# Anvil Range Pit Lakes
# Evaluation of In-Situ Treatment
# 2004/05 Task 14c

***Prepared for***

***Deloitte and Touche Inc.***

***On behalf of***

***Faro Mine Closure Planning Office***

***Prepared by***

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## Deloitte and Touche Inc.

**On behalf of**

## Faro Mine Closure Planning Office

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# 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 in 2004 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 has been prepared as part of the ongoing technical evaluation for the closure planning of the Faro Mine, which 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. Aspects of this report may have been superceded by subsequent technical studies.

# 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.

More recent assessments of the plug dam suggest that the flood elevation of only 1173.5 may not be feasible, but rather a flood elevation of about 1168 masl may be more reasonably achieved. At the lower flood elevation, the wall rock loadings are expected to increase by about 7.4 percent. For example, the zinc loading would increase from about 15,000 kg to about 16,100 kg per year. The pit is expected to spill in early 2007. At the time of spilling, for the base case assessment (i.e. inclusive of waste rock loadings) the zinc concentration is estimated to be about 4.9 mg/L, and the long term average concentration is predicted to be about 3.1 mg/L.

### 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 (1173.5 m) | 24,000 | 2,000 | 27,000 | 15,000 | 2,000 | 17,000 |
| | Base & Isolated Pit (1168 m)* | 24,000 | 2,000 | 27,000 | 16,100 | 2,000 | 18,100 |
| | Reduced Loadings (1173.5 m) | 24,000 | 1,000 | 25,000 | 15,000 | 1,000 | 16,000 |
| | Reduced Loadings (1168 m)* | 24,000 | 1,000 | 25,000 | 16,100 | 1,000 | 17,100 |
| 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 |

Note: * Loadings in the event an 1173.5 m asl flood elevation is not feasible.

# 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/m$^2$/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 wall rocks 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**

| Location | Removal Rate (kg/year) | | | |
|---|---|---|---|---|
| | Initial | | Long Term | |
| | Avg. | Max. | Avg. | Max. |
| Faro Pit lake (1173.5 m) | 14,000 | 30,700 | 19,500 | 42,200 |
| Faro Pit lake (1168 m)* | 14,000 | 30,700 | 18,600 | 40,200 |
| Grum Pit Lake | 2,500 | 5,400 | 7,200 | 16,000 |
| Vangorda Pit Lake | 1,800 | 3,800 | 4,300 | 9,000 |

Note: * Removal rates in the event an 1173.5 m asl flood elevation is not feasible.

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 (at a flood elevation of 1173.5 m). 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. Should the pit lake be flooded only to an elevation of 1168, the removal rates are predicted to be equal to the loadings at the base case conditions. However, it should be noted that there are significant uncertainties in the estimated wall rock loadings as well as the waste rock loadings as discussed in Section 6.7 below.

- **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, without any further treatment, the concentration will remain approximately at the predicted long-term steady state concentration of about 0.33 mg/L. 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.

## 6.7 Effects of Waste Rock Loadings to Faro Pit

Future loadings from the waste rock to the pit lake may significantly impact the feasibility of biological treatment within the Faro Pit. The initial assessment of the biological treatment has been completed on the basis of estimated ‘current average’ loadings from the waste rock. For the base case the zinc loading combined from all the contributing waste rock dumps, assuming rudimentary covers were placed on the waste rock was estimated to be about 2,100 kg per year. This loading is estimated to increase to about 124,000 kg per year under future worst case conditions, with rudimentary covers in place. The Faro Valley dumps are estimated to contribute approximately 83,000 (or 67 %) to the total loading. Adding the wallrock loadings, the total zinc loading to the pit lake would be about 139,000 kg per year.

Compared to the average and maximum biological removal capacity (see Table 6.2), biological treatment could remove only a fraction of the total annual loading. Removal of the Faro Valley dumps would reduce the estimated annual loading to about 55,000 kg per year, which would still exceed the estimated maximum removal capacity. Biological treatment would not be viable should future worst case conditions develop unless additional remediation measures are undertaken to reduce metal loadings from the waste rock.

# 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.

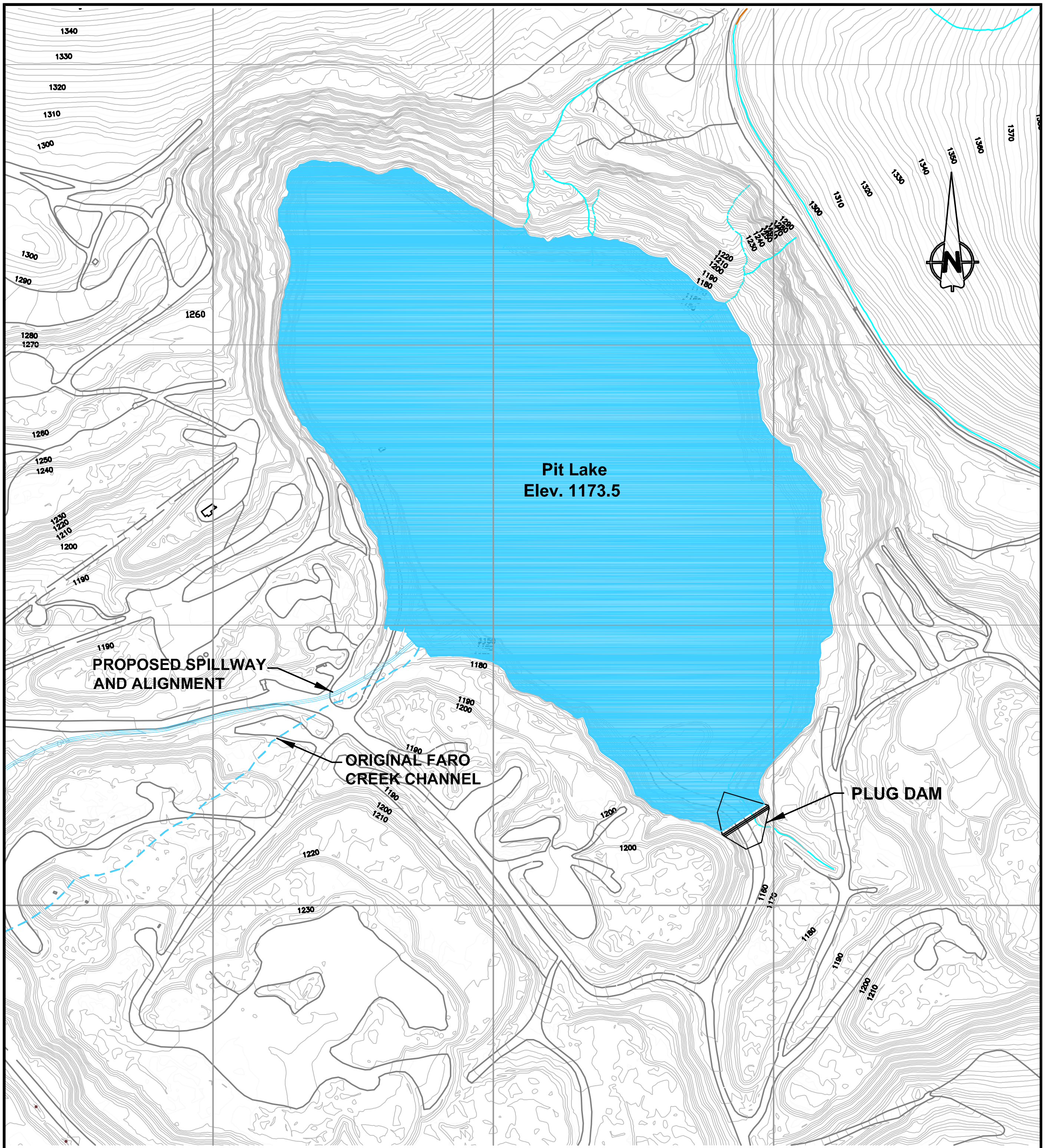
As noted in Section 6.3, to treat the current inventory of zinc concurrently with the annual loadings will require that the pit lake elevation be raised to near the spill elevation. This would maximise the pit lake surface area and thus the treatment capacity. Once the desired flood elevation is reached, 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

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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**

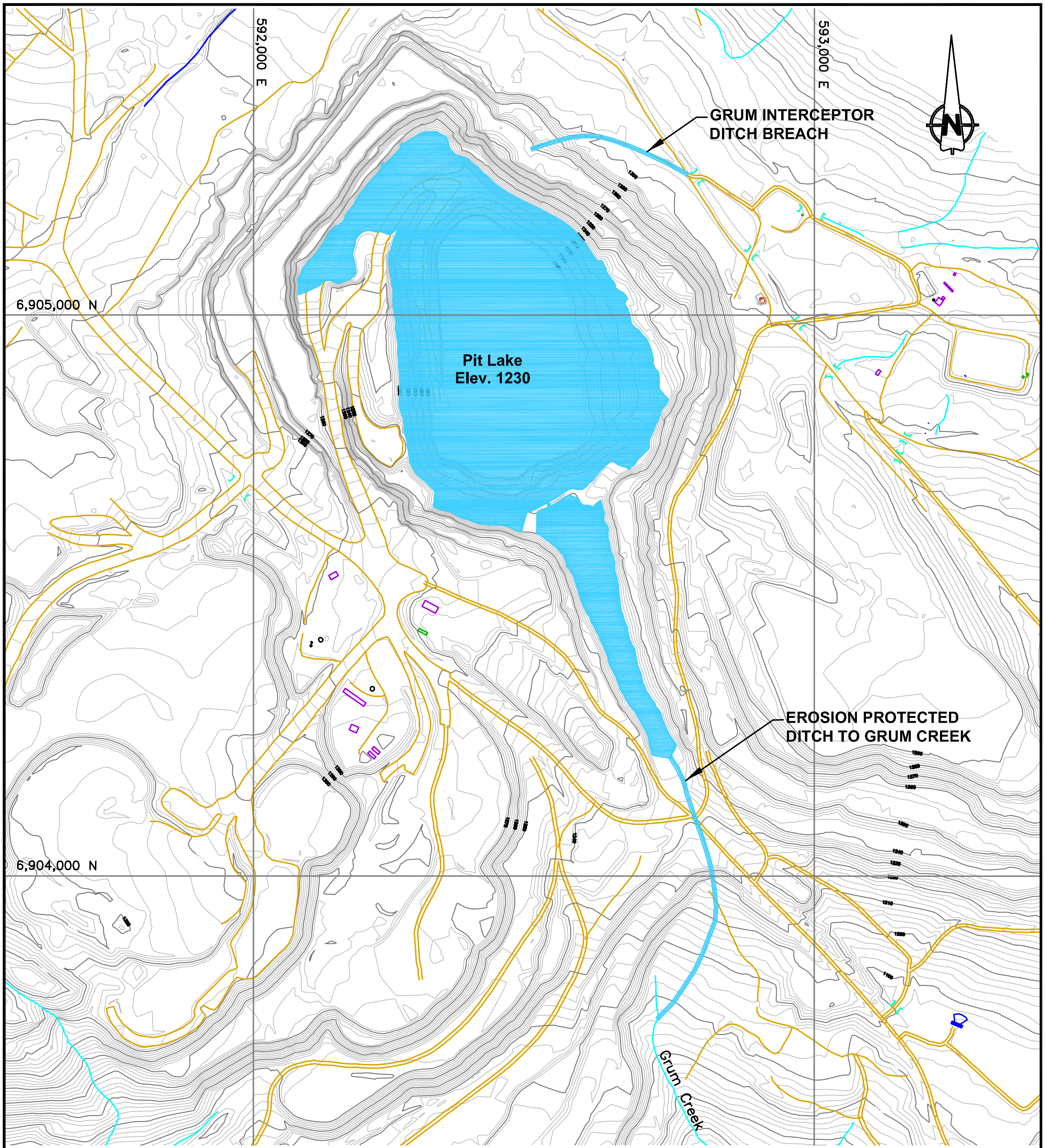
| Year | Elevation (m asl) | Barrels per week | Total Barrels |
|---|---|---|---|
| 2005 | 1187.5 | 3.0 | 30.3 |
| 2006 | 1190.0 | 3.1 | 31.4 |
| 2007 | 1192.0 | 3.3 | 32.6 |
| 2008 | 1194.5 | 3.5 | 34.6 |
| 2009 | 1196.5 | 3.6 | 36.0 |
| 2010 | 1198.5 | 3.7 | 37.4 |
| 2011 | 1200.5 | 3.9 | 38.9 |
| 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

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## 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.

This report, **"Anvil Range Pit Lakes, Evaluation of In-Situ Treatment – 2004/05 Task 14c"**, has been prepared by SRK Consulting (Canada) Inc.

John Chapman, P.Eng.

Daryl Hockley, P.Eng.

# 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

# Algal growth in Faro Mine pit lake water

## A Project Report submitted to:

## SRK Consulting

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**November 2004**

# Executive Summary

Microbial Technologies, Inc. investigated the effects of fertilizers on algal growth in waters from the Faro, Grum, and Vangorda pit lakes. This laboratory study complemented a field trial in the Grum pit to evaluate the removal of zinc by induced algal blooms.

Algae were grown in water from all the pit lakes, even in Vangorda water which has high zinc concentrations. When fertilized, waters from each of these pit lakes was found to sustain a unique algal population. In addition, algae were found to grow on sediments from these pit lakes. However, they always grew attached to these sediments.

Dilution tests showed that elevated zinc concentrations slowed down growth and limited overall yield, but did not prevent algal growth.

Algae grown from an ice sample retrieved from the Grum pit were grown to a high density and were used to inoculate water from each of the pit lakes. Tests were conducted without fertilizer, a low fertilizer dose (1 mg/L ammonia-nitrogen and 0.1 mg/L phosphate-phosphorus), or a high fertilizer dose (5 mg/L ammonia-nitrogen and 0.5 mg/L phosphate-phosphorus). A duplicate test of Grum water was fertilized with fish fertilizer instead of chemical fertilizer.

The high dose fish fertilizer treatment supported the most rapid algal growth in Grum water. Algal growth appeared within nine days. The high fertilizer treatment in Faro water also produced rapid, but not as luxuriant algal growth. Most of the other fertilizer treatments also supported algal growth, but growth was more limited. While adding ammonia-nitrogen to 5.0 mg/L may accelerate production of an algal bloom, its concentration should be maintained at 2.0 mg/L to sustain good algal growth.

A phenomenon of “cell clumping” was observed in Grum and Faro high fertilizer treatments. Planktonic (free-floating) algae that grew to high densities formed clumps that settled from the water column. However, the remaining planktonic algae eventually grew back in the water column.

Algal blooms did not alter water pH significantly. They appeared to increase nitrate concentrations in water, but this was not a very significant effect. Although zinc concentrations decreased in pit lake waters during the study, this effect could not be conclusively attributed to algal blooms.

# Table of Contents

**APPENDICES**

# List of Tables

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# 1 Introduction

An updated mine reclamation plan is being developed for the Faro Mine complex , with a view to have a workable closure plan by 2006. This reclamation plan includes detoxification and reclamation of the open pits and development of pit lakes in the Faro, Grum, and Vangorda pits.

Previous studies have shown that algae may remove toxic metals from surface waters (Hrycenko and Sobolewski, 1999; Pelletier *et al.*, 2002; Crosius *et al.*, 2002). Another study at the Vangorda Mine suggested that algae may be grown in pit lakes at the mine, despite elevated zinc concentrations (Sobolewski, 2003). Thus, the concept of using algae to remove toxic metals has been proposed, and this was recently identified as a possible water management option for the Grum pit (Gartner-Lee, 2003). However, the results to date can only be considered tentative, and a more thorough evaluation of this concept is necessary.

The laboratory study was conducted as a precursor to a more comprehensive evaluation of this treatment alternative. It assessed the fertilizer requirements to stimulate and support algal growth in waters from the Faro, Grum, and Vangorda pit lakes and examines the potential toxicity of these waters to algae. Finally, the study intended to determine if induced algal blooms remove zinc from these waters.

The study was divided in several tasks. In Task 1, an algal inoculum was developed for use in subsequent tasks. In Task 2, the “toxicity threshold” for pit lake waters was determined. This test determined what dilution of pit lake water may be necessary to obtain observable algal growth. In Task 3, the effects of different doses and types of fertilizer on algal growth and zinc concentrations were determined.

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# 2 Materials and Methods

## 2.1 Sample collection

Water samples collected by Laberge Environmental Services from the Faro, Grum, and Vangorda pit lakes were shipped to Microbial Technologies on May 14, 2004. Nine collapsible 22 L (5 gal) containers were retrieved on May 15, and stored in the cold until May 17, when the study was started. Separately, sediment samples were collected from the near-shore of each pit lake and ice with green algae was collected from the Grum pit. These were also received on May 15. The sediment samples were stored in the cold until used in the study. The thawed ice samples was exposed to sunlight until subsequent use in the study.

## 2.2 Experimental Set-up

To grow algae for an inoculum used in subsequent tasks, 100 mL of the Grum ice, Grum 1m, Faro 5m and Vangorda 5 m water samples were fertilized to 10 mg/L $NH_3$-N using $(NH_4)_2SO_4$ and 1 mg/L $PO_4$-P using $Na_2HPO_4$ and placed in baffled shake flasks. These were shaken at 120 rpm on an orbital shaker at room temperature under strong full-spectrum illumination (Figure 1). In addition, 100 mL of Grum 1m, Faro 5m and Vangorda 5 m water samples and 20 g of their corresponding sediment samples were fertilized and incubated as above.

**Figure 1. Algal cultures in shake flasks on orbital shaker.**

Once algae grew in the Grum ice sample, they were used to inoculate test tubes for the toxicity threshold and plastic containers for the fertilizer tests.

For the toxicity threshold test, water from the Faro 5m, Grum 5m, and Vangorda 5m samples were serially diluted  To this end, a volume of pit lake water was mixed with an equal volume of dilution water, resulting in a two-fold diluted subsample. Part of this subsample was used for the toxicity threshold test, the remainder was diluted again. Part of the resulting diluted subsample was used for the toxicity threshold test, the remainder was diluted again, until a series of four two-fold dilution is obtained.

For the above dilutions, purified water was supplemented with 2.25 g/L $CaSO_4.2H_2O$, producing an effective $Ca^{+2}$ concentration of 130 mg/L. The pH of this dilution water was adjusted to 6.9 before use.

After all the dilution series were prepared for all the pit lake waters, fertilizer was added to every sample, bringing ammonia-N concentrations to 10 mg/L using $(NH_4)_2SO_4$ and phosphate-P to 1 mg/L using $Na_2HPO_4$. Each fertilized 10 mL sample was dispensed in a sterile screw-cap test tube, inoculated with 0.1 mL of the grown Grum ice sample and incubated flat on an orbital shaker under full-spectrum illumination (See Figure 5 for photograph of all the test tubes).

Mine water from the 22-liter containers was distributed evenly among eleven 20-liter plastic pails. Samples collected at 5 and 40 m were mixed before being distributed to each tank. The tanks were kept under high illumination at room temperature, aerated, and covered with clear plastic film to minimize evaporation. During the study, the temperature ranged from 20-26 ºC, the light source consisted of several wide spectrum fluorescent tubes for plants and aquariums on a 16/8 hour photoperiod, and aeration in each tank was provided through one 4 inch air rock attached to a Maxima 2.5 psi aquarium air pump. The air flow was restricted with a valve so that every container received approximately the same, gentle bubbling from the air stone.

Water from the Vangorda pit lake contained orange suspended particulates, likely iron oxyhydroxides formed after collection. Since they can adsorb zinc, it was important to remove them from the water before starting the test. Most of these particulates were removed by decanting Vangorda water after they had settled to the bottom of the plastic containers. The decant was returned to the containers and topped up with fresh Vangorda water. A single decant was sufficient to remove virtually all the orange particulates, with only faint traces left. Subsequent chemical analysis showed that zinc concentrations in these samples remained very high.

Each of the filled plastic containers received 4.0 mL of the Grum ice algal inoculum. In addition, some water samples received fertilizer according to the addition rates shown in Table 1. Ammonium sulphate [$(NH_4)_2SO_4$] was used to supply nitrogen and phosphoric acid ($H_3PO_4$) was used to supply phosphorus to the chemically-fertilized samples. Alaska Fish Fertilizer$^{TM}$ was used for the Grum fish fertilizer treatment.

**Table 1. Treatments during the algal growth study.**

| **Treatment** | **Name** | **Algal inoculum** | **Amount N (mg/L)** | **Amount P (mg/L)** |
|---|---|---|---|---|
| **Controls** | Ctrl | 4.0 mL | - | - |
| **Faro** | low NP | 4.0 mL | 1 | 0.1 |
| | high NP | 4.0 mL | 5 | 0.5 |
| **Vangorda** | low NP | 4.0 mL | 1 | 0.1 |
| | high NP | 4.0 mL | 5 | 0.5 |
| **Grum chemical** | low NP | 4.0 mL | 1 | 0.1 |
| | high NP | 4.0 mL | 5 | 0.5 |
| **Grum fish fertilizer** | low FF | 4.0 mL | 1 | 0.1 |
| | high FF | 4.0 mL | 5 | 0.5 |

## 2.3 Measurements

The instruments and techniques used during the study are listed in Table 2. Other chemical analyses (metals, Chlorophyll "a") were performed by a contract laboratory (ALS Environmental, Vancouver, BC). These analyses were done on cooled, unpreserved 50 mL samples that were filtered immediately upon receipt at ALS. The filter cake was analyzed for Chlorophyll "a", whereas the filtrate was preserved with nitric acid and analyzed for metals by ICP.

**Table 2. Types of measurements taken and instruments used in study.**

| Measurement | Instruments Used |
|---|---|
| pH | VWR Model SP21 portable pH/ISE meter with pH electrode. |
| Conductivity | HANNA 8733 Conductivity meter. |
| Dissolved Oxygen | ORION model 810 with DO probe. |
| Ammonium | ORION model 290A with 95-12 ammonia probe. |
| Nitrate | GENESYS 6 Spectrophotometer with NitraVer 5 reagent kit. |
| Phosphate | GENESYS 6 Spectrophotometer with PhosVer 3 reagent kit. |

### 2.3.1 pH

Solution pH was measured using a calibrated pH electrode. The pH meter was calibrated every week before taking readings using standard solutions of pH = 7.01 and pH = 4.00.

### 2.3.2 Conductivity

Solution conductivity was measured using a calibrated conductivity electrode. The conductivity meter was calibrated at the beginning of the study using a 10.00 mS conductivity standard.

### 2.3.3 Dissolved Oxygen

Dissolved oxygen concentrations were measured using an oxygen-specific electrode. The dissolved oxygen meter was calibrated immediately before taking readings. In addition, every week new filling solution was added to the probe.

### 2.3.4 Ammonia

Ammonia-nitrogen concentrations were measured using an ammonia-specific electrode. The ammonia electrode was calibrated throughout the study using 0.0, 1.0, 3.0, and 10 mg/L $NH_3$-N using an ammonium chloride standard solution. Measurements in mV were taken after adding 1 ml of ammonia pH adjusting solution to 50 mL of each standard. The mV readings for each of the standards were plotted to generate a calibration curve. The curve was subsequently used to determine mg/L ammonia from mV readings taken in this study. The electrode was recalibrated five times during the study.

Ammonia concentrations were determined by taking a 50 mL sample from each tank and adding 1 ml of ammonium pH adjusting solution. The solution was mixed with a magnetic stir bar and a measurement, in mV, was taken using the ammonium probe. The mV readings were converted into mg/L of ammonia nitrogen by using the calibration curve.

### 2.3.5 Nitrate

Nitrates were measured by the cadmium reduction method (APHA, 1995), using a reagent kit supplied by Hach Inc.. The Spectrophotometer was calibrated at the beginning of this study using standard concentrations of sodium nitrate. A NitraVer 5 reagent pillow was added to 10 mL of each standard or sample, mixed with a vortex mixer and allowed to stand for 10 minutes before absorbance was measured at 500 nm. Absorbance was converted to concentrations using the above calibration curve.

### 2.3.6 Phosphate

Phosphate was measured by the ascorbic acid method (APHA, 1995), using a reagent kit supplied by Hach Inc.. The Spectrophotometer was calibrated at the beginning of this study using standard concentrations of potassium phosphate. A PhosVer 3 reagent pillow was added to 10 mL of each standard or sample, mixed with a vortex mixer and allowed to stand for 10 minutes before absorbance was measured at 890 nm. Absorbance was converted to concentrations using the above calibration curve.

### 2.3.7 QA/QC

On Week 2 of the study, samples from each container were collected and shipped to ALS for nitrate and phosphate analysis. Duplicate samples were analyzed at Microbial using the Hach reagent kits. The two sets of results are compared in Table 3.

**Table 3. Comparison of analytical results from ALS with those from Microbial.**

| Sample ID | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $NO_3$-N ALS | 0.19 | 0.080 | 0.71 | 0.18 | 0.19 | 0.086 | 0.098 | - | 1.0 | 1.0 | 0.93 |
| Microbial | 1.4 | 0.29 | 0.29 | 0.43 | 2.3 | 0.43 | 0.57 | 0.43 | 0.86 | 1.1 | 8.7 |
| $PO_4$-P ALS | 0.007 | 0.0051 | 0.011 | 0.0056 | 0.014 | 0.0038 | 0.0034 | - | 0.0081 | 0.0074 | 0.061 |
| Microbial | 0.0093 | 0.0046 | 0.0046 | 0.13 | 0.30 | 0.44 | 4.5 | 0.097 | 0.43 | 0.18 | 0.60 |

The Microbial results were generally higher than the ALS data and their correlation was relatively poor.

### 2.3.8 Cell Counts

Algal cells were counted under transmission microscopy at 400X magnification on a Zeiss Standard microscope using a Petroff-Haueser counting chamber. At the beginning of the study, cells with distinct morphologies were examined at 400X and at 1,000X magnification for unambiguous identification as an alga (presence of coloured pigments, chloroplasts, etc). Subsequently, cells with known morphologies were counted as algae.

### 2.3.9 Secchi Depth

A conventional method for assessing algal density in a lake is to measure the "Secchi Depth". In this application, a Secchi disk[1] is lowered into the water of a lake until its alternating black and white quadrants are no longer distinct. This depth of disappearance, called the Secchi depth, is a measure of the ***transparency*** of the water. Transparency decreases as water color, suspended sediments, or algal abundance increases. In this study, this technique was adapted to measure algal density (Figure 2).

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[1] An 8-inch (20 cm) disk with alternating black and white quadrants

**Figure 2. Secchi depth measurement for algal cultures.**

A sectored disk was placed at the end of a ruler, and this ruler was lowered until the sectors could no longer be distinguished. This was designated as the Secchi depth.

# 3 Results

## 3.1 Initial Sample Characterisation

Water samples collected by Laberge Environmental were analyzed for a complete suite of parameters (See Appendix I). Key parameters that were measured throughout the study are presented in Table 4.

**Table 4. Key parameters measured at the outset of the study.**

| Sample | pH | Cond | $NH_3$-N | P[1] | Zn[1] | Chl "a" |
|---|---|---|---|---|---|---|
| | | µS | mg/L | mg/L | mg/L | µg/L |
| Faro 5m | 7.17 | 1220 | 1.70 | <0.01 | 12.3 | 2 |
| Faro 40 m | 6.64 | 1395 | 1.94 | 0.01 | 2.90 | n/a |
| Grum 5m | 7.39 | 1070 | <0.05 | 0.01 | 12.9 | <1 |
| Grum 40m | 7.46 | 1035 | <0.05 | 0.05 | 13.1 | <1 |
| Vangorda 5m | 5.97 | 1930 | 0.90 | <0.01 | 116 | <1 |
| Vangorda 40m | 5.96 | 2000 | 0.94 | 0.02 | 119 | <1 |

[1] Expressed as Total Metals. Differences between dissolved and total were negligible.

The water analysis shows there are a few differences between water from each pit lake. Vangorda water is slightly acidic, whereas Faro and Grum waters are circumneutral. Vangorda water has much higher conductivity and zinc concentrations. The zinc concentration is 116 mg/L in the 5m Vangorda sample compared with 12.3 and 12.9 mg/L for Faro and Grum, respectively.

Nutrient concentrations are low in all the water samples, except for ammonia, with concentrations around 1 mg/L in both Faro and Vangorda water. Chlorophyll "a" concentrations are also very low in all the pit lakes.

## 3.2 Task 1: Inoculum Development

A sample of ice apparently containing green algae was collected at the surface of the Grum pit lake. This sample was placed in a shake flask, fertilized with 10 mg/L $NH_3$-N and 1 mg/L P, and incubated at room temperature under illumination. Water samples from Faro, Grum, and Vangorda pit lakes were similarly fertilized and incubated. A duplicate set of pit lake sample received sediments collected in shallow near-shore areas.

Each of the above samples grew algae, however, the onset of visible algal growth, as well as the type of algae that grew differed markedly (Figure 3).

**Figure 3. Algal growth in various water samples. Top row: Grum ice sample (left), Vangorda water (middle), and Grum water with sediments. Bottom row: Faro and Grum water (left), and Faro water with sediments.**

Growth in the Grum ice sample was first seen 2-3 weeks after fertilization, as algae attached to the bottom of the shake flask. However, there was distinct planktonic (free-floating) growth a week later (June 14). By their appearance in the microscope, these comprised a mix of Chlorella or Euglena. In addition, there was visible growth on the surface of sediments from the Grum and Faro samples. The latter algae were filamentous and remained attached to the sediments for the entire three months of the lab study, never producing visible planktonic growth.

Planktonic growth appeared later in the fertilized Vangorda (Week 5), Faro (Week 6-7), and Grum (> 2 months) pit lake water samples. The algae in each of these samples were distinctly different. Vangorda algae were green-brown (possibly diatoms), Faro algae were bright green, whereas the Grum algae were blue-greens (See Figure 3). No attempt was made at taxonomic identification, as this was beyond the scope of the project.

## 3.3 Task 2: Toxicity Threshold

This test was conducted to determine if the pit lake waters are toxic to algal growth. It is not a toxicity test *per se*, but rather a test to determine the effect of dilution on algal growth. Water from each pit lake was fertilized, inoculated with algae from the Grum ice sample, and incubated at full-strength, half-strength, quarter-strength, and so on.

Algae were found to grow in water from every pit lake, even in undiluted water. However, observable growth occurred sooner in the more diluted waters. The rate of growth was somewhat difficult to quantify because much of the early growth was of algae attached onto the inner surface of the glass test tubes (Figure 4, taken one week after inoculation).

**Figure 4. First algal growth in toxicity threshold test. Top: Grum water (tubes with growth are circled). Bottom left: Faro water. Bottom right: Vangorda water. Dilutions are indicated on labels.**

Algal numbers were counted at the end of the test (Table 5). On average, all the full-strength water samples had lower cell numbers than diluted water. For the Grum sample, there were five times fewer cells in full-strength water compared with diluted water. Moreover, diluted Grum water averaged nearly twice more cells (8.8 x $10^6$) compared with diluted Faro (4.9 x $10^6$) and diluted Vangorda (4.6 x $10^6$) waters.

However, these results do not reflect all growth because attached algae could not be counted. While, planktonic algae predominated in Faro water, attached algae predominated in Grum and Vangorda waters (Figure 5). Thus, the cell counts results underestimate the differences between Faro, Grum and Vangorda waters. Still, it is clear that algae can grow in full-strength pit lake water, albeit slower than in diluted water.

**Figure 5. Algal growth at the end of toxicity threshold test. Note mix of attached and planktonic growth.**

**Table 5. Counts of planktonic algae at the end of the toxicity threshold test.**

| | Cell Count (Cells/mL) | | |
|---|---|---|---|
| **Dilution** | Faro | Grum | Vangorda |
| Full-strength | $3.0 \times 10^6$ | $1.2 \times 10^6$ | $2.0 \times 10^6$ |
| Half | $6.5 \times 10^6$ | $1.1 \times 10^7$ | $3.5 \times 10^6$ |
| Quarter | $5.3 \times 10^6$ | $8.5 \times 10^6$ | $4.0 \times 10^6$ |
| Eighth | $2.7 \times 10^6$ | $7.3 \times 10^6$ | $4.5 \times 10^6$ |
| Sixteenth | $5.1 \times 10^6$ | $8.5 \times 10^6$ | $6.5 \times 10^6$ |
| Average of diluted samples | $4.9 \times 10^6$ | $8.8 \times 10^6$ | $4.6 \times 10^6$ |

## 3.4 Task 3: Algal Growth in Fertilized Pit Lake Water

Water from each pit lake was fertilized with high and low fertilizer doses according to the regime shown in Table 1. Algal growth and water chemistry were measured in waters from the pit lake throughout the six-week incubation. Parameters measured routinely during the study included:

- pH
- Temperature
- Conductivity
- Dissolved oxygen
- Ammonia nitrogen
- Nitrate
- Phosphate
- Dissolved zinc concentrations

### 3.4.1 Water Chemistry

#### 3.4.1.1 Water pH

Except for Faro high fertilizer, the changes in pH in all the fertilizer treatments were comparable with those in the non-fertilized controls (Figure 6). Water pH in the Vangorda water remained between 7.1 and 7.4 throughout the study, that in the Grum treatments remained at approximately 8.5, whereas water pH in the Faro treatments remained between 8.0 and 8.5.

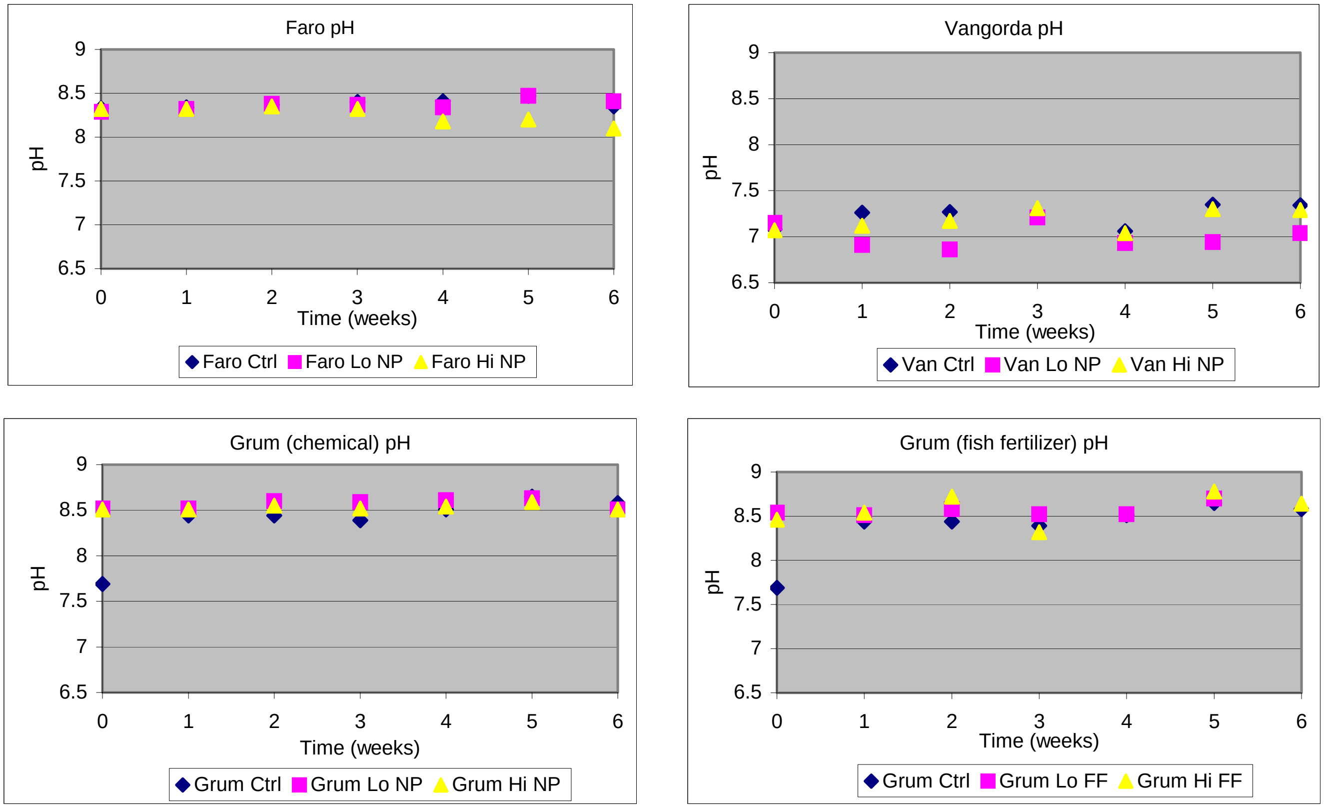


**Figure 6. Water pH in Faro, Grum, and Vangorda fertilized water.**

### 3.4.1.2 Temperature

Water temperature ranged from 20.4 to 26.9 ºC and averaged 24.3 ºC during the entire study. No single treatment was warmer of cooler than the others, indicating there was no bias introduced by the position of the containers during the six week incubation.

### 3.4.1.3 Conductivity

Conductivity varied somewhat during the study due to evaporative water losses and water replenishment (Figure 7).

Grum water had the lowest conductivity, ranging from 1017 to 1393 µS. Conductivity in the chemical fertilizer treatment averaged 1251 µS, whereas the fish fertilizer treatment averaged 1147 µS, a relatively insignificant difference.

Faro water had a conductivity averaging 1344 µS, ranging from 1119 to 1503 µS. Water was replenished in the high fertilizer treatment on Weeks 4 and 6, and in the Control incubation on Week 6, resulting in marked decreases in conductivity.

Vangorda water had the highest conductivity during the study, averaging 2122 µS and ranging from 1907 to 2500 µS. Conductivity increased steadily in all the treatments during the study, apparently from high evaporative losses. Water was replenished in the low fertilizer treatment on Weeks 4 and 6, and in the high fertilizer incubation on Week 6, resulting in marked decreases in conductivity.

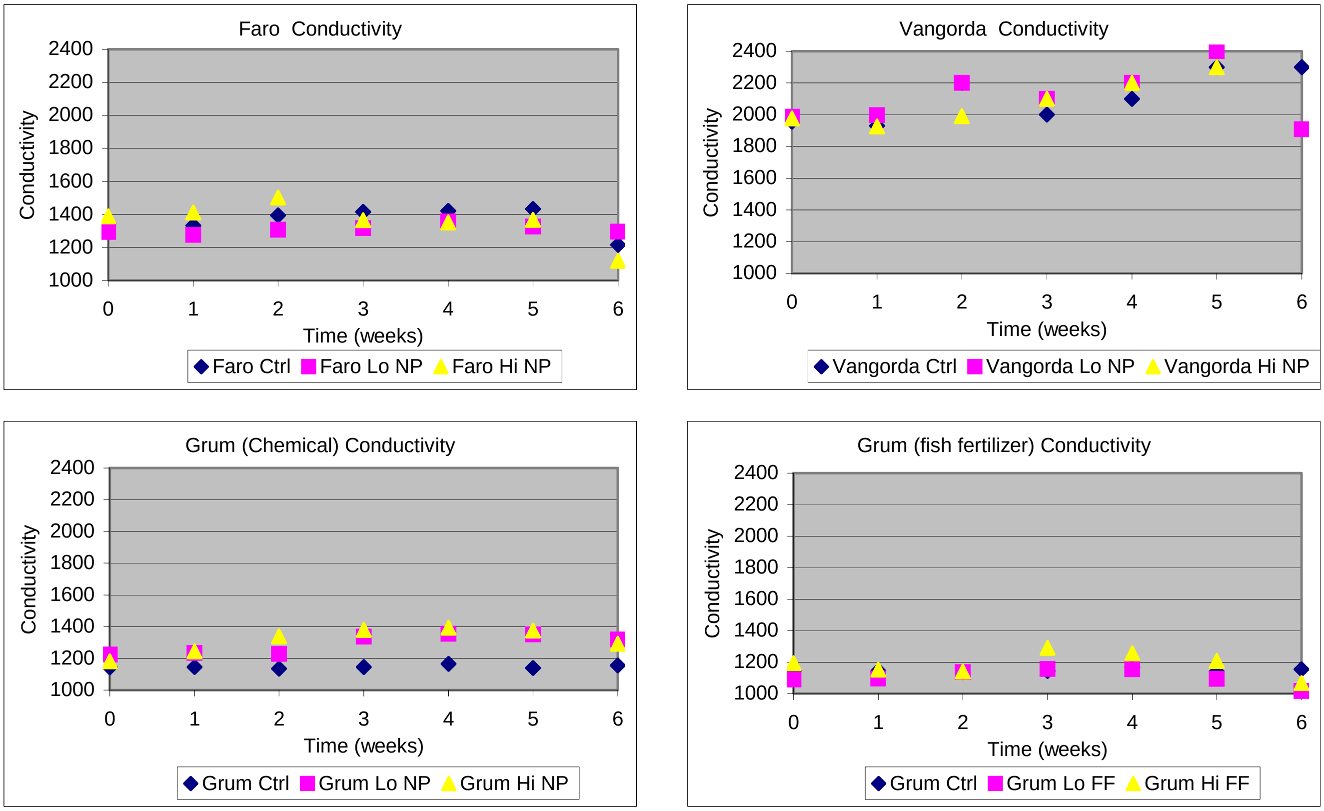


**Figure 7. Conductivity in Faro, Grum, and Vangorda fertilized water.**

#### 3.4.1.4 Dissolved Oxygen

Dissolved oxygen remained fairly constant between 6.0 and 8.0 mg/L during the entire study, averaging 6.76 ± 0.080 mg/L. This reflects the good aeration provided during the study as well as the production of oxygen by photosynthetic algae. Given its constancy, dissolved oxygen measurement were discontinued after Week 4.

#### 3.4.1.5 Ammonia

Ammonia is the preferred source of nitrogen for algae, hence its use in this study. Ammonia concentrations typically decreased in treatments where algal growth was significant (Figure 8). Thus, ammonia concentrations decreased gradually in the Faro high and low NP, Vangorda low NP, and Grum high and low NP and high and low FF treatments, where algae grew well (See Table 6). In contrast, ammonia concentrations remained low and constant in all the Control incubations.

The Faro high NP treatment had a gradual decrease in ammonia concentrations, starting from 6.8 mg/L to approximately 0.5 mg/L by Week 4. The ammonia decrease was more muted in the Faro low NP treatment, but the trend was similar.

Ammonia concentrations remained elevated in the Vangorda high NP treatment. However, it followed the same pattern of gradual decrease in the low NP treatment, starting from approximately 2 mg/L to less than 0.1 mg/L by the end of the study.

Ammonia concentrations decreased rapidly in all the Grum treatments (Figure 8). This was most rapid in the Grum high FF, decreasing from initial concentrations of approximately 5 mg/L to approximately 1mg/L by Week 2. More fertilizer was added by Week 3, but its concentrations continued to decrease rapidly thereafter. In the low NP and low FF treatments, ammonia also decreased rapidly, down to approximately 0.1 mg/L by Week 2.

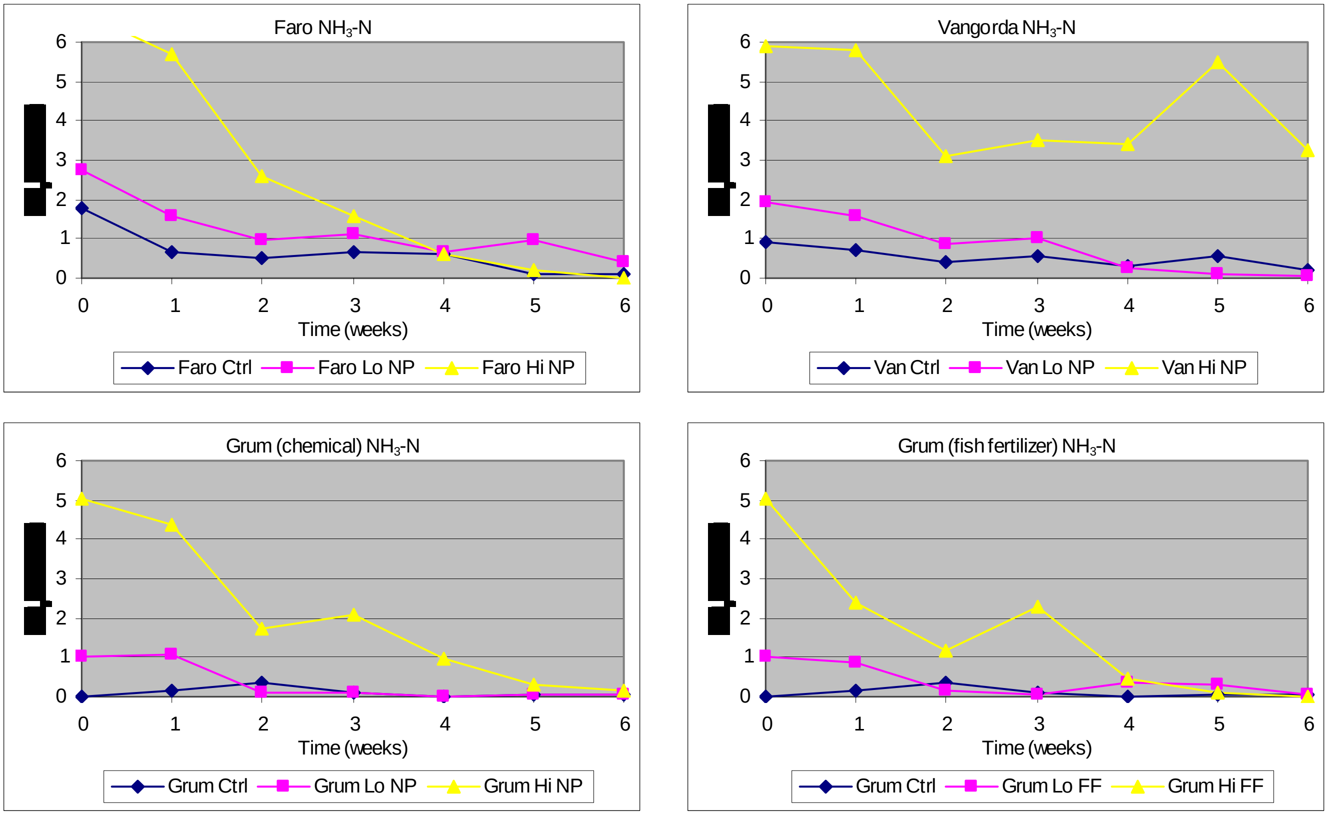


**Figure 8. Ammonia-nitrogen in Faro, Grum, and Vangorda fertilized water.**

### 3.4.1.6 Nitrate

Nitrate-nitrogen can be used as a nitrogen source in the absence of ammonia. It is also produced when algae die and accumulate at the bottom (of lakes or our containers). This only occurs to a measurable extent when algal biomass is high, as we observed in previous laboratory studies. Finally, it can be produced by bacterial oxidation of ammonia (nitrification).

Nitrate exhibited an interesting pattern during this study (Figure 9). Nitrate-nitrogen was very low in all the treatments except for Faro high NP and Grum high fish fertilizer. The increase in nitrate concentrations in the Faro and Grum treatments coincide with periods of high algal biomass (Figure 18). Coincidentally, algae in these treatments also formed clumps at those times (See below). However, these results must be taken tentatively in light of the QA/QC results.

