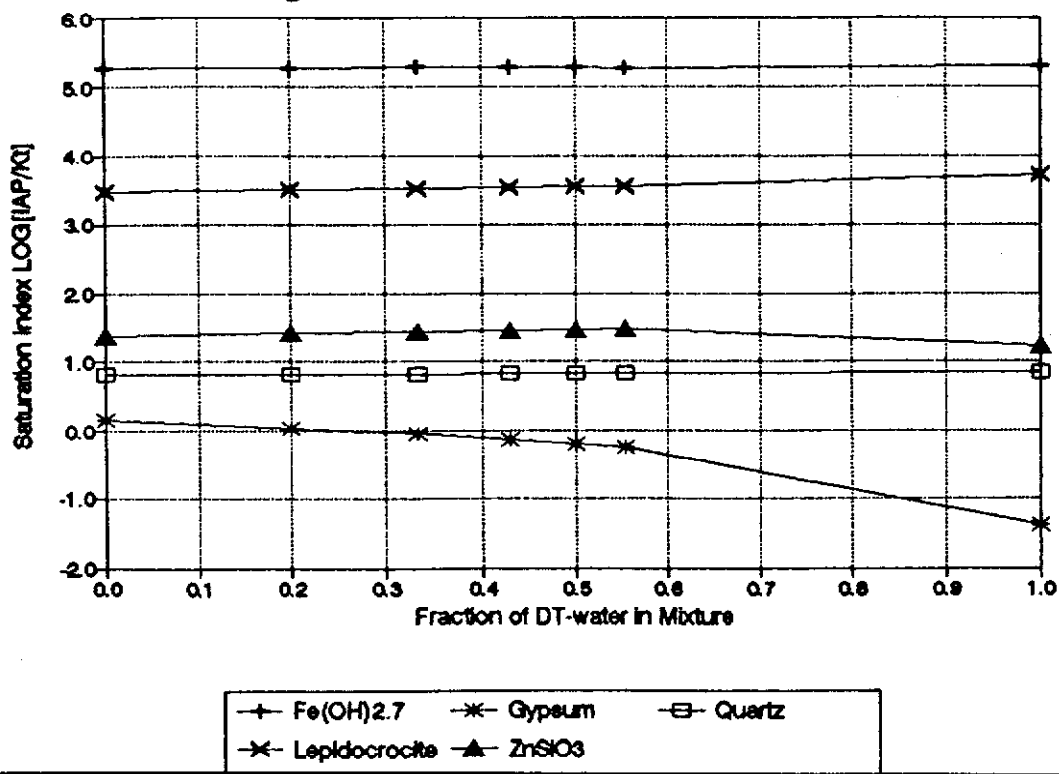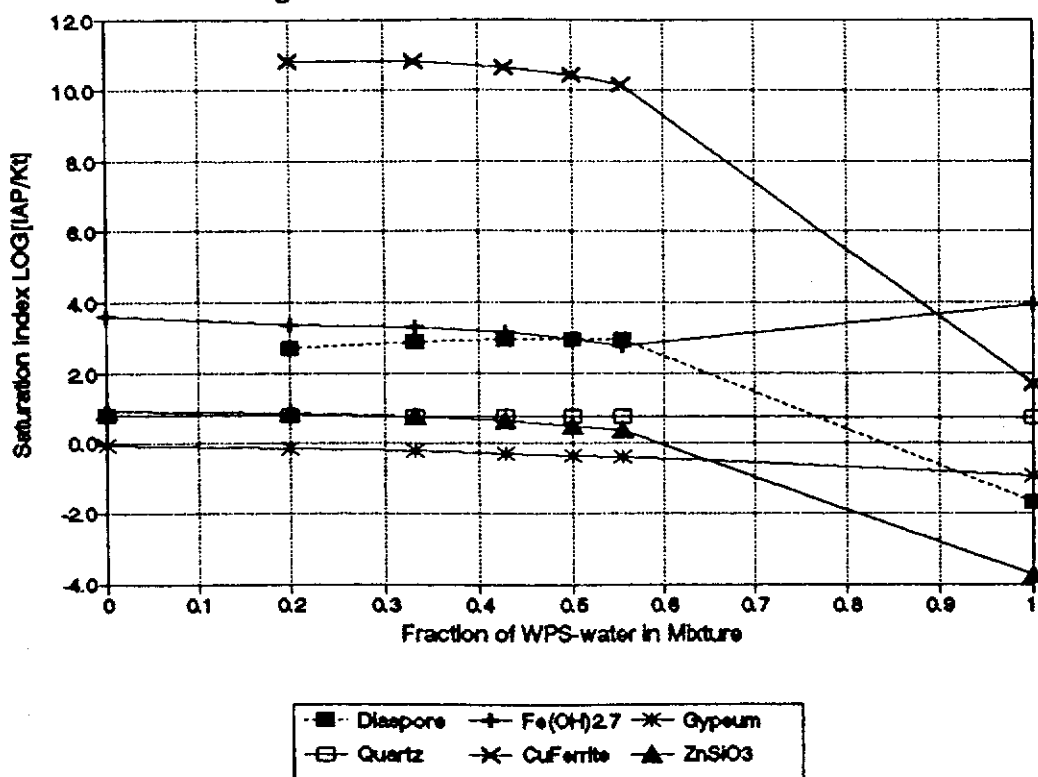
Figure 5-A. Mixtures: WPS and EPS water
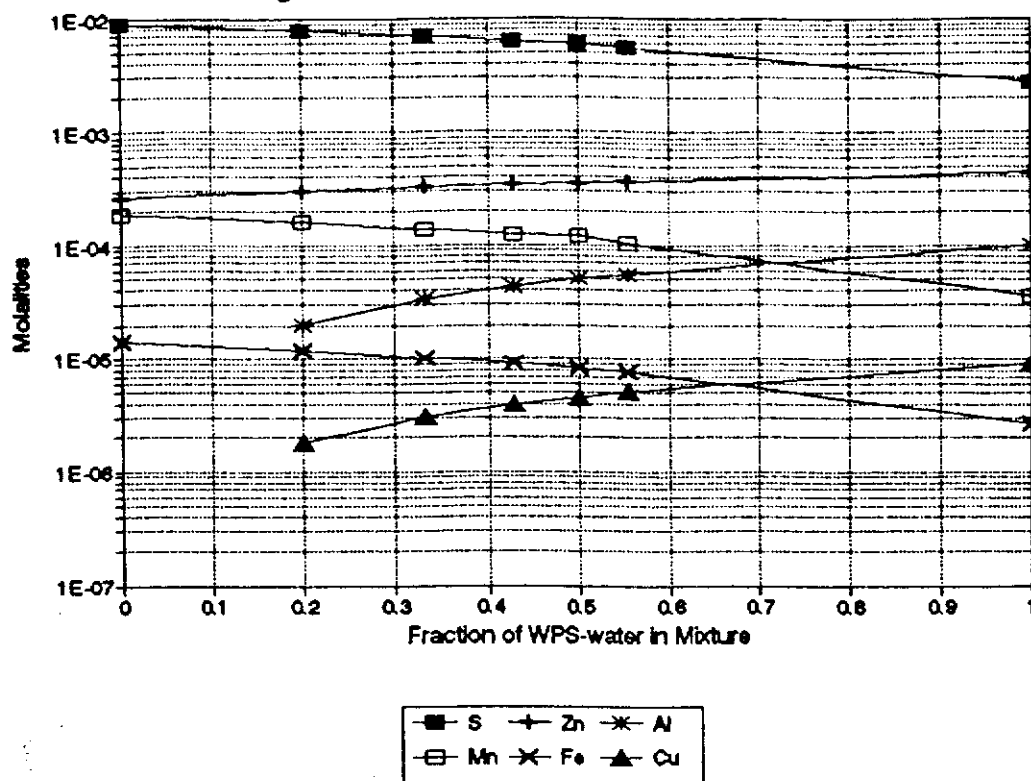
Figure 5-B. Mixtures: WPS and EPS water

