Anvil Range Pit Lakes
Evaluation of In-Situ Treatment

Report Prepared for

Deloitte and Touche Inc.

Interim Receiver of Anvil Range Mining Corporation

Report Prepared by

SRK Consulting
Engineers and Scientists

December 2004

Anvil Range Pit Lakes
Evaluation of In-Situ Treatment

Deloitte and Touche Inc.

Interim Receiver of Anvil Range Mining Corporation
Suite 1900, 79 Wellington Street West
Toronto, ON M5K 1B9

SRK Project Number 1CD003.048

SRK Consulting (Canada) Inc.
Suite 800, 1066 West Hastings Street
Vancouver, B.C. V6E 3X2

Tel: 604.681.4196   Fax: 604.687.5532
E-mail: vancouver@srk.com   Web site: www.srk.com

December 2004

Author
John Chapman

Reviewed by
Daryl Hockley

Table of Contents

List of Tables

List of Figures

List of Appendices

1 Introduction

An assessment of the Faro, Vangorda and Grum pit lakes completed in 2003 concluded that concentrations of contaminants in the water would trend towards levels that could be amenable to in situ biological treatment. At the planning meeting held in February 2004 it was decided that further testing of the in situ treatment option was warranted.

Biological treatment of pit lakes is a relatively new method. To ensure that the test program would take the latest experience and research into consideration, a number of experts in the field were invited to a meeting to discuss the program. From that group, teams were selected to carry out the following:

i) *Laboratory Program*. Laboratory tests were undertaken to evaluate the feasibility of enhancing phytoplankton growth in the Grum Pit Lake, and to assess fertilizer and amendment requirements. The laboratory program was carried out by Microbial Technologies Inc.

ii) *Field Testing.* The Grum pit lake was fertilized to promote phytoplankton growth and then monitored for primary production and metal removal. Additional field testing to evaluate phytoplankton growth under different conditions was completed in limnocorrals, or enclosures used to isolate portions of the pit lake.

iii) *Assessment of Physical Limnology*. The possibility of meromixis (i.e. permanently stratified conditions) developing in each pit lake was assessed.

iv) *Source Characterization.* Contaminant sources in the pit areas were investigated to improve estimates of the future metal concentrations to the pit lakes.

The pit lake fertilization limnocorral and programs were carried out by Lorax Environmental Services Inc. in association with Laberge Environmental Services. The assessment of physical limnology was completed by Lawrence Associates. The source characterization was carried out by SRK Consulting.

This report provides an overview of the results form each component of the program. The results are then used to evaluate the potential for biological treatment to be implemented in each of the pit lakes.

2 Laboratory Investigations

2.1 Introduction

The laboratory study was conducted as a precursor to the field limnocorral and Grum Pit Lake fertilization program. The primary objectives of the investigation included:

- Assessment of the fertilizer requirements to stimulate and support algal growth in waters from the Faro, Grum, and Vangorda Pit Lakes; and,
- Evaluation of the potential toxicity of these waters to algae.

A secondary objective of the study was to determine if algal blooms could remove zinc from the pit lake water.

The study comprised three tasks. In the first task, an algal inoculum was developed from Vangorda water for use in subsequent tasks. The second task attempted to determine "toxicity thresholds" for the pit lake waters by evaluating growth rates at various freshwater dilution ratios. The third task evaluated the effects of different doses and types of fertilizer on algal growth rates.

Water samples collected by Laberge Environmental Services from the Faro, Grum and Vangorda Pit Lakes were shipped to Microbial Technologies on May 14, 2004 and used in the laboratory testing program.

The complete report prepared by Microbial Technologies is provided in Appendix A. The following sections briefly summarise the results and discusses the conclusions from the program.

2.2 Summary of Results

The analysis of water samples from the Faro, Grum, and Vangorda Pit Lakes indicated nutrient limiting conditions. The Faro water contained some ammonia, but very little phosphorus. Phosphorus was present at low concentrations in the Grum Pit Lake; however, the ammonia-nitrogen concentration was low. The Vangorda Pit Lake water contained little of either nutrient.

Grum ice samples were found to contain algae which grew very rapidly subsequent to fertilization. The inoculum used for all other tests was developed from these algae. However, it was found a distinct algae population grew in each of the pit lake waters when fertilized, suggesting that algae were already present in each of the pit lakes.

While various dilution ratios were tested to determine potential toxic threshold concentrations, it was found that algae grew in every full-strength pit lake water sample, despite elevated zinc concentrations. Growth in diluted pit lake water however was faster than in full-strength water for all the pit lakes.

Both fish and chemical fertilizer were found to support algal growth. The fertilizer tests also indicated that amendment rates of about 5 mg/L NH_3-N and 0.5 mg/L PO_4-P would be adequate to produce vigorous algal growth in waters from all of the pit lakes.

The laboratory scale tests further suggested that algal blooms go through cycles of planktonic growth to a high cell density, before clumping and settling reduces the cell density. However, zinc removal was not apparent in these tests when compared with control tests.

2.3 Conclusions

The main conclusions from the laboratory testing program can be summarised as follows:

- Algae appear to already be present in each of the pit lakes.
- Fertilization by either fish or chemical fertilizers should stimulate and maintain algal growth in all three pit lakes.
- Elevated zinc concentrations present in the pit lakes may impair, but do not appear to prevent, algal growth.
- Results with respect to zinc removal were inconclusive and zinc removal by algae would require additional demonstration.

Since algal growth was achieved in the laboratory scale tests, the investigation moved into the field limnocorral and whole lake fertilization phase.

3 Field Investigations

3.1 Biological Treatment Assessment

3.1.1 Introduction

The field program comprised three limnocorrals and the whole lake fertilization of the Grum Pit Lake. The limnocorral tests were designed to assess alternative water treatment options, with including one test amended with EDTA to reduce zinc toxicity, one test to evaluate fish fertilizer, and one test set up as a control with no fertilizer added. The field testing commenced in the first week of July 2004 and continued to the second week of September 2004.

In addition to water quality and biological parameters, physical parameters were also monitored. The complete report prepared by Lorax Environmental Services is provided in Appendix B. Salient results and conclusions are presented and discussed briefly below.

3.1.2 Results and Discussion

Limnocorrrals

Primary production or algal growth was readily promoted in both the fish fertilized and the EDTA amended (chemically fertilized) limnocorrals. Monitoring results for these two limnocorrals indicated that there were no significant differences in growth rate between the EDTA (chemically fertilized) and fish fertilizer amended limnocorrals. The algae production rates in these two tests also were very similar to that observed in the whole lake fertilization program and well above the growth rate observed for the control test.

Due to the similarities between these two tests, and the success achieved in the whole lake program, it became apparent that these tests were not providing any additional useful information. Consequently the operating strategies for the tests were changed to assess the effects of fertilizer cessation (fish fertilizer amended test) and the introduction of Vangorda water to the test (EDTA amended test).