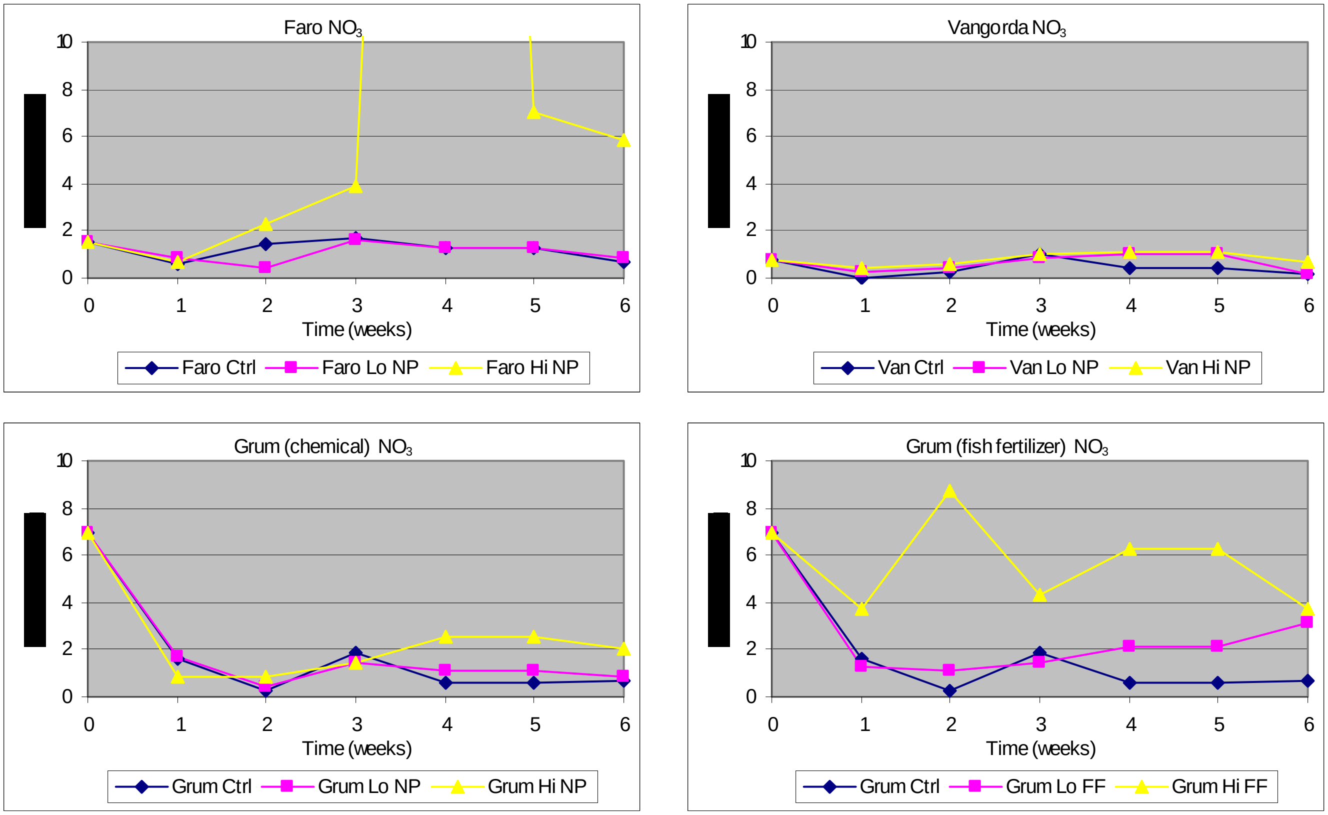


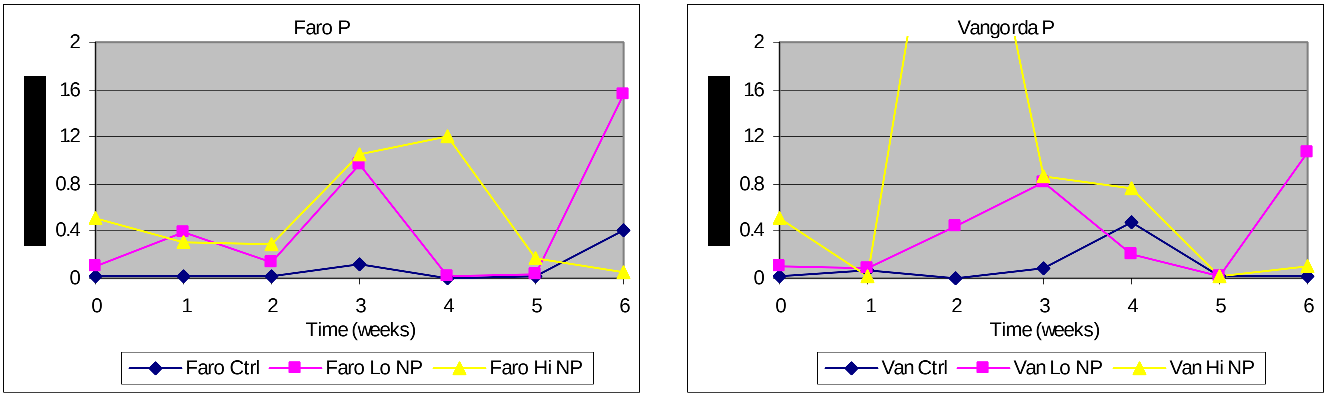
**Figure 9. Nitrate-nitrogen in Faro, Grum, and Vangorda fertilized water.**

### 3.4.1.7 Phosphate

Phosphate concentrations did not follow a consistent pattern during this study (Figure 10). Even in the Control incubations, phosphate concentrations were low for the Faro and Vangorda waters, but they were more erratic for the Grum Controls. It is possible that some substance in the Grum water interfered with the phosphate assay, given the discrepancies noted in QA/QC analysis.

Ignoring a few outliers, phosphate concentrations appeared to follow a decreasing trend in the Faro treatments. However, the Vangorda treatments did not show such a pattern.

Taken altogether, the results of these analyses are inconclusive.



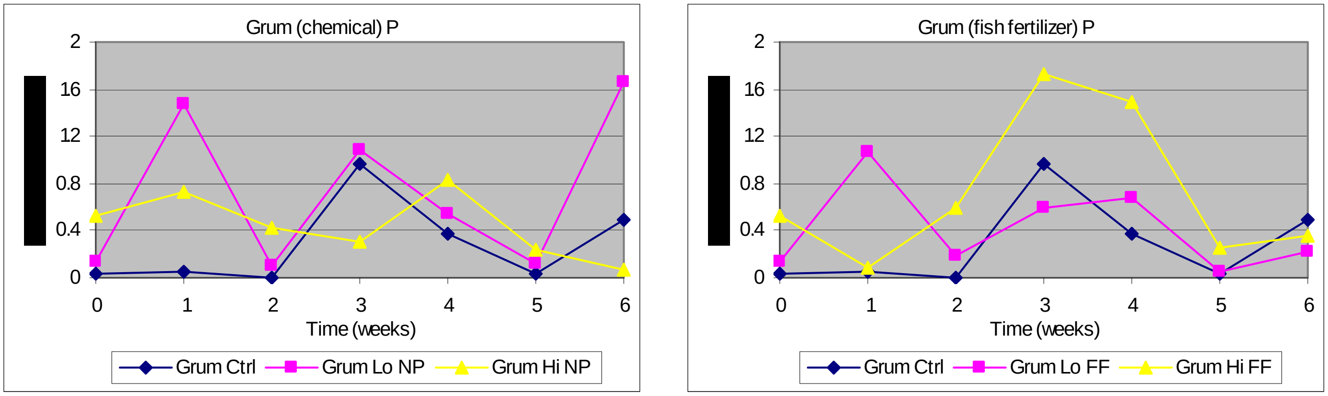


**Figure 10. Soluble P in Faro, Grum, and Vangorda fertilized water.**

### 3.4.1.8 Zinc

Zinc concentrations did not follow the expected pattern during the study. In every treatment, zinc concentrations decreased at the same rate as in the Control incubation (Figure 11). Moreover, the initial zinc concentrations in Grum and Vangorda waters were much higher than in any subsequent sampling. The Vangorda 5 and 40m samples averaged 117 mg/L zinc, whereas it concentrations two weeks later averaged 79 mg/L in the Control and fertilized treatments. Similarly, zinc concentrations in Grum water was measured at 12.9 mg/L initially, but by Week 2, it averaged 0.57 in the Control and fertilized treatments.

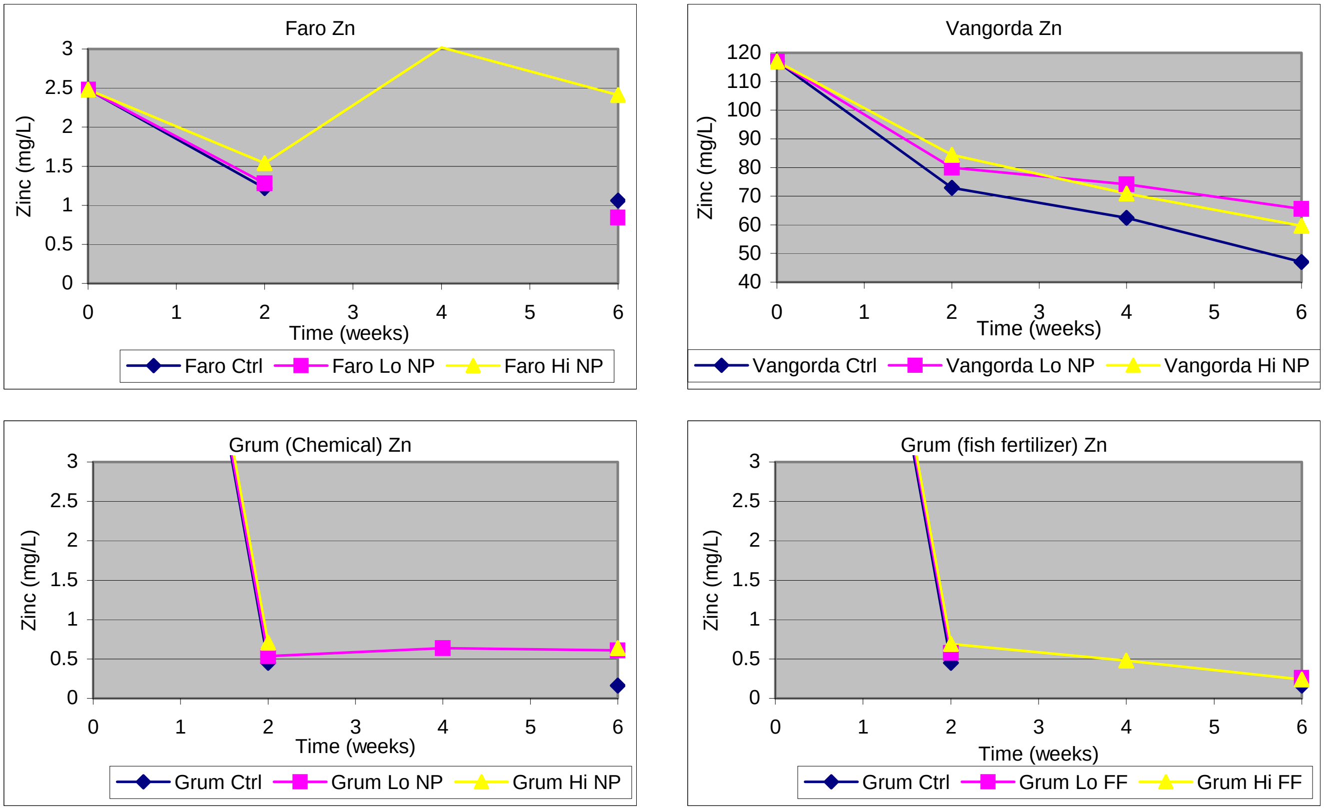


**Figure 11. Zinc concentrations in Faro, Grum, and Vangorda fertilized water. Zinc concentrations in Grum water were 12.9 mg/L initially (off-scale on y-axis).**

The fact that zinc concentrations decreased in all the treatments and in Control incubations suggests that its removal was independent of algal biomass. Nor was it dependent on water pH, since it decreased as well in alkaline water (Faro, Grum) as in neutral water (Vangorda). It is possible that it adsorbed to the walls of the containers used for the test[2], but there was no evidence for this. At present, there is no explanation for this observation.

### 3.4.2 Algal Growth

Algal growth was evaluated in four different ways:

- Visual observations
- Cell count
- Chlorophyll "a" density
- Secchi disk depth

The results of these different tests are presented below.

#### 3.4.2.1 Visual Observations

Visually, there were obvious differences between the treatments, though the same algal inoculum was added to every fertilized water sample. None of the Control incubation exhibited any visible sign of algal growth during the test, whereas there was obvious green growth in the other treatments (Figure 12).

**Figure 12. Photograph[3] of containers at end of test. White arrows point to Control incubations.**

Within nine days, an algal bloom started to develop in the Grum high fish fertilizer treatment (Figure 13). By Week 2, water in this treatment was bright green (Figure 14). However, most of the algae in that treatment were clumped (See Figure 15), so that cell counts did not reveal the true extent of algal growth. Towards the end of the study, a second algal bloom developed, but much of the algal growth was also on the walls of the container, again preventing an accurate cell count (Figure 16, both for Grum high FF [left] and Vangorda low NP [right]).

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[2] These are plastic containers, which should be unreactive towards metals.

[3] All the photographs were taken with the same camera settings, but lighting varies, affecting picture colour. As little as possible software compensation was applied to restore colour fidelity.

**Figure 13. Algal growth in Grum high fish fertilizer treatment, far right. Taken on Day 9.**

**Figure 14. Algal growth in Grum high fish fertilizer treatment, far left, as well as in Faro high NP, far right. Taken on Day 15.**

**Figure 15. Algae growing as clumps in the Grum high fish fertilizer treatment.**

**Figure 16. Algae growing on wall of container in Grum high fish fertilizer treatment (White arrows). Taken on Week 6.**

Algal growth was also visible in the Faro high fertilizer treatment by Day 15, and in most other treatments later on. Growth was mostly planktonic in these treatments (Figure 17).

**Figure 17. Algal growth in Grum low fish fertilizer treatment. Notice the absence of growth on the walls of the container. Taken on Week 6.**

Algal growth was first observed during the study at the times indicated in Table 6. These times do not correspond completely with cell counts (See below). These observations show that fertilization was required to produce observable algal growth. In addition, high fertilizer applications usually resulted in faster growth, except for the Grum chemical fertilization (Grum low NP faster than Grum high NP).

**Table 6. Time of first observable algal growth.**

| Treatment | First observable algal growth |
|---|---|
| Faro Control | None |
| Grum Control | None |
| Vangorda Control | None |
| Faro low NP | None |
| Faro high NP | Day 9 |
| Vangorda low NP | Day 30 |
| Vangorda high NP | Day 15 |
| Grum low NP | Day 15-18 |
| Grum high NP | Day 21 |
| Grum low FF | Day 25 |
| Grum high FF | Day 9 |

### 3.4.2.2 Cell counts

Cell counts indicated the number of planktonic algae in a water sample. This number does not account for algae growing in clumps or on the container surface. However, these data reveal some of the population dynamics that occurred in response to the various fertilizer addition.

Unfertilized Faro water supported little planktonic growth (Figure 18). Similarly, Faro water receiving the low fertilizer dose only supported modest algal growth near the end of the study. In contrast, Faro water receiving the high fertilizer dose supported good algal growth throughout the study, with maximum cell counts of 1.6 x $10^6$ cells/mL. A bloom develop by Week 1 and was sustained until Week 4. This bloom crashed by Week 5, but algal growth had resumed by the following week.

Algal growth was negligible in the Control and the high fertilizer treatment in Vangorda water. Cell counts never reached higher than 1.0 x $10^5$ cells/mL. Algal growth was somewhat better in the low fertilizer treatment, but its onset was delayed until the end of the study, when cell numbers reached 1.8 x $10^6$ cells/mL.

There was modest algal growth in the Grum chemically-fertilized water. Cell numbers started to increase after Week 3, peaking at around $10^6$ cells/mL on Week 4 before declining by Week 5. However, this decline in planktonic cell numbers coincides with the appearance of algal growth on the container walls, suggesting that algae merely switched to an attached mode of growth.

Grum water receiving fish fertilizer produced the highest cell numbers in this study, with planktonic algae reaching 2.4 x $10^6$ cells/mL by Week 1. Cell counts would suggest that this population crashed within a week, but visual observations show that they actually switched to an attached/clumped mode of growth (See Figure 15). However, the population of planktonic algae gradually increased again, exceeding its original high numbers by Week 6, when they reached 2.8 x $10^6$ cells/mL.

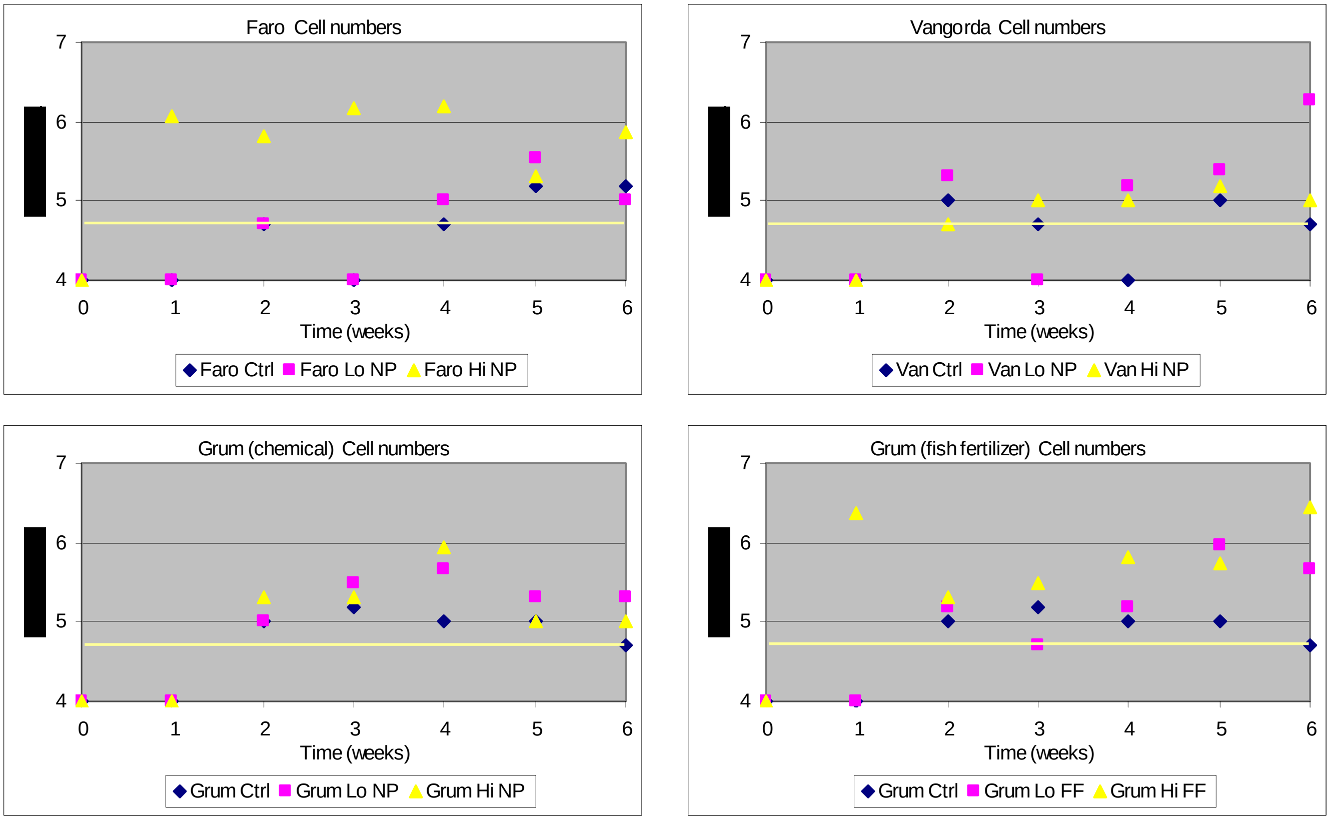

**Figure 18. Cell numbers in Faro, Grum, and Vangorda fertilized water. Detection limits indicated by light yellow bar.**

The above results indicate that algae growth began shortly after inoculation and fertilization in Faro and Grum waters, whereas it was delayed considerably or negligible in Vangorda water. This pattern coincides with that of zinc concentrations measured in these water. In addition, it appears that algal growth changed from a planktonic mode to an attached or clumped mode when their numbers exceed 1-2 x $10^6$ cells/mL, as seen in the Faro high NP and Grum high FF treatments, and possibly in the Grum high NP treatment. In both the former cases, planktonic algae grew back shortly after their population decreased below 1 x $10^6$ cells/mL.

### 3.4.2.3 Secchi depth

Secchi depth was only partly useful in measuring algal density. The Secchi depth for all the Controls, Grum (chemical) and Vangorda treatments, and in the Faro low NP, was greater than 10 inches, the depth of water in the containers used in this study. For the other treatments, the Secchi depth is shown in Figure 19.

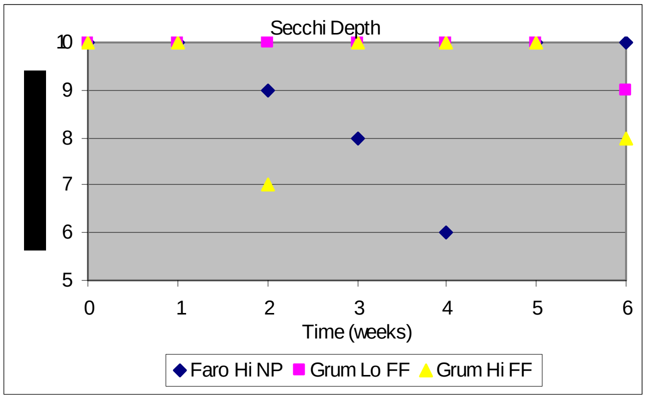

**Figure 19. Secchi depth of treatments during algal growth study.**

### 3.4.2.4 Chlorophyll "a"

Chlorophyll "a" is the pigment used by green algae and plants for photosynthesis[4]. Therefore, its concentration in water provides a direct quantitative measure of algal density. Chlorophyll "a" concentrations were measured on three occasions during the study to provide additional data from which to calculate algal biomass[5].

Its concentrations were high in the Faro and Grum (fish) high fertilizer treatments, but otherwise low in the other treatments (Figure 20). Interestingly, chlorophyll "a" concentrations increased steadily with time in the Faro high NP treatment, in parallel with the steady increase in Secchi depth (Figure 19), but despite an apparently *constant* cell number (Figure 18). Evidently, there *must* have been more algae in this treatment, but these were not being counted, since they were in clumps.

Similarly, chlorophyll "a" concentrations peaked on Week 2 in the Grum high FF treatment, but cell numbers were actually lower on Week 2 than on Week 1 (Figure 18)[6]. Again, this suggests that the cell counts underestimated the actual cell number, likely due to cell clumping.

Chlorophyll "a" concentrations in all the other treatments remained low during the study. They increased slightly in the Grum chemical fertilizer treatments, consistent with earlier observations (e.g., Table 6). Somehow, chlorophyll "a" concentrations never increased in the Vangorda high NP treatment, despite showing signs of algal growth early during the study. In contrast, chlorophyll "a" concentrations increased slightly at the end of the study in the Vangorda low NP treatment, consistent with other results (e.g., Table 6).

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[4] There are other chlorophylls in different algae, but chlorophyll "a" is common to all.

[5] The algal biomass (ash-free dry weight) is estimated by multiplying the chlorophyll "a" content by a factor of 67.

[6] Cell counts on Week 4 are only slightly lower than on Week 1, but the chlorophyll "a" concentration for Week 4 is much lower, indicating that algal biomass had peaked on Week 2 – according to the chlorophyll "a" data, rather than on Week 1 – according to the cell count data.

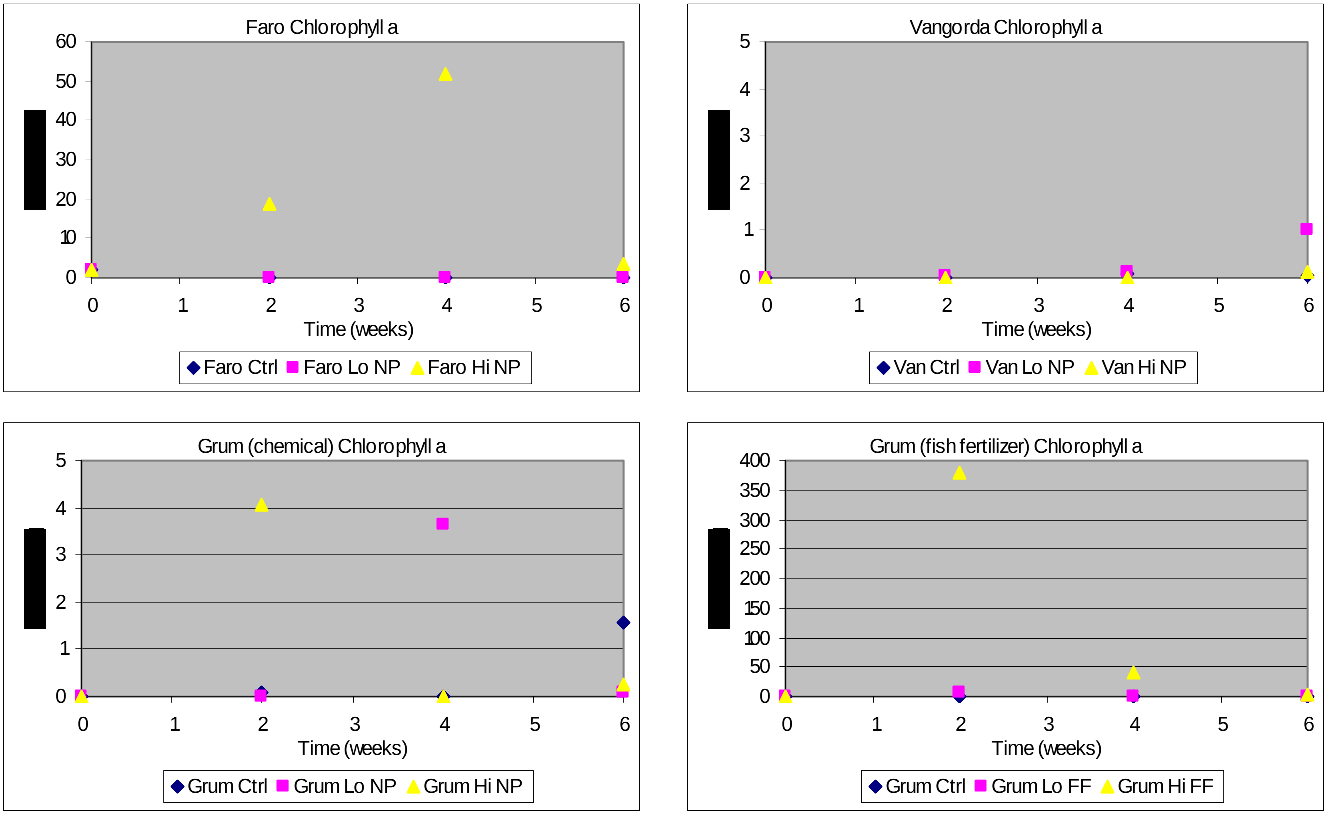

**Figure 20. Chlorophyll "a" concentrations in Faro, Grum, and Vangorda waters during the study. Note the different scales in the above graphs.**

# 4 Discussion and Recommendations

The initial analysis of water samples showed that Faro, Grum, and Vangorda pit lakes had limiting nutrient concentrations (Table 4). Faro water had some ammonia, but little phosphorus. Grum water had some phosphorus, but little ammonia, and Vangorda had little of either nutrient. Thus, fertilization would be expected to be necessary for growing algae in these waters

Algae from the Grum ice sample proved to be the best source of inoculum for this study, as algae grew very rapidly from this sample. However, every fertilized water sample grew distinct algae, indicating that algae were present in every pit lake water sample (Figure 3). Algae also grew from every sediment sample, but their growth was epiphytic, not planktonic. These facts suggest that each pit lake will develop its own algal population.

Algae grown from the Grum ice inoculum were used to determine potential toxic threshold concentrations in each pit lake water sample. Algae grew in every full-strength pit lake water sample. This was somewhat surprising at the time, since the Vangorda water had high zinc concentrations. It was clear that growth in dilute pit lake water (for all the pit lakes) was faster than in full-strength water. Thus, zinc was impairing growth, but did not prevent it. Of course, only zinc-resistant algae grew while zinc-sensitive species did not.

The above finding suggests that, in a pit lake, algal growth will be best immediately after snow melt, when water at the lake surface will be diluted. A remedial strategy may be to apply fertilizer directly over the ice before breakup.

Much of the algal growth in the toxicity threshold test was on the test tube walls (Figure 4). This caused us to underestimate the true extent of algal growth in this test and in the subsequent fertilizer test.

The fertilizer tests produced a number of interesting findings. First, the study demonstrated that 5 mg/L $NH_3$-N and 0.5 mg/L $PO_4$-P is adequate to produce an algal bloom in any of the pit lakes. The lower fertilizer dose did not produce the same level of growth.

While the fish fertilizer and chemical fertilizer both supported algal growth, there appeared to be a qualitative difference between them. The algal bloom resulting from the fish fertilizer seemed more luxuriant than that from the chemical fertilizer (See Figure 13 and Figure 14). This may be due to the presence of growth factors in fish fertilizer that enhance cell growth. If so, fish fertilizer may be preferable to chemical fertilizer to establish an initial algal bloom.

Both the Faro high NP and Grum high FF treatments produced good algal blooms early in the test. In both cases, there is evidence that cells formed clumps when they reached high densities. For the Grum high FF treatment, this was obvious visually (Figure 15) and was supported by an analysis of Secchi depth, cell counts, and chlorophyll “a”. These test results showed that, while cell counts peaked at Week 1, Secchi depth and chlorophyll “a” peaked at Week 2, when cell counts were low. Similar results were obtained with the Faro high NP treatment.

An interesting observation for the Faro high NP, and particularly the Grum high FF treatment, is that planktonic cell growth resumed towards the end of the six-week test (Figure 18). Thus, it may be that algal blooms go through cycles of planktonic growth to a high cell density, clumping and settling to reduce cell density, followed by another round of planktonic cell growth. This cycling appears to have been accelerated by the second addition of fish fertilizer in the Grum high FF treatment on Week 3.

Conceivably, an algal bloom induced in a pit lake may undergo several cycles of planktonic growth, clumping and settling during a growing season, if nutrients are not depleted from surface water. This suggest a process for enhancing metal removal in surface waters. The cycling of planktonic-clumped-planktonic growth could be promoted by repeated fertilization. Assuming that metals are removed from surface waters when algae clump and settle away from the water column, this cycling process may accelerate metal removal. However, fertilizer dosage would have to be monitored to avoid excessive nitrogen and phosphorus concentrations.

The algal blooms that developed in all the treatments never reach such high levels as to affect general water chemistry significantly. Thus, water pH in all the treatments remained the same as in Controls. Somewhat surprisingly, there were also no obvious decreases in zinc concentration caused by these algal blooms, when compared with Controls. This is contrary to expectations and remains unexplained.

Algae appeared to use up ammonia-nitrogen quickly (Figure 8). This was most obvious in the Grum High FF treatment, where a second fertilizer application was made after $NH_3$-N concentrations had decreased from 5 mg/L to approximately 1 mg/L. Despite this second application on Week 3, the continued consumption of $NH_3$-N maintained its concentration to less than 1 mg/L.

Unfortunately, the corresponding critical concentration for phosphate could not be determined in this study because the test results were inconclusive.

Given the above findings, a number of recommendations follow for the treatment of a pit lake:

**Fertilizer dose**

The application of 5.0 mg/L $NH_3$-N and 0.5 mg/L PO4-P-P is adequate to initiate the development of algal blooms. After a bloom is established, $NH_3$-N concentrations should be maintained at 2 mg/L.

**Fertilizer type**

The study results suggest that fish fertilizer may be preferred to initiate an algal bloom, as it appears to promotes more luxuriant algal growth at the same dose as the chemical fertilizer. However, subsequent fertilization can be done using chemical fertilizers.

**Fertilizer application**

It would be preferable to apply fertilizer before ice breakup, since algae grew best when pit lake water was slightly diluted and melt water dilutes surface water. Once an algal bloom is established, fertilization should be continued to maintain ammonia-nitrogen concentrations around 2 mg/L.

# 5 References

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# APPENDIX I

# MONITORING AND ANALYTICAL RESULTS

# Monitoring results for Faro pit lake sample

Week 0 - June 14th

| **Sample ID** | **Sample #** | **pH** | **Temp** | **Cond.** | **DO** | **NH4-N** | **NO3** | **PO4** | **Cell count** | **Secchi Depth** |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ºC | µS | mg/L | mV | $OD_{500}$ | $OD_{890}$ | Cells/0.005µL | Inch |
| Faro Ctrl | **1** | 8.33 | 26 | 1345 | 6.76 | | | | 0 | >10" |
| | | | | | | | | | | |
| Van Ctrl | **2** | 7.08 | 26.2 | 1957 | 7.01 | | | | 0 | >10" |
| | | | | | | | | | | |
| Grum Ctrl | **3** | 7.69 | 26.3 | 1144 | 7.15 | | | | 0 | >10" |
| | | | | | | | | | | |
| Faro Lo NP | **4** | 8.29 | 26.2 | 1293 | 7.01 | | | | 0 | >10" |
| | | | | | | | | | | |
| Faro Hi NP | **5** | 8.32 | 26.7 | 1387 | 8.02 | | | | 0 | >10" |
| | | | | | | | | | | |
| Van Lo NP | **6** | 7.15 | 26.5 | 1987 | 6.49 | | | | 0 | >10" |
| | | | | | | | | | | |
| Van Hi NP | **7** | 7.07 | 26.7 | 1977 | 7.69 | | | | 0 | >10" |
| | | | | | | | | | | |
| Grum Lo NP | **8** | 8.52 | 26.3 | 1223 | 6.08 | | | | 0 | >10" |
| | | | | | | | | | | |
| Grum Hi NP | **9** | 8.51 | 26.6 | 1181 | 6.25 | | | | 0 | >10" |
| | | | | | | | | | | |
| Grum Lo FF | **10** | 8.54 | 25.4 | 1090 | 6.47 | | | | 0 | >10" |
| | | | | | | | | | | |
| Grum Hi FF | **11** | 8.46 | 25.5 | 1193 | 6.33 | | | | 0 | >10" |

## Monitoring results for Faro pit lake sample

Week 1 - June 21st

| Sample ID | Sample # | pH | Temp | Cond. | DO | NH4-N | NO3 | PO4 | Cell count | Secchi Depth |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| Faro Ctrl | **1** | 8.34 | 25.9 | 1331 | 6.78 | 203.2 | 0.004 | 0.003 | 0 | >10" |
| | | | | | | | | | | |
| Van Ctrl | **2** | 7.26 | 26.1 | 1930 | 6.67 | 202.5 | 0 | 0.014 | 0 | >10" |
| | | | | | | | | | | |
| Grum Ctrl | **3** | 8.44 | 26.8 | 1145 | 7.05 | 244.1 | 0.011 | 0.01 | 0 | >10" |
| | | | | | | | | | | |
| Faro Lo NP | **4** | 8.32 | 26.8 | 1276 | 8 | 180.1 | 0.006 | 0.083 | 0 | >10" |
| | | | | | | | | | | |
| Faro Hi NP | **5** | 8.32 | 26 | 1411 | 6.76 | 144.4 | 0.005 | 0.065 | 23 | >10" |
| | | | | | | | | | | |
| Van Lo NP | **6** | 6.91 | 25.9 | 1996 | 6.49 | 180.2 | 0.002 | 0.017 | 0 | >10" |
| | | | | | | | | | | |
| Van Hi NP | **7** | 7.12 | 26.9 | 1925 | 6.09 | 144 | 0.003 | 0.003 | 0 | >10" |
| | | | | | | | | | | |
| Grum Lo NP | **8** | 8.52 | 25.7 | 1235 | 6.38 | 190.8 | 0.012 | 0.317 | 0 | >10" |
| | | | | | | | | | | |
| Grum Hi NP | **9** | 8.51 | 25.6 | 1244 | 7.58 | 151.9 | 0.006 | 0.156 | 0 | >10" |
| | | | | | | | | | | |
| Grum Lo FF | **10** | 8.51 | 26.9 | 1095 | 6.42 | 195.8 | 0.009 | 0.231 | 0 | >10" |
| | | | | | | | | | | |
| Grum Hi FF | **11** | 8.54 | 24.8 | 1152 | 6.09 | 168.5 | 0.026 | 0.019 | 47 | >10" |

# Monitoring results for Faro pit lake sample

Week 2 - July 1st

| **Sample ID** | **Sample #** | **pH** | **Temp** | **Cond.** | **DO** | **NH4-N** | **NO3** | **PO4** | **Cell count** | **Secchi Depth** |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| Faro Ctrl | **1** | 8.37 | 23.1 | 1394 | 6.96 | 212.1 | 0.01 | 0.077 | 1 | >10" |
| | | | | | | | | | | |
| Van Ctrl | **2** | 7.27 | 23.5 | 2200 | 6.92 | 217.6 | 0.002 | 0.076 | 2 | >10" |
| | | | | | | | | | | |
| Grum Ctrl | **3** | 8.44 | 25.1 | 1136 | 6.92 | 223 | 0.002 | 0.048 | 2 | >10" |
| | | | | | | | | | | |
| Faro Lo NP | **4** | 8.38 | 24.8 | 1306 | 7.13 | 193.4 | 0.003 | 0.226 | 1 | >10" |
| | | | | | | | | | | |
| Faro Hi NP | **5** | 8.35 | 23.2 | 1503 | 8 | 166.2 | 0.016 | 0.112 | 13 | 9 |
| | | | | | | | | | | |
| Van Lo NP | **6** | 6.86 | 24.3 | 2200 | 7.69 | 196.8 | 0.003 | 0.071 | 4 | >10" |
| | | | | | | | | | | |
| Van Hi NP | **7** | 7.17 | 24.7 | 1990 | 6.3 | 161.3 | 0.004 | 0.112 | 1 | >10" |
| | | | | | | | | | | |
| Grum Lo NP | **8** | 8.6 | 24.4 | 1227 | 6.14 | 260.5 | 0.003 | 0.101 | 2 | >10" |
| | | | | | | | | | | |
| Grum Hi NP | **9** | 8.55 | 24.3 | 1338 | 6.46 | 177.3 | 0.006 | 0.093 | 4 | >10" |
| | | | | | | | | | | |
| Grum Lo FF | **10** | 8.58 | 24.7 | 1137 | 6.04 | 241.3 | 0.008 | 0.04 | 3 | >10" |
| | | | | | | | | | | |
| Grum Hi FF | **11** | 8.72 | 24 | 1140 | 6.32 | 188.1 | 0.061 | 0.13 | 4 | 7 |

# Monitoring results for Faro pit lake sample

Week 3 - July 7th

| **Sample ID** | **Sample #** | **pH** | **Temp** | **Cond.** | **DO** | **NH4-N** | **NO3** | **PO4** | **Cell count** | **Secchi Depth** |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| Faro Ctrl | **1** | 8.4 | 20.4 | 1414 | 6.19 | 203.9 | 0.012 | 0.024 | 0 | >10" |
| | | | | | | | | | | |
| Van Ctrl | **2** | 7.24 | 21.4 | 2000 | 6.82 | 207.9 | 0.007 | ..019 | 1 | >10" |
| | | | | | | | | | | |
| Grum Ctrl | **3** | 8.39 | 21.7 | 1145 | 6.86 | 257.9 | 0.013 | 0.21 | 3 | >10" |
| | | | | | | | | | | |
| Faro Lo NP | **4** | 8.37 | 22 | 1316 | 6.78 | 188.9 | 0.011 | 0.209 | 2 | >10" |
| | | | | | | | | | | |
| Faro Hi NP | **5** | 8.32 | 20.4 | 1364 | 7.64 | 180.3 | 0.027 | 0.229 | 30 | 8 |
| | | | | | | | | | | |
| Van Lo NP | **6** | 7.21 | 21.4 | 2100 | 6.36 | 191.8 | 0.006 | 0.176 | 0 | >10" |
| | | | | | | | | | | |
| Van Hi NP | **7** | 7.31 | 22.3 | 2100 | 7.4 | 157.7 | 0.007 | 0.188 | 2 | >10" |
| | | | | | | | | | | |
| Grum Lo NP | **8** | 8.59 | 21.6 | 1336 | 6 | 251.8 | 0.01 | 0.233 | 6 | >10" |
| | | | | | | | | | | |
| Grum Hi NP | **9** | 8.52 | 21.6 | 1379 | 6.26 | 172.3 | 0.01 | 0.067 | 4 | >10" |
| | | | | | | | | | | |
| Grum Lo FF | **10** | 8.52 | 21.8 | 1156 | 6.45 | 266.6 | 0.01 | 0.127 | 1 | >10" |
| | | | | | | | | | | |
| Grum Hi FF | **11** | 8.32 | 21.2 | 1290 | 6.17 | 169.7 | 0.03 | 0.373 | 6 | >10" |

# Monitoring results for Faro pit lake sample

Week 4 - July 14th

| **Sample ID** | **Sample #** | **pH** | **Temp** | **Cond.** | **DO** | **NH4-N** | **NO3** | **PO4** | **Cell count** | **Secchi Depth** |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Blank: -0.001 | Blank: 0.000 | | |
| Faro Ctrl | **1** | 8.41 | 23.1° | 1420 | 6.78 | 148.3 | 0.009 | 0.001 | 1 | >10" |
| | | | | | | | | | | |
| Van Ctrl | **2** | 7.06 | 23.7° | 2100 | 6.76 | 163.8 | 0.003 | 0.103 | 0 | >10" |
| | | | | | | | | | | |
| Grum Ctrl | **3** | 8.51 | 24.1° | 1166 | 7.04 | 231.3 | 0.004 | 0.081 | 2 | >10" |
| | | | | | | | | | | |
| Faro Lo NP | **4** | 8.34 | 24.1° | 1357 | 6.82 | 146 | 0.009 | 0.003 | 0 | >10" |
| | | | | | | | | | | |
| Faro Hi NP | **5** | 8.18 | 23.3° | 1351 | 7.93 | 148.6 | 0.59 | 0.259 | 32 | 6" |
| | | | | | | | | | | |
| Van Lo NP | **6** | 6.93 | 23.8° | 2200 | 6.5 | 169.1 | 0.007 | 0.045 | 3 | >10" |
| | | | | | | | | | | |
| Van Hi NP | **7** | 7.04 | 24.2° | 2200 | 7.61 | 108.8 | 0.008 | 0.164 | 2 | >10" |
| | | | | | | | | | | |
| Grum Lo NP | **8** | 8.61 | 23.9° | 1355 | 6 | 252.8 | 0.008 | 0.117 | 9 | >10" |
| | | | | | | | | | | |
| Grum Hi NP | **9** | 8.54 | 23.8° | 1393 | 6.32 | 138.4 | 0.018 | 0.18 | 17 | >10" |
| | | | | | | | | | | |
| Grum Lo FF | **10** | 8.52 | 24.2° | 1155 | 6.38 | 162.3 | 0.015 | 0.146 | 3 | >10" |
| | | | | | | | | | | |
| Grum Hi FF | **11** | 87.4 | 23.9° | 1257 | 6.25 | 155.4 | 0.044 | 0.322 | 13 | >10" |

## Monitoring results for Faro pit lake sample

Week 5 - July 21st

| **Sample ID** | **Sample #** | **pH** | **Temp** | **Cond.** | **DO** | **NH4-N** | **NO3** | **PO4** | **Cell count** | **Secchi Depth** |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| Faro Ctrl | **1** | 8.47 | 24.6 | 1433 | | 185.4 | 0.009 | 0.004 | 3 | >10" |
| | | | | | | | | | | |
| Van Ctrl | **2** | 7.35 | 25.3 | 2300 | | 151.3 | 0.003 | 0.002 | 2 | >10" |
| | | | | | | | | | | |
| Grum Ctrl | **3** | 8.65 | 25.9 | 1140 | | 217.9 | 0.004 | 0.006 | 2 | >10" |
| | | | | | | | | | | |
| Faro Lo NP | **4** | 8.47 | 25.4 | 1326 | | 138 | 0.009 | 0.008 | 7 | >10" |
| | | | | | | | | | | |
| Faro Hi NP | **5** | 8.2 | 24.9 | 2400 | | 173.1 | 0.049 | 0.035 | 4 | >10" |
| | | | | | | | | | | |
| Van Lo NP | **6** | 6.94 | 25.3 | 2300 | | 189.6 | 0.007 | 0.004 | 5 | >10" |
| | | | | | | | | | | |
| Van Hi NP | **7** | 7.3 | 25.8 | 1352 | | 97.9 | 0.008 | 0.002 | 3 | >10" |
| | | | | | | | | | | |
| Grum Lo NP | **8** | 8.63 | 25.3 | 1375 | | 218.5 | 0.008 | 0.026 | 4 | >10" |
| | | | | | | | | | | |
| Grum Hi NP | **9** | 8.59 | 25.4 | 1094 | | 165.2 | 0.018 | 0.05 | 2 | >10" |
| | | | | | | | | | | |
| Grum Lo FF | **10** | 8.7 | 26 | 1207 | | 162.9 | 0.015 | 0.012 | 19 | >10" |
| | | | | | | | | | | |
| Grum Hi FF | **11** | 8.78 | 24.8 | | | 185 | 0.044 | 0.055 | 11 | >10" |

# Monitoring results for Faro pit lake sample

Week 6 - July 28th

| **Sample ID** | **Sample #** | **pH** | **Temp** | **Cond.** | **DO** | **NH4-N** | **NO3** | **PO4** | **Cell count** | **Secchi Depth** |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| Faro Ctrl | **1** | 8.35 | 22.4 | 1216 | | 150.1 | 0.005 | 0.089 | 3 | >10" |
| | | | | | | | | | | |
| Van Ctrl | **2** | 7.34 | 22.9 | 2300 | | 135.4 | 0.001 | 0.002 | 1 | >10" |
| | | | | | | | | | | |
| Grum Ctrl | **3** | 8.58 | 23.2 | 1155 | | 161.4 | 0.005 | 0.107 | 6 | >10" |
| | | | | | | | | | | |
| Faro Lo NP | **4** | 8.41 | 23.4 | 1295 | | 123.3 | 0.006 | 0.336 | 2 | >10" |
| | | | | | | | | | | |
| Faro Hi NP | **5** | 8.1 | 22.9 | 1119 | | 192.6 | 0.041 | 0.012 | 15 | >10" |
| | | | | | | | | | | |
| Van Lo NP | **6** | 7.04 | 23 | 1907 | | 167.1 | 0.001 | 0.23 | 37 | >10" |
| | | | | | | | | | | |
| Van Hi NP | **7** | 7.29 | 23.5 | 2500 | | 82.9 | 0.005 | 0.022 | 2 | >10" |
| | | | | | | | | | | |
| Grum Lo NP | **8** | 8.51 | 22.8 | 1318 | | 169.8 | 0.006 | 0.36 | 4 | >10" |
| | | | | | | | | | | |
| Grum Hi NP | **9** | 8.51 | 23.1 | 1292 | | 140.8 | 0.014 | 0.016 | 2 | >10" |
| | | | | | | | | | | |
| Grum Lo FF | **10** | 9.1 | 23.4 | 1017 | | 166.8 | 0.022 | 0.049 | 50 | 9 |
| | | | | | | | | | | |
| Grum Hi FF | **11** | 8.64 | 22.8 | 1068 | | 194.6 | 0.026 | 0.076 | 55 | 8 |