7.42

```
PC Shell Version 6              Directory Print              ID =  BUCHANS1993
--------------------------------------------------------------------------------
Path=B:\MAPS
    Name      Ext     Size #Clu   Date     Time   Attributes
    SCHEM-1A  CDR     22379   44 12/10/93 10:21a      A
    SCHEM-1B  CDR     21809   43 12/10/93 10:31a      A
    SCHEM-1C  BAK     21307   42 12/10/93  9:55a      A
    SCHEM-1C  CDR     21305   42 12/10/93  9:56a      A
    SCHEM-2   BAK     23867   47 12/09/93 11:06a      A
    SCHEM-2   CDR     23879   47 12/10/93 11:24a      A

    6 files LISTed        134,546 bytes    6 files in sub-dir =   134,546 bytes
    0   files SELECTed          0 bytes    Available on volume =   23,552 bytes
```

7.43   7.44

```
PC Shell Version 6              Directory Print              ID =  BUCH93-TEXT
--------------------------------------------------------------------------------
Path=B:\
    Name      Ext     Size #Clu   Date     Time  Attributes
    BUCREP93  BAK    120987  237 12/22/93  6:10p     A
    BUCREP93  D20    120987  237 12/22/93  6:10p     A

    2 files LISTed        241,974 bytes    2 files in sub-dir =   241,974 bytes
    0   files SELECTed          0 bytes    Available on volume = 1,214,976 bytes
```

PC Shell Version 6   Directory Print   ID =   BUCHANS1993

Path=B:\DATA

Name	Ext	Size	#Clu	Date	Time	Attributes	
ACID-ALK	WQS	315139	616	12/21/93	6:10p	A	Fig 29a, 29b, 29c, 29d Fig 32a, 32b, Table 12
BPDAT-93	WQS	29876	59	12/16/93	3:05p	A	
BR-DATA	WQS	25670	51	12/10/93	11:47a	A	
BRH-DATA	WQS	4221	9	12/06/93	10:48a	A	
DT-DATA	WQS	60502	119	12/18/93	6:56p	A	Fig l: graf DT-FLOW Fig 3: Fig 4:
FG28-TB9	WQS	30871	61	12/21/93	3:33p	A	Table 9: Fig 28:
FIG-27	WQS	59307	116	12/21/93	2:15p	A	Fig 27
FIG18-20	WQS	13925	28	12/19/93	5:28p	A	Fig 18: Fig 19:, Fig 20
FIG21	WQS	6687	14	12/19/93	5:52p	A	Fig 21:
FIG24AB	WQS	85600	168	12/19/93	7:12p	A	Fig 24a, Fig 24b
FIG26	WQ1	7802	16	12/19/93	7:02p	A	Fig 26:
FLD-8-93	WQS	16561	33	12/10/93	11:37a	A	
LS-APRIL	WQS	4768	10	12/18/93	7:04p	A	
LS-DATA	WQS	35845	71	12/18/93	7:06p	A	Fig 2: graf LS-DT-ELE-FL, Fig 5a, 5b, Fig 6
MIX-TAB	WQS	5614	11	12/10/93	3:08p	A	Table 7:
OEP-4-93	WQS	13925	28	12/10/93	1:19p	A	
OEP-DATA	WQS	99428	195	12/19/93	4:25p	A	Fig 8: , Fig 10:, Fig 11
OEP-O2	WQS	4069	8	12/10/93	3:06p	A	Table 2:
OEP-OWP	WQS	63187	124	12/10/93	3:00p	A	Fig 23a, Fig 23b
OEP-OWPB	WQS	43352	85	12/10/93	3:04p	A	Fig 23c, Fig 23d
OEP-PREC	WQS	5120	10	12/19/93	5:59p	A	Table 5:
OEP-PROF	WQS	22073	44	12/19/93	4:29p	A	Fig 9:
OEP-ZINC	WQS	6687	14	12/10/93	2:56p	A	
OEPOWPSS	WQS	4314	9	12/10/93	3:06p	A	
OEPWQ493	WQS	14410	29	12/10/93	3:08p	A	
OWP-DATA	WQS	36831	72	12/19/93	5:07p	A	Fig 7: Fig 17
OWP-ICP	WQS	10050	20	12/10/93	3:10p	A	
OWP-SED	WQS	13782	27	12/12/93	5:27p	A	
RETENT	WQS	5213	11	12/19/93	6:31p	A	Table 6:
S-T-1992	WQS	12577	25	12/19/93	6:06p	A	Fig 22:
SB-DATA	WQS	23374	46	12/10/93	12:51p	A	
TAB-10	WQS	14188	28	12/21/93	6:35p	A	Table 10:
TAB-11	WQS	3884	8	12/21/93	3:25p	A	Table 11:
TABLE1	WQS	10050	20	12/19/93	5:34p	A	Table 1:
TABLE2	WQS	4069	8	12/19/93	5:37p	A	
TABLE3	WQS	14410	29	12/19/93	5:41p	A	Table 3:
TABLE4	WQS	4314	9	12/19/93	5:47p	A	Table 4:
TABLE7	WQS	5614	11	12/19/93	6:33p	A	
TB8-FG25	WQS	18691	37	12/21/93	4:00p	A	Table 8a, Table 8b
TP1-DATA	WQS	37875	74	12/19/93	4:35p	A	Fig 12: Fig 13:
TP2-DATA	WQS	59165	116	12/19/93	4:43p	A	Fig 14, Fig 15, Fig 16
WR-PONDS	WQS	32146	63	12/21/93	6:22p	A	Fig 31:

```
42 files LISTed       1,285,186 bytes    42 files in sub-dir =  1,285,186 bytes
0  files SELECTed             0 bytes    Available on volume =      23,552 bytes
```