Cessation of fertilizer addition did not lead to an immediate ‘shut-down’ of primary production. Primary production persisted and resulted in a marginal increase of chlorophyll “a” in the surface layer. These results indicate that the ‘system’ is comparatively robust against upsets in fertilization, should it occur at full-scale. However, metal uptake rates decreased, which indicates that sustained metal removal will require a sustained fertilization regime.

Introduction of Vangorda water into the second system was unsuccessful. The Vangorda water was significantly denser than the cooler epilimnion water of the Grum Pit, and, as a result, ‘sank’ out of the bottom of the limnocorral.

The control test results indicated that there was a resident population of algae present in the Grum Pit Lake before testing commenced. However, typical of a nutrient limited system, the algae population decreased over time. In all other respects, conditions in the control test were similar to the whole lake conditions.

Pit Lake Fertilization

Measurement of the physical parameters of the water column indicated that the pit lake stratified early in the season to form a stable thermocline about 4 to 5 m from the surface of the lake. The thermocline persisted for the entire testing period. The results also indicated that the near surface water had a lower dissolved salt content than the rest of the water column, likely due to ice-melt, and freshwater run-in from the spring freshet.

Chemical analysis of the Grum Pit Lake water indicated that phosphate, an essential nutrient for algal growth, was below detection at all depths. This, together with the fact that algae were detected in the water column, indicated that the pit lake system was nutrient deficient which limited algal growth.

The Grum Pit Lake was fertilized on a weekly basis at rates of about 2,340 mg nitrogen per square meter, and 220 mg phosphorus per square meter. (This equates to about concentrations of about 0.4 mg/L N and 0.04 mg/L P in the stratified surface layer.) The chlorophyll “a” monitoring results indicated a rapid response in algal growth to fertilization due to the fact that there was a significant algal population already present in the water column.

The peak algal population density for the entire depth of the surface layer occurred approximately two weeks after fertilization commenced. Field observations of the colour of the lake, which turned green, then brown, and then back to green, suggested that the algal growth may have cycled through various stages. However, the integrated chlorophyll “a” value increased with ongoing fertilization through to the end of the test period, indicating that good growth was maintained throughout the testing period. In comparison to the control limnocorral, which received no fertilizer, the growth that was achieved in the pit lake was considerable.

The results further indicated that nutrients were more or less consumed as they were added. No build-up of phosphorus occurred during the testing period. However, there was a marginal increase in nitrogen species over the test period. The latter results indicated that the ratio of phosphorus to nitrogen should be slightly increased if the method is used in future.

Zinc Removal

Water quality monitoring results indicated that initially there was a rapid transfer of zinc from the dissolved to the particulate form, as indicated by the initial decrease in the measured dissolved zinc concentration while total zinc concentrations remained unchanged. Total zinc removal occurred when the particulates started to settle from the water column. Total and dissolved concentrations of zinc concentrations in the shallow surface layer (to a depth in excess of 1 m) decreased to below 0.3 mg/L by the middle of August. Thereafter, zinc concentrations increased marginally.

The marginal increase of the zinc concentration in late summer to early fall can in part be attributed to the decay of the thermocline (mixing of higher concentration zinc water from depth with the shallow low concentration water) and, in part, to ongoing source loadings to the surface as discussed in the next chapter.

Lorax completed zinc concentration calculations integrated over the depth of the surface layer which showed a net decrease in zinc concentration in the pit lake from about 30 g/m^2 to about 7 g/m^2 over the testing period. These integrated concentrations can be converted to removal rates specific to the surface layer. The removal rate is calculated from these results to be about 0.33 g/m^2/day for the entire test period. This rate represents an average net removal and does not account for any additional loading from the wall rocks that may have affected the pit lake water quality. The actual removal rate is likely to have been greater than these calculations indicate. The maximum rate of removal occurred during the first four weeks at which time zinc was removed at about 0.78 g/m^2/day.

The control limnocorral, which received no fertilizer, yielded a zinc removal rate of about 0.27 g/m^2/day for the period starting on the 1st of July and ending on the 25th of August. This is not very different to that observed over the same time period of the whole lake (about 0.45 g/m^2/day). However, it should be noted that the control was isolated and was not subject to any additional loads from wallrocks. In addition, in contrast to the pit lake results (which decreased to below 0.3 m/L), the zinc concentration in the surface layer of the control limnocorral did not decrease below 5 mg/L. Therefore, the effectiveness of zinc removal in the pit lake due to algal growth is apparent.

Zinc removal from the water column was confirmed by the sediment traps that that were installed within the pit lake and below the limnocorrals. The sediment traps were installed at depths of 12 m and 40 below surface. The sediment traps at 12 m depth clearly showed organic matter containing on average 2.7 percent zinc. The zinc removal rates, estimated from the sediment flux rates at about 0.096 g/m^2/day were lower, however, than those calculated from the overall water and load balances. The reason for the difference is likely due to slow settling rates so that not all of the algae had settled from the water column at the time the sediment traps were sampled. Therefore, the overall mass balance calculations for the surface layer of the lake provide a more accurate indication of actual zinc removal rates.

3.1.3 Conclusions

The field investigation concluded that amendments to reduce metal toxicity, such as EDTA, would not be required to establish algal growth in the Grum Pit Lake. In fact, the pit lake responded rapidly to fertilization with excellent phytoplankton growth occurring within two weeks of fertilization. It was also concluded that chemical fertilizers are suitable and that fish fertilizer would not be required.

Zinc removal by phytoplankton was demonstrated to the extent that total zinc concentrations in the near surface water were reduced to below 0.3 mg/L. It was concluded that actively growing cells were more effective at zinc removal or uptake.

It was furthermore concluded that sustaining a continuous growth of algae by frequent fertilization programs would result in more effective metal removal compared to pulsed eutrophication (i.e. stimulating successive algae blooms and then allowing them to ‘die-off’).

In a comparison to conditions in the Faro and Vangorda Pit Lakes, Lorax concluded that it it would be possible to initiate and sustain algae growth in both these pit lakes. The larger surface area of Faro pit would result in a proportionally larger metal removal capacity. The strongly anoxic conditions at depth in the Vangorda Pit may promote sulphate reduction which could lead to the formation of stable insoluble sulphide minerals.

4 Physical Limnology

4.1 Introduction

A climate station was established on the raft that was used to commission the limnocorrals. As well, conductivity-temperature-density (CTD) profiles of the Grum Pit were monitored during the open water summer period. CTD profiles were also obtained for the Faro and Vangorda Pit Lakes. These results were reviewed by Lawrence and Associates, who commented on the stability of the pit lake systems. Their report is provided in Appendix C and is summarised briefly below.

4.2 Summary of Results

The CTD profiles from all three pits in early summer shows a thin, warm and fresh surface layer, likely the result of ice melt and spring runoff. In Grum and Vangorda Pit Lakes the surface layer extended to a depth of 3 m deep, and close to 6 m in the Faro Pit Lake.