# Toxicity Threshold test

| Sample | Raw count | Cell No. |
|---|---|---|
| F full | 3 | |
| F full | 5 | |
| F full | 10 | 3.00E+06 |
| F half | 2 | |
| F half | 8 | |
| F half | 29 | 6.50E+06 |
| F quarter | 12 | |
| F quarter | 13 | |
| F quarter | 7 | 5.33E+06 |
| F eighth | 3 | |
| F eighth | 6 | |
| F eighth | 7 | 2.67E+06 |
| F sixteenth | 8 | |
| F sixteenth | 2 | |
| F sixteenth | 21 | 5.17E+06 |

| Sample | Raw count | Cell No. |
|---|---|---|
| G full | 3 | |
| G full | 0 | |
| G full | 4 | 1.17E+06 |
| G half | 17 | |
| G half | 32 | |
| G half | 15 | 1.07E+07 |
| G quarter | 8 | |
| G quarter | 24 | |
| G quarter | 19 | 8.50E+06 |
| G eighth | 24 | |
| G eighth | 5 | |
| G eighth | 15 | 7.33E+06 |
| G sixteenth | 3 | |
| G sixteenth | 28 | |
| G sixteenth | 20 | 8.50E+06 |

| Sample | Raw count | Cell No. |
|---|---|---|
| V full | 2 | |
| V full | 4 | |
| V full | 6 | 2.00E+06 |
| V half | 6 | |
| V half | 2 | |
| V half | 13 | 3.50E+06 |
| V quarter | 10 | |
| V quarter | 11 | |
| V quarter | 3 | 4.00E+06 |
| V eighth | 5 | |
| V eighth | 10 | |
| V eighth | 12 | 4.50E+06 |
| V sixteenth | 11 | |
| V sixteenth | 10 | |
| V sixteenth | 18 | 6.50E+06 |

| | |
|---|---|
| **Project** | Faro Water analysis |
| **Report to** | Microbial Technologies Inc. |
| **ALS File No.** | U5065 |
| **Date Received** | 29/06/2004 |
| **Date:** | INTERIM |

**RESULTS OF ANALYSIS**

| **Sample ID** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 10a |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Date Sampled** | 29/06/2004 | 29/06/2004 | 29/06/2004 | 29/06/2004 | 29/06/2004 | 29/06/2004 | 29/06/2004 | 29/06/2004 | 29/06/2004 | 29/06/2004 | 29/06/2004 | 29/06/2004 |
| **Time Sampled** | 11:00 | 11:00 | 11:00 | 11:00 | 11:00 | 11:00 | 11:00 | 11:00 | 11:00 | 11:00 | 11:00 | 11:00 |
| **ALS Sample ID** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| **Nature** | Water | Water | Water | Water | Water | Water | Water | Water | Water | Water | Water | Water |
| | | | | | | | | | | | | |
| **Nutrients** | | | | | | | | | | | | |
| Nitrate Nitrogen N | 0.189 | 0.0799 | 0.711 | 0.176 | 0.191 | 0.086 | 0.0976 | - | 1.03 | 1.02 | 0.926 | 1.02 |
| Total Dissolved Phosphate P | 0.007 | 0.0051 | 0.0107 | 0.0056 | 0.0144 | 0.0038 | 0.0034 | - | 0.0081 | 0.0074 | 0.0611 | 0.0047 |
| | | | | | | | | | | | | |
| **Dissolved Metals** | | | | | | | | | | | | |
| Aluminum D-Al | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | - |
| Antimony D-Sb | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | - |
| Arsenic D-As | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | - |
| Barium D-Ba | 0.018 | 0.021 | 0.043 | 0.019 | 0.019 | 0.027 | 0.025 | 0.048 | 0.051 | 0.051 | 0.043 | - |
| Beryllium D-Be | <0.0050 | <0.0050 | <0.0050 | <0.0050 | <0.0050 | <0.0050 | <0.0050 | <0.0050 | <0.0050 | <0.0050 | <0.0050 | - |
| Bismuth D-Bi | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | - |
| Boron D-B | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | 0.14 | 0.14 | <0.10 | <0.10 | <0.10 | <0.10 | - |
| Cadmium D-Cd | <0.010 | 0.065 | <0.010 | <0.010 | <0.010 | 0.079 | 0.076 | <0.010 | <0.010 | <0.010 | <0.010 | - |
| Calcium D-Ca | 127 | 210 | 109 | 137 | 159 | 221 | 215 | 136 | 144 | 109 | 108 | - |
| Chromium D-Cr | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | - |
| Cobalt D-Co | 0.035 | 0.511 | 0.02 | 0.043 | 0.042 | 0.51 | 0.547 | 0.023 | 0.035 | 0.023 | 0.029 | - |
| Copper D-Cu | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | - |
| Iron D-Fe | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | - |
| Lead D-Pb | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | - |
| Lithium D-Li | 0.04 | 0.036 | 0.032 | 0.054 | 0.062 | 0.035 | 0.063 | 0.027 | 0.038 | 0.035 | 0.025 | - |
| Magnesium D-Mg | 53.1 | 83 | 62.9 | 57.1 | 58 | 84.1 | 88.2 | 62.6 | 62 | 67.9 | 67.7 | - |
| Manganese D-Mn | 2.43 | 31.8 | 0.473 | 2.59 | 2.58 | 31.4 | 33.2 | 0.423 | 0.429 | 0.481 | 0.372 | - |
| Molybdenum D-Mo | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | - |
| Nickel D-Ni | 0.147 | 0.48 | 0.116 | 0.115 | 0.082 | 0.52 | 0.55 | 0.162 | 0.198 | 0.186 | 0.174 | - |
| Phosphorus D-P | <0.30 | <0.30 | <0.30 | <0.30 | <0.30 | <0.30 | <0.30 | <0.30 | <0.30 | <0.30 | <0.30 | - |
| Potassium D-K | 9.3 | 2.5 | 3.3 | 10.6 | 8 | 3.6 | 4.2 | 2.4 | 2.6 | 3.9 | 6.3 | - |
| Selenium D-Se | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | - |
| Silicon D-Si | 1.99 | 2.57 | 2.92 | 2.12 | 2.31 | 2.61 | 2.61 | 2.19 | 2.12 | 2.39 | 2.64 | - |
| Silver D-Ag | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | - |
| Sodium D-Na | 19.8 | 5.1 | 9.6 | 21 | 21.6 | 5.2 | 5.4 | 9.5 | 9.1 | 10.7 | 13.7 | - |
| Strontium D-Sr | 0.47 | 1.23 | 0.816 | 0.504 | 0.534 | 1.25 | 1.28 | 0.803 | 0.795 | 0.85 | 0.837 | - |
| Thallium D-Tl | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | - |
| Tin D-Sn | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | - |
| Titanium D-Ti | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | 0.011 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | - |
| Vanadium D-V | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | - |
| Zinc D-Zn | 1.22 | 72.9 | 0.451 | 1.28 | 1.54 | 79.9 | 84.4 | 0.534 | 0.707 | 0.578 | 0.69 | - |
| | | | | | | | | | | | | |
| **Organic Parameters** | | | | | | | | | | | | |
| Chlorophyll a | <0.011 | <0.011 | 0.077 | <0.011 | 18.9 | 0.053 | <0.011 | - | 4.08 | 7.93 | 381 | 0.032 |

**Footnotes:**

Results are expressed as milligrams per litre except where noted.

< = Less than the detection limit indicated.

Chlorophyll a results are expressed as milligrams per litre except where noted.

| | |
|---|---|
| **Project** | Faro Pit Detox Water Analysis |
| **Report to** | Microbial Technologies Inc. |
| **ALS File No.** | U5831 |
| **Date Received** | 16/07/2004 |
| **Date:** | INTERIM |

**RESULTS OF ANALYSIS**

| **Sample ID** | 2 | 5 | 6 | 7 | 8 | 11 |
|---|---|---|---|---|---|---|
| **Date Sampled** | 15/07/2004 | 15/07/2004 | 15/07/2004 | 15/07/2004 | 15/07/2004 | 15/07/2004 |
| **Time Sampled** | 14:15 | 14:15 | 14:15 | 14:15 | 14:15 | 14:15 |
| **ALS Sample ID** | 1 | 2 | 3 | 4 | 5 | 6 |
| **Nature** | Water | Water | Water | Water | Water | Water |
| **Dissolved Metals** | | | | | | |
| Aluminum D-Al | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 |
| Antimony D-Sb | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 |
| Arsenic D-As | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 |
| Barium D-Ba | 0.023 | 0.013 | 0.02 | 0.018 | 0.045 | 0.045 |
| Beryllium D-Be | <0.0050 | <0.0050 | <0.0050 | <0.0050 | <0.0050 | <0.0050 |
| Bismuth D-Bi | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 |
| Boron D-B | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 |
| Cadmium D-Cd | 0.076 | <0.010 | 0.064 | 0.057 | <0.010 | <0.010 |
| Calcium D-Ca | 233 | 147 | 241 | 211 | 157 | 115 |
| Chromium D-Cr | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 |
| Cobalt D-Co | 0.507 | 0.034 | 0.493 | 0.492 | 0.025 | 0.022 |
| Copper D-Cu | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 |
| Iron D-Fe | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 |
| Lead D-Pb | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 |
| Lithium D-Li | 0.041 | 0.052 | 0.043 | 0.043 | 0.017 | 0.021 |
| Magnesium D-Mg | 85.4 | 49 | 80.8 | 79.3 | 61.3 | 66.5 |
| Manganese D-Mn | 31.5 | 1.94 | 29.7 | 29.6 | 0.356 | 0.242 |
| Molybdenum D-Mo | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 |
| Nickel D-Ni | 0.419 | 0.053 | 0.457 | 0.461 | 0.147 | 0.125 |
| Phosphorus D-P | <0.30 | <0.30 | <0.30 | <0.30 | <0.30 | <0.30 |
| Potassium D-K | 2.9 | 8.7 | 2.9 | 2.1 | 3 | 5.7 |
| Selenium D-Se | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 |
| Silicon D-Si | 2.48 | 2.11 | 2.43 | 2.24 | 2.1 | 2.63 |
| Silver D-Ag | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 |
| Sodium D-Na | 5.5 | 19.6 | 5.4 | 5.1 | 9.8 | 14.9 |
| Strontium D-Sr | 1.19 | 0.429 | 1.17 | 1.13 | 0.776 | 0.823 |
| Thallium D-Tl | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 |
| Tin D-Sn | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 |
| Titanium D-Ti | <0.010 | <0.010 | 0.013 | <0.010 | 0.012 | <0.010 |
| Vanadium D-V | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 |
| Zinc D-Zn | 62.4 | 3.02 | 74.1 | 70.9 | 0.637 | 0.478 |
| **Organic Parameters** | | | | | | |
| Chlorophyll a (a) | 0.1 | 52.1 | 0.133 | <0.024 | 3.65 | 39.9 |

**Footnotes:** here noted.

< = Less than the detection limit indicated.

(a) Results are expressed as micrograms per litre.

**Project** Faro Water Analysis
**Report to** Microbial Technologies Inc.
**ALS File No.** U6470
**Date Received** 4/08/2004
**Date:** INTERIM

## RESULTS OF ANALYSIS

| **Sample ID** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Date Sampled** | 3/08/2004 | 3/08/2004 | 3/08/2004 | 3/08/2004 | 3/08/2004 | 3/08/2004 | 3/08/2004 | 3/08/2004 | 3/08/2004 | 3/08/2004 | 3/08/2004 |
| **Time Sampled** | 12:00 | 12:00 | 12:00 | 12:00 | 12:00 | 12:00 | 12:00 | 12:00 | 12:00 | 12:00 | 12:00 |
| **ALS Sample ID** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| **Nature** | Water | Water | Water | Water | Water | Water | Water | Water | Water | Water | Water |
| **Dissolved Metals** | | | | | | | | | | | |
| Aluminum D-Al | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 |
| Antimony D-Sb | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 |
| Arsenic D-As | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 |
| Barium D-Ba | 0.014 | 0.02 | 0.04 | 0.018 | 0.015 | 0.021 | 0.02 | 0.046 | 0.041 | 0.015 | 0.031 |
| Beryllium D-Be | <0.0050 | <0.0050 | <0.0050 | <0.0050 | <0.0050 | <0.0050 | <0.0050 | <0.0050 | <0.0050 | <0.0050 | <0.0050 |
| Bismuth D-Bi | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 |
| Boron D-B | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 |
| Cadmium D-Cd | <0.010 | 0.063 | <0.010 | <0.010 | <0.010 | 0.061 | 0.067 | <0.010 | <0.010 | <0.010 | <0.010 |
| Calcium D-Ca | 125 | 232 | 111 | 136 | 113 | 233 | 222 | 148 | 144 | 65.4 | 86.3 |
| Chromium D-Cr | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 |
| Cobalt D-Co | 0.034 | 0.458 | 0.011 | 0.027 | 0.027 | 0.451 | 0.474 | 0.019 | 0.017 | 0.013 | 0.017 |
| Copper D-Cu | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 |
| Iron D-Fe | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 |
| Lead D-Pb | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 |
| Lithium D-Li | 0.043 | 0.046 | 0.022 | 0.052 | 0.028 | 0.033 | 0.036 | 0.031 | 0.015 | 0.019 | 0.019 |
| Magnesium D-Mg | 48.5 | 80.6 | 60.2 | 52 | 36.9 | 72.9 | 78.5 | 54 | 55.1 | 56.5 | 48.2 |
| Manganese D-Mn | 1.9 | 30.4 | 0.326 | 1.99 | 1.24 | 27.4 | 29.7 | 0.286 | 0.24 | 0.101 | 0.0712 |
| Molybdenum D-Mo | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 |
| Nickel D-Ni | 0.075 | 0.396 | 0.065 | 0.079 | <0.050 | 0.435 | 0.473 | 0.105 | 0.13 | 0.091 | 0.09 |
| Phosphorus D-P | <0.30 | <0.30 | <0.30 | <0.30 | <0.30 | <0.30 | <0.30 | <0.30 | <0.30 | <0.30 | <0.30 |
| Potassium D-K | 9 | 3.8 | 3.3 | 9.1 | 6.2 | 3.2 | 3.7 | 3.4 | <2.0 | 3.8 | 5 |
| Selenium D-Se | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 |
| Silicon D-Si | 1.87 | 2.31 | 2.66 | 1.9 | 1.74 | 2.24 | 2.07 | 1.96 | 1.94 | 2.02 | 1.97 |
| Silver D-Ag | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 |
| Sodium D-Na | 19.5 | 5.3 | 10 | 20.7 | 15.1 | 5 | 5.2 | 8.8 | 8.9 | 10.2 | 11.1 |
| Strontium D-Sr | 0.414 | 1.17 | 0.737 | 0.449 | 0.333 | 1.1 | 1.16 | 0.719 | 0.709 | 0.39 | 0.614 |
| Thallium D-Tl | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 |
| Tin D-Sn | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 |
| Titanium D-Ti | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 |
| Vanadium D-V | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 |
| Zinc D-Zn | 1.06 | 47 | 0.161 | 0.844 | 2.41 | 65.6 | 59.6 | 0.61 | 0.636 | 0.261 | 0.239 |
| **Organic Parameters** | | | | | | | | | | | |
| Chlorophyll a (a) | 0.038 | 0.03 | 1.58 | 0.041 | 3.51 | 1.03 | 0.123 | 0.094 | 0.258 | 0.351 | 2.24 |

**Footnotes:**
Results are expressed as milligrams per litre except where noted.
< = Less than the detection limit indicated.
(a) Results are expressed as micrograms per litre.

# Appendix B

## Field Investigation Program

## Report Prepared by Lorax Environmental Services

# Appendix C

## Limnology Assessment

Report Prepared by Lawrence Associates

**SRK Consulting**
*Engineers and Scientists*

# *Assessment of Biological Treatment of the Faro, Grum and Vangorda Pit Lakes*

*October 2004*

LORAX
ENVIRONMENTAL

# Executive Summary

SRK Consulting
Engineers and Scientists

# Executive Summary

In support of ongoing closure planning for the Anvil Range Mine site, an assessment of bio-remediation to lower zinc levels in the Grum, Vangorda and Faro Pit Lakes was conducted. The study involved a whole-lake fertilization of Grum Pit Lake including alternate manipulations in mesocosm experiments (limnocorrals). In addition, physical and geochemical conditions in both Faro and Vangorda Pit Lakes were studied to assess bioremediation in these systems as well.

A resident population of algae in Grum Pit Lake facilitated the rapid onset to a highly productive system with the addition of nutrients; neither fish fertilizer nor EDTA were required to enhance algal growth. Similar conditions do not exist for either the Vangorda or Faro Pit Lake and as a result, lake preconditioning (*i.e.,* early spring fertilization) would likely be required to realize algal growth.

The response of Zn in Grum Pit Lake to enhanced productivity was an initial transfer from the dissolved to particulate fraction followed by settlement of particulate (organic matter) out of the surface layer and into deeper waters. The growth rate of algae was more important to Zn removal than the concentration of algal cells as adsorption sites saturated quickly and became unavailable.

The quantity of Zn removed from Grum Lake surface water resulting from fertilization from late June, 2004 to the beginning of September, 2004 was sufficient to allow discharge of the upper two to three metres of lake water to the receiving environment had it been deemed necessary (i.e. surface water concentrations of Total Zn $<100$ μg/L). An experiment in one of the limnocorrals in which fertilization ceased at week 6 indicated that a program of pulsed eutrophication (*i.e.,* addition of nutrients followed by a period of no nutrient addition) was not capable of reducing Zn to low levels. The best mitigation results arise from sustained growth.

Both Faro and Vangorda Pit Lakes appear to host conditions suitable to bio-remediation particularly if under-ice fertilization in the early spring occurs. The added advantage of fertilization in both Vangorda and Faro Pit Lakes relates to their pre-existing stratification. Because these systems are stratified and suboxic at depth, they may produce hydrogen sulphide at depth under conditions of higher productivity and thereby draw Zn out of the lower water column through sulphide precipitation.

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SRK Consulting

Engineers and Scientists

# Table of Contents

1. INTRODUCTION

2. METHODS

3. RESULTS

4. DISCUSSIONS

5. CONCLUSIONS

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# 1. Introduction

SRK Consulting
Engineers and Scientists

# 1. Introduction

In support of ongoing closure planning for the Anvil Range Mine site, an assessment of the efficacy of pit lake bioremediation to lower zinc levels was conducted. Dissolved Zn has accumulated in the three pit lakes (Faro, Grum and Vangorda) due to runoff from pit walls and seepages and has reached concentrations too high to discharge water to the receiving environment.

Recent research has suggested that Zn (and other metals) sorbs to organic surfaces and that bioremediation (in the form of elevated biological productivity in surface waters) holds potential to remove Zn from the water column.

Accordingly, Lorax Environmental Services Ltd. (Lorax) was commissioned to conduct an assessment of the efficacy of lake fertilization to lower Zn levels in these pit lakes. The study involved the fertilization of the Grum Pit Lake, one of the three lakes on site. In addition, the operation and study of mesocosm experiments using limnocorrals attached to a raft moored within the lake were conducted.

This report presents the findings of this study and focuses on the feasibility of fertilization as a treatment strategy to mitigate Zn concentrations in each of the three pit lakes. Chapter 2 presents the methodologies employed within the study and Chapter 3 forwards the results. Chapter 4 discusses the applicability of whole-lake fertilization to treating each of the three Anvil Range pit lakes.

# 2. Methods

# 2. Methods

The objective of the Grum Lake study was to define the efficacy of bioremediation through nutrient amendment to remove Zn from the water column of Grum Pit Lake (Figure 2-1). To this end, a whole-lake manipulation was performed in addition to a suite of limnocorral experiments. While the pit lake manipulation (addition of nutrients to the pit lake) was designed to directly assess the efficacy of bioremediation, the limnocorrals were to serve both as a control and as alternative manipulation strategies.

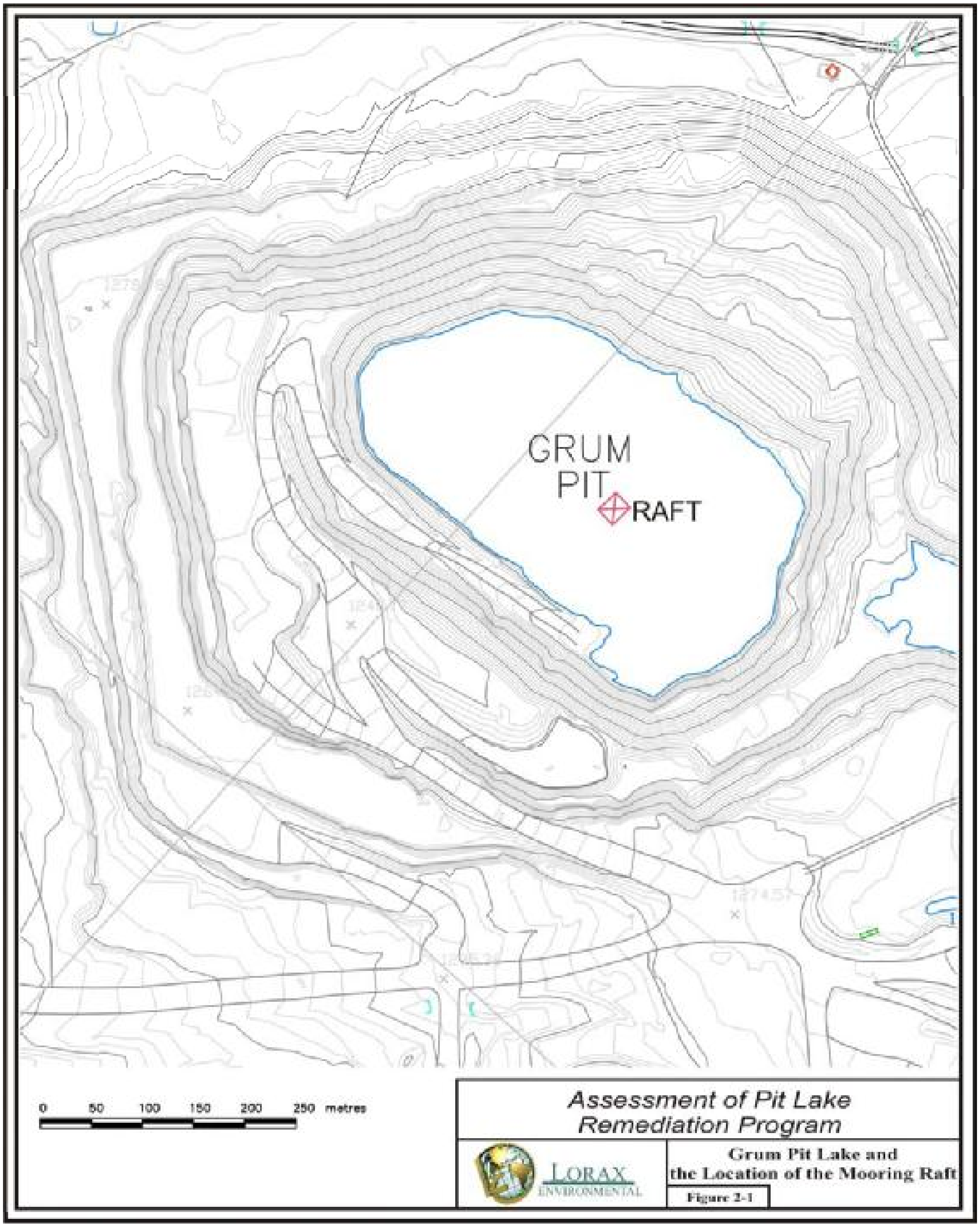
The whole-lake manipulation involved the addition of a relatively simple nutrient blend. The limnocorrals received either no additions (control), additions of nutrient plus fish fertilizer (a source of additional micronutrients) and addition of nutrients and EDTA (to mediate potential toxicity from Zn).

Fertilization and field sampling was conducted by Laberge Environmental Services. The details of these manipulations and sampling program are described below.

## 2.1 Nutrient Amendment Program

A variety of parameters influence the concentration of nutrient in the water column of a lake following nutrient addition, most notably the thickness of the mixed layer. Accordingly, specific concentrations within surface waters are difficult to target and as a result, nutrient additions are typically described in terms of nutrient addition per lake surface area rather than as absolute water column concentrations.

In determining the potential nutrient addition rate, data was considered from the experimental lakes work conducted in Ontario in the 1970's and 1980's (*e.g.,* Schindler, 1978; Schindler et al., 1978; Schindler et al., 1987) and was designed to force Grum Lake in hyper-eutrophia for the three-month period encompassed by the open-water experiment. Given that phosphorus is typically the ultimate limiting nutrient in such systems, the nutrient additions were based on calculated phosphorus content while ensuring that the nitrogen content of the fertilizer was sufficiently in excess (*i.e.,* in excess of the redfield ratio N:P ≈ 16) to prevent nitrogen limitation. The fertilizer used was a custom blend agricultural liquid fertilizer with a 29-5-0 blend of urea ammonium nitrate and ammonium phosphate. The fertilizer mixture produced a N:P ratio of 10.4:1 by weight or a molar ratio of approximately 23 thereby providing N in excess of the N:P ratio at which most phytoplankton acquire nutrients.



Assessment of Pit Lake Remediation Program

Grum Pit Lake and the Location of the Mooring Raft

Figure 2-1

Fertilizer was applied to Grum Lake and to the limnocorrals at the same concentration, based on an estimate lake area of 200,000 $m^2$ (SRK, 2004). Fertilizer was supplied in 55 gallon drums.

Three drums of fertilizer were added each week, providing a fertilization rate of 1170 mg $N/m^2/wk$ and 110 mg $P/m^2/wk$. This dose is approximately twice as high as the highest fertilization rate reported in the literature. The high concentration used was chosen to achieve the maximum phytoplankon growth over the short growing season that exists at Faro. Experiments at Equity Silver in Houston, B.C. (Crusius et al., 2001; McNee et al., 2003) had shown that similar concentrations of nutrients had produced higher phytoplankton biomass than achieved in lake fertilizations reported in the literature (*i.e.,* the experimental lakes) which typically try to achieve maximum growth rates without the commensurate build up of biomass associated with eutrophic conditions. Since eutrophication was not a concern in Grum Lake in the short term, conditions suitable for maximum biomass production were utilized.

## 2.2 Whole-Lake Manipulation

The whole-lake manipulation involved weekly additions of ~625 L of the nutrient mixture from the stern of a small boat. The nutrient mixture was pumped from a 55 gallon drum on board the boat into the prop wash to facilitate mixing with the lake water (Figure 2-2). Flow rates were optimized to disperse the nutrient addition as widely through the lake as possible.

While nutrient addition occurred weekly, water column sampling occurred on alternate weeks. Water column samples were collected from the moored raft at depths of 1, 3, 5, 7, 10, 20, 30 and 40 meters depth by peristaltic pump and in-line filter (where required) immediately prior to fertilization. Samples were collected for analysis of total metals, dissolved metals, nutrients and physical parameters. All samples were preserved and shipped to ALS Laboratory in Vancouver. Concurrent with the water sampling, the water column was profiled with a CTD equipped with a fluorometer. Sediment traps were deployed in the lake adjacent to the raft. Trap samples were analyzed for organic carbon, nitrogen and metals.

**Figure 2-2: Weekly fertilization of Grum Lake utilizing controlled flow of fertilizer from a 55-gallon drum into a prop wash.**

## 2.3 Limnocorrals

As explained above, the limnocorral experiments were conducted to assess the potential of alternative water column amendment should Grum Lake water be unable to sustain algal growth. Three limnocorrals were installed and maintained attached to the raft: a control, an amendment with EDTA and an amendment with fish fertilizer (Figure 2-3).

Limnocorrals are experimental water column enclosures, which are open at the top and the bottom and isolate a portion of the water column from lateral mixing within the lake. The limnocorrals used in this project were 3 m in diameter and approximately 12 m in length. They were designed to isolate the mixed surface layer, which according to data from previous years (Gartner Lee, 2003) extended into the 4 to 5 meter depth range.

The control limnocorral, which received no nutrients, served as a control for the mesocosm experiments and for the Grum Lake manipulation.

**Figure 2-3: Grum Lake raft with three limnocorrals attached to periphery.**

The EDTA experiment (EDTA) was conducted in the event that algae would not grow due to Zn toxicity. Prior to whole-lake manipulation, zinc concentrations in Grum Lake were on the order of 10 mg/L, well above known toxicity thresholds for a variety of phytoplankton species. It was felt that the addition of EDTA could serve to lower the free-ionic concentration of zinc in the water column and thereby mitigate or reduce any associated growth inhibition to algae. At the beginning of the limnocorral experiment Zn was added to one limnocorral in a quantity sufficient to complex an assumed inventory of dissolved Zn equivalent to a concentration of 5 mg/L in the upper 4 metres of the water column. It was assumed that the water associated with ice melt would reduce surface water Zn concentrations from 10 to approximately 5 mg/L.

The fish fertilizer treatment (Fish) was conducted in response to previous laboratory experiments (Sobelewski, 2003) that suggested that algal growth responded more rapidly in the presence of such an amendment. While the mechanism was unclear, it was thought that fish fertilizer provided either metal-complexation capacity (hence, toxicity amelioration of Zn) or a suite of micronutrients unavailable in the lake water of previous experiments. Therefore, commercial fish fertilizer was added to one of the limnocorrals at start-up at a dose of 0.5 L/m$^2$. This addition was designed to emulate as closely as possible the concentration of fish fertilizer used in the previous laboratory experiments.

It should be noted that the concentration of nutrients or other amendments in the field is difficult to compare directly to laboratory conditions as the absolute concentration in the field depends on the thickness of the mixed layer and effect of wind mixing to disperse the amendment into the water column.

Nutrient additions occurred in both the EDTA and Fish limnocorrals at the same surface application rate and on the same days as at Grum Lake. Accordingly, approximately 22 mL of nutrient mixture was added to each limnocorral every week. As noted, the control limnocorral received no nutrient additions.

Limnocorral sampling occurred commensurate with the Grum Lake sampling program and involved profiling of the water column with a fluorometer-equipped CTD in addition to the collection of water samples by peristaltic pump at six depths (1, 3, 5, 7, 10 and 13 metres). Samples were pumped to the surface and filtered in-line (where necessary). Samples were collected for total metals, dissolved metals, nutrients, physical parameters and chlorophyll “a” in some cases.

Sediment traps were installed at the bottom of each limnocorral and trap sediments were analyzed for dry mass, organic carbon, nitrogen and metal content.

All samples were shipped to the ALS laboratory in Vancouver.

*Program Amendment*

By early August, due to high productivity in the Grum whole lake, it became evident that neither the EDTA nor Fish limnocorral experiments were required. Rather than shutting them down completely, it was determined that two additional experiments could be run. To one limnocorral, nutrient additions were ceased in order to observe the effect of nutrient limitation on the removal of Zn and algae from the water column. Vangorda surface water was added to the other limnocorral in an attempt to verify that algal growth could be induced in water which was known to contain considerably higher concentrations of Zn. To facilitate this latter experiment, Vangorda water was collected in a pump truck and layered over the upper 5 metres of Grum water. It was hoped that the warm temperature of the Vangorda surface water would offset its elevated density associated with its higher TDS. This, however, proved not to be the case and over the period of one to two weeks, the Vangorda surface water sank and mixed into the Grum Lake water within the limnocorral.

## 2.4 Other Instrumentation

A suite of autonomous data-logging instrumentation was installed at the Grum Lake site in support of potential physical lake modelling in future. Specifically, a Hobo weather station (monitoring wind speed, direction, temperature, precipitation, insolation) was installed on the raft in Grum Lake. In order to complement the CTD data, highresolution thermal data of the lake water column were collected using a thermistor chain suspended from the raft. Thermistors were also installed in the potential inflow streams to the Grum, Faro and Vangorda feeder streams to assess the density of inflows in a "flow-through" configuration.

# 3. Results

# 3. Results

## 3.1 Physical and Geochemical Evolution

Grum Lake is a relatively small pit lake hosting a present day volume on the order of 2.2 million $m^3$ and a surface area of approximately 200,000 $m^2$. The maximum lake depth at the time of the study was marginally greater than 40 m.

The data suggest that Grum Lake stratifies early in the open-water season; by the end of June, 2004 (the commencement of sampling in the present study), there was not only a pronounced thermocline (a rapid change in temperature with depth) centered at approximately 2 metres depth, but a strong halocline (a rapid change in salt content or conductivity with depth) at the same location (Figures 3-1 and 3-2). As the primary source of contaminants to Grum Lake is pit wall runoff and seepage (SRK, 2004), the mechanism for formation of this open-water stratification must be related to the spring melt. It is suspected that under ice, the water column is stratified thermally with colder water adjacent to the ice overlying warmer water near the temperature of maximum density (~4 to 4.5°C). Water conductivity is likely near uniform from the previous fall turn-over event at approximately 1000 µS/cm. As the air temperature warms, melt water from the ice (having a very low conductivity) dilutes the water of the surface layer and creates a situation in which physical stability is maintained by the disparity in salinity (the content of dissolved salts) between the upper few metres and water at greater depths (Figure 3-1). The strength of the halocline and thickness of the surface mixed layer from year to year are likely a function of the degree of wind mixing that occurs commensurate with ice break up. Regardless, the halocline is sufficiently strong to prevent vertical mixing of surface water into the lake interior in the spring even when surface water warms through its temperature of maximum density (fresh water is at its most dense at 4°C).

As the surface layer continues to warm though the spring and summer, the stratification is intensified and the lake is physically stable until the fall when turn-over occurs. This tendency can be seen in the current study through the evolution of temperature and conductivity in the water column through the summer and fall (Figure 3-2).

The conductivity data (Figure 3-1) suggests that input of relatively fresh surface water contributes to the stability of the surface layer by progressively lowering the salinity and increasing the strength of the halocline. However, during the fall, the weakening thermocline promotes a thickening of the mixed layer, erosion of the halocline and a corresponding increase in conductivity (and Zn) in the mixed layer (Figure 3-1). Eventually the entire water column mixes and reoxygenates.

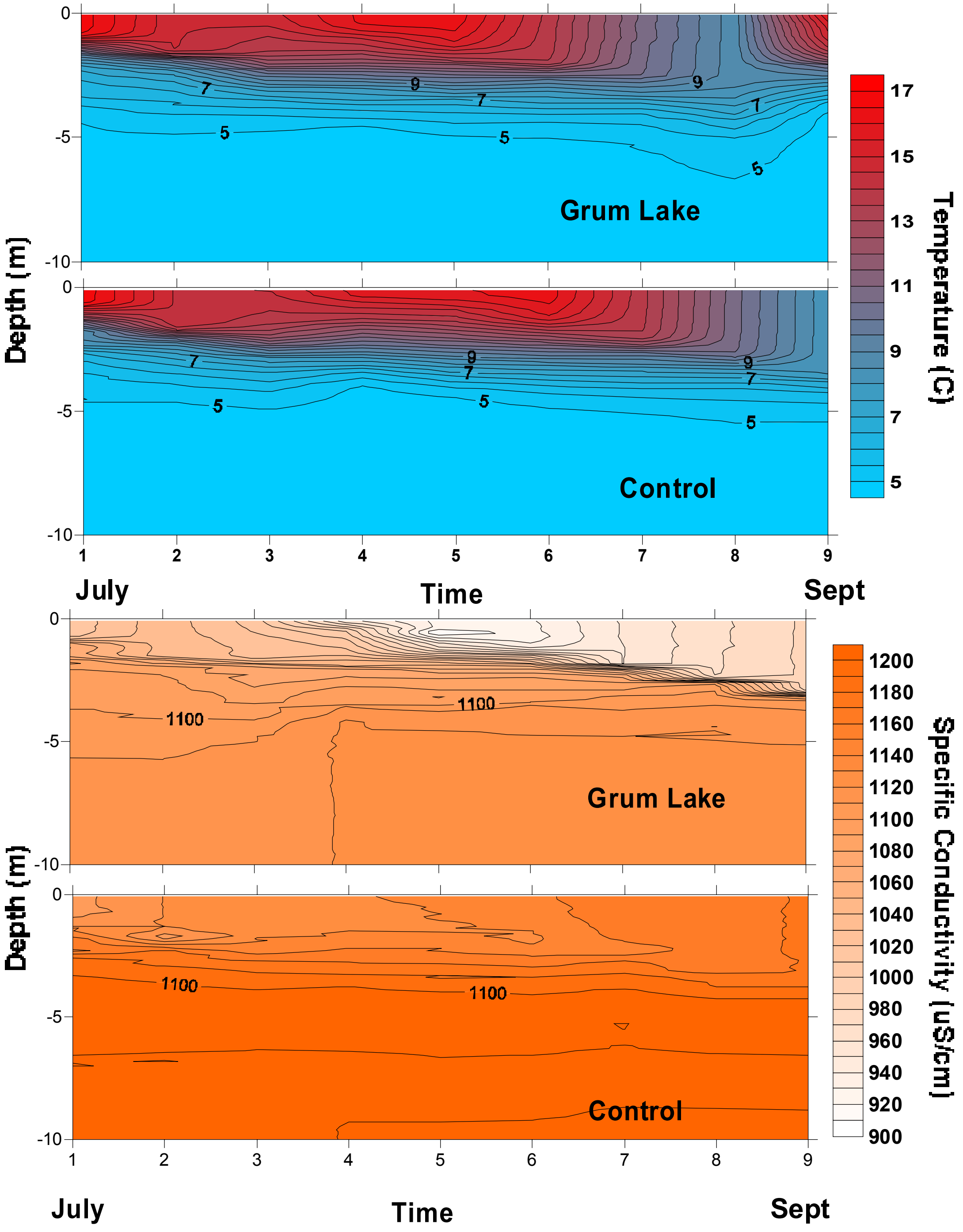


**Figure 3-1: Temperature and specific conductivity with time in the surface waters of Grum Lake and the control limnocorral.**

Oxygenation must occur seasonally as there is no evidence of low oxygen conditions or suboxia even though a base level of primary productivity exists within the lake (fluorescence profile in Figure 3-2; discussed in greater detail below). This notion is supported by previous data which indicate high concentrations of dissolved oxygen throughout the water column even in August after a summer's worth of primary productivity (Gartner Lee, 2003; SRK, 2004).

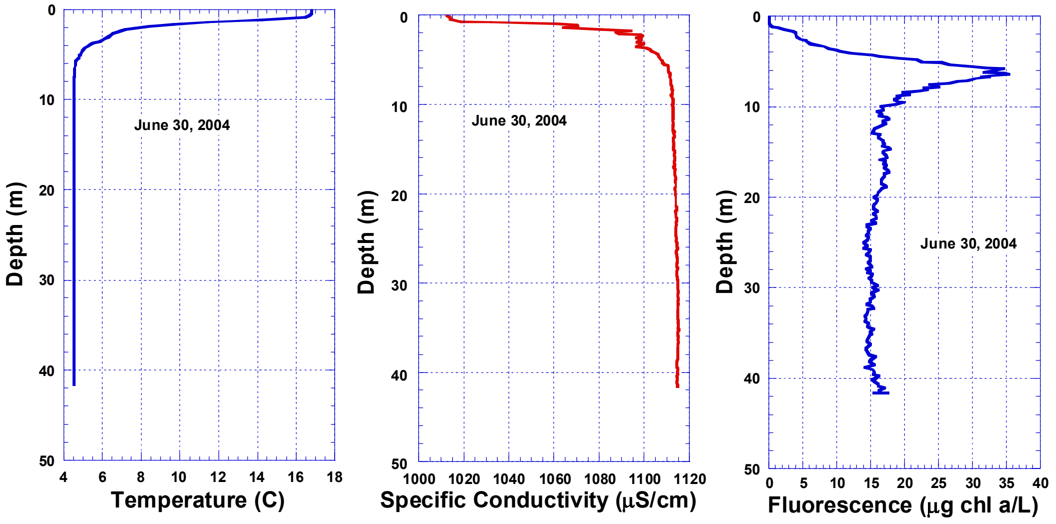


**Figure 3-2: Temperature, specific conductivity, and chlorophyll in Grum Lake at the study start-up (June 30, 2004).**

It is suggested that the seasonal distribution of Zn in Grum Lake follows a recurring pattern dictated largely by the processes described above. The well oxygenated water column suggests that marked lake-wide mixing occurs, most likely in the fall. Thus, during the fall and possibly in the winter (under ice), the water column hosts a near uniform distribution of Zn at a concentration near that currently observed in the deeper waters (*i.e.,* ~10 mg/L). With freshet comes an inventory of Zn from rinsing of the pit walls, but more important is the dilution of the surface layer associated with ice melt. The comparatively fresh ice melt water is devoid of Zn and reduces the mixed layer Zn concentration from ~10 mg/L to approximately 5 mg/L. Under normal conditions, this inventory is further reduced to a small degree by the base-level of productivity in the lake (described later); however, evidence of this removal is erased from the water column at fall turn-over when the lake mixes to depth.

## *3.2 Fertilization and Photosynthetic Biomass*

### 3.2.1 Fertilization of Grum Lake

Fertilization of Grum Lake involved the weekly application of a mixture of liquid urea ammonium nitrate and liquid ammonium phosphate at a rate of 1170 mg N/m$^2$ and 110 mg P/m$^2$.

The aim of the fertilization program was to stimulate and sustain the growth of phytoplankton in the lake. The study was completed between June 30th and Sept. 8th, 2004.

At the start of the fertilization program there was a significant population of phytoplankton present in Grum Lake, with a maximum concentration at 6 m depth, approximately the depth of the pyconcline, and little phytoplankton at the surface (Figure 3-3). This situation is typical of a phytoplankton community whose growth has been limited. Phosphate, the nutrient that typically limits freshwater phytoplankton growth, was below detection limit at all depths on June 30th, confirming that the natural phytoplankton inhabiting Grum Lake was under phosphorus limitation . The chlorophyll profile in the control limnocorral was similar to that in Grum Lake (Figure 3-3).

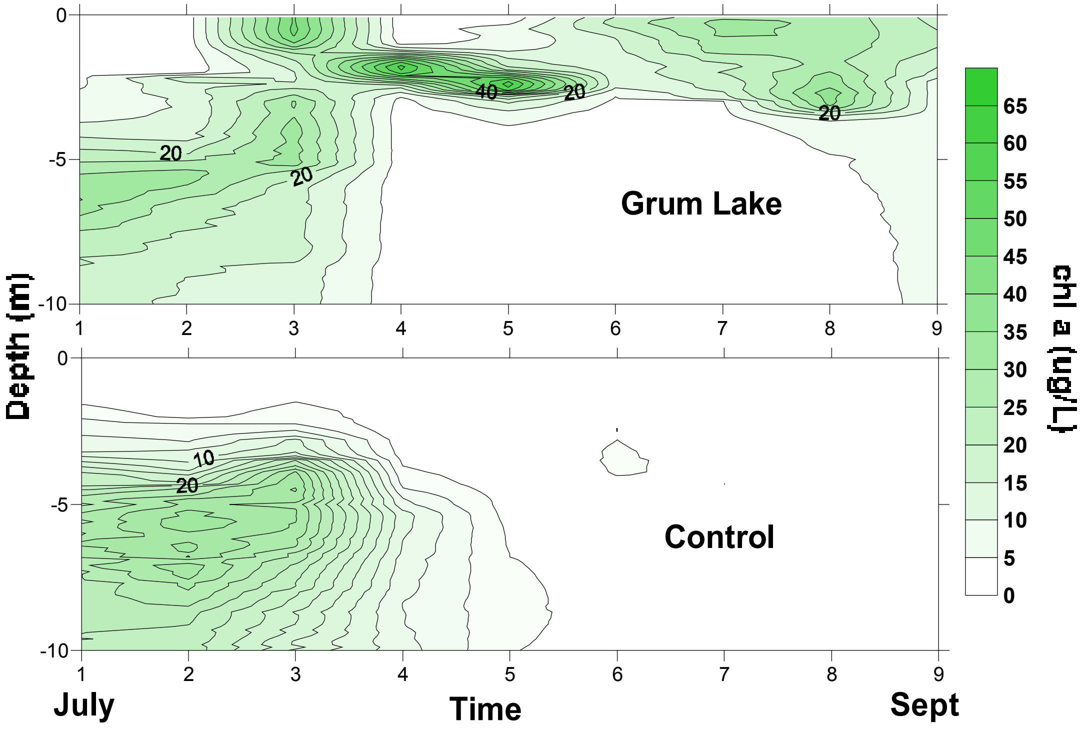


**Figure 3-3: Chloropyll a concentrations with time in Grum Lake and the control limnocorral.**

The pre-existence of phytoplankton at the initiation of the fertilization program allowed for a rapid response to the increased nutrient addition. Integrated chlororphyll “a” value (mass of chlororphyll “a” per unit area over a given depth interval) in the top 4 m doubled from 15 to 28 mg Chl $m^{-2}$ one week after initial fertilization (Figure 3-4). After 2 weeks of fertilization integrated chlororphyll “a” values had increased to 110 mg Chl $m^{-2}$ over the same 4 m depth interval. At this time there were 2 maxima of chlorophyll in the water column, one at the surface and a subsurface maximum at around 5 m depth.

Maximum concentration of chlororphyll “a” (hence phytoplankton) anywhere in the water column in Grum Lake throughout the course of the summer occurred in August when peak chlorophyll was greater than 60 μg/L at 2 m deep. At this time the concentration of phytoplankton was low in the upper metre of water, yet the integrated chlorophyll value was ~70 mg Chl $m^{-2}$ in the upper 4 m, an intermediate value. There are two possible explanations for this behaviour.

The first possible reason for this behaviour is that these profiles were indicative of nutrient limitation in the surface water, as discussed above for initial conditions. In other words, the algal biomass remained constant within the water column (as indicated by the constant integrated chlorophyll value for the upper 4 m) but the population of algae had settled towards the base of the mixed layer (as evinced by the deepening chlorophyll maximum). Phosphate concentration at this time was above detection limit but remained low (~0.02 mg/L). Since measurements of nutrients and chlorophyll were made a week after fertilization, it is possible that nutrients were consumed in the first few days after addition and that phytoplankton sank to the pycnocline (a rapid change in density as a result of changes in temperature and/or salinity with depth) subsequent to nutrient depletion.

The second and more likely reason for the growth patterns in Grum Lake surface water relates to observations of changing watercolour by field personnel during the sampling program. During the whole lake manipulation, watercolour was observed to evolve from green to brown and back to green (K. Nordin, pers comm.). The change in colour is indicative of a shift in algal species assemblage and corresponds to three zones of increase in the integrated chlororphyll “a” values (Figure 3-4). In mid to late July, the Grum Lake surface water was noted to change to a brown colour (possibly indicative of diatom dominance); the “brown” water lasted approximately one month, corresponding to an algal crash and regrowth phase (as indicated by integrated chlororphyll “a” data; Figure 3-4). Finally, in mid/late August, Grum Lake water was noted to revert to the original green colour, corresponding to another decrease and progressive increase in integrated chlororphyll “a” (Figure 3-4). The final increase in chlororphyll “a” likely represents a species assemblage change back to the population that originally colonized the lake. It is important to note that in general, regardless of the species assemblage, the integrated chlororphyll “a” value increased with ongoing fertilization through to the end of the experiment (Figure 3-4).

In the control limnocorral, to which no nutrients were added and which was isolated from the additions to Grum Lake, the relatively high initial phytoplankton concentration that was present below 3 m gradually declined to near detection limits by mid August. This further demonstrates the dramatic effect of nutrient additions in Grum Lake to increasing primary productivity. In the control limnocorral, conditions of light and temperature were the same as in the whole lake, but the lack of nutrients prevented phytoplankton growth.

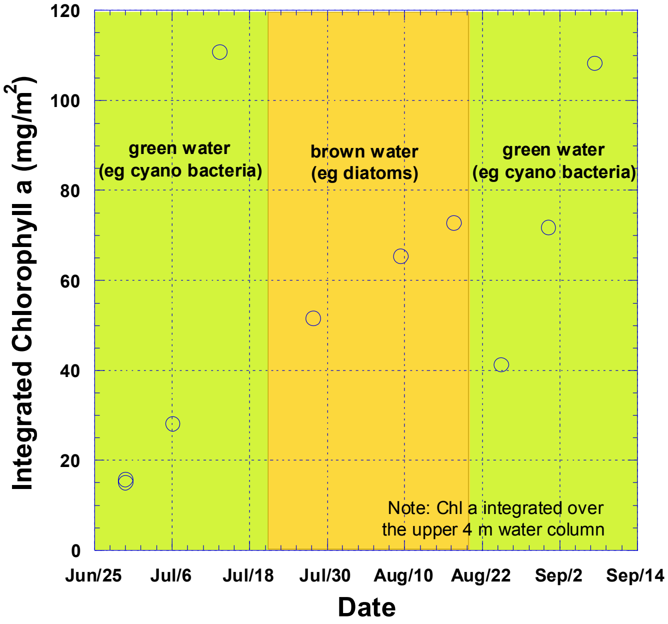


**Figure 3-4: Integrated chlororphyll "a" concentration over the upper 4 metre of water column and observed colour changes of Grum Pit Lake surface water.**

Despite the high fertilization rate used in this experiment, relative to concentrations reported in the literature, there was no build-up of a phosphate in the water column over the course of the experiment (Figure 3-5). There was, however, a small increase in nitrate and ammonium over the course of the experiment, but total N remained low; some inventory of the nitrate is likely associated with the nitrification of ammonium. This indicates that higher concentrations of P could be assimilated by phytoplankton and used for growth if they were made available. The N:P ratio used was apparently close to the ratio at which these elements were absorbed, but may be adjusted slightly lower in future fertilizations as evinced by the progressive build up of nitrogen species (Figure 3-5).

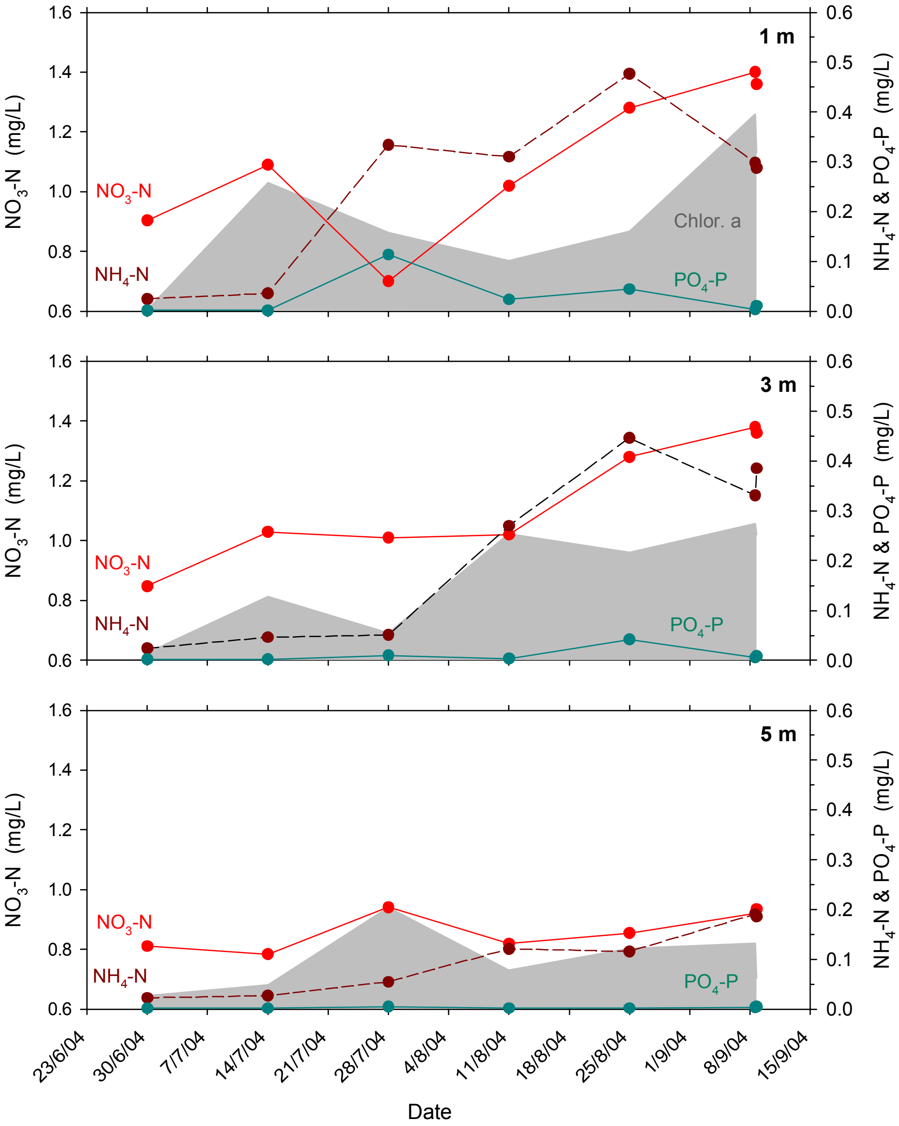


**Figure 3-5: Temporal variations of nutrient concentrations in Grum Lake.**

### 3.2.2 Limnocorrals

The chlororphyll “a” data for the Fish and EDTA limnocorrals are presented in Figure 3-6. For the first 6 weeks, these two limnocorrals were operated in their original configuration and showed no significant departures in behaviour from Grum Lake. Specifically, the baseline productivity at depth below the mixed surface layer disappeared within the first 5 to 6 weeks similar to both the control limnocorral and Grum Pit Lake (Figure 3-3). Similarly, the surface mixed waters of both the Fish and EDTA limnocorrals displayed the large increase and subsequent decline in chlororphyll “a” seen in Grum Pit Lake over the first 6 weeks.

At the 6-week mark, the Fish and EDTA limnocorrals were converted to alternate experiments as described previously. Fertilization ceased in the Fish limnocorral while the EDTA limnocorral received water from the Vangorda pit lake. The Vangorda water proved to be too dense and flowed out of the bottom of the limnocorral; however, the cessation of fertilization in the Fish limnocorral offered insight into the application of pulsed eutrophication to the Grum Pit Lake system (a situation in which productivity is increased rapidly and then nutrients additions cease, promoting rapid uptake of Zn and settlement of the associated particulate organic matter).

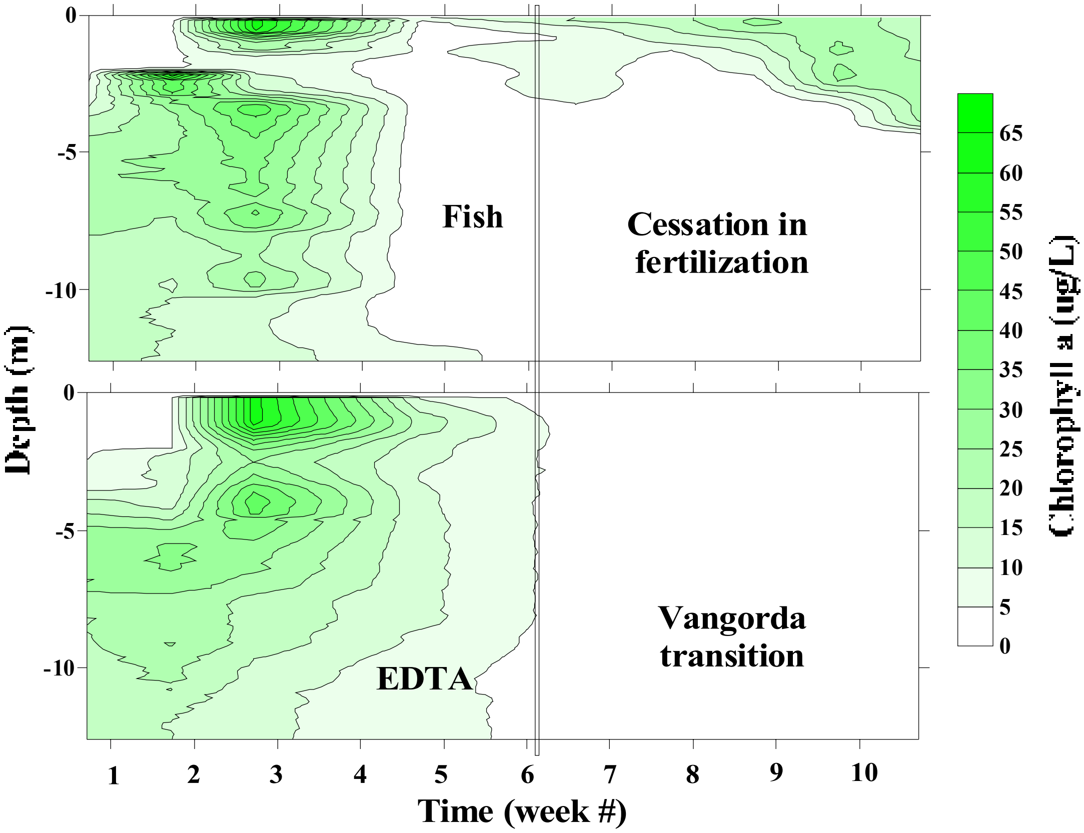


**Figure 3-6: Fluorescence data from the Fish and EDTA limnocorrals; weekly fertilization ceased in Fish on August 10 while the EDTA limnocorral**

The cessation of nutrient additions to the Fish limnocorral did not have the effect of immediately shutting down primary productivity. As can be seen in Figure 3-6, chlororphyll “a” concentrations remained and increased marginally in the mixed surface layer. The continued existence of measurable chlororphyll “a” in the surface layer is not unanticipated as the internal recycling of algae (an nutrient) often occurs in such systems. The progressive increase in chlorophyll towards the end of the experiment likely reflects the deepening of the mixed layer and the introduction of nutrient from water below the pre-existing thermocline.

## 3.3 Zn Removal

The most salient impact of elevating primary productivity in the mixed layer is on the behaviour and distribution of Zn. At the beginning of the experiment in late June, virtually 100% of the Zn in the water column was dissolved (Figure 3-7). The dissolved Zn concentration in the surface layer was ~5 mg/L, whereas the water at depth (>5m) contained approximately 10 to 11 mg/L Zn. The reduced surface concentration was brought about by dilution with ice melt water.

Within two weeks (*i.e.,* by July 14), a substantial fraction of the Zn in the mixed layer (as represented by the 1 m depth sample) had transferred to the particulate phase (Figure 3-7). Following the initial transfer from a dissolved to particulate phase, Zn was progressively removed from the mixed surface layer by settling particulates. This notion is supported by sediment trap samples which hosted Zn concentrations in excess of 2.5 wt. % (discussed below).

The Zn removal process is best illustrated in the temporal variation of total zinc (T-Zn) and dissolved zinc (D-Zn) concentrations at different depths in the upper water column as illustrated in Figure 3-7 along with the corresponding chlororphyll “a” concentrations (gray background). Initial T-Zn and D-Zn concentrations at 1 m depth are relatively low compared to those at other depths illustrating both dilution of surface waters with ice melt water in concert with the zone of maximum algal growth. As discussed above, virtually all of the primary productivity associated with fertilization occurred in the upper mixed layer (*i.e.,* 1 to 3 metres) where nutrients were added and where light needed for photosynthesis is greatest.

Initially, a rapid increase of the chlororphyll “a” concentration occurred in the surface water. Concurrently, a large proportion of the D-Zn inventory transferred to the particulate phase, which resulted in a decrease in D-Zn but not in T-Zn. The T-Zn is not removed until particulate concentrations become greater and settling becomes significant.

During the mid phase of the experiment (*i.e.,* week 4 through 6; August), T-Zn at the 1 m interval is at its lowest concentration (<0.1 mg/L), whereas T-Zn in the 3 m layer continues to decrease (Figure 3-7).

Towards the end of August through the end of the experiment in early September (weeks 8 through 10) the T-Zn and D-Zn concentrations appear to increase slightly in both the 1 and 3 m depth intervals, due to erosion of the thermocline. By mid-late August, the thermal stratification is beginning to break down and wind mixing forces both the thermocline and haloclines deeper into the water column (Figure 3-1). An important effect of this evolution is the entrainment of water from deeper depths into the surface mixed layer. As described above, this is readily seen in the late summer/fall increase in conductivity in the mixed surface layer and is visible here as a commensurate increase in dissolved Zn in the 1 and 3 m samples through the same period of time (Figures 3-1 and 3-7).

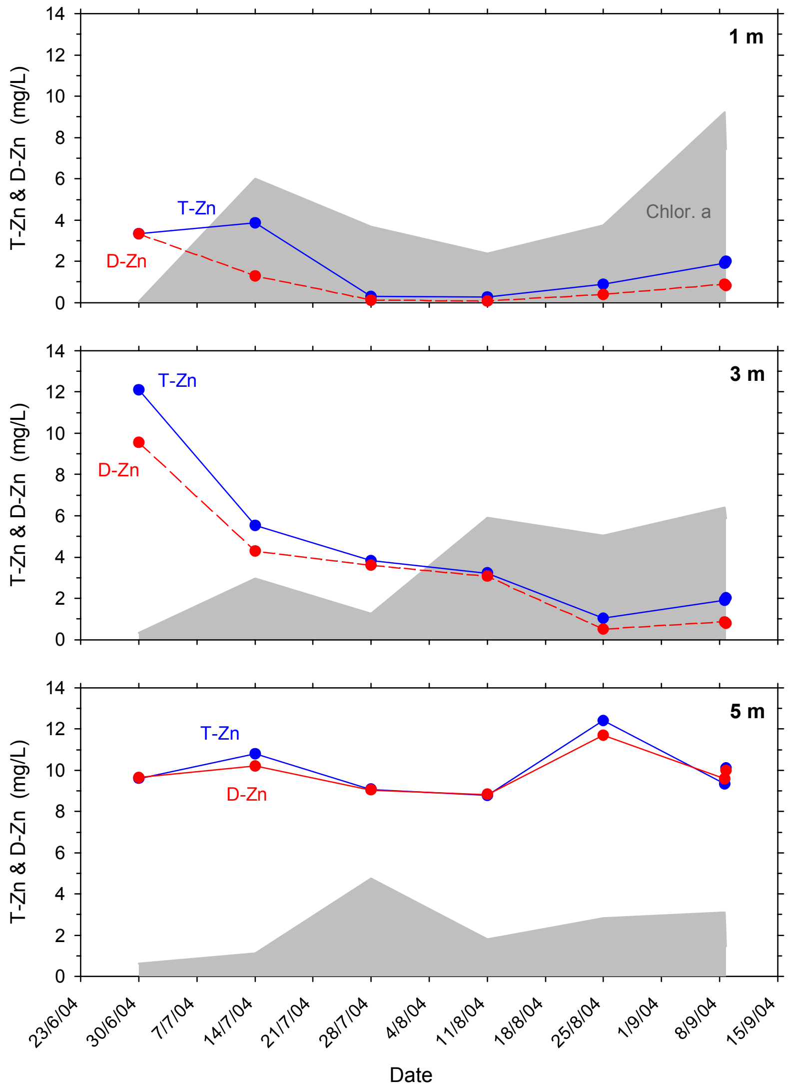


**Figure 3-7: Temporal variation of T-Zn and D-Zn concentrations in Grum Lake. Note: sampling dates occur at two-week intervals.**

The T-Zn concentration at 5 m depth, immediately below the thermocline, is almost entirely dissolved and remains relatively constant and high during the course of the experiment (Figure 3-7). Similarly, the T-Zn concentration in the control limnocorral (all depths) is almost entirely dissolved zinc. The T-Zn concentrations at 1 m and 3 m depth vary between 3 mg/L and 6 mg/L while concentrations at the other depths are generally around 10 mg/L supporting the notion that ice melt has contributed to dilution of the surface water Zn.

Interestingly, even though the lowest concentrations of Zn were achieved in the 1 m depth interval, the largest quantity of Zn was removed at 3 m depth (no Zn removal occurred at 5 m or greater depth). It appears as though the absolute quantity of Zn removed is proportional to the concentration where organic sorption sites are available. This notion is supported by the removal of Zn from the mixed layer during active algal growth through the duration of the experiment (Figure 3-8). Worthy of note is the base level of Zn removal in the absence of fertilization (*i.e.,* in the control limnocorral). This removal is associated with the baseline productivity in the Grum Lake surface layer and is not associated with a limnocorral artifact (*i.e.,* adsorption onto the limnocorral wall) given that removal is restricted to the mixed layer and does not occur at depth in any of the limnocorrals (Figure 3-9).

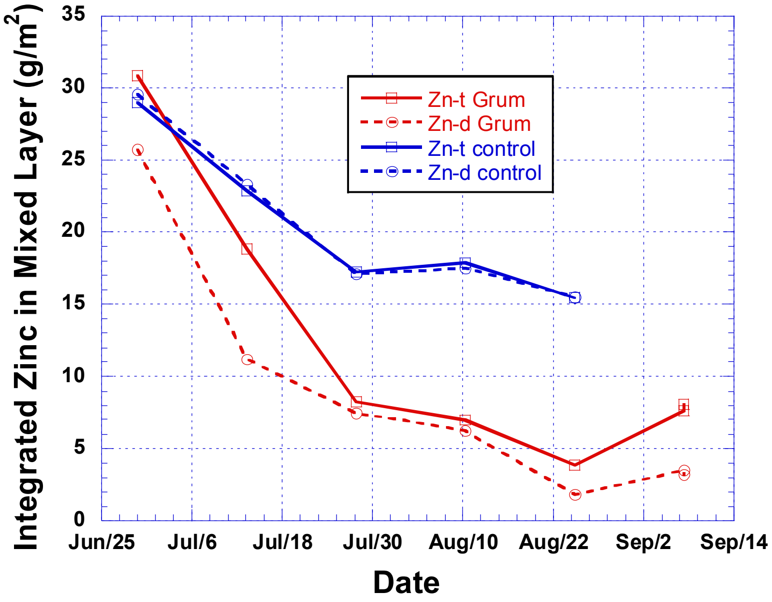


**Figure 3-8: Integrated total and dissolved Zn in the mixed layer (upper 4 metres) through the duration of the experiment.**

The transfer of zinc from the dissolved to the particulate phase is generally attributed to the combined effect of biological uptake (assimilation) and adsorption to cell walls. Biological uptake will be greatest during periods with increased productivity while adsorption will occur throughout the entire fertilization period unless adsorption sites at cell walls have become saturated in which case it too will be governed by growth rate.

Removal of Zn through settling particulates is supported by the sediment trap data which show high concentrations of Zn in the solid-phase of trapped material (Table 3-1). Concentrations of Zn were on the order of 2.7 wt.% in the 12 metre traps. This concentration is very high when compared with typical crustal abundances, which are 100 to 200-fold lower (Turekian and Wedepohl, 1961). While the flux of material to the

40 m traps was higher by one order of magnitude (Table 3-1), the corresponding concentration of Zn was considerably lower (*i.e.,* ~0.6 wt.%). Visual observation of the deep trap samples indicated a predominance of what appeared to be lithogenic material (*i.e.,* derived from pit walls rather than organic productivity) while the shallow trap material appeared predominantly organic in nature.

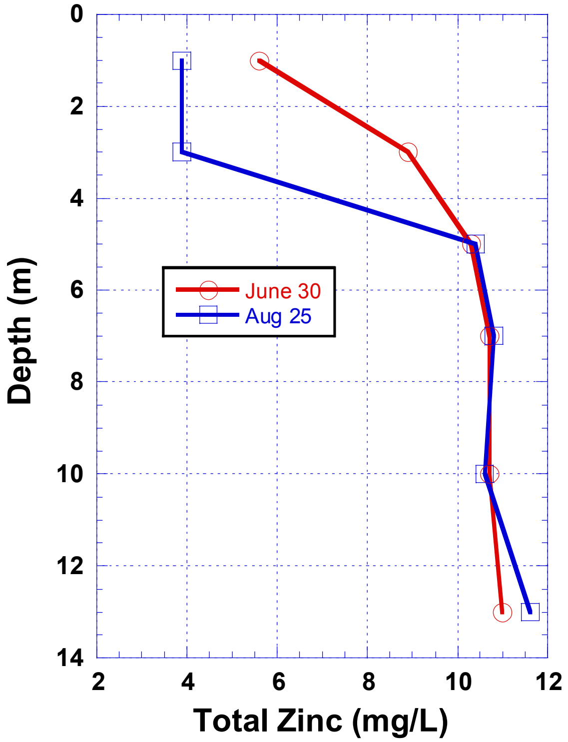


**Figure 3-9: Total Zn in the control limnocorral at the beginning (June 30, 2004) and late (August 25, 2004).**

**Table 3-1:**
**Sediment Flux, Zn content and Zn Flux in Grum Lake Sediment Traps**

| | **SedimentFlux (g/m$^2$/day)** | | **Zn (wt.%)** | | **Zn Flux (g/m$^2$/day)** | |
|---|---|---|---|---|---|---|
| **replicate** | 1 | 2 | 1 | 2 | 1 | 2 |
| **12 m trap** | 3.6 | 3.5 | 2.75 | 2.64 | 0.099 | 0.092 |
| **40 m trap** | 34.8 | 37.3 | 0.584 | 0.647 | 0.203 | 0.241 |

With the cessation of fertilization of the Fish limnocorral at approximately 6 weeks into the experiment came the opportunity to assess the impact of pulsed eutrophication on the removal of Zn. Figure 3-10 illustrates the removal of Zn from the water column. After the cessation of fertilization, there was no further reduction in Zn in the water column.

The data suggest that an inventory of algal biomass was recycled in the mixed layer but was unable to further reduce the content of Zn.

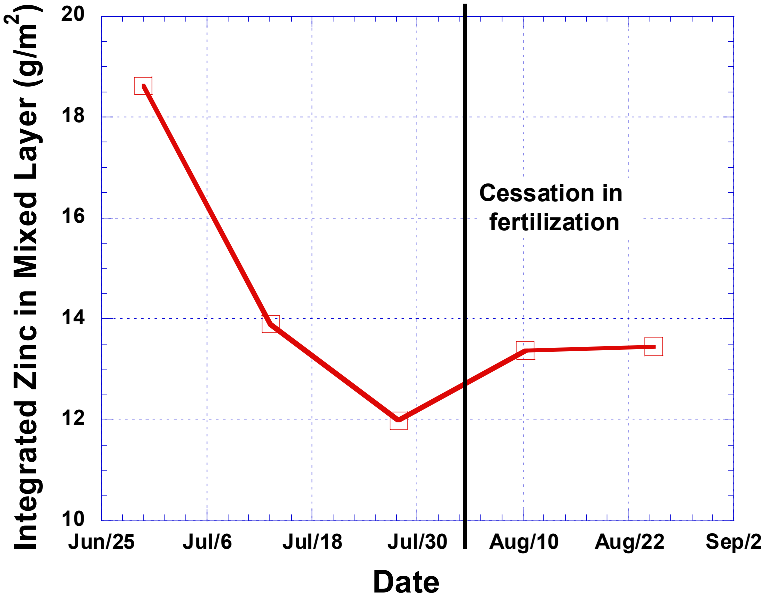


**Figure 3-10: Integrated Zn in the surface mixed layer (upper 4 metres) before and after the cessation of fertilization of the Fish limnocorral**

### *3.4 Characteristics of Faro and Vangorda Pit Lakes*

Initial surveys were conducted for both the Faro and Vangorda pit lakes in order to supplement existing information on their physicochemical state and to facilitate determinations as to their potential to be bioremediated.

Vertical profiles of conductivity, temperature and fluorescence measured in the water column of each lake are presented in Figure 3-11 while profiles of dissolved oxygen (DO) and total zinc (T-Zn) are compared in Figure 3-12.

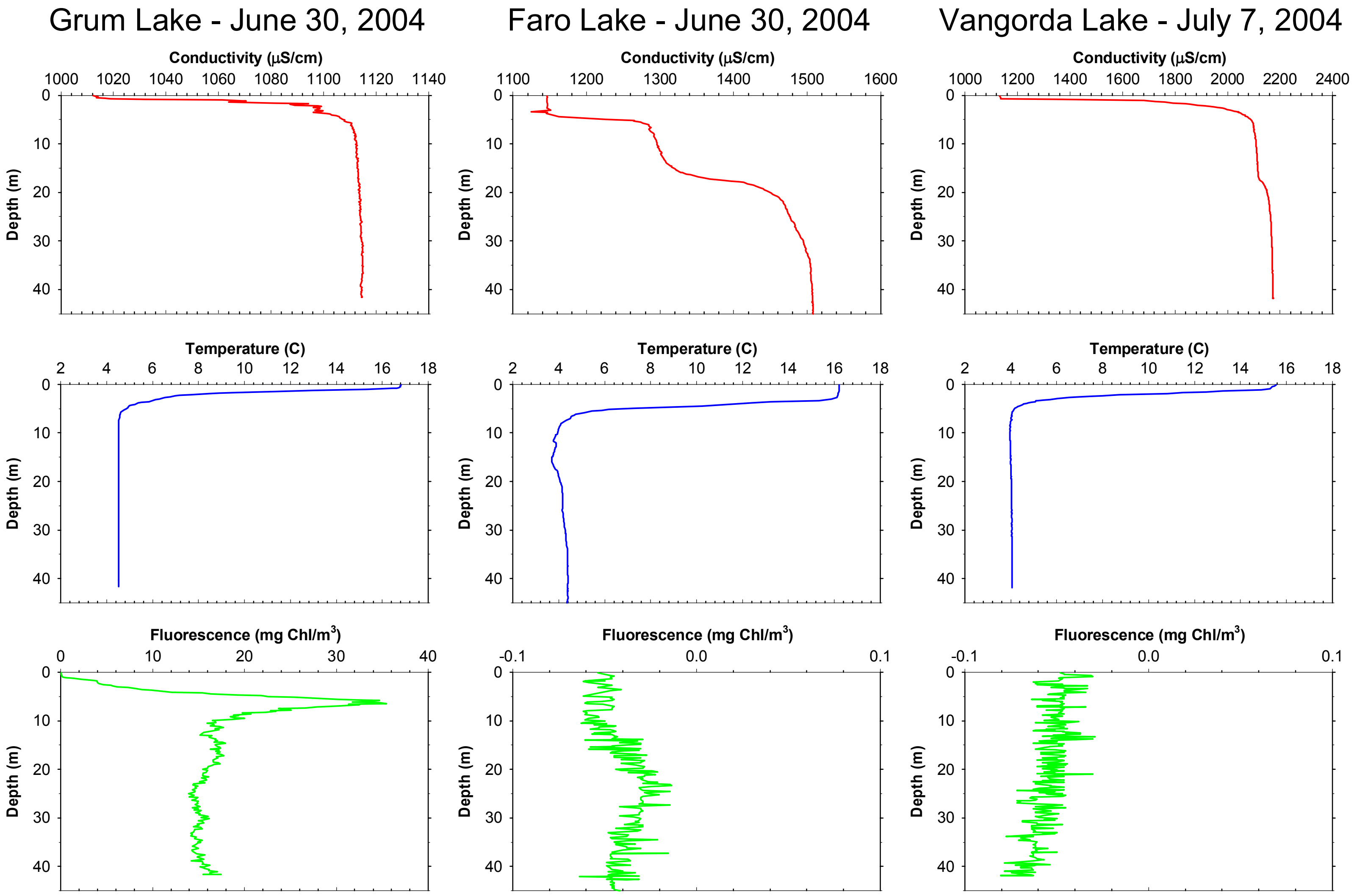
In contrast to Grum Lake, Faro and Vangorda Lakes appear to be permanently stratified. Faro Lake is characterized by two haloclines: one at 3-5 m depth and the other at approximately 15-20 m depth (Figure 3-11). The thermocline at 3-5 m depth coincides with the shallow halocline. In Vangorda Lake a strong halocline and thermocline exist at 2-3 m depth; the lower regions of the lake are compositionally homogenous. It is possible that the magnitude of the Vangorda halocline was influenced by the large addition of low conductivity water earlier in the season. Nevertheless, the associated density contrast must be a permanent feature of the lake given the existence of reducing conditions below.

Both Faro and Vangorda Lakes have suboxic bottom waters. The DO profiles (Figure 3-12) suggest that permanent stratification occurs at the lower halocline at 15-20 m depth (decoupled from the thermocline) in Faro Lake and at 2-3 m depth in Vangorda Lake (in association with the thermocline). Interestingly, the haloclines in Grum and Faro Lakes associated with the shallow thermoclines are relatively small in comparison to that of Vangorda. Presumably, the resulting pycnocline is too weak to prevent fall turn over in the mixed layer. While Grum Lake mixes top to bottom, Faro Lake turns over to its deeper halocline where the additional increase in density is a sufficient barrier to mixing thereby creating anoxic conditions below depths of 15 to 20 metres.

The DO profiles indicate that the lower water column in both Faro and Vangorda lakes is suboxic. Sampling artifacts (bottle exposed to atmosphere) resulted in the presence of measurable oxygen in the deep samples of both lakes. It is suspected that the measurement of oxygen in deep waters is erroneous given the ancillary data (*i.e.,* Fe, Mn etc), which suggest that suboxic conditions at depth prevail. Given the low levels of baseline productivity in each of these lakes, suboxia can only be achieved if the water column is permanently stratified.

The suggested permanent stratification and indeed, of the redox state, is reflected in the vertical profiles of the total zinc in both Faro and Vangorda pit lakes. Total zinc concentrations in the suboxic zone of the water column at Faro Lake are considerably lower than those in the oxic zone suggesting that some of the Zn inventory may have been removed through sulphate reduction and sulphide precipitation. The opposite applies to the Vangorda Lake where the total zinc concentrations in the suboxic zone are twice as high as those in the oxic zone. Despite the strong stratification, fully anoxic conditions do not prevail, as there is no evidence of sulphide precipitation. Worthy of note is the fact that total zinc concentrations in the water column of Vangorda Lake are one order of magnitude higher than those in either Faro or Grum Lakes.

Finally, the fluorescence data in Figure 3-11 suggest that, in contrast to Grum Lake, there is no ‘indigenous’ photosynthetic biomass present in the water column of Faro Lake and Vangorda Lake. The fluorescence measured in the water column of each lake is virtually zero.



Grum Lake - June 30, 2004

Faro Lake - June 30, 2004

Vangorda Lake - July 7, 2004

**Figure 3-11: A Comparison of Water Column Characteristics of Grum, Faro and Vangorda Lakes.**

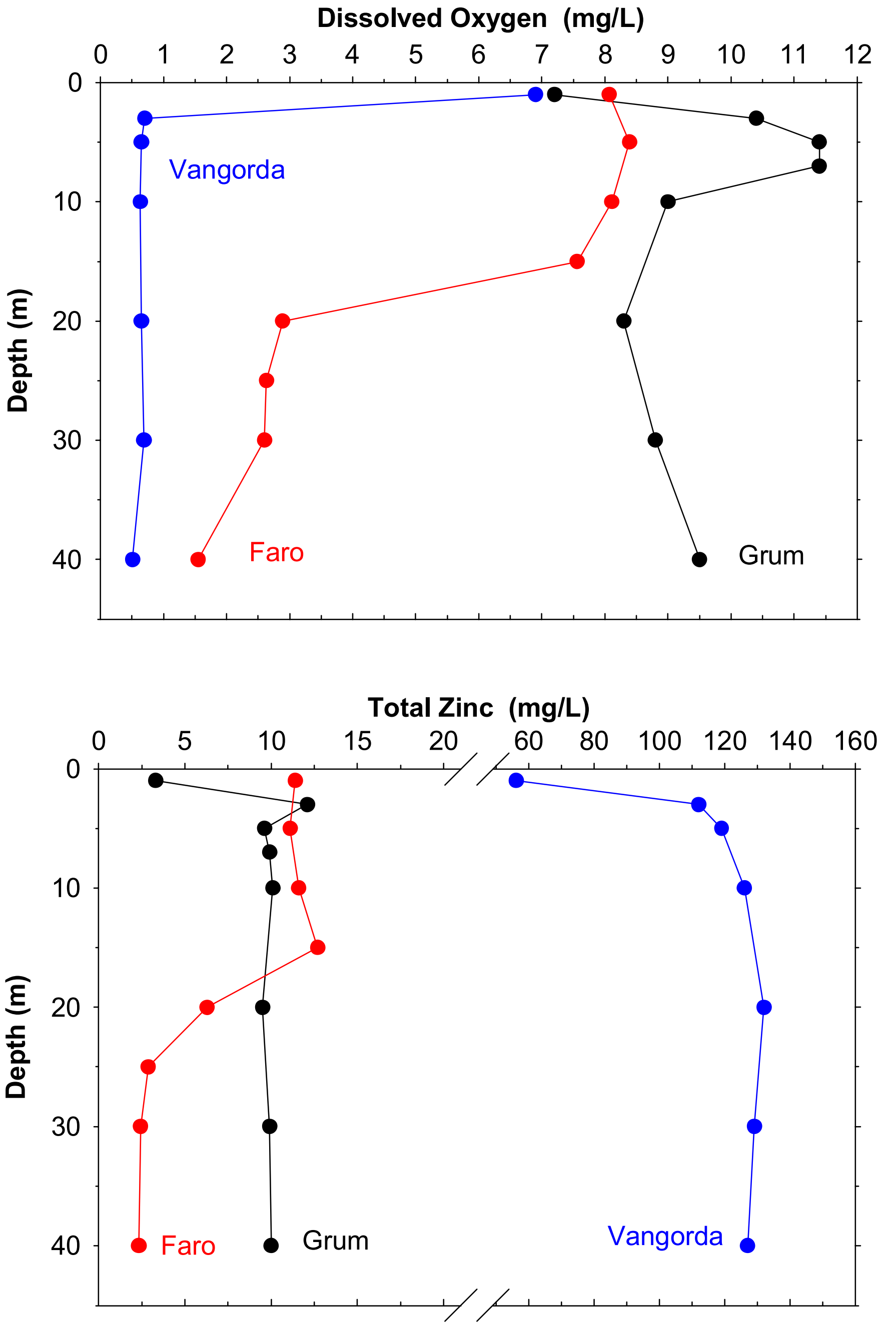


Figure 3-12: Profiles of dissolved oxygen and Total Zinc Concentrations in the Faro, Grum and Vangorda Pit Lakes.

# 4. Discussions

SRK Consulting
Engineers and Scientists

# 4. Discussion

The investigation demonstrated Zn removal from the water column of Grum Pit Lake. There are two active removal mechanisms: 1) incorporation of Zn into the algal cell and, 2) uptake of dissolved Zn onto adsorption sites on cell surfaces. Both processes are followed by settlement of Zn-laden particulate organic matter out of the water column. However, the data clearly indicate that Zn uptake is restricted to surface water where algal growth occurs and not deeper in the water column despite a substantial flux of algal biomass settling through the water column. The implication is that algal cells have a finite inventory of binding sites, and even though they host enormous surface areas, the binding sites can become rapidly saturated in the presence of high concentrations of dissolved Zn. In other words, the transfer of dissolved Zn to particulate algal cells only occurs when rapid growth is underway as Zn uptake requires the formation of fresh adsorption sites. Thus, the growth rate is more important to metal removal than the abundance of algal cells. Algal abundance is more important to the creation of reducing conditions at depth in the water column and the commensurate removal of Zn through sulphide precipitation.

## 4.1 Comparison between Lake and Limnocorrals

The lake and the limnocorrals are well-coupled thermally and the limnocorrals do not appear to limit algal growth. The primary distinction arises in the very aspect the limnocorrals are designed to do: isolate a portion of the water column. Specifically, it was noted in Section 3.1 that the physical structure of Grum Lake evolves through the open water season through the continual addition of fresh water. In contrast, the limnocorrals isolated the surface layer at the time of their installation and as a result, conductivity remained relatively constant. The impact of dilution on the inventory of Zn is difficult to discern; however, the results show a net removal in the pit lake relative to the limnocorral.

## 4.2 Efficacy of Phytoremediation for Grum Lake

Grum Lake is very well poised for remediation; there is an existing standing stock of phytoplankton as evinced by the elevated fluorescence data throughout the water column and the visible presence of ice algae. Thus, there was no lag time in growth associated with nutrient addition; the lake was visibly green with a measurable increase in chlorophyll a one week after fertilization and within two weeks there was prolific algal growth. Subsequent fertilization campaigns would be expected to respond in the same rapid fashion.

It is unclear why Grum Lake is so well suited to growth of algae, however, it is suggested that the water column hosts a seasonally available and recycled inventory of nutrients. The source of this nutrient inventory is not immediately evident; however, the effectiveness of the fertilization program can in part be attributed to the strengthening of existing productivity cycles. As discussed below, this has important implications for the other two pit lakes.

An important implication of the base level of productivity in Grum Lake relates to the associated level of Zn removal which occurs in the absence of external fertilization. Evidence for such removal was seen in the control limnocorral in which Zn decreased from a starting concentration of ~5 mg/L to a final concentration approaching 3 mg/L early in the experiment. This degree of Zn removal is anticipated annually but is likely offset by Zn additions from pit wall runoff and seepage.

The chlorophyll a data from Grum Lake (Figure 3-3) mid season (where the algae display behaviour indicative of P limitation) suggest that the lake could accommodate more frequent fertilization than the weekly schedule dictated by the experiment; indeed, P concentrations were at or near detection limits throughout the experiment. More frequent additions or a continuous flow delivery system might accommodate more rapid algal growth. While the mixed layer Zn removal in Grum Lake would not necessarily be advanced by such a strategy (*i.e.,* total and dissolve Zn levels in the upper mixed layer are already very low), the higher organic flux rate could facilitate improved Zn removal at deeper depths by both providing more free adsorption sites in addition to providing a stronger driving force towards reducing conditions (and sulphide precipitation) at depth.

The current fertilization program has demonstrated that the mixed layer of Grum Lake (approximately 400,000 $m^3$) can be treated to the extent that release to the receiving environment could occur with minimal dilution achieving receiving water quality criteria for the protection of aquatic life.

Pulsed eutrophication (*i.e.,* addition of nutrient followed by cessation of nutrient addition) is not an effective remediation strategy for Grum Lake despite the fact that considerably quantities of Zn are removed from surface water. Rather, the most effective treatment strategy involves prolonging the algal growth season as long as practically possible.

The water column nitrogen data (nitrate, nitrite and ammonia) suggest that an alternate and more cost-effective liquid fertilizer with a lower nitrogen content could be used for future applications. A lower nitrogen mix would have the added benefit of improving surface water quality from a discharge perspective if progressive seasonal discharge of Grum Lake waters were deemed necessary.

Therefore, if the objective is to use whole-lake fertilization to treat sufficient water for annual discharge to the receiving environment, the current program would suffice. This notion is based on the observation that the upper two metres of water column (representing at least 400,000 $m^3$ at current size) can be treated to near-compliancy within one summer season.

Optimization of the nutrient delivery system could result in a cost effective treatment system. However, if the objective is to treat the entire water column for Zn or, to use Grum Lake as a treatment system for other site waters, a longer treatment time frame with the objective of inducing sulphate reduction at depth would be in order. Under such circumstances, engineering of the physical structure of the water column (*i.e.,* inducing salt stratification) could be beneficial in achieving this goal.

## 4.3 Efficacy of Phytoremediation for Faro and Vangorda Lakes

While considerably less data exists for either the Faro or Vangorda pit lakes, several generalized statements can be made regarding their amenabilities towards Zn mediation through fertilization.

*Faro Lake*

Unlike Grum Lake, Faro Lake does not have a population or resident algae; there is undetectable fluorescence in the water column (Figure 3-3). Accordingly, it would take considerably longer for a viable algal population to establish following the commencement of fertilization and a substantial portion of the ice-free growing season could be lost for Zn removal. However, a strategy involving the intentional maintenance of an over-wintering algal population similar to those found in Grum Lake could facilitate a rapid spring growth response. Strategic winter fertilization of the under-ice surface waters could be sufficient to foster spring growth of algae prior to ice break up such that rapid growth rates could be achieved shortly after the first open-water fertilizations. Indeed, the first nutrient addition could be dispersed on the ice surface prior to break up facilitating an early start to algal growth.

Faro Lake is considerably larger than Grum Lake and hosts a surface area three times the size (~600,000 $m^2$). The larger lake would require a commensurately larger nutrient load than either Grum or Vangorda Lakes.

Even though Faro Lake is stratified at depth, the upper 15 to 20 m of the water column resemble Grum Lake in that it turns over and oxygenates seasonally (Figure 3-9). In this regard, it is conceivable that in subsequent fertilization years, a resident population of algae could remain in the intermediate waters such that rapid algal growth could be realized with successive amendment seasons. Nutrient and algal biomass will be lost to the deep, stratified layer; however, this will foster more strongly reducing conditions at depth and more sulphide precipitation of Zn (and other metals) than presently occurs.

In essence, the primary limitation to fertilization of Faro pit lake is the absence of a standing crop of phytoplankton.

*Vangorda Lake*

Like Faro Lake, Vangorda Lake has a very small to non-existent standing crop of algae. It also has Zn concentrations more than one order of magnitude higher than either Grum or Faro Lakes. Despite these Zn concentrations, the laboratory study suggested that algae could grow in these waters (Microbial Technologies, 2004).

Vangorda Lake has extremely strong stratification due to a large salinity gradient in the 2 to 3 m depth range (the largest of the three lakes). While the magnitude of this halocline may have been increased by the unusually large quantity of water entering the system in the spring, this density feature likely exists year-round and governs the physical stability of the lake. It is the most likely driving force towards reducing conditions at depth (via the absence of atmospheric contact and reoxygenation) as there appears to be little to no productivity to drive a significant oxygen demand.

The relatively small size of Vangorda Lake makes it an appealing test case for fertilization. It would require similar or small quantities of fertilizer given its smaller surface area (120,000 $m^2$) and relatively thin mixed layer. Moreover, the near-suboxic conditions at depth offer the best potential for large-scale mitigation of Zn through the precipitation of ZnS. While deep waters host relatively high concentrations of Fe, ZnS precipitation can be expected to occur given the relative solubilities of ZnS and FeS (Postma, 1996).

However, like Faro Lake, Vangorda could take some time to respond to initial nutrient amendments given the absence of a microbial population. If a full-scale manipulation were to be considered, a strategy similar to that described for Faro Lake above should be considered.

A general strategy to be applied to these high latitude pit lakes where both light and nutrients limit growth would be as follows:

1. Facilitate growth of seed population of algae which can capitalize rapidly on available nutrient early in the growing season when light is plentiful. This might be accomplished through strategic fertilization/inoculations of lake surface waters through the ice in the spring once daylight hours become longer. Growth at this time will be slow due to low temperature, but the establishment of even a modest seed population will be advantageous.

2. Initiate the first fertilizations as early as possible in the growing season. The growing season is short but light conditions are not limiting. Thus, the first fertilization could be deposited directly on the ice such that the initial dose occurs at break up, a period on the lake normally difficult to access.
3. Since growth rate is important to Zn uptake, nutrient additions should be spaced as closely together as practically possible. Once established, the algae will consume nutrient rapidly and cycle between active growth and limitation if fertilization events are separated by too much time.

# 5. Conclusions

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# 5. Conclusions

Following is a suite of conclusions derived from the Grum Pit Lake fertilization program conducted during the open-water season in 2004.

- The limnocorrals used in this study represented good proxies for the physical and geochemical evolution of the Grum Pit Lake. The primary exception was related to the isolation of the surface layer from external input of surface runoff. Specifically, it became apparent that the seasonal evolution of Grum Lake surface water is influenced by fresh water input, either through seepage, precipitation or pitwall runoff.
- Amendment programs such as the addition of fish fertilizer or EDTA were not required to initiate algal growth in the Grum Pit Lake.
- Primary productivity in Grum Pit Lake responded very rapidly to fertilization due largely to the pre-existing seed population of algae in the water column. Chlorophyll a concentrations increased rapidly and the corresponding transition of dissolved Zn to the particulate fraction occurred within the first few weeks of fertilization. Subsequent settlement of Zn-laden particulate matter removed total Zn from the water column.
- Fresh algal cells were most effective in removing Zn from surface waters as settling organic matter did not appear to remove additional Zn from the water column below the thermocline. Accordingly, the growth rate of algae is more important to Zn uptake than the absolute concentration of algal cells.
- The fertilization program undertaken in Grum Pit Lake was sufficient to reduce total Zn concentrations to values that could be discharged to the receiving environment before degradation of the thermocline. The degradation of the thermocline in the fall facilitated mixing of Zn-rich water at depth into the surface layer thereby increasing the total Zn concentration.
- Despite several successions of algal populations, continued fertilization of Grum Pit Lake resulted in an overall net increase in chlorophyll a in the surface mixed layer. Accordingly, the best approach to bio-remediating Grum Lake involves initiating fertilization as early as possible in the spring to capitalize on as long a growing season as possible.
- Pulsed eutrophication is not recommended for Grum Pit Lake as the entire open-water growing period is required to maximized Zn removal.

The above points likely apply to the Faro and Vangorda Pit Lakes. Comments germane to these latter two systems are as follows:

- Seed population of algae does not appear to exist in either Faro or Vangorda Pit Lakes suggesting that algae may not be as quick to respond to nutrient additions as seen in Grum Pit Lake. However, once established, a standing crop is expected to persist through winter to allow rapid growth the following spring. Rapid growth conditions early in the year could be improved in these other pit lakes by pre-fertilizing the lake in the early spring before ice-free conditions occur. Under such conditions, remediation of both Faro and Vangorda Pit Lakes is feasible.
- Both Faro and Vangorda Pit Lakes are strongly stratified and appear to be seasonally, if not permanently, anoxic at depth. An additional benefit to fertilization of these two systems is the enhanced potential for onset to further reducing redox potential at depth and inducing sulphate reduction. Such a process would serve to further remove Zn from bottom waters in excess of the algal removal anticipated to occur in surface water.