The Grum Pit Lake showed a decrease in surface conductivity from June 30 onward, which suggests an input of fresh water. By the end of August, the surface layer started to cool and deepened to about 4.5 m by September 8.

The moored climate data showed winds to be moderate and air temperatures generally decline from mid-August and vary around 0°C by early September. Solar radiation declined through the period of record. The surface layer temperature in the Grum Pit Lake varied from 14 to 18 °C during the summer with diurnal warming evident on sunny days. Surface layer cooling was found to be greatest during periods of high wind and low air temperature.

At depth Grum Pit Lake (>10 m) temperature was 4.5 ºC at the onset of the monitoring period. It increased slightly to about 4.7 ºC over the summer as a result of low-level mixing in the hypolimnion, which normally occurs in lakes.

4.3 Conclusions

Study suggests that the three pit lakes may be quite different due to the deep-water variability in conductivity amongst the lakes. Vangorda has the highest salinity contrast between surface and deep water and the smallest salinity contrast is observed in the Grum Pit Lake.

Based on the CTD profiles it was also concluded that significant fresh water input may be occurring to the surface of the Grum Pit Lake though summer and early fall.

It was also concluded that under-ice CTD sampling from all three pit lakes will be crucial to completing stability assessments and determining the potential for permanent stratification to develop. Ice samples would also be required to assess the amount of salts trapped in the ice, which would be indicative of the freshwater layer that would be formed during spring melt.

5 Source Characterization

5.1 Introduction

Water and load balances were developed for each of the Faro, Grum and Vangorda Pit Lakes and have been reported previously (SRK, 2004). A refinement of the estimated contaminant loadings presented in that report was identified as a key element in the evaluation of the biological water treatment in the Anvil Range pit lakes. Therefore, during 2004 additional investigations comprising wallrock mapping verification, pit wall seepage sampling and analysis, and incorporating the updated waste rock loading estimates in the pit lake water and load balances. The results from these additional investigations were incorporated into the previously developed water and load balances to provide updated estimates of potential future water quality. The complete report is presented in Appendix D and the results and conclusions are briefly summarised below.

5.2 Summary of Results

5.2.1 Faro Pit

Three scenarios were considered in the water quality estimates for the Faro Pit Lake as follows:

- *Base Case*. Faro Creek diversion would be breached and allowed to spill into the pit.
- *Isolated Pit*. The diversion would be maintained and the pit lake would be allowed to fill naturally
- *Reduced Loading*. This case is the same as the base case but the Faro Valley Dump would be removed.

In all three cases it was assumed that the loadings from the ore stockpiles would be removed from the pit catchment by other remediation methods, and that the Zone II pit discharges would be directed to the water treatment plant. It was also assumed that a plug dam would be constructed across the southeast pit ramp, to increase the flood elevation to 1173.5 masl.

The results indicate that in the base case the water level is expected to reach the 1173.5 masl spill elevation in about 2007. At that time the estimated zinc concentration would be about 5 mg/L. In the long-term, the zinc concentration is expected to decrease to about 3 mg/L.

For the isolated pit conditions, the pit lake would be expected discharge by about 2047. At that time, the zinc concentration is expected to be about 22 mg/L. Thereafter, the zinc concentration is expected to continue to increase for about 200 years to about 32 mg/L.

Removing the Faro Valley Dump as a contaminant source will result in only a marginal change from the base case concentrations. The zinc concentration is expected to be about 4.6 mg/L when the pit overflows, and it would then decrease to about 2.7 mg/L in the long-term.

5.2.2 Grum Pit

Since there are no major diversions around the Grum Pit Lake and since there are no waste rock loadings to the pit lake, only one scenario was evaluated. For this scenario it was assumed that the Grum Interceptor ditch would be breached. The calculations indicate that the Grum Pit Lake is expected to reach the 1230 masl spill elevation at about 2030. At that time, the zinc concentration would be about 2.9 mg/L and in the long term it would decrease to about 0.33 mg/L. However, the long-term concentration would be reached only in about 200 years due to the small inflow to the pit.

5.2.3 Vangorda Pit

As for the Faro Pit Lake, three scenarios were considered for the Vangorda Pit Lake. In the *Base Case*, it was assumed that the Vangorda Creek diversion would be breached and allowed to spill into the pit. The *Isolated Pit Case* addresses conditions whereby the diversion is maintained, and the *Reduced Loading Case* examined the effects of removing the Southeast (SE) Ramp Dump and the Hairpin Dump from the source loadings.

All three cases assumed that the pit will ultimately overflow the northwest side of the pit at the approximate plan location of the original Vangorda Creek channel. This would result in an ultimate pit lake elevation of 1130 masl.

In the Base Case, with the Vangorda Creek diversion breached, Vangorda Pit Lake is expected to spill within a year. The calculations indicate that the zinc concentration would be about 33 mg/L at that time. In the long term, the zinc concentration would be expected to decrease to about 1.5 mg/L.

In the Isolated Pit Case, the pit is expected to discharge by about 2023 at which time the zinc concentration would be about 102 mg/L. In the very long term the zinc concentration would be expected to decrease to about 67 mg/L.

Eliminating the loadings of the Vangorda in-pit dumps in the third case is expected result in conditions similar to those estimated for the base case. At the time the pit lake spills, the zinc concentration is expected to be about 33 mg/L, and in the long term it would decrease to a concentration of 1.3 mg/L.

5.3 Conclusions

The results from the calculations indicate that the water quality in the short and long term is not expected to change significantly from the range of water quality that presently exists in the three pit lakes. It is therefore concluded that implementation of biological treatment in the pits would not be constrained by the metal concentrations that could develop in the pit lakes. The performance of biological treatment will therefore depend on the net loadings to each of the pit lakes. Estimated zinc loadings for each of the scenarios developed for each of the pit lakes have been extracted and are shown in Table 5.1. These loadings are used in the next section to assess the potential success that may be achieved with biological treatment.

Table 5.1 Summary of Estimated Zinc Loadings to the Pit Lakes

Location	Case	Zinc Loadings (kg/year)					
		Initial			Fully Flooded		
		Wallrock	Dumps	Total	Wallrock	Dumps	Total
Faro	Base & Isolated Pit	24,000	2,000	27,000	15,000	2,000	17,000
	Reduced Loadings	24,000	1,000	25,000	15,000	1,000	16,000
Grum	Base Case	350	-	350	100	-	100
Vangorda	Base & Isolated	18,000	2,000	20,000	13,000	2,000	15,000
	Reduced Loadings	18,000	-	18,000	13,000	-	13,000

6 Pit Lake Treatability Assessment

6.1 Introduction

In this chapter, the combined findings from the laboratory and field testing programs and the source characterization are used to evaluate the feasibility for implementing biological treatment tat the Faro, Grum and Vangorda Pit Lakes.

The initial evaluations below assume that the current pits would be operated as flow-through lake systems in the long term, i.e. all diversions would be breached. It is also assumed that "dimictic", i.e. that their layers would turn over at least twice a year. The implications of permanent stratification or "meromictic" conditions, and the modifications of the Faro Pit by the addition of tailings, are discussed later.

6.2 Biological Treatment Effectiveness

Removal rates for zinc were calculated from overall mass balances derived for the surface layer of each of the limnocorrals and the Grum Pit Lake. The results are summarised in Table 6.1. Removal rates were calculated in two ways as follows. In the first series of calculations, the overall removal from the start of testing to the applicable monitoring date was calculated. The rate represents the average rate of removal over that period. The second series of calculations provide an estimate of the removal rate incrementally for each period as shown in the second part of the table.

The results indicate a maximum rate of removal of about 0.80 g/m^2/day for the whole lake. The EDTA amended limnocorral indicated a slightly higher rate of 1.1 g/m^2/day, with a maximum of only 0.68 g/m^2/day observed in the fish fertilizer amended limnocorral. As noted before, the control yielded a relatively high rate of removal of about o.4 g/m^2/day. The average removal for the test periods were 0.37 g/m^2/day and 0.24 g/m^2/day respectively for the whole lake and the control limnocorral. It should however be noted that it is likely that removal would have continued beyond the monitoring period since cell growth would not have terminated until freeze-over occurred.

Table 6.1 Summary of Estimated Zinc Removal Rates

Period		Zinc Removal Rates (g/m²/day)			
From	**To**	**Fish**	**EDTA**	**Control**	**Whole Lake**
Cumulative					
30-Jun-04	14-Jul-04	0.68	1.12	0.41	0.80
30-Jun-04	28-Jul-04	0.48	0.62	0.40	0.78
30-Jun-04	11-Aug-04	0.25	0.41	0.26	0.68
30-Jun-04	25-Aug-04	0.19	-	0.24	0.55
30-Jun-04	08-Sep-04	-	-	-	0.37
Incremental					
30-Jun-04	14-Jul-04	0.68	1.12	0.41	0.80
14-Jul-04	28-Jul-04	0.27	0.12	0.40	0.76
28-Jul-04	11-Aug-04	-0.20	-0.004	0.26	0.09
11-Aug-04	25-Aug-04	-0.01	-	0.24	0.22
25-Aug-04	08-Sep-04	-	-	-	-0.29

Both these calculations represent net removal rates and do not account for any loadings from wallrocks nor are the potential effects of dilution (from freshwater inputs) accounted for. However, it should be noted that the sulphate mass contained in the surface layer of the Grum Pit Lake marginally increased through the test period (by about 2%) and a similar trend was observed for the sodium content. It is therefore concluded that the net additional loadings likely nullified the potential effects of dilution. (The same conclusion however does not necessarily apply to the limnocorrals, since they were isolated from external loads. However, it should be noted that average lake evaporation (135mm) exceeds average precipitation (115 mm) for July and August.) The estimated removal rates therefore are considered reasonable for estimating removal rates that may be achieved by a biological treatment system.

As shown by the monitoring results presented by Lorax, there was no net increase in phosphorus in the water column during the growing season. It is therefore possible that even higher growth rates could have been achieved through increased fertilization without resulting in a net accumulation of phosphorus. Since the rate of removal is proportional to the rate of algal growth, it is possible that even higher rates of removal could be affected. However, for the purposes of this evaluation, it is considered reasonable to adopt the maximum observed pit lake rate of 0.80 g/m^2/day as an upper bound for zinc removal. Similarly, the period average of 0.37 g/m^2/day for the whole lake is considered a reasonable estimated for evaluating average removal performance.

By the time testing commenced in the Grum Pit Lake, the temperature in the stratified surface layer had already reached about 17 ^{o}C. Had fertilizer been applied at the time of ice-melt, it is conceivable that zinc metal removal for a period in excess of the test would have been observed. Conservatively, however, a growth season corresponding to the test period (i.e. 70 days) will be used for further evaluation. The corresponding annual zinc removal capacity is about 560 kg/ha at the maximum rate of removal, and about 260 kg/ha at the average rate of removal.

6.3 Treatment of Long Term Contaminant Loadings

The rates derived from the Grum Pit Lake assessment presented in Table 6.1 indicate that zinc removal rates range from a maximum of 0.80 $g/m^2/day$ to and average of 0.37 $g/m^2/day$ over a 70 day period. The removal capacities that may be achieved for each pit was calculated as the pits filled for the average rate and the maximum observed rates, sustained over a 70 day period. As noted before this will provide a conservative estimate of the potential annual removal that may be achieved. It should also be noted that the removal rates have not as yet been optimized.

The estimated zinc removals are summarised in Table 6.2. The initial rates correspond to the pit lakes at their current elevation and the long term rates correspond to the fully flooded pit lakes.

Table 6.2 Estimated Range of Zinc Removal Rates

	Removal Rate (kg/year)			
	Initial		Long Term	
Location	Avg.	Max.	Avg.	Max.
Faro Pit lake	14,000	30,000	19,000	41,000
Grum Pit Lake	2,500	5,400	7,200	16,000
Vangorda Pit Lake	1,800	3,800	4,300	9,000

When the removal rates in Table 6.2 are compared to the estimated net loadings to the pit lakes presented in Section 5, and summarized in Table 5.1, the following conclusions can be drawn:

- **Faro Pit Lake.** The net zinc loadings to the pit lake are estimated to be 26,600 kg/year currently and are expected to decrease to about 17,100 kg/year. The initial maximum annual removal rate exceeds both current and future loadings, and, once the pit is fully flooded, the average removal rate should also exceed the estimated annual loadings. Therefore it is possible that the total loading to the pit lake could be removed by biological treatment.

- **Grum Pit Lake.** The estimated rates of zinc removal by biological treatment greatly exceed the estimated annual loadings.

- **Vangorda Pit Lake**. The estimated net annual loadings to the pit lake exceed the estimated removal capacity, for fully flooded conditions. The residual zinc loading for the base case would result in a long term average concentration of about 1.3 mg/L at an average removal rate. Should a maximum removal rate be achieved, the zinc concentration would decrease to about 0.75 mg/L. The corresponding concentrations for a reduced loading case are estimated to be about 1.1 and 0.45 mg/L respectively. Biological treatment could be successful only if removal rates of between 1.3 and 1.7 $g/m^2/day$ could be achieved. Based on current data, these rates appear unlikely to be achieved by biological treatment alone.

Therefore, a comparison of the estimated annual loadings and removal rates indicate that biological treatment would be expected to successfully treat the Faro and the Grum Pit Lakes. In contrast, currently available data suggest that a flow-through system at the Vangorda Pit relying on biological treatment alone is not likely to achieve water quality acceptable for discharge.