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# Appendices

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# Appendix A

| Date | Station | pH field | pH lab | Temp °C | Cond. µS/cm | D.O. mg/L | Secci m | Chlor a mg/m$^3$ | TSS mg/L | Alk mg/L | $NH_4$-N mg/L | $NO_3$-N mg/L | $NO_2$-N mg/L | $PO_4$-P mg/L | T-Zn mg/L | D-Zn mg/L | P-Zn mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6/30/04 | GL_1 | 8.05 |  | 16.6 | 906 | 7.2 | 5 | 0.06 | 3.0 | 152 | 0.025 | 0.90 | 0.011 | 0.002 | 3.3 | 3.3 | 0.01 |
| 6/30/04 | GL_3 | 7.56 |  | 13.2 | 975 | 10.4 |  | 0.48 | 3.0 | 168 | 0.024 | 0.85 | 0.002 | 0.002 | 12.1 | 9.6 | 2.55 |
| 6/30/04 | GL_5 | 7.74 |  | 11.9 | 966 | 11.4 |  | 0.89 | 3.0 | 166 | 0.023 | 0.81 | 0.002 | 0.002 | 9.6 | 9.6 | -0.04 |
| 6/30/04 | GL_7 | 7.58 |  | 11.1 | 975 | 11.4 |  | 1.50 | 3.0 | 169 | 0.025 | 0.86 | 0.003 | 0.002 | 9.9 | 10.1 | -0.25 |
| 6/30/04 | GL_10 | 7.25 |  | 11.4 | 976 | 9.0 |  | 0.77 | 3.0 | 170 | 0.026 | 0.98 | 0.003 | 0.002 | 10.1 | 10.2 | -0.10 |
| 6/30/04 | GL_20 | 7.01 |  | 10.1 | 976 | 8.3 |  | **0.55** | 3.0 | 167 | 0.030 | 0.97 | 0.002 | 0.002 | 9.5 | 9.5 | -0.01 |
| 6/30/04 | GL_30 | 6.54 |  | 9.1 | 980 | 8.8 |  |  | 3.0 | 167 | 0.030 | 0.96 | 0.003 | 0.002 | 9.9 | 10.1 | -0.23 |
| 6/30/04 | GL_40 | 6.04 |  | 7.4 | 980 | 9.5 |  |  | 3.0 | 168 | 0.026 | 0.96 | 0.003 | 0.002 | 10.0 | 10.3 | -0.30 |
| 7/14/04 | GL_1 | 8.66 |  | 16.2 | 1169 | 9.7 | 0.5 | 8.60 | 5.8 | 169 | 0.036 | 1.09 | 0.009 | 0.002 | 3.9 | 1.3 | 2.57 |
| 7/14/04 | GL_3 | 8.16 |  | 15.5 | 1189 | 1.9 |  | 4.25 | 6.8 | 170 | 0.046 | 1.03 | 0.008 | 0.002 | 5.5 | 4.3 | 1.25 |
| 7/14/04 | GL_5 | 8.04 |  | 13.2 | 1304 | 9.8 |  | 1.62 | 3.0 | 182 | 0.027 | 0.79 | 0.004 | 0.002 | 10.8 | 10.2 | 0.60 |
| 7/14/04 | GL_7 | 7.99 |  | 12.7 | 1324 | 10.8 |  | 15.70 | 3.0 | 185 | 0.028 | 0.88 | 0.003 | 0.003 | 11.4 | 11.2 | 0.20 |
| 7/14/04 | GL_10 | 7.69 |  | 11.8 | 1364 | 7.8 |  | 13.50 | 3.0 | 185 | 0.050 | 0.94 | 0.003 | 0.004 | 11.4 | 10.9 | 0.50 |
| 7/14/04 | GL_20 | 7.53 |  | 10.7 | 1414 | 7.5 |  | **4.23** | 3.0 | 186 | 0.025 | 0.95 | 0.003 | 0.002 | 10.5 | 10.5 | 0.00 |
| 7/14/04 | GL_30 | 7.28 |  | 9.1 | 984 | 7.6 |  |  | 3.0 | 185 | 0.034 | 0.95 | 0.002 | 0.002 | 11.0 | 10.9 | 0.10 |
| 7/14/04 | GL_40 | 7.28 |  | 8.4 | 986 | 7.3 |  |  | 3.0 | 183 | 0.050 | 0.94 | 0.003 | 0.005 | 11.6 | 11.0 | 0.60 |
| 7/28/04 | GL_1 | *8.73* |  | 15.9 | 722 | 8.3 | 0.6 | 5.25 | 5.4 | 89 | 0.334 | 0.70 | 0.003 | 0.114 | 0.3 | 0.1 | 0.17 |
| 7/28/04 | GL_3 | *8.06* |  | 13.6 | 768 | 8.0 |  | 1.81 | 3.0 | 159 | 0.051 | 1.01 | 0.007 | 0.010 | 3.8 | 3.6 | 0.22 |
| 7/28/04 | GL_5 | *7.80* |  | 8.6 | 699 | 7.9 |  | 6.80 | 3.0 | 175 | 0.055 | 0.94 | 0.002 | 0.005 | 9.1 | 9.0 | 0.03 |
| 7/28/04 | GL_7 | *7.61* |  | 8.2 | 688 | 7.8 |  | 6.80 | 3.0 | 170 | 0.041 | 0.94 | 0.002 | 0.004 | 8.9 | 9.1 | -0.25 |
| 7/28/04 | GL_10 | *7.34* |  | 8.0 | 697 | 7.8 |  | 2.29 | 3.0 | 168 | 0.576 | 0.94 | 0.003 | 0.005 | 9.4 | 8.9 | 0.43 |
| 7/28/04 | GL_20 | *7.44* |  | 8.0 | 721 | 7.8 |  | 5.60 | 3.0 | 172 | 0.041 | 0.94 | 0.003 | 0.005 | 9.1 | 9.3 | -0.25 |
| 7/28/04 | GL_30 | *7.29* |  | 9.2 | 711 | 7.8 |  | 6.03 | 3.0 | 169 | 0.048 | 0.93 | 0.003 | 0.004 | 5.5 | 8.9 | -3.39 |
| 7/28/04 | GL_40 | *7.28* |  | 7.9 | 699 | 7.8 |  | 6.01 | 3.8 | 176 | 0.046 | 0.93 | 0.003 | 0.004 | 9.1 | 9.1 | -0.02 |
| 8/11/04 | GL_1 | 8.80 | 8.47 | 15.8 |  | *7.9* | 1.7 | 3.39 | 3.0 | 97 | 0.310 | 1.02 | 0.009 | 0.024 | 0.3 | 0.1 | 0.20 |
| 8/11/04 | GL_3 | 7.96 | 8.24 | 13.2 |  | *7.9* |  | 8.45 | 6.2 | 146 | 0.270 | 1.02 | 0.009 | 0.004 | 3.2 | 3.1 | 0.16 |
| 8/11/04 | GL_5 | 7.55 | 8.12 | 9.2 |  | *7.3* |  | 2.59 | 3.0 | 172 | 0.121 | 0.82 | 0.004 | 0.002 | 8.8 | 8.8 | -0.05 |
| 8/11/04 | GL_7 | 7.22 | 7.81 | 7.6 |  | *7.0* |  | 1.44 | 3.0 | 173 | 0.084 | 0.91 | 0.003 | 0.002 | 9.5 | 9.7 | -0.23 |
| 8/11/04 | GL_10 | 6.98 | 7.90 | 7.1 |  | *7.4* |  | 1.98 | 3.0 | 170 | 0.079 | 0.95 | 0.003 | 0.002 | 10.3 | 9.9 | 0.36 |
| 8/11/04 | GL_20 | 7.35 | 7.92 | 10.4 |  | *7.5* |  | 1.71 | 3.0 | 170 | 0.069 | 0.90 | 0.004 | 0.002 | 10.0 | 9.9 | 0.12 |
| 8/11/04 | GL_30 | 7.29 | 7.96 | 9.1 |  | *7.6* |  | 2.47 | 3.0 | 170 | 0.081 | 0.93 | 0.004 | 0.002 | 10.4 | 9.6 | 0.81 |
| 8/11/04 | GL_40 | *7.28* | 7.97 | *7.5* |  | *7.8* |  | 1.80 | 3.0 | 172 | 0.088 | 0.88 | 0.005 | 0.002 | 9.3 | 9.4 | -0.14 |
| 8/25/04 | GL_1 | 9.03 | 8.50 | 13.3 | 856 | 7.4 | 0.9 | 5.35 | 6.5 | 115 | 0.477 | 1.28 | 0.013 | 0.045 | 0.9 | 0.4 | 0.49 |
| 8/25/04 | GL_3 | 9.03 | 8.53 | 12.9 | 857 | 7.8 |  | 7.21 | 6.5 | 116 | 0.446 | 1.28 | 0.012 | 0.042 | 1.0 | 0.5 | 0.53 |
| 8/25/04 | GL_5 | 7.79 | 7.90 | 13.2 | 987 | 6.7 |  | 4.05 | 3.0 | 173 | 0.116 | 0.86 | 0.004 | 0.002 | 12.4 | 11.7 | 0.70 |
| 8/25/04 | GL_7 | 7.69 | 7.89 | 10.9 | 988 | 6.2 |  | 1.49 | 3.0 | 172 | 0.086 | 0.91 | 0.003 | 0.003 | 12.8 | 12.3 | 0.50 |
| 8/25/04 | GL_10 | 7.69 | 7.91 | 9.3 | 992 | 7.0 |  | 1.38 | 3.0 | 170 | 0.083 | 0.92 | 0.003 | 0.003 | 12.2 | 12.2 | 0.00 |
| 8/25/04 | GL_20 | 7.64 | 7.90 | 8.2 | 993 | 7.2 |  | 1.60 | 3.0 | 169 | 0.114 | 0.90 | 0.004 | 0.003 | 12.2 | 12.4 | -0.20 |
| 8/25/04 | GL_30 | 7.64 | 7.90 | 7.8 | 995 | 7.4 |  | 1.20 | 3.0 | 168 | 0.116 | 0.89 | 0.004 | 0.002 | 12.2 | 12.3 | -0.10 |
| 8/25/04 | GL_40 | 7.61 | 7.91 | 7.1 | 997 | 7.8 |  | 1.37 | 3.0 | 169 | 0.117 | 0.88 | 0.004 | 0.002 | 12.1 | 11.9 | 0.20 |
| 9/8/04 14:37 | GL_0 | 8.61 |  | 8.5 | 990 | 10.0 |  | 13.70 | 8.0 | 130 | 0.317 | 1.36 | 0.013 | 0.012 | 1.9 | 0.9 | 1.01 |
| 9/8/04 14:37 | GL_1 | 8.72 |  | 8.1 | 996 | 11.0 | 0.4 | 13.20 | 9.0 | 129 | 0.298 | 1.40 | 0.015 | 0.004 | 1.9 | 0.9 | 1.01 |
| 9/8/04 14:37 | GL_2 | 8.69 |  | 8.3 | 993 | 10.9 |  | 17.60 | 7.0 | 129 | 0.333 | 1.36 | 0.013 | 0.035 | 1.9 | 0.8 | 1.10 |
| 9/8/04 14:37 | GL_3 | 8.61 |  | 8.1 | 995 | 10.2 |  | 9.13 | 6.0 | 128 | 0.331 | 1.38 | 0.014 | 0.006 | 1.9 | 0.9 | 1.05 |
| 9/8/04 14:37 | GL_5 | 7.66 |  | 7.5 | 1127 | 8.5 |  | 4.42 | 3.0 | 176 | 0.191 | 0.92 | 0.005 | 0.004 | 9.3 | 9.6 | -0.24 |
| 9/8/04 14:37 | GL_7 | 7.77 |  | 5.7 | 1138 | 7.9 |  | 0.17 | 3.0 | 174 | 0.104 | 0.94 | 0.004 | 0.004 | 10.0 | 8.9 | 1.12 |
| 9/8/04 14:37 | GL_10 | 7.23 |  | 5.7 | 1137 | 8.0 |  | 1.28 | 3.0 | 171 | 0.105 | 0.94 | 0.004 | 0.004 | 8.6 | 8.9 | -0.28 |
| 9/8/04 14:37 | GL_20 | 7.85 |  | 6.8 | 1131 | 7.5 |  | 0.71 | 3.0 | 166 | 0.221 | 0.92 | 0.005 | 0.002 | 8.9 | 9.0 | -0.18 |
| 9/8/04 14:37 | GL_30 | 7.22 |  | 6.3 | 1140 | 6.7 |  | 3.32 | 3.0 | 168 | 0.156 | 0.92 | 0.005 | 0.002 | 9.1 | 9.4 | -0.22 |
| 9/8/04 14:37 | GL_40 | *7.38* |  | *6.3* | *1135* | *7.3* |  | 0.68 | 3.0 | 166 | 0.143 | 0.91 | 0.005 | 0.002 | 9.6 | 9.1 | 0.53 |
| 9/8/04 18:25 | GL_0 | 8.71 |  | 8.4 | 993 | 10.9 |  | 14.20 | 5.0 | 129 | 0.293 | 1.36 | 0.014 | 0.010 | 2.0 | 0.9 | 1.10 |
| 9/8/04 18:25 | GL_1 | 9.05 |  | 7.0 | 1000 | 10.4 |  | 10.60 | 8.5 | 127 | 0.288 | 1.36 | 0.013 | 0.011 | 2.0 | 0.8 | 1.19 |
| 9/8/04 18:25 | GL_2 | 8.67 |  | 6.8 | 1000 | 9.6 |  | 14.70 | 9.5 | 130 | 0.298 | 1.35 | 0.013 | 0.007 | 2.0 | 0.8 | 1.23 |
| 9/8/04 18:25 | GL_3 | 8.95 |  | 6.8 | 1001 | 10.1 |  | 8.39 | 6.5 | 130 | 0.385 | 1.36 | 0.014 | 0.008 | 2.0 | 0.8 | 1.23 |
| 9/8/04 18:25 | GL_5 | 7.81 |  | 6.6 | 1113 | 8.5 |  | 2.10 | 3.0 | 176 | 0.186 | 0.94 | 0.005 | 0.005 | 10.1 | 10.0 | 0.10 |
| 9/8/04 18:25 | GL_7 | 7.73 |  | 6.4 | 1133 | 8.4 |  | 6.45 | 3.0 | 173 | 0.092 | 0.95 | 0.004 | 0.007 | 10.3 | 10.3 | 0.00 |
| 9/8/04 18:25 | GL_10 | 7.00 |  | 5.7 | 1138 | 7.8 |  | 5.36 | 5.0 | 172 | 0.084 | 0.94 | 0.005 | 0.004 | 10.4 | 10.0 | 0.40 |
| 9/8/04 18:25 | GL_20 | 7.27 |  | 5.5 | 1141 | 7.4 |  | 2.72 | 3.0 | 167 | 0.104 | 0.93 | 0.006 | 0.003 | 10.5 | 10.3 | 0.20 |
| 9/8/04 18:25 | GL_30 | 7.12 |  | 5.5 | 1142 | 6.9 |  | 0.84 | 3.0 | 169 | 0.109 | 0.93 | 0.006 | 0.003 | 10.2 | 10.1 | 0.10 |
| 9/8/04 18:25 | GL_40 | 7.15 |  | 5.5 | 1144 | 6.8 |  | 0.96 | 3.0 | 164 | 0.117 | 0.92 | 0.005 | 0.002 | 9.9 | 9.1 | 0.79 |

# Appendix B

| Date | Station | pH field | pH lab | Temp °C | Cond. µS/cm | D.O. mg/L | Secci m | Chlor a mg/m$^3$ | TSS mg/L | Alk mg/L | NH$_4$-N mg/L | NO$_3$-N mg/L | NO$_2$-N mg/L | PO$_4$-P mg/L | T-Zn mg/L | D-Zn mg/L | P-Zn mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6/29/04 | C_1 | 7.84 | | 17.8 | 929 | 9.3 | 5.0 | 0.06 | 3.0 | 155 | 0.025 | 0.90 | 0.008 | 0.002 | 5.6 | 5.6 | 0.02 |
| 6/29/04 | C_3 | 7.74 | | 11.8 | 955 | 12.1 | | 0.34 | 3.0 | 164 | 0.020 | 0.86 | 0.005 | 0.002 | 8.9 | 9.2 | -0.32 |
| 6/29/04 | C_5 | 7.56 | | 9.2 | 976 | 12.9 | | 0.47 | 3.0 | 169 | 0.027 | 0.90 | 0.002 | 0.002 | 10.3 | 11.2 | -0.90 |
| 6/29/04 | C_7 | 7.07 | | 8.6 | 981 | 11.9 | | 0.54 | 3.0 | 168 | 0.020 | 0.92 | 0.002 | 0.002 | 10.7 | 11.2 | -0.50 |
| 6/29/04 | C_10 | 6.63 | | 7.5 | 984 | 10.2 | | 0.45 | 3.0 | 169 | 0.021 | 0.97 | 0.002 | 0.002 | 10.7 | 10.3 | 0.40 |
| 6/29/04 | C_13 | 6.28 | | 6.6 | 985 | 10.1 | | 0.53 | 3.0 | 168 | 0.029 | 0.97 | 0.003 | 0.002 | 11.0 | 11.3 | -0.30 |
| 7/14/04 | C_1 | 8.11 | | 15.2 | 952 | 8.7 | 2.9 | 0.63 | 3.0 | 173 | 0.111 | 0.89 | 0.008 | 0.002 | 5.5 | 5.4 | 0.07 |
| 7/14/04 | C_3 | 8.02 | | 13.9 | 952 | 9.6 | | 4.12 | 3.0 | 174 | 0.052 | 0.89 | 0.007 | 0.004 | 5.9 | 6.2 | -0.29 |
| 7/14/04 | C_5 | 7.91 | | 8.7 | 981 | 13.4 | | 13.20 | 3.0 | 183 | 0.027 | 0.85 | 0.002 | 0.002 | 10.1 | 10.1 | 0.00 |
| 7/14/04 | C_7 | 7.49 | | 7.7 | 983 | 11.4 | | 12.70 | 3.0 | 187 | 0.027 | 0.87 | 0.003 | 0.002 | 10.1 | 10.2 | -0.10 |
| 7/14/04 | C_10 | 6.90 | | 7.3 | 982 | 9.3 | | 5.40 | 3.0 | 184 | 0.053 | 0.95 | 0.002 | 0.002 | 9.9 | 10.1 | -0.22 |
| 7/14/04 | C_13 | 6.52 | | 6.9 | 990 | 9.4 | | 0.71 | 3.0 | 184 | 0.044 | 0.96 | 0.003 | 0.002 | 10.5 | 10.6 | -0.10 |
| 7/28/04 | C_1 | 7.97 | | 16.0 | 825 | 8.8 | 2.9 | 0.15 | 3.0 | 160 | 0.093 | 0.90 | 0.010 | 0.004 | 3.2 | 3.0 | 0.22 |
| 7/28/04 | C_3 | 7.89 | | 13.3 | 760 | 10.5 | | 0.38 | 3.0 | 162 | 0.091 | 0.86 | 0.005 | 0.002 | 5.4 | 5.6 | -0.14 |
| 7/28/04 | C_5 | 7.90 | | 9.3 | 708 | 11.7 | | 1.17 | 3.0 | 166 | 0.058 | 0.82 | 0.003 | 0.002 | 8.8 | 8.9 | -0.13 |
| 7/28/04 | C_7 | 7.90 | | 8.4 | 672 | 11.3 | | 4.10 | 3.0 | 168 | 0.032 | 0.86 | 0.002 | 0.002 | 8.7 | 9.2 | -0.45 |
| 7/28/04 | C_10 | 7.82 | | 7.7 | 659 | 9.5 | | 7.69 | 3.0 | 167 | 0.042 | 0.96 | 0.002 | 0.003 | 8.9 | 8.9 | 0.01 |
| 7/28/04 | C_13 | 7.87 | | 7.4 | 678 | 8.9 | | 3.51 | 3.4 | 174 | 0.042 | 0.94 | 0.003 | 0.004 | 9.2 | 8.9 | 0.37 |
| 8/11/04 | C_1 | 7.83 | 8.07 | 15.3 | | | 4.0 | 0.61 | 3.0 | 162 | 0.096 | 0.88 | 0.010 | 0.002 | 3.4 | 3.3 | 0.06 |
| 8/11/04 | C_3 | 7.57 | 8.08 | 13.3 | | | | 0.91 | 3.0 | 164 | 0.081 | 0.85 | 0.007 | 0.002 | 5.5 | 5.4 | 0.13 |
| 8/11/04 | C_5 | *7.48* | 8.05 | 9.4 | | | | 0.26 | 3.0 | 171 | 0.099 | 0.80 | 0.002 | 0.002 | 9.6 | 9.5 | 0.02 |
| 8/11/04 | C_7 | 7.39 | 8.04 | 7.4 | | | | 1.84 | 3.0 | 168 | 0.064 | 0.86 | 0.002 | 0.002 | 9.8 | 9.8 | 0.01 |
| 8/11/04 | C_10 | 7.25 | 7.87 | 7.3 | | | | 1.41 | 3.0 | 170 | 0.064 | 0.94 | 0.002 | 0.002 | 10.1 | 10.3 | -0.20 |
| 8/11/04 | C_13 | 7.15 | 8.00 | 6.8 | | | | 1.56 | 3.0 | 175 | 0.083 | 0.92 | 0.003 | 0.002 | 10.1 | 10.4 | -0.30 |
| 8/25/04 | C_1 | 8.26 | 7.86 | 11.5 | 963 | | 4.5 | 0.56 | 3.0 | 160 | 0.099 | 0.89 | 0.010 | 0.002 | 3.9 | 3.8 | 0.02 |
| 8/25/04 | C_3 | 8.34 | 7.99 | 12.5 | 961 | | | 0.45 | 3.0 | 163 | 0.098 | 0.88 | 0.010 | 0.002 | 3.9 | 3.9 | -0.03 |
| 8/25/04 | C_5 | 7.96 | 7.78 | 7.8 | 977 | | | 0.97 | 3.0 | 169 | 0.104 | 0.80 | 0.002 | 0.002 | 10.4 | 10.6 | -0.20 |
| 8/25/04 | C_7 | 7.76 | 7.78 | 6.4 | 978 | | | 0.86 | 3.0 | 174 | 0.098 | 0.86 | 0.002 | 0.002 | 10.8 | 10.7 | 0.10 |
| 8/25/04 | C_10 | 7.65 | 7.78 | 6.2 | 992 | | | 1.16 | 3.0 | 166 | 0.077 | 0.93 | 0.002 | 0.002 | 10.6 | 10.5 | 0.10 |
| 8/25/04 | C_13 | 7.66 | 7.84 | 6.1 | 995 | | | 0.99 | 3.0 | 170 | 0.089 | 0.91 | 0.003 | 0.003 | 11.6 | 11.5 | 0.10 |
| 9/8/04 | C_1 | 8.05 | | 7.5 | 1101 | 9.6 | 4.9 | | | | | | | | | | |
| 9/8/04 | C_3 | 8.14 | | 7.5 | 1102 | 9.1 | | | | | | | | | | | |
| 9/8/04 | C_5 | 7.75 | | 6.9 | 1114 | 9.7 | | | | | | | | | | | |
| 9/8/04 | C_7 | 7.21 | | 5.5 | 1128 | 10.5 | | | | | | | | | | | |
| 9/8/04 | C_10 | 6.99 | | 5.3 | 1136 | 8.2 | | | | | | | | | | | |
| 9/8/04 | C_13 | 6.90 | | 5.2 | 1147 | 8.2 | | | | | | | | | | | |

*interpolated data*
detection limit
**measured at 15 m depth**

# Status of Field Data for Faro Pit-Lakes Stability, 2004

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## Introduction

Assessing remediation options for the Faro pit-lakes (Faro, Grum and Vangorda) requires an understanding of the dynamics within each water body, including the likelihood of meromixis. To address this and other issues, a field program was undertaken by SRK Consulting (program oversight), Lorax Environmental (program design) and Laberge Environmental Services (program execution). Our role is program design and data analysis in regard to physical circulation and stability of these pit-lakes. Here we summarize and assess the data collected in 2004 as it relates to the physical limnology.

Typically lakes undergo fall overturn when surface waters cool through 4 °C. If a lake has a significant salinity contrast, this may inhibit the mixing of the surface layer beyond a certain depth and the lake is meromictic. The critical time period for observing meromixis is during lake cooling from the end of summer to freeze up. The purpose of data collection was to compare the salinity stability of the pit-lake at the end of the warming period (late August), St*, to the reduction in salinity stability during the cooling period, ΔSt. The meromictic ratio St*/ΔSt is an indicator of the likelihood of meromixis.

## Data Collected

Data collected to date is summarized as follows:

CTD (Conductivity-Temperature-Depth) profiles collected with a Seabird SBE-19plus:

| Faro | Grum | Vangorda |
|---|---|---|
| June 30 | June 30 | |
| | July 7, 14 & 28 | July 7 |
| | Aug 10, 18 & 25 | |
| | Sept 1 & 8 | |

Temperature chain and meteorological data from Grum raft:

- **June 29 – Sept 9:** Onset Hobo Water Temp Pro instruments at 1, 2, 3, 5, 7, 10, 15, 20, 30, and ~40 m from surface, and RBR TR1050 at ~42 m (depths to be confirmed), in total water depth of 44.2 m.
- **Aug 12 – Sept 9:** Meteorological data.

Temperature monitoring of creeks:

- **June 29 – Sept 9:** Record of stream temperature (Hobo Water Temp Pro) for Faro, Grum and Vangorda Creeks.

Additional data include pit-lake levels, stream flows and a shore based meteorological station; these have not been assessed.

**Data Overview**

CTD profiles from all three pits in early summer are given in Figure 1. Each profile shows a thin, warm and fresh surface layer, likely the result of ice melt and spring runoff. In Grum and Vangorda the surface layer was 3 m deep, but in Faro it was close to 6 m deep, reflecting the larger surface area of Faro. Surface layer temperatures were similar in all three pits (15-17 °C, Fig. 1a). What is notable is the large range of deep conductivity (Fig. 1b), with deep conductivity in Vangorda (~2000 μS/cm) about double that in Grum (~1050 μS/cm); deep conductivity in Faro was intermediate (~1400 μS/cm). Both Vangorda and Faro show a step in deep-water conductivity near 20 m, perhaps a remnant of fall mixing in the previous year. In contrast the deep conductivity in Grum pit is relatively uniform. In Vangorda, despite the high conductivity at depth, the surface layer conductivity was similar to that of Faro and Grum. Note record rainfall occurred during a period in mid-June that resulted in a breach of the diversion ditch for Vangorda Creek.

The evolution of Grum pit through the summer is well documented; selected CTD profiles are shown in Figure 2. The decrease in surface conductivity from June 30 onward suggests significant input of fresh water. By the end of August, the surface layer begins to cool and deepens to ~4.5 m by September 8. The cooling and deepening of the pit-lake had only begun by this early date, with the surface layer still near 8 °C.

Since the given data ends in early fall, we are unable to compute the change in stability during the cooling period and hence unable to assess the likelihood of meromixis. Changes during the cooling period could be determined from CTD profiles collected after freeze up.

The moored data for summer and early fall are shown in Figure 3. Winds are moderate (Fig. 3a). Air temperatures (Fig. 3b) generally decline from mid-August and vary around 0 °C at the end of the record. Solar radiation is beginning to decline through the period of record (Fig. 3c). The surface layer temperature in the pit-lake (Fig 3d) varies from 14 to 18 °C during the summer with diurnal warming evident on sunny days. Surface layer cooling is greatest during periods of high wind and low air temperature. For example, during the storm of Aug 26-28 the surface layer deepened just beyond 3 m. By the end of the record the surface layer has almost deepened to 5 m.

The deep (>10 m) temperature of Grum was 4.5 ºC and warmed slightly to 4.7 ºC over the summer as a result of low-level mixing in the hypolimnion as occurs in most temperate lakes. Note the small, but sudden, jump in deep temperature on July 18 (Fig.

3d). This jump is also seen in the CTD data and may have resulted from a rock fall and associated mixing.

## Conclusion

A tantalizing picture is emerging of three quite different pit-lakes. The deep-water conductivity varies significantly between the lakes. Vangorda has the highest salinity contrast between surface and deep water. In contrast, Grum has the smallest salinity contrast and has a relatively uniform deep-water profile.

Unfortunately only one CTD profile was collected from Faro and Vangorda, making it difficult to assess changes over the summer. CTD profiles from Grum suggest significant fresh water input to the surface and shows the evolution of surface layer though summer and early fall. Both mooring and CTD data from Grum extend only to September 9, and do not cover the critical isothermal period of late fall needed to assess stability. The temperature mooring and meteorological station have been redeployed (Rob Goldblatt pers. com.). However, as salinity is key to meromixis, under-ice CTD sampling from all three pit-lakes is crucial to making stability assessments.

## Recommendations

1. ***Under-ice CTD profiles*** We highly recommend that under-ice Seabird CTD profiles be taken in all three pit-lakes from surface to bottom. Without this information we cannot assess the changes that took place during the cooling period when the surface layer was mixed down. Without this additional data, the value of the earlier data is lost. We recommend that this sampling be conducted as soon as the ice thickness allows.

2. ***Late August CTD casts*** CTD casts should not only be taken at the start of summer (showing initial conditions) but also at end of August/early September in all pits to characterize fresh water input over summer.

3. ***Ice samples*** We recommend that ice samples be taken during under-ice profiling. This will provide important information about the amount of salts trapped in the ice. Solid pieces of ice should be put in a clean dry container such as wide mouth jar, allowed to melt and decanted into a 500 mL HDPE narrow mouth Nalgene bottle for conductivity analysis.

4. ***Conductivity bottles*** Whenever water samples are collected from the open pit, please include a 500 mL HDPE narrow mouth Nalgene bottle (airtight) for conductivity analysis. These bottles should be kept cool and shipped directly to UBC as soon as possible. Conductivity bottles from diverted streams, from any waterfalls and seeps entering the pits are also requested. These flows should be sampled during freshet and summer flow.

5. ***Thermistor chains and weather station*** We recommend that thermistor chains and weather station remain moored throughout the year, including the high accuracy RBR TR1050. This provides important data, especially during the ice-on and ice-off periods when profile sampling is not possible.

6. ***CTD calibration*** We recommend that the Seabird CTD profiler be calibrated twice a year in our calibration facility here at UBC. This will help provide error bounds for changes observed in the pit-lakes.

7. ***Flow estimates*** We recommend that site staff provide quick estimates of diverted creeks and of any pit inflows they encounter. Flow estimates can be made by visually estimating the width, depth and velocity (from the transit time of 'orange peels' moving an estimated distance down the creek). These estimates should also be undertaken during diversion breaches. Such quick estimates, while very approximate, give the order of magnitude and bound changes observed in the pit-lakes.

8. ***Pit wall photos*** To assess pit wall failures, a series of overlapping photos should be taken from a standard location (e.g. raft) during each sampling trip.

9. ***Secchi depths*** Measurement of the Secchi depth should accompany each CTD cast as a quick, easy and useful estimate of surface water clarity. Secchi data indicates the penetration depth of solar radiation.

10. ***CTD Cast rate*** Seabird suggests a cast rate of 1 m/s appropriate for oceanographic observations. However, with surface layers as small as 2 m in these pit-lakes, we recommend that the cast rate be reduced to 0.25 m/s. This increases the cast time from ~ 1 minute to ~ 4 minutes. (The CTD should be soaked for 2 minutes at the start of the cast, internal data averaging should be turned off, and casts should always profile the entire water column.)

11. ***Relative humidity*** A relative humidity sensor should be added to the weather station on the Grum raft. Relative humidity is important to computing air-water fluxes.

**Figure 1.** CTD profiles, Early Summer, 2004

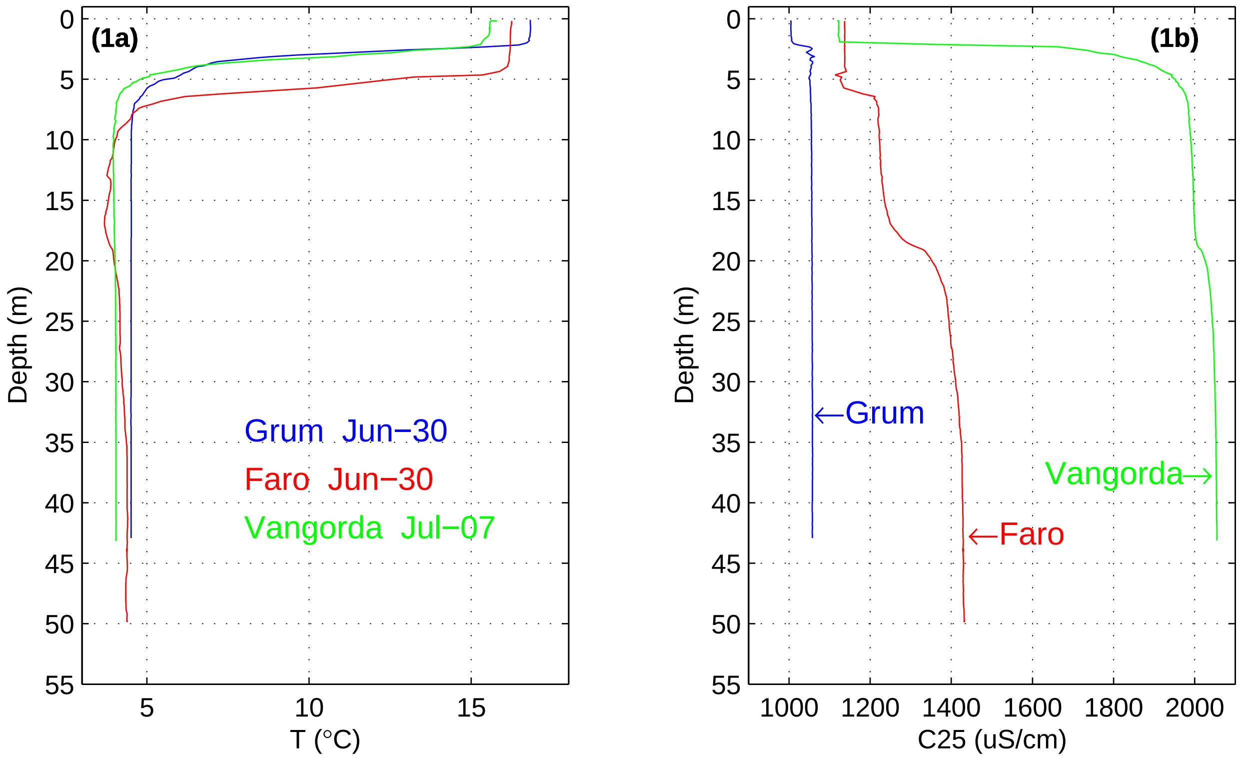


**Figure 2.** Selected CTD profiles, Grum, 2004

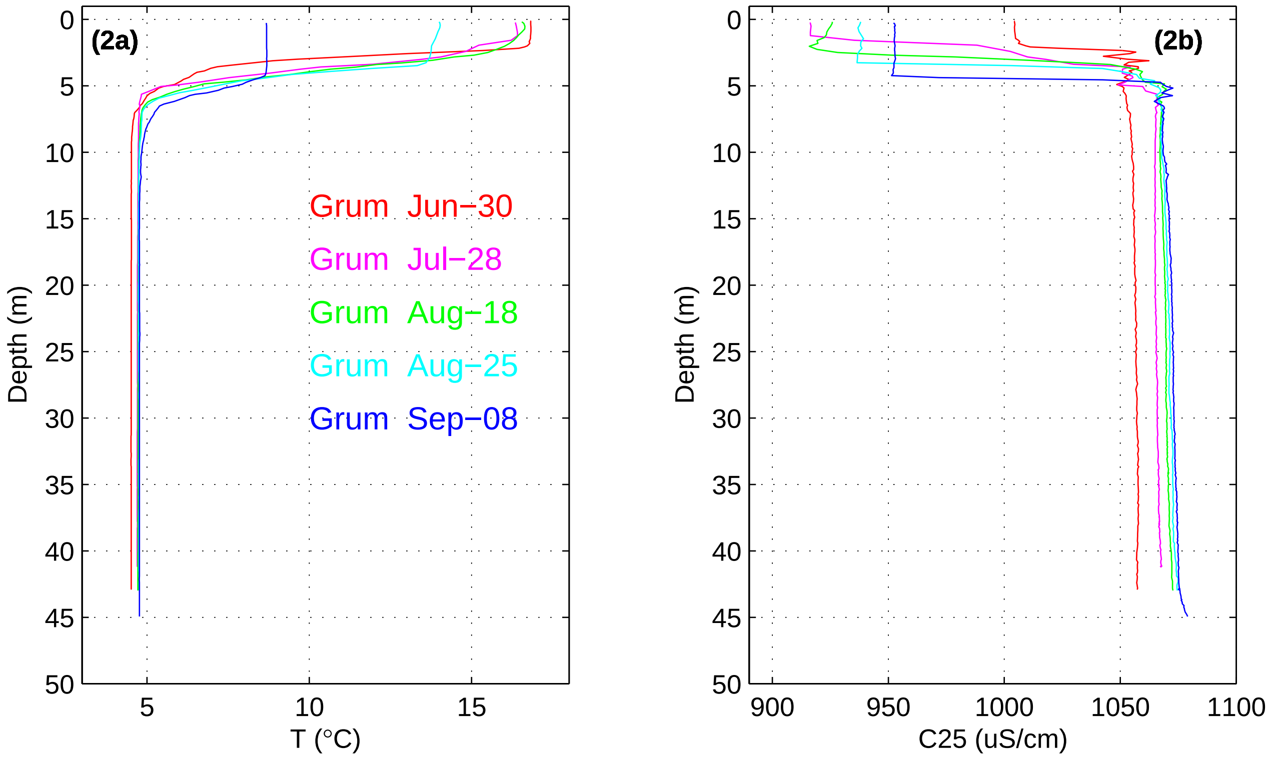
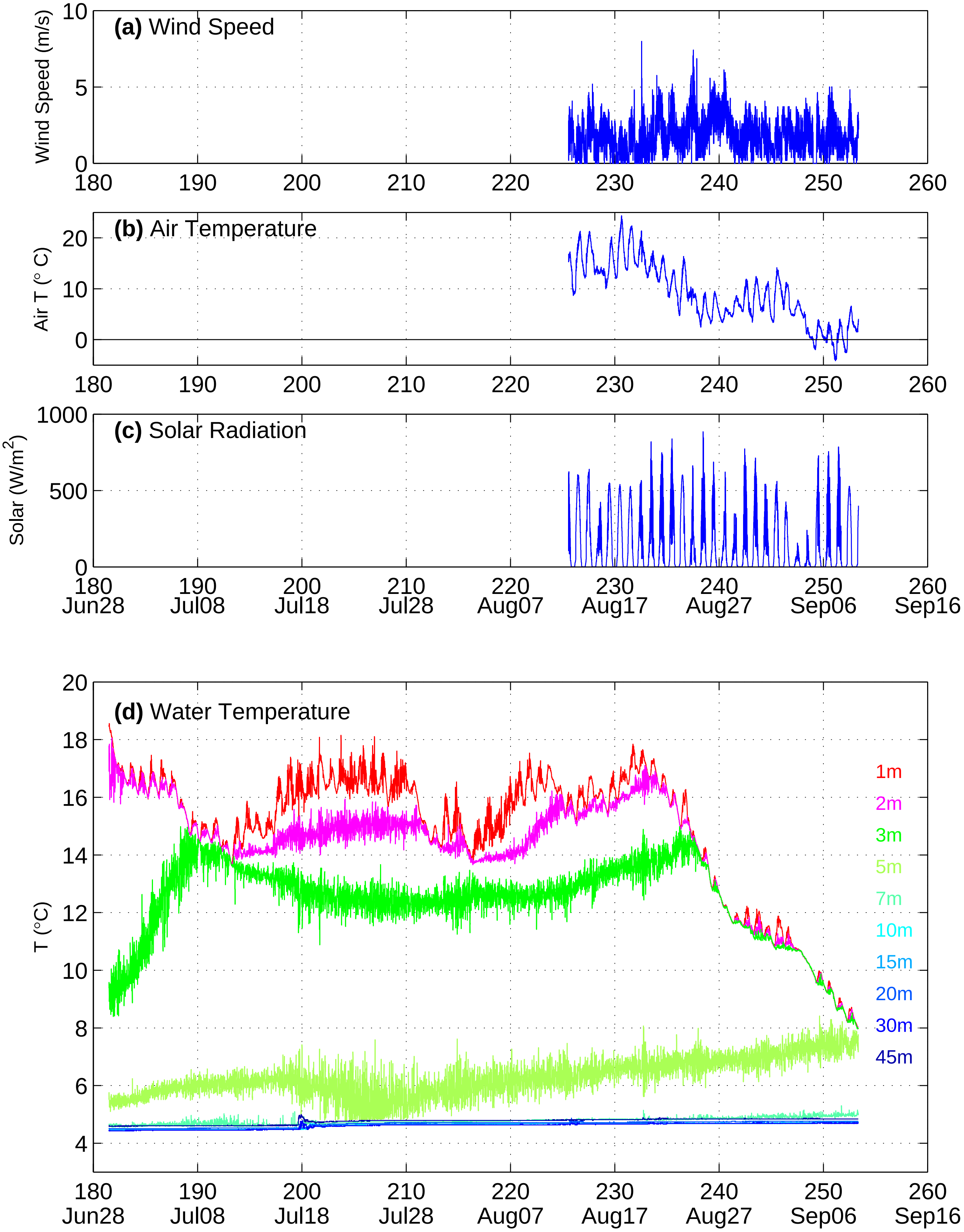


**Figure 3.** Grum Meteorological and Mooring Data, 2004



# Appendix D

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

# Updated Estimates of Post-closure Water Quality in Faro, Grum, and Vangorda Pit Lakes

**Prepared for**

**Deloitte & Touche Inc.**

**On behalf of**

**Faro Mine Closure Planning Office**

**Prepared by**

**SRK Consulting**
*Engineers and Scientists*

**January 2006**

# Updated Estimates of Post-closure Water Quality in Faro, Grum, and Vangorda Pit Lakes

## Deloitte & Touche Inc.

**On behalf of**

## Faro Mine Closure Office

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**SRK Project Number 1CD003.046**

**January 2006**

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# 1 Introduction

## 1.1 Overview

Biological treatment of the Faro, Grum and/or Vangorda pit lakes has been identified as a potential alternative for removal of metals. An extensive field and laboratory study was initiated in 2004 to further characterize the limnological and chemical characteristics of the pit lakes, characterize sources of metal loading to the pit lakes, determine fertilization requirements, and assess phytoplankton growth and metal removal rates. A more detailed overview of this program is provided in the accompanying report.

Earlier estimates of source concentrations to the pit lakes and therefore long-term water quality in the pits lakes were made as part of the 2003 pit lake assessment (SRK 2004a). Further refinement of these estimates was identified as a priority for the 2004 field program. The source characterization work included the following.

- Collection of additional seepage and runoff samples from the pit walls, particularly for areas that are above the future elevation of flooding. If suitable samples could be collected, the resulting data were intended to replace the current estimates of seepage concentrations based on data from the waste rock seepage sampling programs.
- Ground-truthing existing mapping. Accessible zones within the pits were briefly examined to define the geochemical variations within the zones and to refine the locations of the contacts between the different zones. A limited number of contact tests, sulphur/sulphate analyses, and solids metal analyses were completed to determine how these materials compare to material in the waste rock dumps.
- Improve understanding of current inflows and outflows from each of the pits to allow calibration of load models. Further information on the water management activities in the Faro and Vangorda pits was obtained and used to construct a water and load balance reflecting current conditions in each of the pits.
- Updated water quality estimates, including sensitivity analyses to determine the probable range of loadings to the pits given different closure alternatives in each of the pits.

This report presents results of the additional field studies, a summary of current conditions in each of the pits, and estimates of future water quality. The estimates presented herein supersede those in the 2003 pit lake assessment (SRK 2004a).

## 1.2 Background Information

There are a number of related studies that were used to improve our understanding of geochemistry and water quality in the pit lakes. A brief description of each of these is as follows.

A number of studies have been completed over the past 20 years to characterize the geochemistry of waste rock at the Anvil Range Mining Complex. A review and compilation of this historical information was completed by SRK in 2002, and supplemental field and laboratory studies were completed in 2002 and 2003 (SRK 2003a and 2004b). These programs included sampling of waste rock and seepage, installation of gas and temperature monitors, and laboratory testing, including static tests, extraction tests, humidity cell tests, and column tests. In 2004, seepage monitoring and gas and temperature monitoring were continued (SRK 2004c). The results of these programs were used to supplement data from the pit lake studies. In particular, data from the seepage surveys were used to supplement the more limited database of pit seep samples, and data from the solids testing programs were used to estimate the long-term weathering behaviour of different types of rock in the pit walls.

Routine monitoring of the pit lake water quality has been completed by site personnel in each of the pits since mining operations ceased and each of the pits were allowed to fill. This has included monthly sampling at Station X22B in Faro Pit Lake since 1996, quarterly sampling at Station V23 in Grum Pit Lake since 1997, and quarterly sampling at Station V22 in Vangorda Pit Lake since 1998.

Detailed studies on Vangorda Pit Lake were completed by SRK in June 2000 (SRK 2000). The study included a pit wall seep survey, sampling of the pit lake at depths of 2 and 12.5 metres, a profile of temperature, pH, conductivity and dissolved oxygen levels, sampling and testing of waste rock and talus, and characterization of secondary minerals found on the pit walls. The study included mass loading estimates, and a preliminary assessment of potential impacts to receiving water quality if untreated water was to be released from the pit.

Estimates of water quality from the waste rock dumps, including the dumps which drain into the Faro pit were made in December 2003 (SRK 2003b). A recent update of those predictions was issued in November 2004 (SRK 2004d). These estimates are the basis for inputs from the waste rock dumps into the pits.

Where relevant, results of the above studies have been incorporated in the summary of current conditions provided in Sections 3 and 4 of the report.

# 2 Field Investigations

## 2.1 Methods

### 2.1.1 Mapping/Ground Truthing

Rough maps of the distribution of lithologies in the current pit walls were produced based on available pit geology maps of existing Faro and Vangorda pits and the design final Grum pit (Brown and McClay 1992; RGI 1996). Limited field mapping and ground truthing of existing maps was undertaken in September of 2003 as part of the initial pit lake assessment (SRK 2004a). Additional field mapping was undertaken in September 2004. Additional mapping consisted of traversing accessible benches and roads within the pits, recording observations of lithology, and photographing pit walls to aid in definition of map units. The mapping included detailed examination of accessible lithologies to assess the degree of uniformity and to define the geochemical variations within each rock type. Additional information on fine scale variations in geology, alteration zones and mineralogy of the units was recorded. For inaccessible sections of pit wall, lithological distribution was verified/ mapped remotely through inspection of visual unit boundaries in pit walls. From the pit rim, the opposite walls were observed, and colour variations in the wall rocks were compared with existing mapped unit boundaries. Where no existing units were defined, colour unit boundaries were mapped and panoramic series of photographs were taken for future reference.

Final map compilation was undertaken by updating existing maps to reflect field observations. Photographs of pit walls were used as a final check on the distribution of lithological units. For Grum Pit, where the available pit geology map was based on the ultimate design pit, photographs were used to define lithological contacts for areas of the pit that were inaccessible. Where lithology of a particular unit could not be verified in the field, unit boundaries were defined based on color variations in pit wall photographs. To apply lithologies to these inaccessible units, the design ultimate pit geology map was consulted and rock units were extrapolated to the current walls. Where these extrapolated units were the same rock type as accessible units, the pit wall photographs were examined to verify visual similarity between these extrapolated units and field-verified units.

A description of rock units and nomenclature at the Anvil Range mines is included in Appendix A.

### 2.1.2 Waste Rock Seepage

Waste rock seepage within the Faro Pit catchment has been collected in spring and fall since 2002 as part of the waste rock seepage monitoring. Up to 100% of the seepage from each of the Faro Valley North, Faro Valley South, Outer Northeast, Upper Northeast, Lower Northeast, Southwest Pit Wall, Ranch, and Ramp Zone Dumps currently reports to the Faro Pit. Waste rock seepage sampling methods and results are described in a separate report (SRK, 2004c).

### 2.1.3 Pit Wall Seepage

During spring 2003, six samples were collected of pit wall seepage/ runoff from accessible areas in Grum Pit, in conjunction with the concurrent waste rock seepage sampling.

In spring 2004, a more extensive pit seep sampling effort was undertaken. Pit wall seeps were collected where presented from accessible benches and access roads. At Grum Pit, a total of 13 seeps were sampled. At Faro Pit, samples were collected by accessing the pit walls by boat from the lake; six pit wall seep samples were collected from the pit lake, with one sample subsequently collected from higher up. At Vangorda Pit, seven samples were collected by boat and an additional nine samples were collected from roads and benches.

Where accessible, samples of seepage located within each pit catchment were collected and submitted for analysis of routine parameters (pH, conductivity, acidity, alkalinity, chloride and sulphate), and dissolved metals (dissolved metals by ICP-OES). The samples were filtered and preserved in the field according to standard methods for collection of environmental samples. Field pH, conductivity, redox, temperature measurements were taken at each station using a WTW meter. Flow estimates were made using the bucket and stopwatch method, by estimating the velocity and cross sectional area of the seep, or by visual estimation. Observations of pit wall lithology at sampling stations were recorded to allow correlation of water chemistry and wall rock lithology.

### 2.1.4 Solids Characterization

Fifteen samples collected during pit traverses were subjected to a distilled water leach extraction to assess the quantity of stored oxidation products in pit wall rock and talus. Samples were collected from talus at the toes of benches and shipped to Canadian Environmental and Metallurgical, Inc. (CEMI) for testing. In the laboratory, as-received samples were screened through a 1 cm mesh sieve. The fines fraction was evaluated for rinse pH and conductivity, using a 1:1 mass ratio of distilled water to solids. Samples were then subjected to a 96-hour distilled water leach at a 3:1 mass ratio of liquid to solids, using 250 g samples. At the end of the extraction, pH and conductivity of the supernatant were measured, and the leachate was filtered and submitted for analysis of acidity, alkalinity, sulphate, and dissolved metals by ICP-OES.

## 2.2 Results

### 2.2.1 Mapping/Ground Truthing

#### Faro Pit

The pre-existing pit geology map for the Faro Pit (RGI, 1996) shows a detailed distribution of rock types, and is based on information from ‘Faro Mine Abandonment Plan’ (Curragh Resources Inc., 1988, referenced in RGI, 1996). Most of the pit walls were inaccessible and prohibited detailed verification of map units; remote visual verification confirmed existing unit boundaries on the basis of color. Where field checking was possible, the existing map was found to be largely representative of existing geological distribution, with a few exceptions described below. The updated Faro Pit map is shown in Figure 2.1.

Field verification led to a change in the lithology assigned to the southwest pit wall, from Unit 2A (ribbon banded graphitic pyritic quartzite) to Unit 3D0 (calc-silicate and related rocks). This change has significant implication for predicted pit water quality, as runoff from Unit 3D0 is expected to be much better quality than runoff from Unit 2A.

Minor changes to two unit boundaries were made on the high northwest pit wall. These included extending Unit 1D4 (quartz muscovite schist) and Unit 10E (hornblende diorite and quartz diorite) to the current pit rim. The pre-existing map had no lithology mapped above Unit 1D4, and thus this change slightly increases estimates of both total pit wall area and area of Unit 1D4. This will increase estimates of loading to the pit lake from the northwest pit wall, as runoff from Unit 1D4 is expected to carry high levels of acidity and metals. The pre-existing map had Unit 1D (biotite schist) mapped from Unit 10E up to the current pit rim; thus, extending Unit 10E to the current pit rim does not change the estimate of total pit wall surface area, but does reduce the exposure of Unit 1D and increases the exposure of Unit 10E. This change will reduce estimates of loading to the pit lake from the northwest pit wall, as runoff from Unit 10E is expected to be better quality than runoff from Unit 1D.

In the southeast pit wall, Unit 1D4 was extended over the pit rim to include a benched area that drains to the pit lake. This will increase estimates of loading to the pit lake due to the poor runoff water quality expected from Unit 1D4.

Active failure of the east wall of Faro Pit results in ongoing changes to the areas of each rock unit exposed at each elevation. Sloughed material covering the pit wall prevents remote updates of pit wall geology, and access to this active failure area for field mapping is dangerous at best. Because this wall largely consists of Unit 1D, the changes in lithological distribution are assumed to be minimal, and for the purposes of pit lake water quality prediction, the pre-existing distribution of rock units (RGI, 1996) is considered to be acceptable.

### Grum Pit

The pre-existing Grum Pit geology map was based on the ultimate pit design in the original mine plan, the block model for which was generated from lithological data collected during exploration drilling. Actual mining at Grum followed an updated mine plan that envisioned a modified ultimate pit. This, coupled with the cessation of mining at an intermediate stage of the mine plan, resulted in the current pit shell being substantially different than that depicted in the initial pit geology map. The initial pit geology map provided guidance on the expected distribution of rock types in general, but was not representative of existing geological unit boundaries.

The majority of wall rock exposed in Grum Pit consists of Vangorda Formation phyllites, which make up the entire west wall of the Grum Pit. These phyllites were further divided during operations into a dark grey to black carbonaceous, weakly calcareous member (Unit 5A0) and a silver to dark grey calcareous member (Unit 5B0). Initially, attempts were made to map the distribution of these units separately. However, complex folding has resulted in intimate bench scale mixing of these two units, and it was found to be impractical to differentiate the two units effectively at the pit scale given that large areas of the pit walls are inaccessible. It was decided to map these rocks as a single unit (Unit 5A0/5B0) of undifferentiated Vangorda Formation phyllites, and to define an average runoff water quality for the bulk unit. The new Grum Pit geology map is shown in Figure 2.2.

The second largest component of Grum Pit walls is till, which forms the entire east wall of the pit. A large portion of the east wall is actively failing, which has resulted in a layer of till masking any wall rock that may exist on the east wall above the current pit lake surface. Since the till is expected to dominate runoff quality, this area was mapped as till.

Small areas of undifferentiated sulphides were mapped at the north and south ends of the pit, extending from the current pit lake level (1185 masl) up to approximately 1255 masl. These areas were identified initially through examination of photographs, and subsequently defined following field mapping. Most of the exposed sulphides will be covered when Grum Pit Lake reaches its final spill elevation of 1230 masl, as shown in Figure 2.2. Small areas of Mt. Mye Formation phyllites were defined based on the pre-existing map and the definition of unit boundaries from colour photographs.

### Vangorda Pit

The pre-existing pit map was developed during advanced stages of mining at Vangorda as part of a doctoral study of the Vangorda deposit (Brown and McClay, 1992). This simplified map differentiates the Vangorda Pit wall rock into 3 units: Mt. Mye Formation, Vangorda Formation, and massive sulphides.

The boundaries of the geological units observed in the field were found to generally agree with those on the existing map (presented in SRK 2004a). The mapped Mt. Mye Formation was further divided during field mapping to Unit 3G0 (non-calcareous phyllite) and Unit 4L0 (bleached pyritic phyllite).Two small additional sulphide zones were located on the upper part of the north wall internal to the previously mapped Mt. Mye Formation. The mapped Vangorda Formation was inspected where exposed above the Vangorda Creek diversion, and the lithology was identified to be Unit 5A0 (carbonaceous phyllite). Figure 2.3 shows the revised Vangorda Pit geology map.

Southeast of the pit ramp, the previously mapped Mt. Mye Formation wall rock was observed to contain high proportions of sulphides and to have thick coatings of secondary oxidation products. For the purposes of prediction of pit lake water quality, the Mt. Mye Formation here has been lumped with the adjacent undifferentiated sulphides unit. It is expected that runoff water quality of the Mt. Mye wall rock in this area will be dominated by the ongoing oxidation of the contained sulphides, and that loadings from this rock will be more typical of sulphide material.

### 2.2.2 Waste Rock Seeps

#### Faro Pit Catchment

Complete results from 2002 through 2004 waste rock seepage monitoring are summarised in the draft report “2004 Waste Rock Seepage Surveys and ARD-related Data Collection” (SRK 2004c).

The largest waste rock seepage input to Faro Pit is water in the former Faro Creek valley that flushes the base of the Faro Valley North and Faro Valley South dumps before flowing over the north pit wall into the lake. This flow can be greater than 1000 L/minute (typically lower), and is sampled at station SRK-FD40. Water quality at SRK-FD40 over the monitoring period has ranged from slightly to strongly acidic (pH 3.0 to 6.2), with zinc concentrations ranging from 47 to 108 mg/L.

Drainage from the Northeast dumps enters the pit at the southern pit ramp. Flow volume can be greater than 1000 L/min (typically lower); this flow is sampled at SRK-FD26, and has neutral pH (6.6 to 7.3) and low zinc concentrations (1.3 to 2.8 mg/L). A number of seeps are collected southeast of the pit (SRK-FD21 through –FD24). These range from neutral to strongly acidic (pH 3.6 to 7.0) and have moderate zinc concentrations (7.2 to 65 mg/L).

The Faro Pit receives occasional waste rock seepage inputs from the low grade ore stockpiles southwest of the pit. These seepage inputs have been present and sampled at SRK-FD38 during two of six sampling events. Flow volumes were low on both occasions (2.5 to 10 L/min), with neutral to acidic pH (pH 3.1 to 7.0) and high zinc concentrations (287 to 595 mg/L). Most loading from the low grade stockpiles to the Faro Pit likely follows a subsurface flowpath, and is rarely available for surface sampling.

There are no waste rock dumps within the catchment of Grum Pit, and therefore all seepage collected within the pit reflects loading from wall rock sources.

#### Vangorda Pit Catchment

No waste dump toe seepage was collected within the Vangorda Pit catchment. Several seeps were collected that have chemical contributions from both pit walls and in-pit dumps; these are discussed in the following section. In general, all waste rock within the Vangorda Pit catchment is expected to generate acidic seepage with high metal concentrations.

One possible source of seepage to Vangorda Pit could be the Vangorda Dump. The pre-mining topography shows a moderate surface gradient from the location of the dump to the pit. The increase in elevation resulting from placement of the waste rock could theoretically result in the formation of a groundwater mound at this location. This increase in elevation combined with the lowering of the water table adjacent to the pit may have caused a high gradient to develop between the dump and the nearest part of the pit. No seeps have been identified from a waste-dump impacted groundwater source, although the seepage observed on the southwest side of the pit ramp (inside the hairpin) may originate as groundwater.

### 2.2.3 Pit Wall Seeps

#### Faro Pit

Faro Pit wall seeps were concentrated along the north and west sides of the pit; seep locations and a summary of water quality results are shown in Figure 2.4. Seep sample locations are also shown on the Faro Pit geology map for reference. Complete pit seep sampling results are provided in Appendix B.1. Faro Pit seeps were collected on June 3, 2004; the area had experienced no precipitation since May 27, and as such the seeps are thought to represent base flow conditions. It should be noted that all seeps wash over wall rock above the point of collection.

Seeps flowing from or over Unit 10E (hornblende diorite and quartz diorite) were neutral to slightly alkaline pH (7.0 to 8.1), with low zinc concentrations (<0.005 to 0.832 mg/L). These flows (seeps 04FP04, -FP05, and -FP07) represent the majority of water entering the pit along the north pit wall. The remainder of the water which enters via the north pit wall flows over Units 1D4 (quartz muscovite schist), 2A (ribbon-banded graphitic pyritic quartzite) and 2E (massive pyritic sulphides). A sample of this water was collected at station 04FP03, and was found to be strongly acidic (pH 3.0) with a high concentration of dissolved zinc (875 mg/L).

Two seeps along the west wall of the Faro Pit (04FP01 and 04FP02) were sampled. This pit wall consists almost entirely of Unit 3D0 (calc-silicate and related rocks) and produces little seepage, as surface and groundwater flow is dominantly driven to the southwest by topography. Sample 04FP02 was collected at the base of the highest section of calc-silicate pit wall. This sample had a slightly alkaline pH (7.5) and a low concentration of dissolved zinc (0.051 mg/L). Sample 04FP01 is adjacent to the west pit ramp, and is likely influenced by upgradient waste rock and low grade ore stockpiles situated near the pit edge. The pH of this sample was slightly acidic (pH 6.5) and the zinc concentration was moderately high (45 mg/L). Due to the likely contamination from low-grade ore and waste rock, this sample was not considered to be representative of Unit 3D0. The water quality measured at 04FP02 was selected to represent runoff from calc-silicate pit walls.

The only pit seep observed originating from the east wall was 04FP06. This water was muddy brown at the time of sampling, with very high total suspended solids derived from the till exposed in the pit wall above. The pH of this water was neutral (pH 7.2) and contained no detectable dissolved zinc. This flow was visually observed to have a similar volume to the seeps on the north pit wall, and likely results from leakage from the Faro Creek diversion.

#### Grum Pit

Results from 2003 and 2004 Grum Pit seep sampling showed no year-over-year change. Seep locations and water quality results are summarized in Figure 2.5. Seep sample locations are also shown on the Grum Pit geology map for reference. Complete results from pit seep sampling are provided in Appendix B.2. Grum Pit seeps were collected on May 31 and June 1, 2004; the area had experienced no precipitation since May 27, and as such the seeps are thought to represent base flow conditions. It should be noted that all seeps wash over wall rock above the point of collection.

Two seeps were collected from the east wall of the pit, from with the actively failing till unit (04GP04 and 04GP05). A third sample which reflects till runoff water quality was collected from the shallow permanent pond located in the depression in the access ramp that exits the pit to the south (sample 04GP13). All three samples had slightly alkaline pH (pH 7.8 to 8.3) with zinc concentrations ranging from below detection to low levels (<0.005 to 0.031 mg/L).

Four seeps from walls composed of various sulphide materials were sampled. One additional seep (04GP14) within a Vangorda phyllite map unit was sampled, but has water quality that is indicative of a sulphide source. This sample is located midway between two mapped areas of sulphide material, and it is assumed that the seep water contacts similar material upgradient. Abundant iron oxyhydroxide precipitates were observed at 04GP14. This sample also returned the highest zinc concentration (97.5 mg/L) and the lowest pH (6.8) of all Grum Pit seepage samples, and for purposes of pit lake water quality prediction, this sample is assumed to be sourced from sulphide material. Taken together, the five samples had slightly alkaline to slightly acidic pH (pH 6.8 to 8.5) and moderate to high zinc concentrations (6.7 to 98 mg/L).

Fourteen seep samples were collected from benches in mixed Vangorda Formation phyllites along the west wall of Grum Pit (03GP03,-05, -06, 04GP01 through -03, -06 through -08, -11, -12). These samples were characterised by neutral to slightly alkaline pH (pH 7.4 to 8.4) and low zinc concentrations ranging from <0.005 to 0.073 mg/L.

### Vangorda Pit

Vangorda Pit seeps were concentrated along the north and east sides of the pit lake, and along the pit access ramp southeast of the pit lake. Seep locations and a summary of water quality results are shown in Figure 2.6. Seep sample locations are also shown on the Vangorda Pit geology map for reference. Complete pit seep sampling results are provided in Appendix B.3. Vangorda Pit seeps were collected on June 1 and 2, 2004; the area had experienced no precipitation since May 27, and as such the seeps are thought to represent base flow conditions. It should be noted that all seeps wash over wall rock above the point of collection.

One seep from Unit 5B0 (Vangorda Formation carbonaceous phyllite) was sampled at the north end of the pit. This seep emerged from the pit wall about 1.5 m above the lake level and had produced a rusty stain on the pit wall below, with local formation of precipitates. Little to no soluble secondary oxidation products were noted in the immediate vicinity; however, abundant salts and secondary copper minerals (green) were observed higher up on the wall within the same unit. This seep had a slightly acidic pH of 6.3 and a high dissolved zinc concentration of 180 mg/L.

Four seeps from Unit 3G0 (Mt. Mye Formation non-calcareous phyllite) were sampled at the north end of the Vangorda Pit. One of these, sample 04VP01, was collected from the wall above the Vangorda Creek Diversion. As this water had contacted at most three metres of pit wall, the water quality is reflective of background conditions with low zinc concentration and neutral pH. The remaining three seeps (04VP11, -12, -13) were collected immediately above the pit lake, and were acidic to neutral pH (pH 3.4 to 7.2) with moderate to high zinc concentrations (2.9 to 42 mg/L). The sources of these seeps had variable amounts of rusty brown staining and bright orange to orangey brown staining. Adjacent rocks and the geological unit as a whole displayed a moderate accumulation of secondary oxidation products. Hard dark grey and occasional tan precipitates were observed on walls that appeared to experience continuous flushing below sources of seepage (04VP12 and -13 only).

One seep was sampled below a till bank along the east wall of the pit south of the pit lake (04VP03). No wall rock was exposed along the flowpath upgradient of this station, and the water quality is assumed to reflect water quality in runoff from exposed till. Where seepage emerged from the till bank, the substrate wais stained a rusty orange; the degree of staining decreased with distance from the seep source. Sample 04VP03 had a neutral pH of 7.6 and no detectable dissolved zinc.

Three seeps from Unit 4L0 (Mt. Mye Formation bleached phyllite) were sampled along the northeast wall of the pit ramp (04VP05 through -07). Unit 4L0 is overlain by siliceous massive sulphides at this location which may be controlling water quality. An undefined amount of sulphide waste was placed on the wide bench above this wall, and seepage may reflect the influence of water acquiring dissolved load as it moves through this waste. However, runoff water quality from Unit 4L0 is expected to be poor, and an average runoff quality defined by these three samples is likely an appropriately conservative approximation.

Seven samples (04VP02, -04, -08, -09, -14, -15, -16) were collected from pit wall runoff and seepage sources draining undifferentiated massive and disseminated sulphides (Figure 2.6). Three of the samples were collected from pit wall runoff immediately above the pit lake surface; these had acidic to neutral pH (pH 3.7 to 7.2) and moderate to high zinc concentrations (19.9 to 238 mg/L). The four samples collected southeast of the pit lake all had acidic pH (2.8 to 5.6) and moderate to very high zinc concentrations (12 to 1550 mg/L). All seepage locations were characterized by orange to rusty brown staining and/ or accumulations of bright reddish orange precipitates. The samples with the highest zinc concentrations (04VP04 and 04VP08) were both downgradient of in-pit sulphide dumps, and seep water quality may reflect dissolved load from these sources. Sample 04VP02 was collected from seepage that had contacted a single bench (~3 m) of blocky siliceous massive sulphide, and the relatively low zinc concentration (12.1 mg/L) is likely reflective of this minimal opportunity for contact.

### 2.2.4 Solids Characterization

Pit wall talus sample locations are shown on the respective pit geology maps for Faro, Grum, and Vangorda Pits (Figures 2.1 through 2.3). Lithological descriptions of each sample are shown in Table 2.1, along with results from contact testing and leach extraction testing. A brief discussion of the results from each pit follows.

### Faro Pit

Seven samples were collected from Faro Pit. Six samples of intrusive, calc-silicate, and biotite schist had neutral to slightly alkaline rinse pH ranging from 7.2 to 8.1, with rinse conductivity ranging from 55 to 1816 µS/cm, as shown in Table 2.1. The lone sample from altered quartz muscovite schist (FP03) had a rinse pH of 2.7 and a rinse conductivity of 2590 µS/cm.

The 96-hour leach extraction testing returned similar pH and conductivity results for all samples, with the altered quartz muscovite schist (FP03) producing acidic leachate (pH 2.6) with higher conductivity (2070 µS/cm) than all other samples. The FP03 leachate had correspondingly high acidity, and elevated concentrations of sulphate and dissolved metals (eg. 19.8 mg/L Zn). The leachate from the remaining Faro Pit talus samples was neutral to slightly alkaline, with low to elevated sulphate and dissolved metal concentrations at or near detection levels.

### Grum Pit

Seven samples were collected from Grum Pit, including six samples of mixed Vangorda Formation phyllites and one sample of pyritic quartzite. All phyllite samples had slightly alkaline rinse pH (8.1 to 8.8) and low to elevated rinse conductivity (130 to 1650 µS/cm), as shown in Table 2.1. The pyritic quartzite sample (GP03) returned a slightly acidic rinse pH (6.4) and a somewhat elevated rinse conductivity (620 µS/cm). Extraction leachate from GP03 had high dissolved zinc (55 mg/L) and lead (1.2 mg/L) concentrations, and detectable concentrations of dissolved cadmium, cobalt, copper, and manganese. Extraction leachate from the various phyllite samples contained dissolved metals at or near detection limits; three samples had detectable dissolved zinc with a maximum concentration of 0.0304 mg/L.

### Vangorda Pit

Two samples were collected from Vangorda Pit. Sample collection in 2004 was limited as solids testing of Vangorda Pit talus samples had been carried out as part of an earlier study (SRK 2000).

One sample of Vangorda Formation carbonaceous phyllite was collected; rinse pH for this sample was slightly acidic (pH 5.9), with a low rinse conductivity 75 µS/cm. Leach extraction on this sample produced a leachate with slightly alkaline pH and elevated conductivity and sulphate. Dissolved metal concentrations were at or near detection levels, with a dissolved zinc concentration of 0.0089 mg/L.

One sample of Mt. Mye Formation non-calcareous phyllite was collected. This lithology was sampled and tested a number of times during the previous investigation, and was subjected only to contact tests as part of the current program. This sample returned an acidic rinse pH of 3.4, and a moderate rinse conductivity of 570 µS/cm.

A total of nineteen samples were collected in the earlier study (SRK 2000), including talus and waste rock. The results indicated six of the samples had rinse pH below 5, eight samples with rinse pH between 5 and 6, and five samples with rinse pH above 6. Most of the samples contained significant amounts of sulphide, and minimal neutralization potential, and are therefore classified as potentially acid generating. The single exception was a till sample. Concentrations of arsenic, cobalt, copper, lead and zinc were elevated, indicating a strong potential for metal leaching. Leach extraction tests completed at a water to solids ratio of 20:1 indicated soluble zinc loads of 14 to 5580 mg/kg of solids. Several other metals were present at elevated concentrations, particularly in the low pH samples. Secondary minerals were observed at many locations in the pit, and included bianchite (a hydrated zinc sulphate), melanterite (iron sulphate), gypsum and iron hydroxides.

## Table 2.1 Sample descriptions, contact test and leach extraction results

| | | **Contact tests** | | **96-hour distilled water extraction** | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | **Physical Parameters and Anions** | | | | | | **Dissolved Metals (mg/L)** | | | | | | | | | |
| Sample ID | Lithological Unit | Rinse pH | Rinse Conductivity (us/cm) | Final pH | Final Conductivity (uS/cm) | Alkalinity (mg CaCO3/L) | Acidity (pH 4.5) (mg CaCO3/L) | Acidity (pH 8.3) (mg CaCO3/L) | Sulphate (mg/L) | Arsenic | Barium | Cadmium | Cobalt | Copper | Iron | Lead | Manganese | Antimony | Zinc |
| FP01 | 10E- Hornblende diorite and quartz diorite | 7.72 | 55 | 7.46 | 48 | 15.75 | 0 | 4 | 8 | <0.20 | 0.06 | <0.010 | <0.010 | <0.010 | 0.387 | <0.050 | 0.0142 | <0.20 | <0.0050 |
| FP02 | 10E- Hornblende diorite and quartz diorite | 8.13 | 1816 | 7.80 | 1555 | 33.5 | 0 | 10.5 | 1818 | <0.30 | 0.037 | <0.010 | <0.010 | <0.010 | <0.030 | <0.050 | <0.0050 | <0.20 | <0.0050 |
| FP03 | 1D4- Altered quartz muscovite schist | 2.69 | 2590 | 2.57 | 2070 | 0 | 520 | 770 | 1054 | 0.58 | 0.013 | 0.247 | 0.546 | 5.95 | 128 | <0.050 | 6.77 | <0.20 | 19.8 |
| FP04 | 1D- Biotite schist | 7.24 | 1278 | 7.82 | 1062 | 36 | 0 | 7.75 | 945 | <0.20 | 0.033 | <0.010 | <0.010 | <0.010 | <0.030 | <0.050 | <0.0050 | <0.20 | 0.0059 |
| FP05 | 3D0- Calc-silicate | 8.53 | 140 | 8.15 | 166 | 65.5 | 0 | 2 | 21 | <0.20 | 0.035 | <0.010 | <0.010 | 0.01 | 0.036 | <0.050 | <0.0050 | <0.20 | <0.0050 |
| FP06 | 1D- Biotite schist | 7.98 | 91 | 7.89 | 108 | 40.5 | 0 | 4.75 | 12 | <0.20 | <0.010 | <0.010 | <0.010 | <0.010 | <0.030 | <0.050 | <0.0050 | <0.20 | <0.0050 |
| FP07 | 10F- Quartz feldspar porphyry | 8.09 | 128 | 8.00 | 191 | 49.25 | 0 | 1.25 | 36 | <0.20 | 0.061 | <0.010 | <0.010 | <0.010 | <0.030 | <0.050 | <0.0050 | <0.20 | <0.0050 |
| GP01 | 5A0/5B0- mixed Vangorda Formation phyllite | 8.25 | 429 | 8.22 | 316 | 72 | 0 | 0.5 | 100 | <0.20 | 0.044 | <0.010 | <0.010 | <0.010 | 0.099 | <0.050 | <0.0050 | <0.20 | <0.0050 |
| GP02 | 5A0/5B0- mixed Vangorda Formation phyllite | 8.10 | 265 | 8.14 | 231 | 62.75 | 0 | 2.25 | 59 | <0.20 | 0.038 | <0.010 | <0.010 | <0.010 | <0.030 | <0.050 | <0.0050 | <0.20 | <0.0050 |
| GP03 | 4C- Pyritic quartzite (mapped as 4EC) | 6.37 | 616 | 6.75 | 448 | 5.5 | 0 | 72.75 | 242 | <0.20 | 0.061 | 0.112 | 0.039 | 0.019 | <0.030 | 1.2 | 0.195 | <0.20 | 55.3 |
| GP04 | 5A0/5B0- mixed Vangorda Formation phyllite | 8.25 | 930 | 8.04 | 1001 | 49.75 | 0 | 5 | 559 | <0.20 | 0.02 | <0.010 | <0.010 | <0.010 | <0.030 | <0.050 | <0.0050 | <0.20 | 0.0061 |
| GP05 | 5A0/5B0- mixed Vangorda Formation phyllite | 8.71 | 193 | 8.19 | 197 | 69 | 0 | 1 | 40 | <0.20 | 0.038 | <0.010 | <0.010 | <0.010 | <0.030 | <0.050 | <0.0050 | <0.20 | <0.0050 |
| GP06 | 5A0/5B0- mixed Vangorda Formation phyllite | 8.75 | 337 | 8.02 | 269 | 64 | 0 | 2.25 | 78 | <0.20 | 0.024 | <0.010 | <0.010 | <0.010 | <0.030 | 0.051 | <0.0050 | <0.20 | 0.0304 |
| GP07 | 5A0/5B0- mixed Vangorda Formation phyllite | 8.28 | 1656 | 7.78 | 1122 | 41.25 | 0 | 8.75 | 1017 | <0.20 | 0.024 | <0.010 | <0.010 | <0.010 | <0.030 | <0.050 | <0.0050 | <0.20 | 0.0148 |
| VP01 | 3G0- Mt. Mye non-calcareous phyllite | 5.93 | 45 | 7.78 | 1137 | 40.5 | 0 | 7.25 | 1029 | <0.20 | 0.027 | <0.010 | <0.010 | <0.010 | <0.030 | <0.050 | <0.0050 | <0.20 | 0.0089 |
| VP02 | 5A0- Carbonaceous phyllite | 3.36 | 357 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |

Note: Sample VP02 was not subjected to to leaching extraction testing

# 3 Current Conditions

## 3.1 Faro Pit Lake

### 3.1.1 Routine Monitoring

Faro Pit Lake water quality is currently sampled as part of the routine monitoring required by the site water license. Samples are collected by site environmental staff from the pit lake surface at station X22B. Sulphate and zinc concentrations at station X22B for the period of 1998 to present are shown in Figure 3.1; dissolved concentrations are plotted where available, and total concentrations were substituted where necessary to complete the record. Complete monitoring results for the 1998-2004 period are provided in Appendix C.1.

The results indicate the pit lake surface water currently has neutral to slightly alkaline pH's (ranging from 6.7 to 7.8), moderate alkalinity levels and sulphate concentrations of approximately 600 mg/L. Calcium and magnesium are the dominant cations. Concentrations of cadmium (0.012 mg/L)[1], cobalt (0.036 mg/L), copper (0.039 mg/L), and zinc (12 mg/L) are elevated. As shown in Figure 3.1, sulphate concentrations indicated some short-term variability, but have typically been in the range of 600 mg/L since the start of monitoring in 1996. Zinc concentrations were typically less than 5 mg/L from 1996 to 2000. From August 2000 to November 2000, there was a brief spike in surface water concentrations. The cause of this temporary increase in surface zinc concentrations is not known, but may be related to high zinc inflows due to site water management. This increase is unlikely to be related to fall turn-over of the lake, as Figure 3.1 shows the bottom water to have a lower zinc concentration. Following the Fall 2002 spike, concentrations then stabilized in the range of 10 to 15 mg/L. However, periodic spikes were observed in March 2002, 2003 and 2004.

### 3.1.2 Depth Profiles

In April 2003 Gartner Lee Limited (GLL) carried out a program of sampling and analysis to characterize water quality in Faro Pit Lake. A similar program was carried out in June 2004 by Lebarge Environmental Services (Lorax, 2004). Complete results are presented in Appendix D.1.

The results shown in Figure 3.2 indicate that the Faro Pit has two haloclines: one at 3-5 metres depth, and the other at 15 to 20 metres depth, with conductivity increasing in two distinct steps. The uppermost layer is characterized by higher pH (7.9), lower conductivity (1070 uS/cm), and generally higher metal concentrations (eg. 11 mg/L zinc), the middle layer shows a slight decrease in pH (7.5 to 7.8), increase in conductivity (1200 uS/cm) and decrease in metal concentrations (eg. 8.4 to 10 mg/L zinc), while the lower layer has the lowest pH (6.9 to 7.3), highest conductivity (1350 uS/cm) and lowest metal concentrations (eg. 1.4 to 3 mg/L zinc).

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[1] Values represent the average of the 2003 and 2004 data.

Suboxic conditions were also observed at depth, and corresponded to a substantial increase in redox sensitive metals such as iron and manganese. As discussed previously, tailings were deposited in the Faro pit. Sulphide minerals in the tailings may help to facilitate sulphate reduction, which could be acting as a sink for metals in this system.

## 3.2 Grum Pit Lake

### 3.2.1 Routine Monitoring Data

Routine monitoring of Grum Pit Lake water quality is currently completed to fulfil the requirements of the site water license. Samples are collected from the surface of the pit lake at station V23, which is located at the bottom of the ramp. Sulphate and zinc concentrations from 1997 to present are shown in Figure 3.3. Complete monitoring results are provided in Appendix C.2.

The pit lake currently has a slightly alkaline pH (approximately 7.8), elevated alkalinity levels and sulphate concentrations of approximately 420 mg/L. Calcium and magnesium are the dominant cations. Concentrations of cadmium (0.012 mg/L)[2], cobalt (0.041 mg/L), copper (0.021 mg/L), and zinc (7.0 mg/L) are somewhat elevated. As shown in Figure 3.3, sulphate concentrations increased over the first two years of filling, and there are no clear trends in zinc concentrations. In general, concentrations of most metals were highly variable, and had the highest concentrations in 2000/2001. For example, zinc concentrations in 2000/2001 ranged from less than detection to 14 mg/L, while more recent concentrations were in the range of 4 to 8 mg/L. It should be noted that the last sample, collected in July 2004 is influenced by the pit lake study.

### 3.2.2 2003/2004 Depth Profiles

Depth profiling was completed in August 2003 by Gartner Lee Limited (GLL 2003) and from July through September 2004 by Lebarge and Lorax (Lorax 2004). Results from both programs indicated the pit lake was thermally stratified during the summer season, with a warm surface layer extending to depths of 2 to 5 metres; the complete set of data is included in Appendix D.2 and summarised in Figure 3.4. The warmer surface layer had consistently lower conductivity, sulphate and metal concentrations compared to samples collected at depth (for example, zinc concentrations were 3 to 4 mg/L at surface and approximately 9 to 12 mg/L at depth). Possible reasons for this include dilution by melting ice, incident precipitation, clean runoff from the pit walls, and partial removal of zinc due to inherent biological activity present in the lake. The stratification is maintained during the summer months due to the strong thermal gradient; further monitoring is being completed to determine fall and winter conditions when the thermal gradient is reversed.

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[2] Values represent the average of the 2003 and 2004 data, excluding the July 2004 data which was influenced by the treatment studies in the pit.

## 3.3 Vangorda Pit Lake

### 3.3.1 Routine Monitoring Data

Routine monitoring of Vangorda Pit Lake water quality is currently completed to fulfil the requirements of the site water license. Samples are collected by site environmental staff from the surface of the pit lake at station V22, which is currently located on the barge. Sulphate and zinc concentrations at station V22 from 1998 to present are shown in Figure 3.5. Complete monitoring results are provided in Appendix C.3.

The results indicate the pit lake currently has a neutral pH, moderate alkalinity levels and sulphate concentrations of approximately 1000 mg/L. Calcium, magnesium and zinc are the dominant cations. Concentrations of cadmium (0.069 mg/L), cobalt (0.44 mg/L), copper (0.045 mg/L), iron (0.81 mg/L), manganese (22 mg/L), nickel (0.38 mg/L) and zinc (66 mg/L) are elevated. As shown in Figure 3.5, sulphate and zinc concentrations increased significantly between 2001 and 2003. This was coupled with a slight decrease in pH (from 7.5 prior to 2001 to less than 7 in the more recent data), and increases in cobalt, manganese and nickel concentrations.

### 3.3.2 2003/2004 Depth Profiles

Depth profiling was completed in September 2003 by SRK (SRK 2004a) and in July 2004 by Lebarge and Lorax (Lorax 2004). A partial profile was also completed in June 2000 by SRK (SRK 2000). Results are provided in Figure 3.6, and Appendix D.3. The results indicated that there was a strong thermocline at a depth of 2 to 3 metres. Results from all three sampling periods indicated that conductivity, sulphate and metal concentrations increased with depth. The differences were more strongly pronounced in the June 2000 and September 2004 results, indicating there is more variability in concentrations in this system. For example, zinc concentrations were 6.3 mg/L in the surface layer and 70 mg/L at depth in June 2000, 92 mg/L at surface and 110 mg/L at depth in August 2003, and 56 mg/L at surface and 131 mg/L at depth in September 2004. The latter results may have been influenced by a short but severe period of fresh water inflow from Vangorda Creek during the large storm event of June 8, 2004.

# 4 Water Quality Estimates

## 4.1 Overview

Water quality estimates for each of the pits were estimated using simple mass balance calculations which considered geometry, water balance, limnology, and specific sources of contaminant loading to each pit lake.

Input assumptions and resulting water quality estimates for each of the pits are presented and discussed in the following sections.

## 4.2 Faro Pit

### 4.2.1 Modelled Scenarios

Three scenarios were considered in the water quality estimates for Faro Pit Lake. In the base case, it was assumed that the Faro Creek diversion would be breached and allowed to spill into the pit. Two additional scenarios were also evaluated to show the effects of: 1) maintaining the diversion, and 2) removing the Faro Valley Dump.

All three scenarios took the ‘Current Average’ waste rock drainage quality (SRK 2004d) as the estimate for waste rock loading to the pit. To examine the sensitivity of each scenario to waste rock loadings, each scenario was also evaluated with the ‘Future Worst Case’ dump drainage prediction (SRK 2004d) providing the waste rock loading estimate.

Any closure alternative which includes in-pit treatment will also include some form of remediation of waste dumps that contribute load to the pit. In the waste rock seepage prediction (SRK 2004d), it was assumed that 45% of incident precipitation leaves uncovered waste rock dumps as either runoff or seepage. For the estimates herein, it was assumed that simple soil covers would be in place on all contributing dumps, and that infiltration (and seepage) would be limited to 25% of incident precipitation.

Assumptions common to all scenarios were that the ore stockpiles would be removed from the pit catchment and that the Zone II pit discharges would be directed to the water treatment plant. In addition, a plug dam would be constructed across the southeast pit ramp, to increase the flood elevation and thus the residence time in the pit. This would result in an ultimate pit lake elevation of 1173.5 masl. The water and load balances assumed that pit filling began on January 1, 2004.

### 4.2.2 Geometry, Flow Conditions and Stratification

The volume-capacity curve for the Faro pit was re-assessed using the topography generated from the 2003 aerial photography. To include the volume of water below the current pit lake level, the new curve was 'meshed' with the new pit bathymetry acquired in 2004. The complete volume-capacity curve is provided in Figure 4.1.

The overall water balance for Faro Pit Lake is summarised in Tables 4.1 and 4.2. Estimates of discharge would apply only after the lake reached the spill elevation. Table 4.1 shows conditions for the scenario where Faro Creek is routed through the pit lake, making the total catchment about 17.1 km$^2$. The mean annual runoff is estimated to be 341 mm and mean annual precipitation 400 mm. The evaporative losses are estimated for a fixed pit lake surface area of about 0.78 km$^2$ using lake evaporation rates provided in the ICAP (RGI, 1996). The pit lake area adopted in the calculations represents the pit lake at fully flooded conditions. It should however be noted that during the flooding period the pit lake will be smaller and the actual evaporative losses will be lower. The net implication is that the time to flooding will be marginally overestimated and, as a result of the longer time to flooding, the contaminant concentrations at the time of spilling will also be slightly overestimated. Table 4.2 shows the Faro Pit annual water balance for the scenario where Faro Creek is diverted around the pit using the proposed East Interceptor and East Interceptor Extension (Golder, 2004). The catchment reporting to the pit in this case would have an area of 1.7 km$^2$.

The pit lake stability assessment (Lawrence, 2004) indicated that if Faro Creek is allowed to flow into the pit lake, the kinetic energy introduced will likely result in a completely mixed system having uniform contaminant concentrations.

### Table 4.1 Summary of Pit Lake Water balance with Faro Creek Flow-through

| | | INFLOWS | | OUTFLOWS | | | | |
|---|---|---|---|---|---|---|---|---|
| **Month** | **Days in month** | **Runoff** (1000 m$^3$) | **Direct Precipitation on Lake Surface** (1000 m$^3$) | **Groundwater Recharge** (1000 m$^3$) | **Lake Evap** (mm) | **Lake Evaporation** (1000 m$^3$) | **Discharge at Pit Outlet** (1000 m$^3$) | (m$^3$/s) |
| Jan | 31 | 123 | 7 | 1 | 0 | 0 | 128 | 0.05 |
| Feb | 28.25 | 91 | 5 | 1 | 0 | 0 | 95 | 0.04 |
| Mar | 31 | 88 | 5 | 1 | 8 | 6 | 78 | 0.03 |
| Apr | 30 | 116 | 6 | 1 | 53 | 41 | 27 | 0.01 |
| May | 31 | 1085 | 58 | 1 | 90 | 70 | 982 | 0.37 |
| Jun | 30 | 1873 | 100 | 1 | 112 | 87 | 1772 | 0.68 |
| Jul | 31 | 858 | 46 | 1 | 108 | 84 | 710 | 0.27 |
| Aug | 31 | 427 | 23 | 1 | 81 | 63 | 304 | 0.11 |
| Sep | 30 | 414 | 22 | 1 | 31 | 24 | 380 | 0.15 |
| Oct | 31 | 392 | 21 | 1 | 10 | 8 | 393 | 0.15 |
| Nov | 30 | 207 | 11 | 1 | 0 | 0 | 217 | 0.08 |
| Dec | 31 | 164 | 9 | 1 | 0 | 0 | 171 | 0.06 |
| Annual | 365.25 | 5838 | 312 | 16 | 493 | 385 | 5257 | 0.17 |

### Table 4.2 Summary of Faro Pit water balance with Faro Creek diverted

| Month | Days in month | INFLOWS | | OUTFLOWS | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Runoff | Direct Precipitation on Lake Surface | Groundwater Recharge | Lake Evap | Lake Evaporation | Discharge at Pit Outlet | |
| | | (1000 $m^3$) | (1000 $m^3$) | (1000 $m^3$) | (mm) | (1000 $m^3$) | (1000 $m^3$) | ($m^3$/s) |
| Jan | 31 | 12 | 7 | 1 | 0 | 0 | 18 | 0.01 |
| Feb | 28.25 | 9 | 5 | 1 | 0 | 0 | 13 | 0.01 |
| Mar | 31 | 9 | 5 | 1 | 8 | 6 | 6 | 0.00 |
| Apr | 30 | 12 | 6 | 1 | 53 | 41 | -25 | -0.01 |
| May | 31 | 109 | 58 | 1 | 90 | 70 | 96 | 0.04 |
| Jun | 30 | 188 | 100 | 1 | 112 | 87 | 200 | 0.08 |
| Jul | 31 | 86 | 46 | 1 | 108 | 84 | 46 | 0.02 |
| Aug | 31 | 43 | 23 | 1 | 81 | 63 | 1 | 0.00 |
| Sep | 30 | 42 | 22 | 1 | 31 | 24 | 38 | 0.01 |
| Oct | 31 | 39 | 21 | 1 | 10 | 8 | 51 | 0.02 |
| Nov | 30 | 21 | 11 | 1 | 0 | 0 | 31 | 0.01 |
| Dec | 31 | 16 | 9 | 1 | 0 | 0 | 24 | 0.01 |
| Annual | 365.25 | 587 | 312 | 16 | 493 | 385 | 498 | 0.02 |

## 4.2.3 Contaminant Inventory and Sources

Pit water quality will be determined by the inventory of contaminants currently present in the pit lake and by the future influx of contaminants. Potential contaminant sources to Faro Pit Lake include seepage and runoff from the wall rock, talus, and in-pit dumps, dissolution of secondary minerals from sheltered areas of the pit walls during flooding, and releases from material at the bottom of the lake, such as tailings and tailings porewater, and any secondary minerals that have precipitated.

### Current Pit Inventory

The contaminant mass currently resident in Faro Pit Lake determines the current pit water quality and provides the starting point for calculating future pit water quality. Resident contaminant mass was calculated from results of depth profiling conducted in June 2004, as discussed in Section 3.1.2. Table 4.3 summarizes the mass of contaminants currently resident in the pit lake.

## Table 4.3 Current contaminant inventory in Faro Pit

| Parameter | Current mass in pit lake (kg) |
|---|---|
| Cl | 37000 |
| SO4 | 18000000 |
| Ca | 4600000 |
| Mg | 1700000 |
| K | 370000 |
| Na | 850000 |
| Al | 1400 |
| Cd | 110 |
| Co | 970 |
| Cu | 240 |
| Fe | 350000 |
| Pb | 27 |
| Mn | 99000 |
| Ni | 2100 |
| Zn | 150000 |

### Wall Rock

Maps and descriptions of the pit wall rock are provided in Section 2.2.1. The relative areas of each rock for current and future flooding levels are presented in Figure 4.2. As indicated in Figure 2.1, the dominant rock type is biotite schist (Unit 1D), with somewhat smaller exposures of calc-silicate (Unit 3D0), hornblende diorite and quartz diorite (Unit 10E), and altered quartz muscovite schist (Unit 1D4). Minor exposures of quartz feldspar porphyry (Unit 10F), graphitic pyritic quartzite (Unit 2A), and massive sulphides (Unit 2E) are also present.

The geochemical characteristics of each of the above rock types are described in *"Geochemical Studies of Waste Rock at the Anvil Range Mining Complex"* (SRK 2004b). This report included an overall classification of the long-term geochemical behaviour based on acid base accounting tests and kinetic tests. In brief:

- Unaltered biotite schist (Unit 1D) unit has been classified as non-acid generating unless it is mixed with sulphides from other rock types
- Calc-silicates (Unit 3DO) are classified as acid consuming
- Intrusives (Unit 10E and 10F), are theoretically acid generating, but are expected to take several decades before acid generation occurs
- Altered quartz muscovite schists (Unit 1D4) and sulphides (Unit 2) are acid generating, and likely already producing acidic seepage.

Given the advanced state of weathering observed in the Faro pit, and the limited amount of material which is expected to change in the longer term, loading from the wall rock is not expected to change significantly over time.

As discussed in Section 2.2.4, the results of the limited wall rock and talus testing indicated that these samples contained relatively little soluble oxidation products. However, a single sample from Unit 1D4 (altered quartz muscovite schist) generated acidic rinse water and contained a high soluble zinc load. Once the pit reaches its ultimate lake elevation (Figure 4.2), this unit will occupy approximately 80,000 m$^2$ of the high northwest wall of the Faro Pit, and will therefore remain a major source of loading to the pit lake in the long term.

Seepage data from the 2004 pit seep surveys (Section 2.2.3) provides the most representative means of estimating source concentrations associated with each of the above rock types. Wall rock runoff quality was assumed to be the average of that in seep/runoff samples collected from within each rock unit. Where seeps were not available for a given rock unit, a water type was selected from the available database of waste rock seepage types. In some cases, results of the leach extraction tests (Section 2.2.4) were helpful in selecting these seepage types. Table 4.4 summarizes the water types used to characterize runoff each of the above rock units. A complete set of parameters for each water type is attached in Appendix E.1.

The total contaminant load from the wall rocks was estimated by multiplying the relative areas of each of the rock types (m$^2$) by the source concentrations in Table 4.4 (mg/L). This was then multiplied by the site runoff (L/(m$^2$.year)) to yield mg/year, and corrected to kg per year. The estimates of total wall rock load are provided in Table 4.5.