While the study to date has not verified the ultimate fate of the metals removed from the water column, experience elsewhere (e.g. Equity Silver, Island Copper) has shown that with the build-up of organic matter from the dead phytoplankton settling from the water column, anoxic conditions will develop. The anoxic conditions together with the presence of excess organic substrate, is expected to lead to sulphate reducing conditions. Sulphate reduction will produce free sulphide ions which will react with free metal ions to re-mineralise as secondary sulphide minerals. These minerals will remain stable indefinitely within the confines of the flooded pit lake. Biological treatment therefore eliminates the potential for remobilisation associated with conventional lime treatment.

6.4 Treatment of Current Contaminant Inventory

A second factor that requires consideration is the current inventory of zinc contained in the pit lake. The total contained inventory of zinc will dictate the zinc concentration in the interim during flooding and in the short term after spilling commences. As the inventory is flushed from the system, the concentrations will decrease to levels corresponding to the long term net loadings to the pit lakes.

The total inventory of zinc contained in each of the pit lakes is shown in Table 6.3. A shown, there is a considerable inventory of zinc contained in both the Faro and Vangorda Pit Lakes. Assuming biological treatment is implemented simultaneously with breaching the diversions, the estimated concentrations for average and maximum removal rates by biological treatment were estimated. The resultant concentrations that would occur at the time of spilling are also shown in Table 6.3.

Table 6.3 Mass Zinc Currently Contained in Each of the Pit Lakes

Pit Lake	Current Zinc Content (kg)	Zinc Concentration at Time of Spill (mg/L)		
		No Treatment	Average Rate	Maximum Rate
Faro	149,000	5	3.5	2.1
Grum	19,800	2.9	~0.01	~0.01
Vangorda	181,000	33	33	32

The following conclusions can be drawn from the analysis:

- **Faro Pit Lake.** Breaching the Faro Creek and allowing uncontrolled flow-through conditions are not likely to achieve water quality acceptable for discharge. The reason for this is that while some of the inventory is depleted, the annual removal capacity does not adequately exceed the annual loadings. A more appropriate strategy would be to partially fill the pit to increase the removal capacity. The pit would then be operated at that flood elevation for a period of time until sufficiently low concentrations are achieved, after which the Faro Creek breach would be completed. Initial calculations suggest that if the flow into the pit lake is controlled at about 1.7 million m^3 per year, the pit would spill in the year 2017. At that time the zinc concentration would decrease to about 0.05 mg/L. At that time the Faro Creek Diversion could be fully breached. Ongoing biological treatment would then be required to maintain the zinc concentration.

- **Grum Pit Lake.** Sustaining average removal rates will require that biological treatment be continued until about the year 2012 (i.e. 8 years) after which the concentration will remain approximately at the expected discharge concentration. Should the maximum rate of removal be sustained, the treatment period would decrease to about 4 years.

- **Vangorda Pit Lake.** As concluded before, biological treatment alone would not achieve water quality acceptable for discharge in a flow-through system. Even for isolated pit conditions biological treatment would not be sufficient to deplete the contained inventory and keep up with the annual loadings.

6.5 Effects of Meromixis

A previous assessment of the pit lakes indicated that meromictic conditions are unlikely to develop in the Faro and Vangorda Pit Lakes under flow-through conditions. Nonetheless, current density and salinity profiles suggest that meromictic conditions may exist or may be developing in the Faro and Vangorda Pit Lakes.

Because the majority of the estimated future contaminant loadings will originate from the pit walls, the loadings are likely to enter the surface layer and mix within that layer. Therefore meromictic conditions will not affect the estimated long term average concentrations in discharge from the pit lakes.

Meromictic conditions will however affect the retention time within the pit lake which may affect the efficiency of biological treatment.

The Faro Pit Lake salinity profile suggests that the mixed surface layer extends to about 15 meters from surface or at an elevation of about 1125 m asl. Assuming that the thickness of this mixed surface layer remained constant through flooding, a large proportion of the contained inventory of zinc would be sequestered in the lower layer thus reducing the demands on biological treatment and water management during the filling period. After filling is complete, i.e. at the time the pit lake spills, with the mixed surface layer extending to a depth of about 15 m from surface, about 10 million m^3 of water would be contained within the surface layer. The average retention time, with the Faro Creek breached, would decrease from about 8.5 years (fully mixed conditions) to about 1.8 years for meromictic conditions. This reduced retention time is not expected to affect the performance of a biological treatment system.

Profiling of the water column suggests that the mixed surface layer of the Vangorda Pit Lake extends about 3 to 4 meters from the surface. The thickness of the surface layer has likely been influenced by pumping for water treatment and the freshwater inflow that occurred during the flood event in

2004. However, if it is conservatively assumed that the mixed layer remains constant, the retention time in the surface layer would be about 1 month with the Vangorda Creek breached. While it may be possible in theory to sustain biological growth at such a low retention time, there will be significant technical demands to maintain biological growth and manage inflows to prevent erosion of the stable layers to the extent that it is considered unlikely that a biological treatment system could successfully be implemented and operated continuously.

Meromictic conditions have no bearing on the Grum Pit Lake evaluation. The biological treatment is anticipated to affect the removal of the contained zinc from the water column before the pit overtops, and because the steady long term concentrations are expected to be acceptable for discharge without the need for further treatment.

6.6 Effects of Tailings Relocation to Faro Pit

In the event that the Rose Creek Tailings are relocated to the Faro Pit, the tailings fill level will be at an elevation of about 1140 m asl. The pit lake that would form above the tailings would be about 33 m deep and have a volume of about 22 million m^3. The total mass of soluble zinc that may be released from the tailings, if placed in the pit lake untreated, could result in zinc concentrations in excess of 1000 mg/L, and biological treatment would not be feasible. A prerequisite therefore would be that the tailings be amended before placement in the pit lake.

At that the final lake volume, the retention time would be about 3.5 years for fully mixed conditions. The loadings from the waste rock and wall rocks would not be affected so that there will be no implications with respect to the implementation and operation of a biological treatment system. However, since there is limited excess treatment capacity available, implementation of a biological treatment system will require that the tailings are amended with lime or limestone before deposition in the pit lake. Furthermore, since lime or limestone amendment of the tailings is unlikely to achieve sufficiently low zinc concentrations in the pit lake to allow immediate implementation of a biological treatment system, it will likely be necessary to pump and chemically treat a significant proportion of the lake to decrease the residual zinc concentration to an acceptable concentration.

7 Example Implementation Concepts

7.1 Faro Pit

7.1.1 Flow-through Pit Lake

Implementation of a biological treatment system would require surface applications of fertilizer as soon as possible to verify that treatment can be carried out successfully within the Faro Pit Lake. During this initial period, fertilizer applications would be optimized and removal rates verified. The plug dam would be installed concurrently.