Secondary mineral salts such as zinc and iron sulphates observed on the pit walls could also be a source of contaminant loading to the pit lake during the flooding period. Scoping level calculations indicate that this source is insignificant in relation to other sources of load.

### Table 4.4 Water types for used to estimate wall rock loadings to Faro Pit Lake

| Water type | Unit | Lithology | pH (s.u.) | Alk (mg/L) | SO4 (mg/L) | Cu (mg/L) | Zn (mg/L) | Exposed rock above final spill elev. (m$^2$) |
|---|---|---|---|---|---|---|---|---|
| FT1 | 1D | Biotite schist | 7.3 | 185 | 720 | 0.010 | 2.5 | 257,000 |
| FT4 | 1D4 | Altered quartz muscovite schist | 3.9 | 16 | 1600 | 2.1 | 109 | 76,000 |
| FT5 | 2E | Barren massive sulphides | 3.4 | 6 | 17000 | 92 | 4260 | 8,000 |
| FT11 | 2A | Ribbon-banded graphitic pyritic quartzite | 4.3 | 10 | 390 | 0.37 | 35 | 18,000 |
| FT12 | 3DO | Calc-silicate | 7.5 | 139 | 430 | 0.010 | 0.051 | 81,000 |
| FT13 | 10E | Hornblende diorite and quartz diorite | 7.5 | 242 | 140 | 0.010 | 0.28 | 102,000 |
| FT13 | 10F | Quartz feldspar porphyry | 7.5 | 242 | 140 | 0.010 | 0.28 | 32,000 |

### Table 4.5 Summary of wall rock contaminant loadings to Faro Pit

| | Initial Loading | After spill elevation reached |
|---|---|---|
| Parameter | Loading (kg/year) | Loading (kg/year) |
| Cl | 970 | 610 |
| SO4 | 259,000 | 173,000 |
| Ca | 32,000 | 23,000 |
| Mg | 25,000 | 18,000 |
| K | 1,500 | 1,100 |
| Na | 14,000 | 7,800 |
| Al | 1,500 | 1,000 |
| Cd | 39 | 24 |
| Co | 36 | 24 |
| Cu | 510 | 310 |
| Fe | 16,000 | 9,600 |
| Pb | 32 | 23 |
| Mn | 2,200 | 1,300 |
| Ni | 49 | 34 |
| Zn | 24,000 | 15,000 |

### Waste Rock

Several waste dumps are within or partially within the Faro Pit Catchment. They will be an ongoing source of loading to Faro Pit Lake. Loadings from low grade ore stockpiles within the dump catchment were not considered, as these stockpiles will likely be removed or covered by a very low infiltration cover in the near future.

A list of waste dumps partially or fully inside the Faro Pit catchment is shown in Table 4.6, along with an estimate of the proportion of seepage from each dump that will report to the pit. Table 4.6 also includes the water quality estimates presented in the waste dump water quality estimates report (SRK 2004d). The estimated contaminant concentrations were multiplied by the net annual infiltration to each waste rock dump to obtain the total annual loading for that dump. Each waste rock dump load was then multiplied by the proportion of seepage reporting to the pit catchment to estimate the corresponding contaminant loads to the pit lake.

The resulting annual load estimates to Faro Pit from waste rock are summarised in Table 4.7. Loadings to Faro Pit are shown for both the base case, with Faro Valley Dump in place, and for the case where the Faro Valley Dump is removed. Zinc loadings and copper loadings are estimated to be reduced by over 1500 kg/year, and 29 kg/year, respectively, through dump relocation.

## Table 4.6 Faro Pit catchment: Waste Rock Dumps and Applied Seepage Quality

| Waste Rock Dump | Proportion in Pit Lake Catchment | Acidity | Alk | Cl | SO4 | Ca | Mg | K | Na | Al | Cd | Co | Cu | Fe | Pb | Mn | Ni | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Faro Valley North | 100% | 11215 | 182 | 35.6 | 18697 | 2006 | 1870 | 74 | 87 | 171 | 1.8 | 3.5 | 24 | 884 | 4.2 | 116 | 6.5 | 1268 |
| Faro Valley South | 100% | 2691 | 44 | 8.6 | 4487 | 481 | 449 | 18 | 21 | 41 | 0.4 | 0.8 | 5.7 | 212 | 1.0 | 28 | 1.6 | 304 |
| Southwest Pit Wall Dump | 70% | 6463 | 105 | 20.5 | 10774 | 1156 | 1077 | 43 | 50 | 99 | 1.1 | 2.0 | 14 | 509 | 2.4 | 67 | 3.7 | 731 |
| Ranch Dump | 20% | 117 | 581 | 5.9 | 4371 | 796 | 624 | 26 | 81 | 0.8 | 0.1 | 0.1 | 0.1 | 3.5 | 0.2 | 9.1 | 0.4 | 51 |
| Ramp Zone Dump | 20% | 80 | 572 | 3.9 | 10532 | 1082 | 1452 | 92 | 622 | 1.0 | 0.1 | 0.1 | 0.1 | 1.6 | 0.3 | 0.7 | 0.4 | 31 |
| Outer Northeast Dump | 100% | 35 | 176 | 1.8 | 1321 | 241 | 188 | 8 | 24 | 0.3 | 0.0 | 0.0 | 0.0 | 1.0 | 0.1 | 2.8 | 0.1 | 15 |
| Lower Northeast Dump | 30% | 289 | 4749 | 43.9 | 10758 | 3083 | 2212 | 90 | 160 | 4.7 | 0.2 | 0.2 | 0.2 | 0.7 | 1.2 | 1.0 | 1.2 | 50 |
| Upper Northeast Dump | 40% | 269 | 4426 | 40.9 | 10025 | 2873 | 2061 | 84 | 149 | 4.3 | 0.2 | 0.2 | 0.2 | 0.7 | 1.1 | 0.9 | 1.1 | 47 |

All units are loadings in kg / year

## Table 4.7 Summary of Estimated Annual Contaminant Loadings to Faro Pit from Waste Rock

| Parameter | Faro Valley Dump in place | Faro Valley Dump removed |
|---|---|---|
| | Loading (kg/year) | Loading (kg/year) |
| Cl | 92 | 48 |
| SO4 | 42000 | 19000 |
| Ca | 6000 | 3500 |
| Mg | 5200 | 2800 |
| K | 210 | 120 |
| Na | 420 | 310 |
| Al | 290 | 73 |
| Cd | 3.2 | 0.95 |
| Co | 5.9 | 1.6 |
| Cu | 39 | 9.8 |
| Fe | 1500 | 340 |
| Pb | 7.9 | 2.6 |
| Mn | 200 | 52 |
| Ni | 12 | 3.7 |
| Zn | 2100 | 580 |

### 4.2.4 Water Quality Estimates

A calculation spreadsheet was used to estimate changes in concentrations that could occur once the plug dam is constructed, the pit is allowed to fill to its final level of 1173.5 masl, and the resident load is flushed from the system. No in-pit removal of contaminants through sorption, particulate settling, biological removal, or sulphate reduction was considered. The calculations also assume that no contaminants will enter the pit water from in-pit tailings or from wall rock below the present lake surface, and that no further contaminant removal will occur through water treatment. Steady-state concentrations are assumed to be reached once the amount of load entering the pit is equal to the amount of load leaving the pit.

In the base case estimates, it was assumed that the Faro creek diversion would be breached and allowed to spill into the pit. In this case, the water level is expected to reach the 1173.5 masl spill elevation in August 2007 (Figure 4.3). Results of the pit lake water quality calculations are presented in Figure 4.4.

The most notable feature of the estimates is the decrease in acidity and zinc concentrations due to the influx of clean water. The modelling suggests that, at the time when the pit would first spill, the acidity would be about 34 mg $CaCO_3$ eq/L, the zinc about 5 mg/L, and the copper about 0.04 mg/L. Zinc would then continue to decrease to a long-term steady-state concentration of about 3 mg/L, and acidity would decrease to about 12 mg/L. However, copper would continue to increase to a long-term average of about 0.06 mg/L. Copper estimates are likely very conservative, as detection limit values were substituted for samples where concentrations were less than detection. This apparent accumulation of copper may be a function of the analytical limitations, and may not be representative of actual copper loadings to the pit.

Two additional scenarios were evaluated to show 1) the effects of continuing to divert Faro Creek flows and 2) the effects of removing the Faro Valley Dump. In the case of diversion, pit filling would occur much slower, with the first predicted discharge occurring in 2047 (Figure 4.5). At this time, modelling suggests that the pit lake water would have an acidity of 101 mg $CaCO_3$ eq/L, a zinc concentration of 22 mg/L, and a copper concentration of 0.39 mg/L. The model predicts that acidity and metal concentrations will continue to increase for at least 200 years under these conditions, and that after 200 years, the pit lake would have an acidity of 127 mg $CaCO_3$ eq/L, a zinc concentration of 32 mg/L, and a copper concentration of 0.64 mg/L (Figure 4.6).

Removing the Faro Valley Dump and allowing Faro Creek to flow into the pit results in little change from the base case predictions. When the pit first discharges (August 2007- Figure 4.3), the pit lake water is predicted to have an acidity concentration of 33 mg $CaCO_3$ eq/L, a zinc concentration of 4.6 mg/L, and a copper concentration of 0.04 mg/L. In the long term, the pit lake water is predicted to have acidity of 11 mg $CaCO_3$ eq/L, zinc concentrations of 2.7 mg/L, and a copper concentration of 0.06 mg/L (Figure 4.7).

A summary of results for the three scenarios modelled is presented in Table 4.8.

**Table 4.8 Estimated Faro Pit water quality with 'Current Average' waste rock inputs**

| Parameter | Base Case | | Faro Creek Diverted | | Faro Valley Dump Removed | |
|---|---|---|---|---|---|---|
| | At spill (Aug. 2007) | Long term (~ yr. 2040) | At spill (yr. 2047) | Long term (yr. 2204) | At spill (Aug. 2007) | Long term (~ yr. 2040) |
| Acidity (mg CaCO3eq /L) | 34 | 12 | 101 | 127 | 33 | 11 |
| Zinc (mg/L) | 4.7 | 3.0 | 22 | 32 | 4.6 | 2.7 |
| Copper (mg/L) | 0.04 | 0.06 | 0.39 | 0.64 | 0.04 | 0.06 |

### Sensitivity to increased waste rock load

It is conceivable that waste dump seepage quality within the Faro Pit catchment could degrade in the future such that waste rock loads to the pit would increase over the loads assumed in the 'Current Average' predictions. As a check on the sensitivity of the water quality predictions to waste rock load inputs, the 'Future Worst' seepage quality estimated in the dump water quality prediction (SRK 2004d) was used as an input. Table 4.9 summarizes the key results of this sensitivity analysis for the three scenarios modelled. Long term concentrations of acidity, zinc, and copper are higher by a factor of 15 to 20 for the Base Case scenario under conditions of 'Future Worst' waste rock loading. The other two scenarios have similar increases in acidity, zinc, and copper concentrations. Clearly, Faro Pit Lake water quality predictions are sensitive to increased loadings from waste rock currently located within the pit catchment.

**Table 4.9 Estimated Faro Pit water quality with 'Future Worst' waste rock inputs**

| Parameter | Base Case | | Faro Creek Diverted | | Faro Valley Dump Removed | |
|---|---|---|---|---|---|---|
| | At spill (Aug. 2007) | Long term (~ yr. 2040) | At spill (yr. 2047) | Long term (yr. 2204) | At spill (Aug. 2007) | Long term (~ yr. 2040) |
| Acidity (mg CaCO3eq /L) | 126 | 218 | 1153 | 2256 | 63 | 76 |
| Zinc (mg/L) | 24 | 46 | 243 | 478 | 11 | 17 |
| Copper (mg/L) | 0.54 | 1.2 | 6.1 | 12 | 0.19 | 0.40 |

## 4.3 Grum Pit

### 4.3.1 Modelled Scenario

Since there is no substantial diversion of water away from Grum Pit, and since there is no waste rock within the pit catchment, a single scenario was considered in the water quality estimate for Grum Pit Lake. The water and load balance assumed that pit filling began on January 1, 2004.

### 4.3.2 Geometry, Flow Conditions and Stratification

The volume-capacity curve for the Grum pit was re-assessed using the topography generated from the 2003 aerial photography. To include the volume of water below the current pit lake level, the new curve was ‘meshed’ with that presented in the ICAP (RGI 1996). The complete volume capacity curve is provided in Figure 4.8.

The overall water balance for Grum Pit Lake is summarised in Table 4.10. The table shows conditions whereby the Grum interceptor ditch is breached and surface runoff within the pit lake catchment is routed through the pit lake, making the total catchment about 1.22 $km^2$. The mean annual runoff is estimated to be 270 mm and mean annual precipitation 450 mm. The evaporation rate is based on a fixed pit lake surface area of about 0.28 $km^2$. As noted for Faro Pit Lake calculations, the calculations represent the pit lake at fully flooded conditions. The net implication is that the time to flooding will be marginally overestimated and, as a result of the longer time to flooding, the contaminant concentrations at the time of spilling will also be slightly overestimated.

**Table 4.10 Summary of Grum Pit water balance with Grum interceptor breached**

| | | INFLOWS | | OUTFLOWS | | | | |
|---|---|---|---|---|---|---|---|---|
| Month | Days in month | Runoff | Direct Precipitation on Lake Surface | Groundwater Recharge | Lake Evaporation | Lake Evaporation | Discharge at Pit Outlet | |
| | | (1000 $m^3$) | (1000 $m^3$) | (1000 $m^3$) | (mm) | (1000 $m^3$) | (1000 $m^3$) | ($m^3$/s) |
| Jan | 31 | 5 | 2 | 0 | 0 | 0 | 8 | 0.003 |
| Feb | 28.25 | 4 | 2 | 0 | 0 | 0 | 6 | 0.002 |
| Mar | 31 | 4 | 2 | 0 | 6 | 2 | 2 | 0.001 |
| Apr | 30 | 8 | 3 | 0 | 38 | 11 | -10 | -0.004 |
| May | 31 | 68 | 26 | 0 | 64 | 18 | 58 | 0.021 |
| Jun | 30 | 70 | 27 | 0 | 80 | 22 | 51 | 0.020 |
| Jul | 31 | 49 | 19 | 0 | 77 | 22 | 24 | 0.009 |
| Aug | 31 | 34 | 13 | 0 | 58 | 16 | 15 | 0.005 |
| Sep | 30 | 46 | 17 | 0 | 22 | 6 | 51 | 0.020 |
| Oct | 31 | 24 | 9 | 0 | 7 | 2 | 29 | 0.011 |
| Nov | 30 | 11 | 4 | 0 | 0 | 0 | 15 | 0.006 |
| Dec | 31 | 8 | 3 | 0 | 0 | 0 | 11 | 0.004 |
| Annual | 365.25 | 329 | 126 | 0 | 352 | 99 | 258 | 0.008 |

### 4.3.3 Contaminant Inventory and Sources

Pit water quality will be determined by the inventory of contaminants currently present in the pit lake and by the future influx of contaminants. Potential contaminant sources to Grum Pit Lake include seepage and runoff from the wall rock and talus, dissolution of secondary minerals from sheltered areas of the pit walls during flooding, and releases from any secondary minerals that have precipitated at the bottom of the lake.

### Current Pit Inventory

The contaminant mass currently resident in Grum Pit Lake determines the current pit water quality and provides the starting point for calculating future pit water quality. The resident contaminant mass was calculated from results of depth profiling conducted in June 2004, as discussed in Section 3.2.2. Table 4.11 summarizes the mass of contaminants currently resident in the pit lake.

**Table 4.11 Current contaminant inventory in Grum Pit**

| Parameter | Current mass in pit lake (kg) |
|---|---|
| Cl | 1100 |
| SO4 | 990000 |
| Ca | 270000 |
| Mg | 160000 |
| K | 7900 |
| Na | 25000 |
| Al | 99 |
| Cd | 21 |
| Co | 65 |
| Cu | 2.1 |
| Fe | 170 |
| Pb | 1.9 |
| Mn | 1100 |
| Ni | 490 |
| Zn | 20000 |

### Wall Rock

Maps and descriptions of the pit wall rock are provided in Section 2.2.1. The relative areas of each rock for current and future flooding levels are presented in Figure 4.9. As indicated in Figure 2.2, the dominant rock types are mixed calcareous and carbonaceous Vangorda Formation phyllite (Unit 5A0/5B0), non-calcareous Mt. Mye Formation phyllite (Unit 3G0), and undifferentiated massive and disseminated sulphides (Unit 4EC). In addition, a large portion of the pit wall surface consists of glacial till (Unit T).

The expected long-term geochemical behaviour of each of the above rock types (SRK 2004b) are summarized as follows:

- Carbonaceous phyllites (Unit 5A) are potentially acid generating, but are expected to react slowly, and may not develop acidic conditions for several decades. Calcareous phyllites (Unit 5B) are net acid consuming. Contaminant loads from the carbonaceous phyllites may therefore increase over time. However, calcareous phyllites are likely to neutralize any acidity and limit loading from this mixed unit.
- Non-calcareous phyllites from the Mt. Mye formation (Unit 3GO) have been classified as acid consuming unless they are mixed with sulphides.

- Sulphides (Unit 4EC) are potentially acid generating, and contaminant loading from this unit may increase slightly with time.

In general, any changes in loading due to further weathering and oxidation of the wall rocks are not expected to significantly effect water quality in the pit lake due to the relatively large amount of alkalinity contributed by the till and the calcareous phyllites.

The results of the limited wall rock and talus testing indicated that the majority of the wall rock contains very little soluble oxidation products, as discussed in Section 2.2.4. Moderate zinc concentrations in the leachate from the sulphide rich samples (Unit 4EC) indicate that that these wall rocks are currently a source of metal loading. This unit largely occurs below the expected 1230 masl flood elevation (Figure 2.2), and as such will not be a major source of loading to the pit lake in the long term.

Seepage data from the 2004 pit seep surveys (Section 2.2.3) provides the most representative means of estimating source concentrations associated with each of the above rock types. Wall rock runoff quality was assumed to be the average of that in seep/runoff samples collected from within each rock unit. Table 4.12 summarizes the water types used to characterize runoff each of the above rock units. A complete set of parameters for each water type is attached in Appendix E.2.

The total contaminant load from the wall rocks was estimated by multiplying the relative areas of each of the rock types by the source concentrations in Table 4.12. The estimates of total wall rock load are provided in Table 4.13.

Secondary mineral salts were rarely observed in the Grum Pit walls. However, solids testing described in section 2.2.4 showed that release of soluble products, primarily from sulphide wall rock (Unit 4EC), could contribute loading to the pit during flooding. Scoping level calculations suggest that dissolution of stored products will contribute a minor incremental load compared to the current contaminant inventory in the pit lake.

### Table 4.12 Water types for used to estimate wall rock loadings to Grum Pit Lake

| Water type | Unit | Lithology | pH (s.u.) | Alk (mg/L) | SO4 (mg/L) | Cu (mg/L) | Zn (mg/L) | Exposed rock above final spill elev. (m^2) |
|---|---|---|---|---|---|---|---|---|
| VG7 | 5A0/5B0, 3G0 | calcareous, carbonaceous, and non-calcareous phyllite | 8.0 | 240 | 630 | 0.0040 | 0.020 | 228,000 |
| VG8 | 4EC | Massive and disseminated sulphides | 7.6 | 220 | 830 | 0.010 | 28 | 11,000 |
| VG9 | T | Till | 8.0 | 110 | 330 | 0.010 | 0.014 | 197,000 |

### Table 4.13 Summary of wall rock contaminant loadings to Grum Pit

| | Initial Loading | After spill elevation reached |
|---|---|---|
| **Parameter** | **Loading (kg/year)** | **Loading (kg/year)** |
| Cl | 83 | 58 |
| SO4 | 65 000 | 41 000 |
| Ca | 14 000 | 8 800 |
| Mg | 12 000 | 7 800 |
| K | 350 | 230 |
| Na | 420 | 260 |
| Al | 7 | 5 |
| Cd | 0.6 | 0.3 |
| Co | 3 | 1 |
| Cu | 0.5 | 0.3 |
| Fe | 180 | 42 |
| Pb | 2 | 1 |
| Mn | 45 | 11 |
| Ni | 16 | 7 |
| Zn | 350 | 80 |

### 4.3.4 Water Quality Estimates

The calculation spreadsheet was used to estimate changes in contaminant concentrations that occur while Grum Pit Lake fills to its final level of 1230 masl, and as the resident load is flushed from the system. No in-pit removal of contaminants through sorption, particulate settling, biological removal, or sulphate reduction was considered. The calculations also assume that no contaminants will enter the pit water from wall rock below the present lake surface, and that no contaminant removal will occur through water treatment. Steady-state concentrations are assumed to be reached once the amount of load entering the pit is equal to the amount of load leaving the pit. The biological treatment assessment will evaluate whether it is possible to achieve sufficient contaminant removal rates during filling such that pit lake surface water is acceptable for discharge to the environment at the time the spill elevation is reached.

With the Grum interceptor ditch breached, Grum Pit Lake is expected to reach the 1230 masl spill elevation in year 2030 (Figure 4.10). Results of the pit lake water quality calculations are presented in Figure 4.11 and summarized in Table 4.14. The modelling suggests that, at the time when the pit would first spill, the acidity would be about 6.1 mg $CaCO_3$ eq/L, the zinc about 2.9 mg/L, and the copper about 0.0014 mg/L. In the long term, zinc and copper would continue to decrease to concentrations of about 0.33 mg/L and 0.0011 mg/L, respectively. Acidity is estimated to decrease to about 1.4 mg/L. As in the case for Faro Pit Lake, copper estimates are likely very conservative, as detection limit values were substituted into water types where sample concentrations were less than detection. This apparent accumulation of copper may be a function of analytical limitations, and may not be representative of actual copper loadings to the pit.

The most notable feature of Grum Pit Lake water quality estimate is that equilibrium conditions require the entire period modelled (200 years) to develop (Figure 4.11). The relatively rapid decline in acidity and zinc concentration over the period of filling (to year 2030) indicates that inflows have lower concentrations than the current pit water. The majority of zinc and acidity expected in the lake when it reaches the 1230 masl level are contained within the current lake inventory.

Over the period of filling, the exposed surface area of sulphide rocks (Unit 4EC) will be greatly reduced (Figure 4.9), thus limiting loading from this unit. This is illustrated in the behaviour of copper as shown in Figure 4.11. In this figure, copper concentrations in Grum Pit Lake peak prior to the estimated spill date, indicating that the decrease in copper loadings due to reduction in exposed Unit 4EC surface area is sufficient to reverse the trend of increasing copper concentration.

**Table 4.14 Estimated Grum Pit water quality**

| Parameter | Base Case | |
|---|---|---|
| | At spill (yr. 2030) | Long term (yr. 2204) |
| Acidity (mg CaCO3eq /L) | 6.1 | 1.4 |
| Zinc (mg/L) | 2.9 | 0.33 |
| Copper (mg/L) | 0.0014 | 0.0011 |

## 4.4 Vangorda Pit

### 4.4.1 Scenarios

Three scenarios were considered in the water quality estimates for Faro Pit Lake. In the base case, it was assumed that the Vangorda Creek diversion would be breached and allowed to spill into the pit. Sensitivity runs were also completed to show 1) the effects of maintaining the diversion and 2) the effects of removing the Southeast (SE) Ramp Dump and the Hairpin Dump.

As discussed in section 4.2.1, any closure alternative which includes in-pit treatment will also include some form of remediation of waste dumps that contribute load to the pit. For the purposes of this exercise, it was assumed that simple soil covers are in place on all contributing dumps, and that infiltration (and seepage) is limited to 25% of incident precipitation.

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. The water and load balances assumed that pit filling began on January 1, 2004.

### 4.4.2 Geometry, Flow Conditions and Stratification

The volume-capacity curve for the Vangorda pit estimated using the topography generated from the 2003 aerial photography. To include the volume of water below the current pit lake level, the new curve was ‘meshed’ with that presented in the ICAP (1996). The complete volume capacity curve is provided in Figure 4.12.

The overall water balance for Vangorda Pit Lake is summarised in Table 4.15. The table shows conditions whereby the Vangorda Creek diversion is breached and routed through the pit lake. The total pit lake catchment becomes about 21.7 km2. Losses to groundwater are assumed to be negligible. The mean annual runoff is estimated to be 362 mm and mean annual precipitation 380 mm. The evaporation rate is based on a fixed pit lake surface area of about 0.17 km$^2$. As noted before, the calculations adopted a lake surface area corresponding to fully flooded conditions. Because of the short time to flooding, this assumption has little effect on the calculation results.

Table 4.16 shows the Vangorda Pit water balance for the scenario where Vangorda Creek is permanently diverted. In this case, the total pit lake catchment has an approximate area of 0.67 km$^2$. This catchment assumes that a surface water interception ditch is constructed above the east edge of the pit south of Vangorda Creek, and that only the catchment below this proposed ditch (SRK 2003c) reports to the Vangorda Pit.

**Table 4.15 Summary of Vangorda Pit water balance with Vangorda Creek diversion breached**

| | | INFLOWS | | OUTFLOWS | | | | |
|---|---|---|---|---|---|---|---|---|
| Month | Days in month | Runoff | Direct Precipitation on Lake Surface | Groundwater Recharge | Lake Evaporation | Lake Evaporation | Discharge at Pit Outlet | |
| | | (1000 m$^3$) | (1000 m$^3$) | (1000 m$^3$) | (mm) | (1000 m$^3$) | (1000 m$^3$) | (m$^3$/s) |
| Jan | 31 | 123 | 1 | 0 | 0 | 0 | 124 | 0.05 |
| Feb | 28.25 | 123 | 1 | 0 | 0 | 0 | 124 | 0.05 |
| Mar | 31 | 119 | 1 | 0 | 8 | 1 | 119 | 0.04 |
| Apr | 30 | 157 | 1 | 0 | 53 | 9 | 149 | 0.06 |
| May | 31 | 1462 | 12 | 0 | 90 | 15 | 1459 | 0.54 |
| Jun | 30 | 2523 | 21 | 0 | 112 | 19 | 2524 | 0.97 |
| Jul | 31 | 1155 | 10 | 0 | 108 | 18 | 1146 | 0.43 |
| Aug | 31 | 575 | 5 | 0 | 81 | 14 | 566 | 0.21 |
| Sep | 30 | 558 | 5 | 0 | 31 | 5 | 558 | 0.22 |
| Oct | 31 | 528 | 4 | 0 | 10 | 2 | 530 | 0.20 |
| Nov | 30 | 279 | 2 | 0 | 0 | 0 | 281 | 0.11 |
| Dec | 31 | 221 | 2 | 0 | 0 | 0 | 222 | 0.08 |
| Annual | 365.25 | 7823 | 65 | 0 | 493 | 84 | 7804 | 0.25 |

### Table 4.16 Summary of Vangorda Pit water balance with Vangorda Creek diverted

| | | INFLOWS | | OUTFLOWS | | | | |
|---|---|---|---|---|---|---|---|---|
| Month | Days in month | Runoff | Direct Precipitation on Lake Surface | Groundwater Recharge | Lake Evaporation | Lake Evaporation | Discharge at Pit Outlet | |
| | | (1000 m$^3$) | (1000 m$^3$) | (1000 m$^3$) | (mm) | (1000 m$^3$) | (1000 m$^3$) | (m$^3$/s) |
| Jan | 31 | 4 | 1 | 0 | 0 | 0 | 5 | 0.00 |
| Feb | 28.25 | 4 | 1 | 0 | 0 | 0 | 5 | 0.00 |
| Mar | 31 | 4 | 1 | 0 | 8 | 1 | 3 | 0.00 |
| Apr | 30 | 5 | 1 | 0 | 53 | 9 | -3 | 0.00 |
| May | 31 | 45 | 12 | 0 | 90 | 15 | 42 | 0.02 |
| Jun | 30 | 78 | 21 | 0 | 112 | 19 | 80 | 0.03 |
| Jul | 31 | 36 | 10 | 0 | 108 | 18 | 27 | 0.01 |
| Aug | 31 | 18 | 5 | 0 | 81 | 14 | 9 | 0.00 |
| Sep | 30 | 17 | 5 | 0 | 31 | 5 | 17 | 0.01 |
| Oct | 31 | 16 | 4 | 0 | 10 | 2 | 19 | 0.01 |
| Nov | 30 | 9 | 2 | 0 | 0 | 0 | 11 | 0.00 |
| Dec | 31 | 7 | 2 | 0 | 0 | 0 | 9 | 0.00 |
| Annual | 365.25 | 243 | 65 | 0 | 493 | 84 | 223 | 0.01 |

## 4.4.3 Contaminant Inventory and Sources

Pit water quality will be determined by the inventory of contaminants currently present in the pit lake and by the future influx of contaminants. Potential contaminant sources to Vangorda Pit Lake include seepage and runoff from the wall rock, talus, and in-pit dumps, dissolution of secondary minerals from sheltered areas of the pit walls during flooding, and releases from treatment plant sludges deposited in the lake and/or any secondary minerals that have precipitated in the bottom of the pit lake.

### Current Pit Inventory

The contaminant mass currently resident in Vangorda Pit Lake determines the current pit water quality and provides the starting point for calculating future pit water quality. Resident contaminant mass was calculated from results of depth profiling conducted in June 2004, as discussed in Section 3.3.2. Table 4.17 summarizes the mass of contaminants currently resident in the pit lake.

## Table 4.17 Current contaminant inventory in Vangorda Pit

| Parameter | Current mass in pit lake (kg) |
|---|---|
| Cl | 750 |
| SO4 | 1800000 |
| Ca | 360000 |
| Mg | 140000 |
| K | 5500 |
| Na | 8300 |
| Al | 74 |
| Cd | 150 |
| Co | 1100 |
| Cu | 350 |
| Fe | 25000 |
| Pb | 13 |
| Mn | 60000 |
| Ni | 990 |
| Zn | 180000 |

### Wall Rock

Maps and descriptions of the pit wall rock are provided in Section 2.2.1. The relative areas of each rock for current and future flooding levels are presented in Figure 4.13. As indicated in Figure 2.3, the dominant rock types are massive and disseminated sulphides (Unit 4EC) and till, with moderate exposures of non-calcareous phyllite (Unit 3G0), and minor amounts of carbonaceous phyllite (Unit 5A0), and bleached phyllite (Unit 4L0).

As discussed in Section 2.2.4, wall rock and talus from the Vangorda pit was characterized in an earlier study (SRK 2000). The results indicated that several of the samples had acidic pH's or were potentially acid generating, indicating that seepage quality is likely to worsen over time, potentially to the point where neutral conditions could not be maintained in the pit. However, for the scenario where the Vangorda Creek diversion would be breached and allowed to flow through the pit, there should be sufficient alkalinity to offset any acidic seepage from the pit walls.

Seepage data from the 2004 pit seep surveys (Section 2.2.3) provides the most representative means of estimating source concentrations associated with each of the above rock types. Where insufficient data is available, data from the waste rock seep surveys was used to supplement this data. Table 4.18 summarizes the seepage data used to represent each of the above rock units. A complete set of parameters for each water type is attached in Appendix E.3.

The total contaminant load from the wall rocks was estimated by multiplying the relative areas of each of the rock types by the source concentrations in Table 4.18. The estimates of total wall rock load are provided in Table 4.19.

The results of the wall rock and talus testing also indicated that several samples contained high soluble zinc loads. These and secondary mineral salts such as zinc and iron sulphates observed on the pit walls could also be a major source of contaminant loading to the pit lake during the flooding period (SRK 2000). These sources have not been included in the wall rock load calculations.

### Table 4.18 Water types used to estimate wall rock loadings to Vangorda Pit Lake

| Water type | Unit | Lithology | pH (s.u.) | Alk (mg/L) | SO4 (mg/L) | Cu (mg/L) | Zn (mg/L) | Exposed rock above final spill elev. (m^2) |
|---|---|---|---|---|---|---|---|---|
| VG10 | 3G0, 5A0 | Carbonaceous phyllite and non-calcareous phyllite | 6.2 | 88 | 620 | 0.32 | 46 | 29,000 |
| VG11 | 4EC | Undifferentiated massive and disseminated sulphides | 5.0 | 17 | 2500 | 6.5 | 450 | 71,000 |
| VG12 | 4L0 | Bleached pyritic phyllite | 3.8 | 4 | 6100 | 6.9 | 780 | 2,000 |
| VG13 | Till | Till | 7.6 | 200 | 25 | 0.010 | 0.0050 | 48,000 |

### Table 4.19 Summary of wall rock contaminant loadings to Vangorda Pit

| | Initial Loading | After spill elevation reached |
|---|---|---|
| Parameter | Loading (kg/year) | Loading (kg/year) |
| Cl | 47 | 36 |
| SO4 | 111 000 | 77 000 |
| Ca | 10 000 | 7 500 |
| Mg | 7 500 | 5 100 |
| K | 340 | 240 |
| Na | 430 | 330 |
| Al | 580 | 420 |
| Cd | 24 | 18 |
| Co | 63 | 42 |
| Cu | 240 | 180 |
| Fe | 11 000 | 8 200 |
| Pb | 30 | 23 |
| Mn | 5 100 | 3 200 |
| Ni | 51 | 37 |
| Zn | 18 000 | 13 000 |

### Waste Rock

Waste rock has been placed within the Vangorda pit ramp area that leads down to the pit lake. Two waste rock piles are located in this area on either side of the access road. The smaller dump is located within the hairpin of the access road (hairpin dump) and the second comprises waste rock that has been placed along the road to the south of the bend and to the east of the road as it descends to the pit lake (SE ramp dump). The hairpin dump represents an area of about 15,000 m$^2$ and the SE ramp dump an area of about 20,000 $m^2$. To be consistent with the assumptions for the wall rock runoff, it was assumed that all of the runoff (i.e. surface overflow and infiltration) would be contaminated. Table 4.20 shows the waste rock seepage quality used in the model to characterize dump loadings to Vangorda Pit Lake.

Previous characterization of the waste rock in these dumps (SRK 2000) indicated that this material was consistently net acid generating, with high concentrations of soluble metals.

The water quality estimates derived in the waste dump and load balances (SRK 2003b) were used directly to estimate the corresponding contaminant loads to the pit lake. The hairpin dump is expected to remain above the water level; however, a layer of about 10 m of waste rock in the second pile would remain below the ultimate lake level. Some reduction in the loadings may result from this which was not accounted for in the calculations.

The in-pit dumps at Vangorda represent a significant source of loading to the pit (Table 4.21). However, if a flow-through pit system is implemented, these dumps would be removed or isolated from the main section of the pit to minimize contaminant loading. The prediction for the case where these dumps are removed provides the best available estimate of the long term water quality facing biological treatment.

### Sludges and Precipitates

The Vangorda pit was reportedly used for a short period to store sludges from the water treatment plant. The quantity of sludges is not known. Under reducing and/or acidic pH conditions, it is possible that these sludges could become remobilized, resulting in increased loading to the pit lake.

Equilibrium modelling of the pit water quality completed in the 2000 pit lake study (SRK 2000) indicated that water in the lower portions of the pit were close to equilibrium with the minerals smithsonite ($ZnCO_3.H_2O$) and rhodochrosite (manganese carbonate). This suggests that these minerals could be present in the bottom sediments. Decreasing zinc concentrations in the water column resulting from changes to the water balance (such as breaching the Vangorda Creek diversion), or changes in the pH could lead to short-term remobilization of these precipitates into the water column.

## Table 4.20 Vangorda Pit catchment: Waste rock dumps and applied seepage quality

| Waste Rock Dump | Proportion in Pit Lake Catchment | Acidity | Alk | Cl | SO4 | Ca | Mg | K | Na | Al | Cd | Co | Cu | Fe | Pb | Mn | Ni | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SE Ramp Dump | 100% | 4088 | 638 | 3.7 | 10950 | 607 | 1233 | 14 | 15 | 26 | 2.3 | 6.2 | 19 | 457 | 0.74 | 645 | 5.5 | 1911 |
| Hairpin Dump | 100% | 84 | 228 | 2.7 | 2819 | 477 | 383 | 13 | 26 | 0.45 | 0.050 | 0.086 | 0.074 | 3.1 | 0.11 | 8.2 | 0.27 | 43 |

All units are loadings in kg / year

## Table 4.21 Summary of Estimated Annual Contaminant Loadings to Vangorda Pit From Waste Rock

| Parameter | In-pit dumps in place | In-pit dumps removed |
|---|---|---|
| | Loading (kg/year) | Loading (kg/year) |
| Cl | 6 | 0 |
| SO4 | 14 000 | 0 |
| Ca | 1 100 | 0 |
| Mg | 1 600 | 0 |
| K | 27 | 0 |
| Na | 41 | 0 |
| Al | 27 | 0 |
| Cd | 2 | 0 |
| Co | 6 | 0 |
| Cu | 19 | 0 |
| Fe | 460 | 0 |
| Pb | 1 | 0 |
| Mn | 650 | 0 |
| Ni | 6 | 0 |
| Zn | 2000 | 0 |

### 4.4.4 Water Quality Estimates

The calculation spreadsheet was used to estimate changes in contaminant concentrations that occur while Vangorda Pit Lake fills to its final level of 1130 masl, and as the resident load is flushed from the system. No in-pit removal of contaminants through sorption, particulate settling, biological removal, or sulphate reduction was considered. The calculations also assume that:

- no contaminants will enter the pit water from treatment sludges stored within the pit;
- no contaminants will enter the pit water from the wall rock below the present lake surface;
- no contaminants will enter the pit water from the stored oxidation products present on the pit walls and within the pit talus;
- no further contaminant additions will occur via pumping of contaminated water to the pit;
- no further contaminant removal will occur through treatment of pit water.

Steady-state concentrations are assumed to be reached once the amount of load entering the pit is equal to the amount of load leaving the pit.

With the Vangorda Creek diversion breached, Vangorda Pit Lake is expected to reach the 1130 masl spill elevation within a single year (Figure 4.14). Results of the base case pit lake water quality calculations are presented in Figure 4.15 and summarized in Table 4.22. The modelling suggests that, at the time when the pit would first spill, the acidity would be about 86 mg$CaCO_3$ eq/L, the zinc about 33 mg/L, and the copper about 0.091 mg/L. In the long term, zinc and copper would continue to decrease to concentrations of about 1.5 mg/L and 0.020 mg/L, respectively. Acidity is estimated to decrease to about 5.8 mg/L. Copper concentrations in Vangorda Pit seeps were at measurable levels, and copper estimates are likely more reflective of field conditions than at the estimates for both Faro and Grum.

Two additional scenarios were evaluated to show 1) the effects of continuing to divert Vangorda Creek flows and 2) the effects of removing the in-pit dumps. In the case of diversion, pit filling would occur much slower, with the first predicted discharge occurring in 2023 (Figure 4.16). At this time, modelling suggests that the pit lake water would have an acidity of 349 mg $CaCO_3$ eq/L, a zinc concentration of 102 mg/L, and a copper concentration of 0.97 mg/L. The model predicts that acidity and metal concentrations will continue to increase for at least 200 years under these conditions, and that after 200 years, the pit lake would have an acidity of 251 mg $CaCO_3$ eq/L, a zinc concentration of 67 mg/L, and a copper concentration of 0.87 mg/L (Figure 4.17).

Removing the Vangorda in-pit dumps and allowing Vangorda Creek to flow into the pit results in little change from base case predictions. When the pit first discharges (July 2004- Figure 4.14), pit lake water is predicted to have an acidity level of 85 mg $CaCO_3$ eq/L, a zinc concentration of 33 mg/L, and a copper concentration of 0.89 mg/L. In the long term, pit lake water is predicted to have acidity of 5.1 mg $CaCO_3$ eq/L, zinc concentrations of 1.3 mg/L, and a copper concentration of 0.018 mg/L (Figure 4.18).

A summary of results for the three scenarios modelled is presented in Table 4.22. A sensitivity analysis for conditions of increased waste rock loading to the Vangorda Pit was not warranted due to the high concentrations of contaminants in pit lake water under 'Current Average' loading conditions.

### Table 4.22 Estimated Vangorda Pit water quality

| Parameter | Base Case | | Vangorda Creek diverted | | In-Pit Dumps removed | |
|---|---|---|---|---|---|---|
| | **At spill (Jul. 2004)** | **Long term (~ yr. 2014)** | **At spill (yr. 2023)** | **Long term (~ yr. 2104)** | **At spill (Jul. 2004)** | **Long term (~ yr. 2014)** |
| Acidity (mg $CaCO_3$eq /L) | 86 | 5.8 | 350 | 250 | 85 | 5.1 |
| Zinc (mg/L) | 33 | 1.5 | 100 | 67 | 33 | 1.3 |
| Copper (mg/L) | 0.091 | 0.020 | 0.97 | 0.87 | 0.89 | 0.018 |

# 5 Conclusions

This project has developed revised estimates of contaminant concentrations in the Faro, Grum, and Vangorda Pit lakes. These estimates are based on the following assumptions.

- January 1, 2004 is the beginning of the modelled water balance.
- All diversions will be breached.
- Summer 2004 contaminant concentrations in each lake provide the starting point for estimates of future concentrations.
- Pit walls and waste rock provide the only significant sources of contaminant loading to each pit lake.
- In-pit removal of contaminants through biological and geochemical processes will be insignificant.
- Influx and outflow of contaminants due to site water management and water treatment will not occur going forward.

Under conditions where Faro Creek is routed through the pit, Faro Pit Lake is estimated to have a zinc concentration of approximately 5 mg/L at the time of first discharge in 2007. Long term water quality in Faro Pit Lake is estimated to be characterized by zinc concentrations of 3 mg/L.

Discharge from Grum Pit Lake is estimated to have zinc a concentration of about 3 mg/L when it first overflows. Zinc concentration is projected to decline slowly over the long term, reaching a concentration of 0.33 mg/L after 200 years.

Under conditions where Vangorda Creek is routed through the pit, Vangorda Pit Lake is estimated to have a zinc concentration of 33 mg/L at the time of first discharge, and to have a long term zinc concentration of 1.5 mg/L.

Additional calculations were completed to examine two remediation options, which consist of permanent diversion of creeks and relocation of contributing waste rock. These estimates indicate that permanent diversion of Vangorda and Faro Creeks will result in higher zinc concentrations and longer periods before the respective pits discharge to surface water. Removal of waste rock from the Vangorda and Faro Pit catchments was estimated to have little impact on pit lake zinc concentrations in both the short and the long term.

This report, "**1CD003.046 - Updated Estimates of Post-closure Water Quality in Faro, Grum, and Vangorda Pit Lakes",** was prepared by SRK Consulting (Canada) Inc.