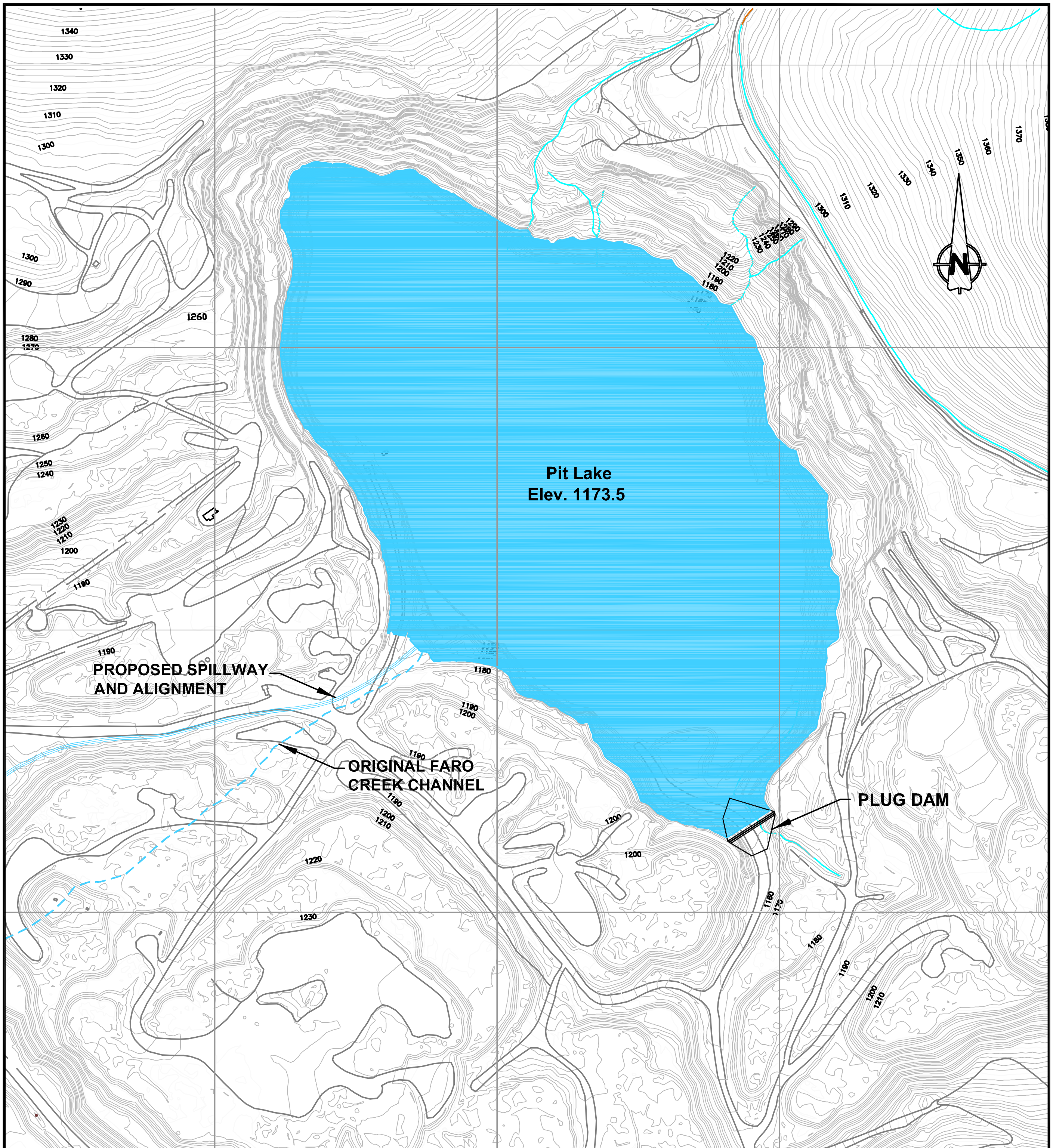
As noted in Section 6.3, to treat the current inventory of zinc concurrently with the annual loadings will require that the pit lake elevation be raised to near the spill elevation. This would maximise the pit lake surface area and thus the treatment capacity. Once the desired flood elevation is reached, the inflows to the pit lake would be minimised until the zinc concentration had decreased to an acceptable level. That process is expected to require a period of some 10 to 15 years.

Prior to allowing flow-through conditions to develop, a spillway would be constructed for long term release of the pit lake outflow. The spillway could be routed through the old Faro Creek bed, as shown in Figure 7.1. The Faro Creek diversion could then be breached to create the flow-through system.

Based on the results of the field testing, biological treatment will require that a liquid fertilizer be added to the pit lake on a weekly basis. The fertilizer could be dispensed from 55 gal drums off the back of a small flat-bottom boat and the propeller wash would be utilized to disperse the fertilizer through the surface layer. To maintain removal rates, the fertilizer demand would increase as the size of the pit lake increases. A schedule of fertilizer demand as a function of the pit lake surface elevation is provided in Table 7.1. The annual demand assumes a 70 day operating period each summer.

Table 7.1 Estimated Schedule of Fertilizer Demand

Elevation (m asl)	Barrels per week	Barrels per Year
1140	16.2	162
1145	17.1	171
1150	18.0	180
1155	19.2	192
1160	20.0	200
1165	20.8	208
1170	21.5	215
1173.5	22.0	220



Faro Mine, Yukon

Contour Interval: 2m
Date of Photography: 03/07/25
Scale of Photography: 1:20000
Survey control derived from existing 1:20000 photography
Survey control based on: UTM Projection, NAD27
Compiled by The ORTHOSHOP, Calgary, September 2003
WO 8856

0 100 200 300 400 Metres
1:10,000

Note:
Waste rock loading to Faro Pit assumes rudimentary covers are in place, and runoff and Infiltration is 25% of annual precipitation

SRK Consulting
Engineers and Scientists

Deloitte & Touche

ANVIL RANGE PIT LAKE TREATMENT

Example Layout of a Faro Pit Flow-through System

PROJECT NO.	DATE	APPROVED	FIGURE
1CD003.046	Dec. 2004		7.1

Dwg Ref: 2003 FARO SITE PLAN1.DWG

7.1.2 Isolated Pit Lake Supplemental Treatment System

The alternative to operating the Faro Pit Lake as a flow-through system would be to operate it as an isolated pit to treat or partially treat contaminated water from other sources. This option would require that the Faro Diversion be maintained, upgraded or rerouted as determined necessary for long term requirements. To maximise the treatment capacity of the pit lake, it would also be desirable that the pit lake level be raised to a maximum level, i.e. by installing a plug.

Two options may be considered. First, the pit lake could be utilized as a combined holding and pre-treatment system, through which all contaminated water can be channelled before it is treated in a conventional lime treatment system. In the second option, the pit lake could be used as a polishing system to which water treated in a conventional lime system is discharged. Biological treatment would then be used to further treat the water before it is released to the receiving environment.

The first option would simplify water management and could reduce metal loadings to be treated by conventional treatment and hence overall sludge production. However, even at the 'full operating elevation' available excess treatment capacity in the pit lake is limited and projected potential long term loadings from the waste rock dumps are expected to overwhelm the biological treatment system. Toxic metals concentrations may develop thus nullifying the potential for biological treatment. The advantages therefore would be reduced only to those associated with water management.

The advantages of the second option would include an increase in the permissible metal concentrations in the treatment plant discharge, with a corresponding decreased in sludge production. At a 'full lake' treatment capacity (i.e. with plug dam installed), it is anticipated that water with zinc concentrations between 3 (average removal) and 30 mg/L (maximum removal) could be discharged from the treatment system to the pit lake at an annual flow of about 600,000 m^3 per year. This represents a significant relaxation on conventional treatment discharge criteria.

Cost implications are discussed below in Section 7.4.

7.2 Grum Pit Lake

7.2.1 Flow-through Pit Lake

The requirements for implementing the biological water treatment system in the Grum Pit are minimal due to the long lead time before the lake will spill. The treatment program could simply follow the process that was undertaken during the 2004 field test. The pit lake would be fertilized at approximately the same rate and frequency. Close monitoring of the nutrient levels would be needed to ensure that no net accumulation occurs within the water column. No other special requirements are anticipated for this pit lake.

In advance of the pit lake reaching its final elevation, the slot cut would be extended to provide a final spillway. The discharge could ultimately be routed to Grum Creek as shown in Figure 7.2.

The anticipated fertilization schedule for the period that treatment will be required is shown in Table 7.2.

Table 7.2 Summary estimated Schedule of Fertilization of the Grum Pit Lake

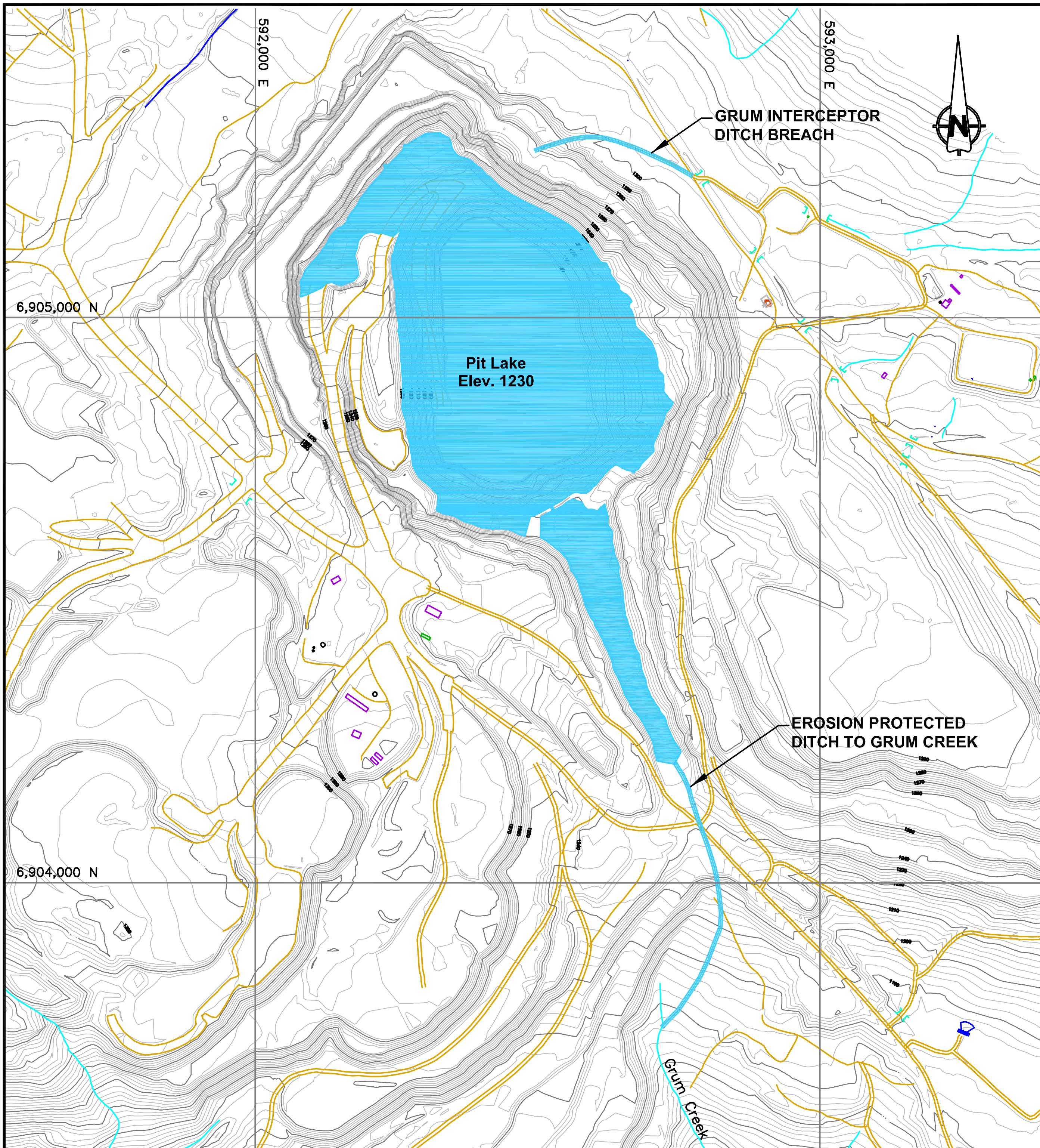
Year	Elevation (m asl)	Barrels per week	Total Barrels
2005	1187.5	3.0	30.3
2006	1190.0	3.1	31.4
2007	1192.0	3.3	32.6
2008	1194.5	3.5	34.6
2009	1196.5	3.6	36.0
2010	1198.5	3.7	37.4
2011	1200.5	3.9	38.9
2012	1202.5	4.0	40.4
2013	1204.5	4.2	41.9

7.2.2 Supplemental Treatment System

The biological treatment capacity of the Grum Pit Lake exceeds the loadings from local sources. Therefore, it may be possible to treat seepage from other areas, such as the Grum waste rock dumps and the Vangorda site, in the Grum Pit Lake.

Based on the estimated water seepage water quality and loadings in the short term, it would be possible to treat all of the Grum waste rock dump seepage utilizing biological treatment in the Grum Pit Lake. In the longer term, if the predicted future worst case loadings from the Grum waste rock dumps materialise, the metal loadings could overwhelm the biological activity. As was the case in the Faro system, the implication would be that the Grum Pit Lake would then be limited to being either a holding pond for conventional lime treatment, or an effluent polishing system.

Water with a zinc concentration range of between 10 mg/L (average removal rates) and 25 mg/L (maximum removal rates) could be discharged from conventional treatment to be ‘polished’ in the pit lake, assuming that all the seepage from the Grum Dumps are captured and treated (approximately 350,000 m^3 per year). If both the Grum and Vangorda seepage are captured, flows would increase to about 960,000 m^3 per year, and the influent concentrations would need to be kept below 4 mg/L and 9 mg/L respectively.



Date of Photography: 2003/07/25
Scale of Photography: 1:20000
Survey control derived from existing 1:20000 photography
Survey control based on: UTM Projection, NAD27
Compiled by The ORTHOSHOP, Calgary, September 2003
WO 8856

0 100 200 300 400 Metres
1:10,000

SRK Consulting
Engineers and Scientists

Deloitte & Touche

ANVIL RANGE PIT LAKE TREATMENT

Example Flow-through Configuration of the Grum Pit

PROJECT NO.	DATE	APPROVED	FIGURE
1CD003.046	Dec. 2004		7.2

Dwg Ref: site_plan_2003.dwg

7.3 Vangorda Pit Lake

The Vangorda Pit Lake has been shown to be not feasible as a flow-through treatment option. In an isolated pit system configuration, the zinc concentration in the pit lake is projected in the long term to stabilize at about 67 mg/L based on current metal loadings. If biological treatment could be sustained, the zinc concentration would be reduced to between about 25 and 48 mg/L, at maximum and average removal rates respectively. Therefore, the pit lake could not be used as a polishing system.

As pre-treatment step, only the annual inflow to the pit lake in an isolated configuration could be considered for treatment, due to the anticipated elevated zinc concentration expected to develop in the pit lake.

7.4 Operating Costs

7.4.1 Flow-through Faro Pit Lake

The operating costs for the Faro Pit Lake would vary according to the lake elevation, with costs increasing as the size of the pit lake increases.

Initially, the annual operating costs would be about $75,000 per annum, comprising $47,000 for fertilizer costs, $18,000 for labour, and the balance for monitoring and miscellaneous costs. The operating cost estimate assumes that two persons would be occupied for 16 hours per week to fertilize and monitor the pit lake system for a 90 day period (13 weeks rather than the assumed 10 week operation). Labour was assumed to be obtained from a local source at a cost of $440 per hour. The cost of the fertilizer, delivered to site was assumed to be the same as that incurred for the field program at $352 per barrel. Monitoring would be undertaken every second week and the analytical costs were assumed to be $1,500 for each event.

The operating costs are expected to increase to about $128,000 per annum, with the fertilizer costs increasing to about $100,000 per annum.

The unit water treatment costs in the long term amount to about $0.022 per m^3. However, if it is considered that effectively only the water from the waste rock within the pit lake catchment and wall rocks is treated, the effective water treatment cost is about $0.255 per m^3. While this compares to conventional treatment costs, it should be considered that the costs and effort associated with sludge disposal are negated, and as are the risks and costs associated with maintaining the Faro Creek Diversion. Therefore, in the long term, these costs become favourable.

Capital costs would include the construction of the plug dam, construction of the spillway along the Faro Creek creek-bed, and breaching the Faro Creek Diversion. The capital cost of the plug dam is expected to be in approximately $4.1 million, though this estimate is actually based on a slightly lower plug dam than called for in this report. The capital cost of the other two work components has not been estimated but is likely to be in the same order of magnitude as the plug dam. More precise estimates would require an optimization of the various design details, including the pit water level, spillway location and elevation and the dam height, as well as a decision regarding whether any or all of the tailings in the Rose Creek Tailings Facility will be relocated to the Faro Pit.

As noted before, these costs need to be compared to the savings in maintaining, upgrading and redirecting the Faro Creek Diversion.

7.4.2 Faro Pit Lake Supplemental Treatment

As discussed a, the Faro Pit Lake as pre-treatment system utilizing biological treatment is not likely to be feasible. Utilizing biological treatment as a polishing treatment system would be most effective at the maximum pit lake elevation. In this scenario, the Faro Creek Diversion would be maintained and all of the waste rock dump seepage would be collected and treated by conventional lime treatment. The surplus treatment capacity of the pit lake would mean that water could be treated by conventional lime treatment to between 3 and 39 mg/L zinc, assuming average and maximum removal rates in the pit lake. The treated water would be discharged to the pit lake where it would be further treated together with the pit inflow.

Since the pit lake elevation would be maximised, the operating costs would be as discussed above for the long term flow-through conditions (i.e. $128,000 per year). At an estimated 1.1 million m^3 of water treated per annum, the unit treatment cost would be about $0.09 per m^3. The current actual lime treatment costs, for treating water with a quality similar to that which would be treated in the pit lake, is about $0.14 per m^3.

The capital costs would be as described for the flow-through system, with the added requirement that the Faro Creek diversion would need to be maintained.

7.4.3 Flow-through Grum Pit Lake

As discussed previously, the Grum Pit Lake would require treatment for a period of about 9 years. During this period, the average annual operating costs are expected to be about $44,000 per year. The estimate was derived using the same labour, fertilizer and monitoring unit costs adopted for the Faro Pit estimates. The total cost to treat the Grum Pit would be about $397,000. The unit cost would be about $0.04 per m^3 which compares very favourably with conventional treatment costs.

Capital costs would include completing the slot cut for the spillway, removing the road-fill at the outlet of the slot-cut, providing erosion protection and constructing a lined ditch to discharge the pit lake outflow to Grum Creek.

7.4.4 Grum Pit Lake Supplementary Treatment

Utilizing Grum Pit Lake as a primary treatment facility, when full, would entail an annual operating cost of about $65,000. At full capacity, about 350,000 m^3 (equivalent to the estimated seepage volume for the Grum Dumps) of water at a zinc concentration of about 25 mg/L could be treated annually at a cost of about $0.18 per m^3, or up to 950,000 m^3 (equivalent to the combined Grum / Vangorda dump seepage volume) at a zinc concentration of about 10 mg/L at a cost of about $0.07 per m^3. In comparison, in 2003 the cost to treat water at an average concentration of 10 mg/L in the Faro Mill treatment plant was $0.14 per m^3. These estimates indicate that there is a clear cost advantage for biological treatment for lower concentration – higher flow rate combinations. As concentrations increase, biological treatment becomes less feasible.

Capital cost expenditures would not change from those identified for the flow-through option.

8 References

SRK Consulting, 2004, *Anvil Range Pit Lakes, Assessment of Post Closure Conditions*. Prepared for Deloitte and Touche Inc., January 2004.

Appendix A

Laboratory Testing Program
Report Prepared by Microbial Technologies

Appendix B

Field Investigation Program
Report Prepared by Lorax Environmental Services

Appendix C

Limnology Assessment
Report Prepared by Lawrence Associates

Appendix D

Pit Lake Source Loadings and Water Quality Report Prepared by SRK Consulting