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**Reviewed by**

Daryl Hockley, P.Eng

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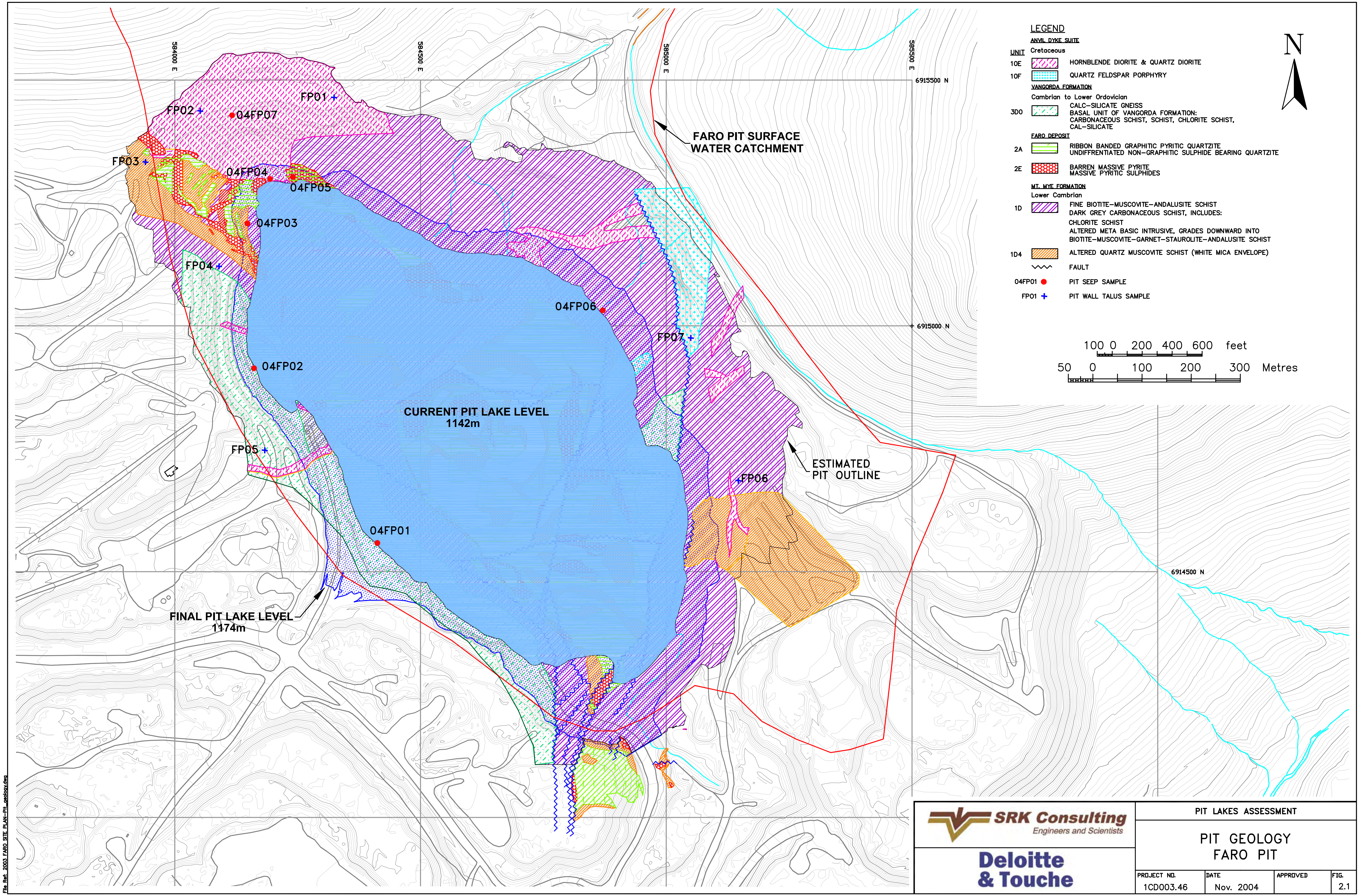
# Figures



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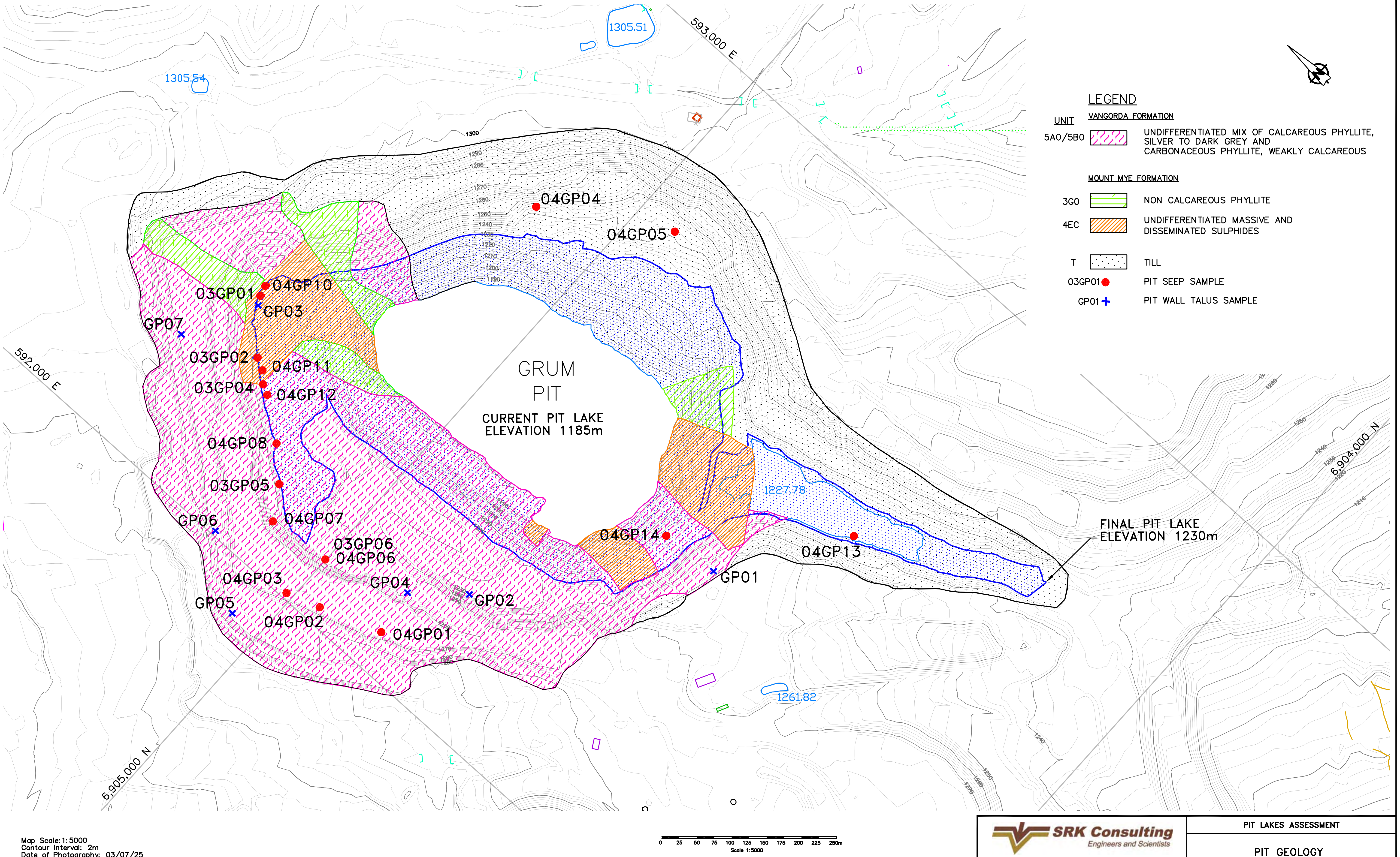
PIT LAKES ASSESSMENT

PIT GEOLOGY
FARO PIT

| PROJECT NO. | DATE | APPROVED | FIG. |
|---|---|---|---|
| 1CD003.46 | Nov. 2004 | | 2.1 |

File Ref: 2003 FARO SITE PLAN-Pit_geology.dwg



LEGEND

| UNIT | | |
|---|---|---|
| | | VANGORDA FORMATION |
| 5A0/5B0 | ▨ | UNDIFFERENTIATED MIX OF CALCAREOUS PHYLLITE, SILVER TO DARK GREY AND CARBONACEOUS PHYLLITE, WEAKLY CALCAREOUS |
| | | MOUNT MYE FORMATION |
| 3G0 | ▨ | NON CALCAREOUS PHYLLITE |
| 4EC | ▨ | UNDIFFERENTIATED MASSIVE AND DISSEMINATED SULPHIDES |
| T | ▨ | TILL |
| 03GP01 | ● | PIT SEEP SAMPLE |
| GP01 | + | PIT WALL TALUS SAMPLE |

Map Scale: 1:5000
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

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PIT LAKES ASSESSMENT

PIT GEOLOGY
GRUM PIT

| PROJECT NO. | DATE | APPROVED | FIG. |
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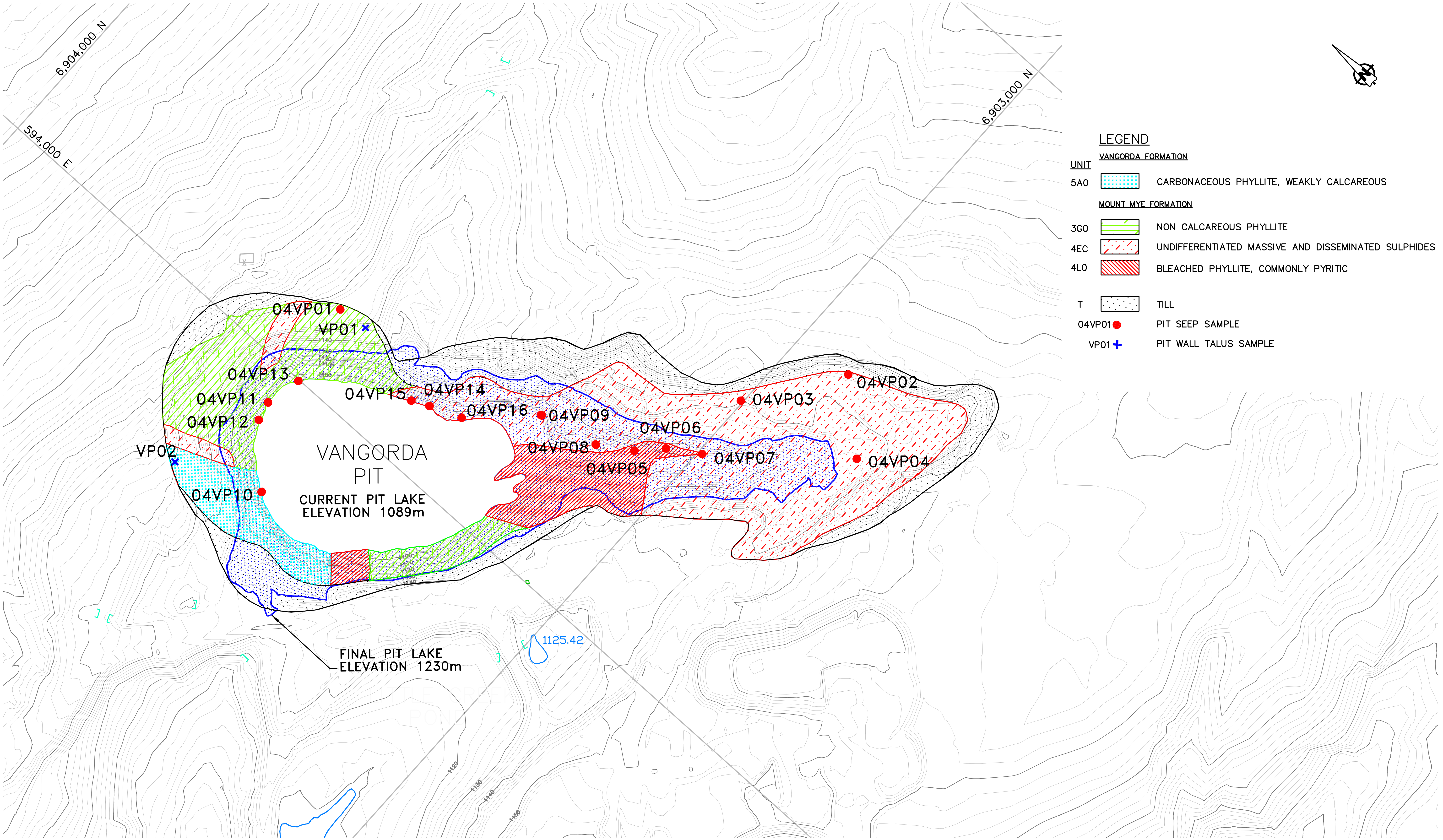

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Contour Interval: 2m
Date of Photography: 03/07/25
Scale of Photography: 1:20000
Survey control derived from existing 1:20000 photography
Survey control based on: UTM Projection, NAD27
Compiled by The ORTHOSHOP, Calgary, September 2003
WO 8856

0 25 50 75 100 125 150 175 200 225 250m
Scale 1:5000

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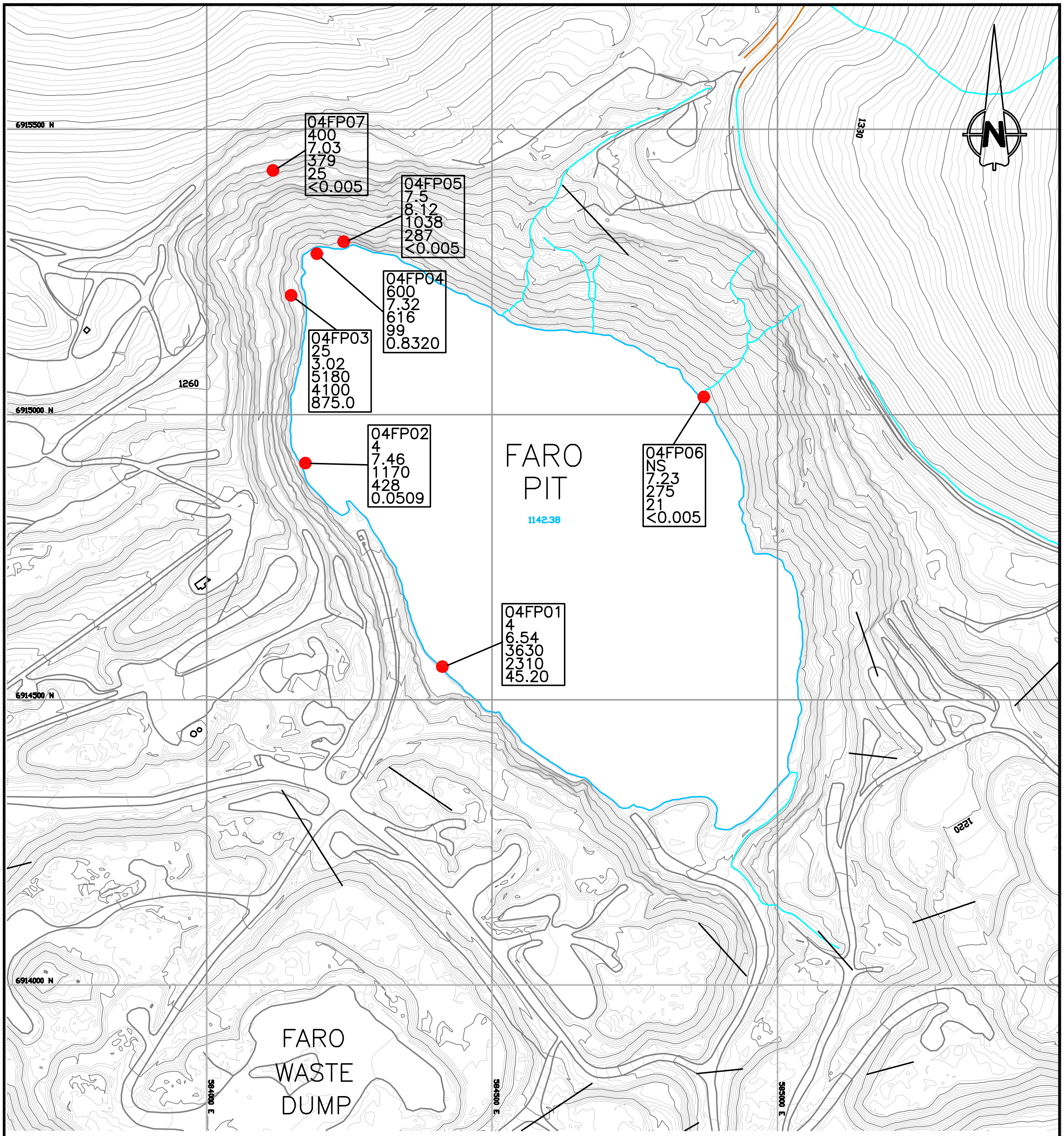
PIT GEOLOGY
VANGORDA PIT

| PROJECT NO. | DATE | APPROVED | FIG. |
|---|---|---|---|
| 1CD003.46 | Nov. 2004 | | 2.3 |



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Scale 1:10,000

● Seep sample location

| | |
|---|---|
| SAMPLE ID | |
| Flow | (L/min) |
| pH | S.U. |
| Conductivity | (uS/cm) |
| Sulphate | (mg/L) |
| Zinc | (mg/L) |

Map Scale : 1:7,500
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

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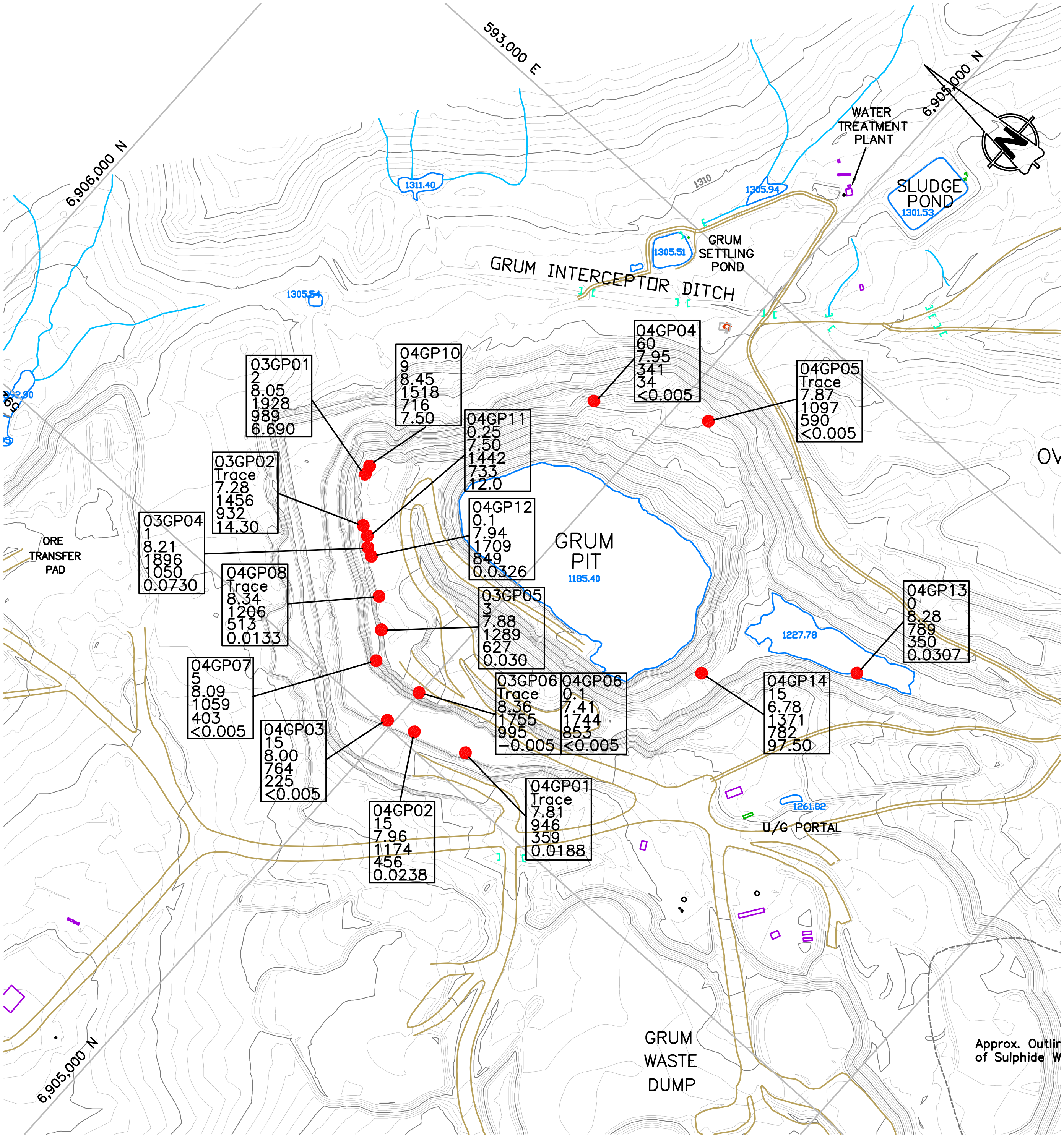
FARO MINE SITE

# FARO PIT
# SEEP SURVEY RESULTS

| PROJECT NO. | DATE | APPROVED | FIGURE |
|---|---|---|---|
| 1CD003.046 | Nov. 2004 | | 2.4 |



0 50 100 150 200 250 300 350 400 450 500m
Scale 1:10,000

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

**LEGEND**

● Seep sample location

| SAMPLE ID | |
|---|---|
| Flow | (L/min) |
| pH | S.U. |
| Conductivity | (uS/cm) |
| Sulphate | (mg/L) |
| Zinc | (mg/L) |

File Ref: Site_plan_2004-Seep.dwg

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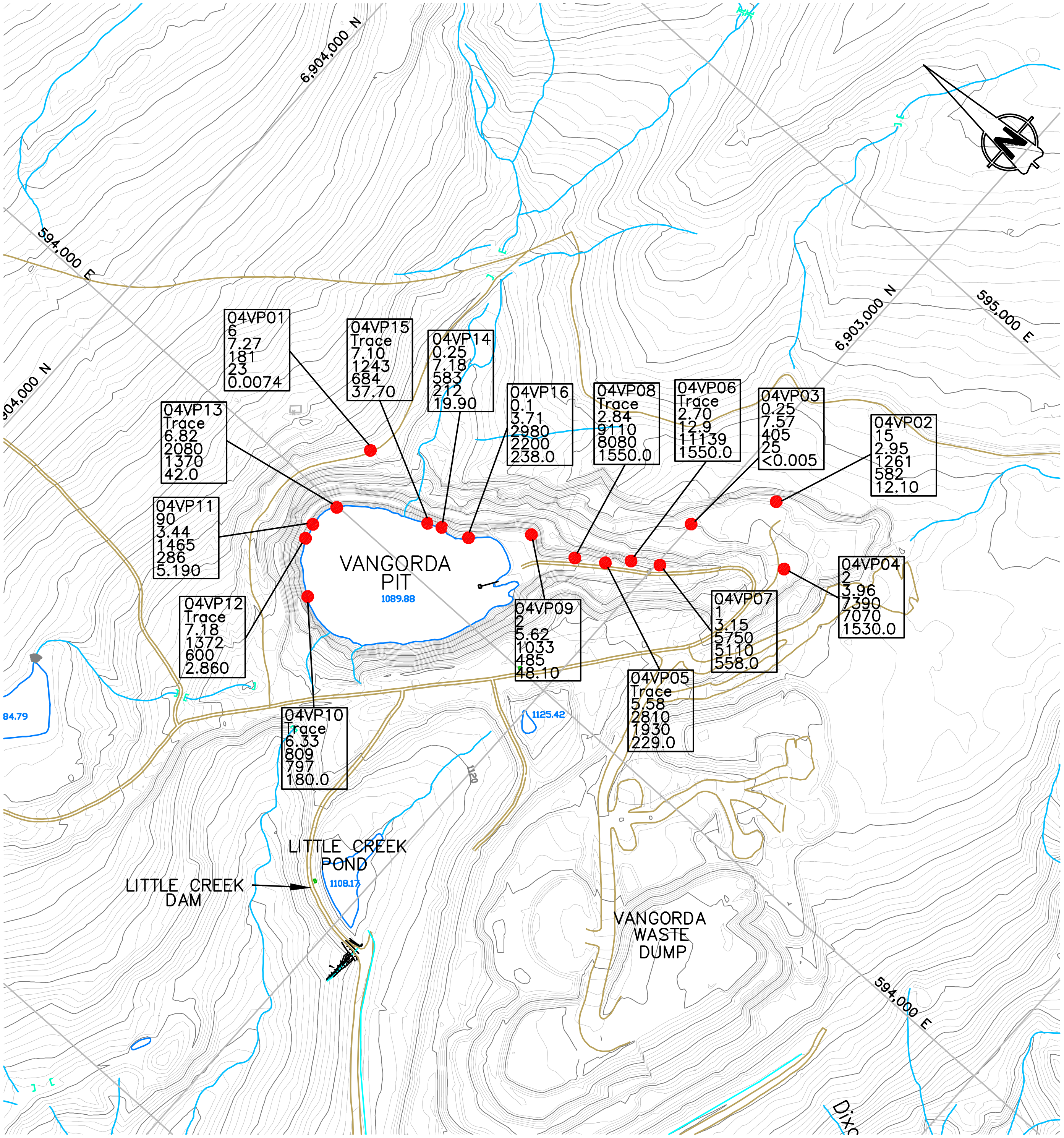
VANGORDA PLATEAU MINE

GRUM PIT
SEEP SURVEY RESULTS

| PROJECT NO. | DATE | APPROVED | FIGURE |
|---|---|---|---|
| 1CD003.046 | Nov. 2004 | | 2.5 |



0 50 100 150 200 250 300 350 400 450 500m

Scale 1:10,000

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

**LEGEND**

● Seep sample location

| SAMPLE ID | |
|---|---|
| Flow | (L/min) |
| pH | S.U. |
| Conductivity | (uS/cm) |
| Sulphate | (mg/L) |
| Zinc | (mg/L) |

File Ref: Site_plan_2004-Seep.dwg

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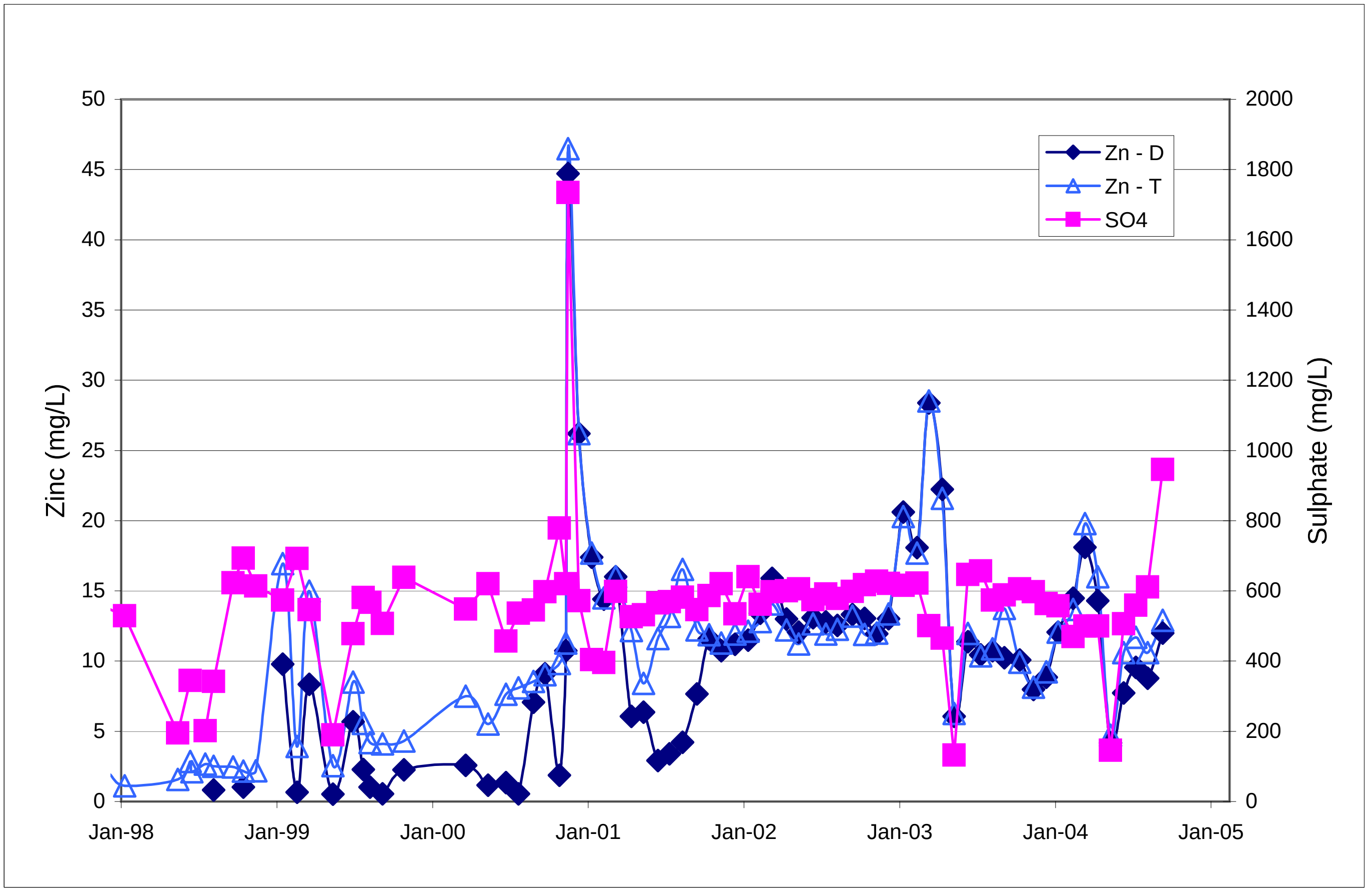
VANGORDA PLATEAU MINE

VANGORDA PIT
SEEP SURVEY RESULTS

| PROJECT NO. | DATE | APPROVED | FIGURE |
|---|---|---|---|
| 1CD003.046 | Nov. 2004 | | 2.6 |



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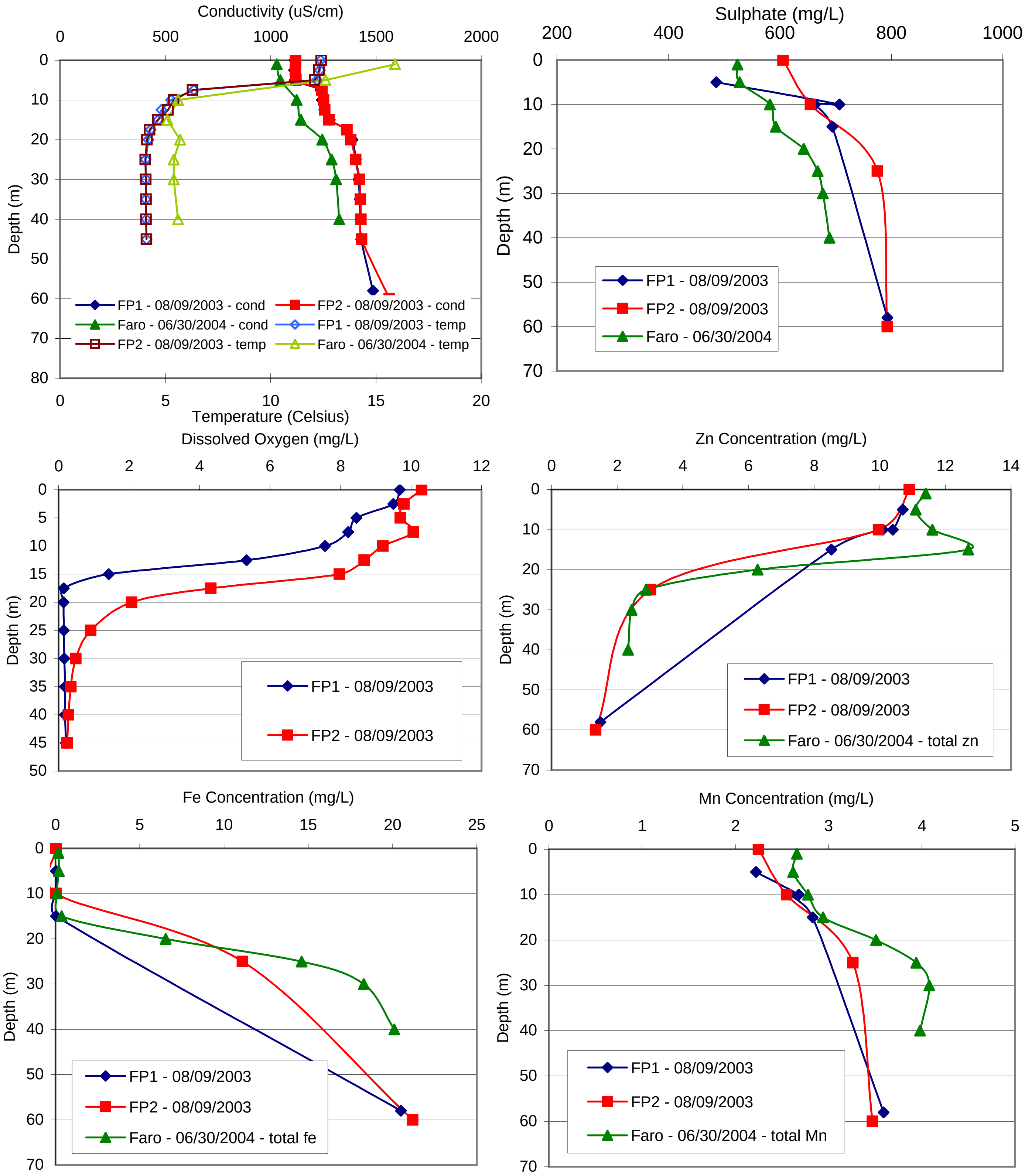
Updated Post-Closure Estimates of Water Quality in the Faro, Grum and Vangorda Pits

## Trends in Sulphate and Zinc Concentrations - Faro Pit Surface Water

| Project | Date | Approved | Figure |
|---|---|---|---|
| 1CD003.46 | Dec-04 | | **3.1** |



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Updated Post-Closure Estimates of Water Quality in the Faro, Grum and Vangorda Pits

Trends in Temperature, Conductivity, Sulphate, Diss. Oxygen, Zinc, Iron and Manganese - Faro Pit

| Project | Date | Approved | Figure |
|---|---|---|---|
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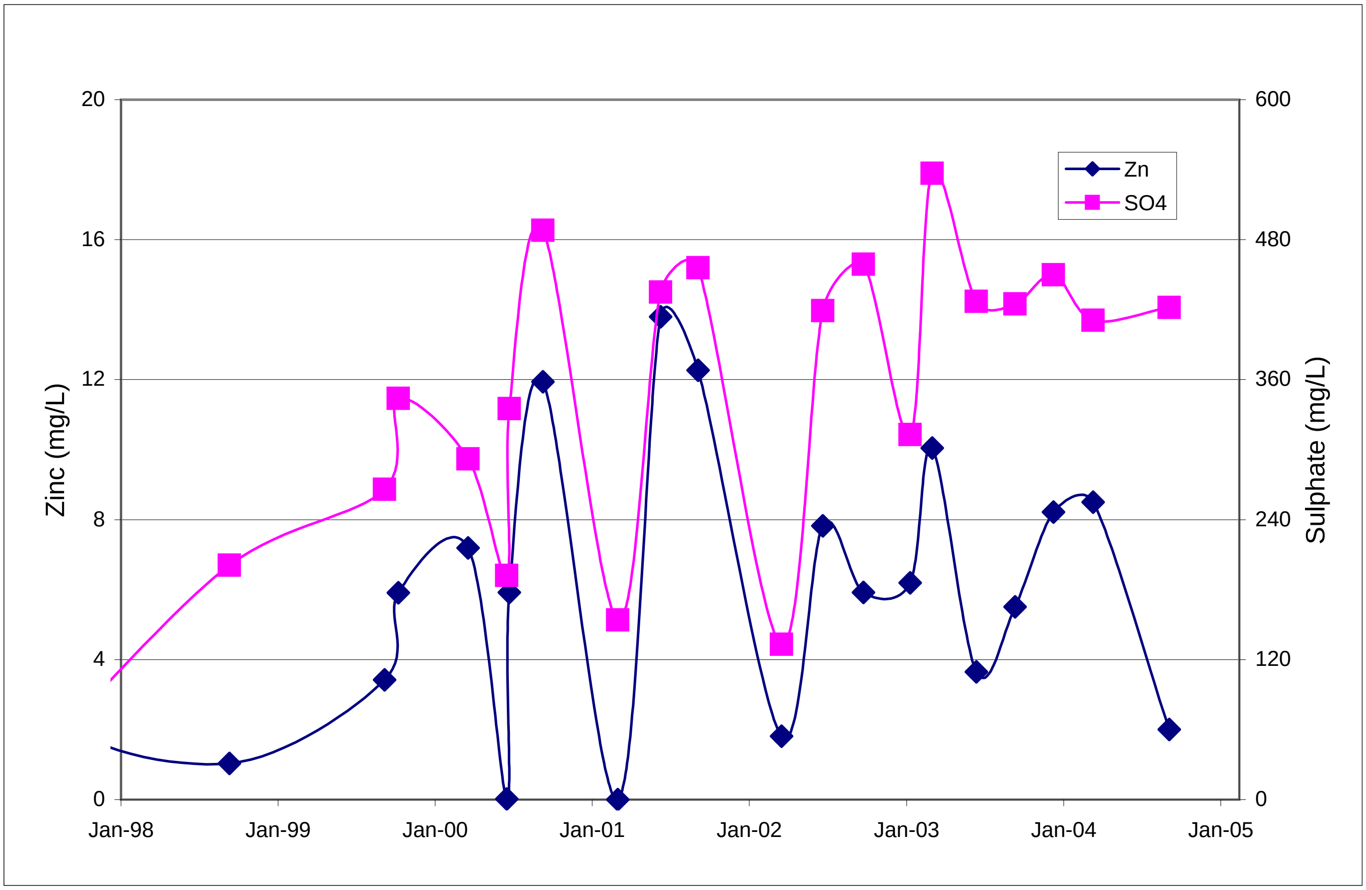

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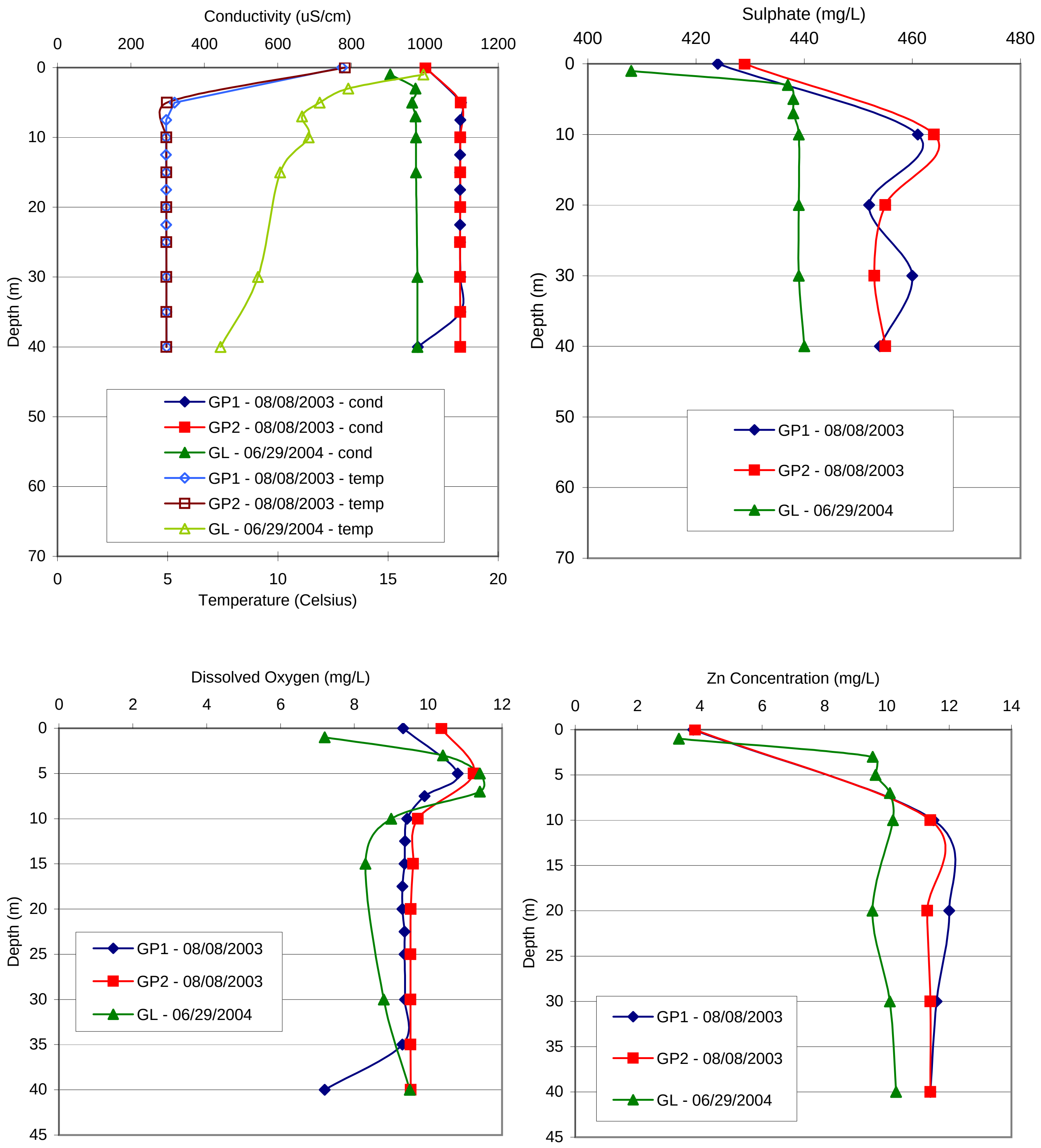
Updated Post-Closure Estimates of Water Quality in the Faro, Grum and Vangorda Pits

## Trends in Sulphate and Zinc Concentrations - Grum Pit Surface Water

| Project | Date | Approved | Figure |
|---|---|---|---|
| 1CD003.46 | Dec-04 | | **3.3** |

Routine_Water_Quality.xls



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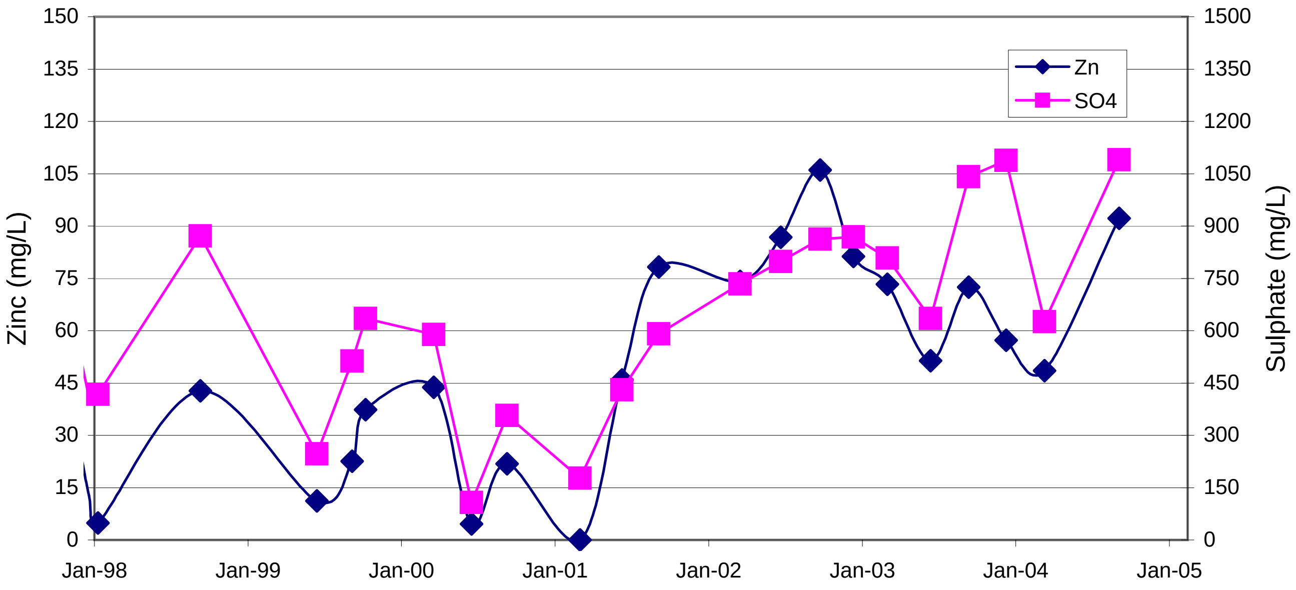
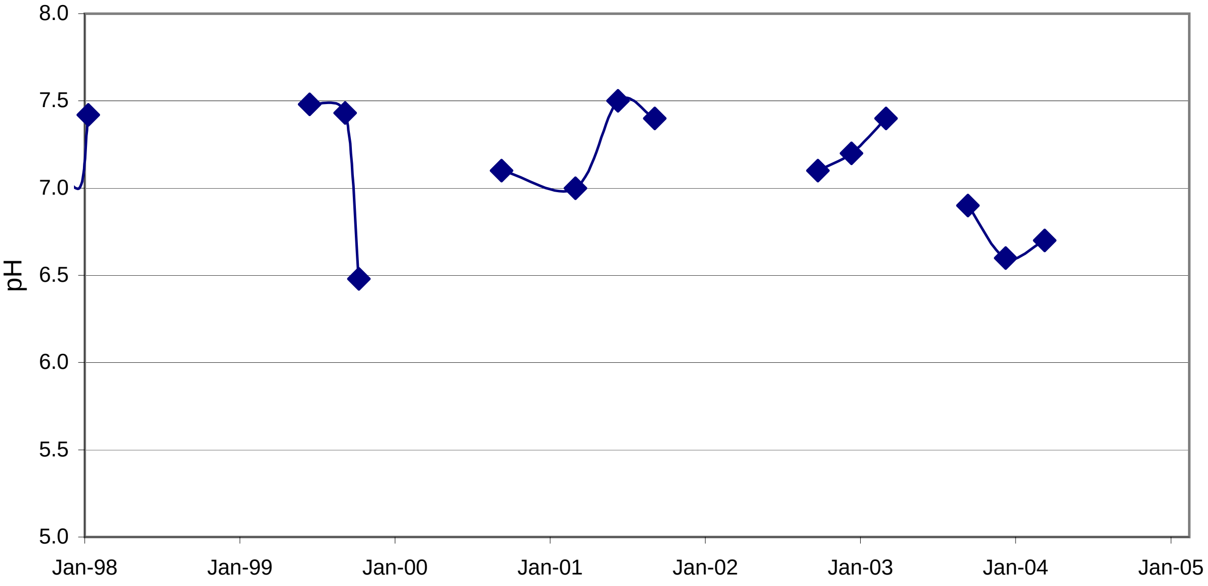
Updated Post-Closure Estimates of Water Quality in the Faro, Grum and Vangorda Pits

Trends in Temperature, Conductivity, Sulphate, Diss. Oxygen and Zinc - Grum Pit

| Project | Date | Approved | Figure |
|---|---|---|---|
| 1CD003.046 | Dec-04 | | **3.4** |





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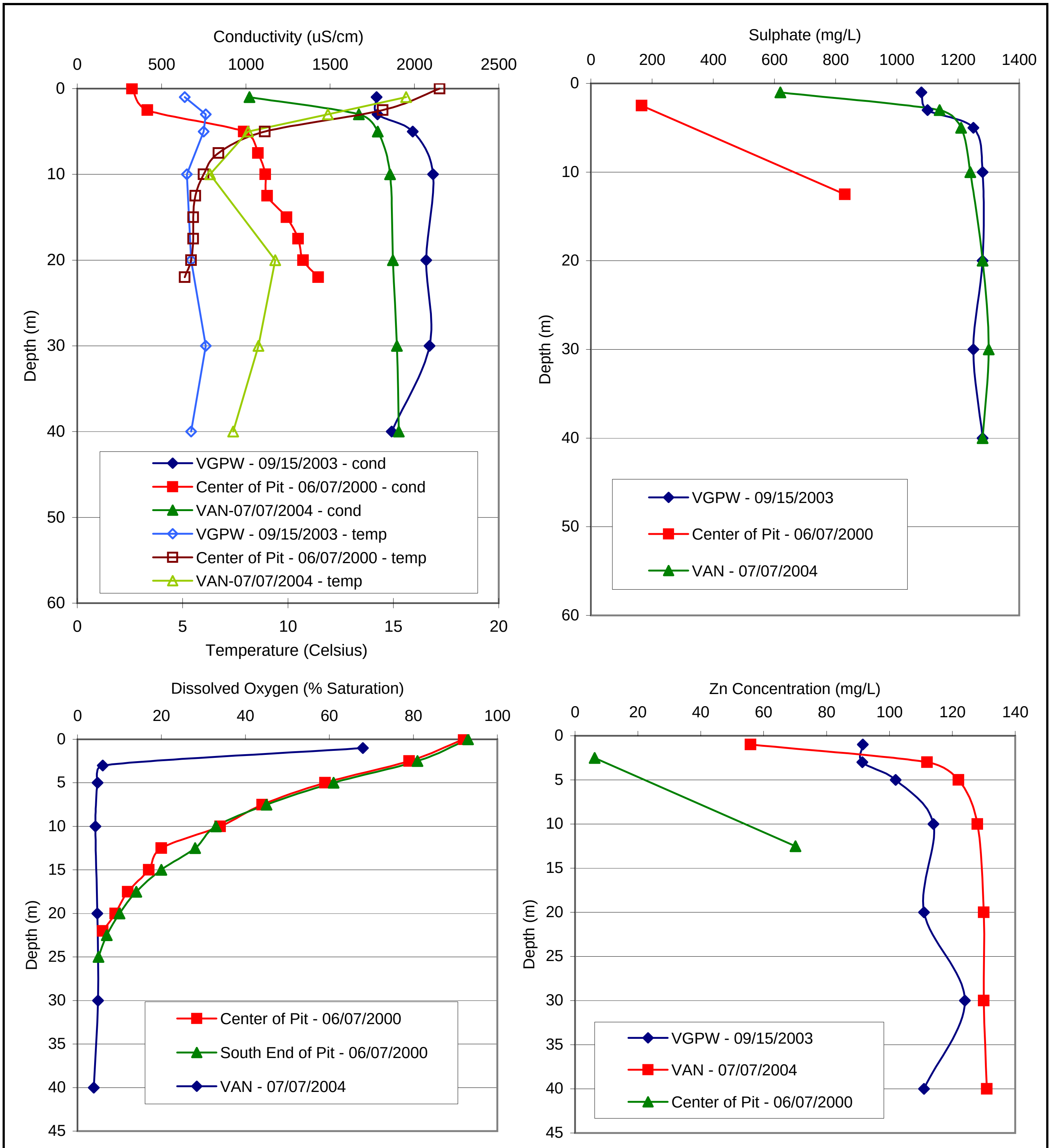
Updated Post-Closure Estimates of Water Quality in the Faro, Grum and Vangorda Pits

Trends in SO4 and Zn Concentrations and pH - Vangorda Pit Surface Water

| Project | Date | Approved | Figure |
|---|---|---|---|
| 1CD003.46 | Dec-04 | | **3.5** |



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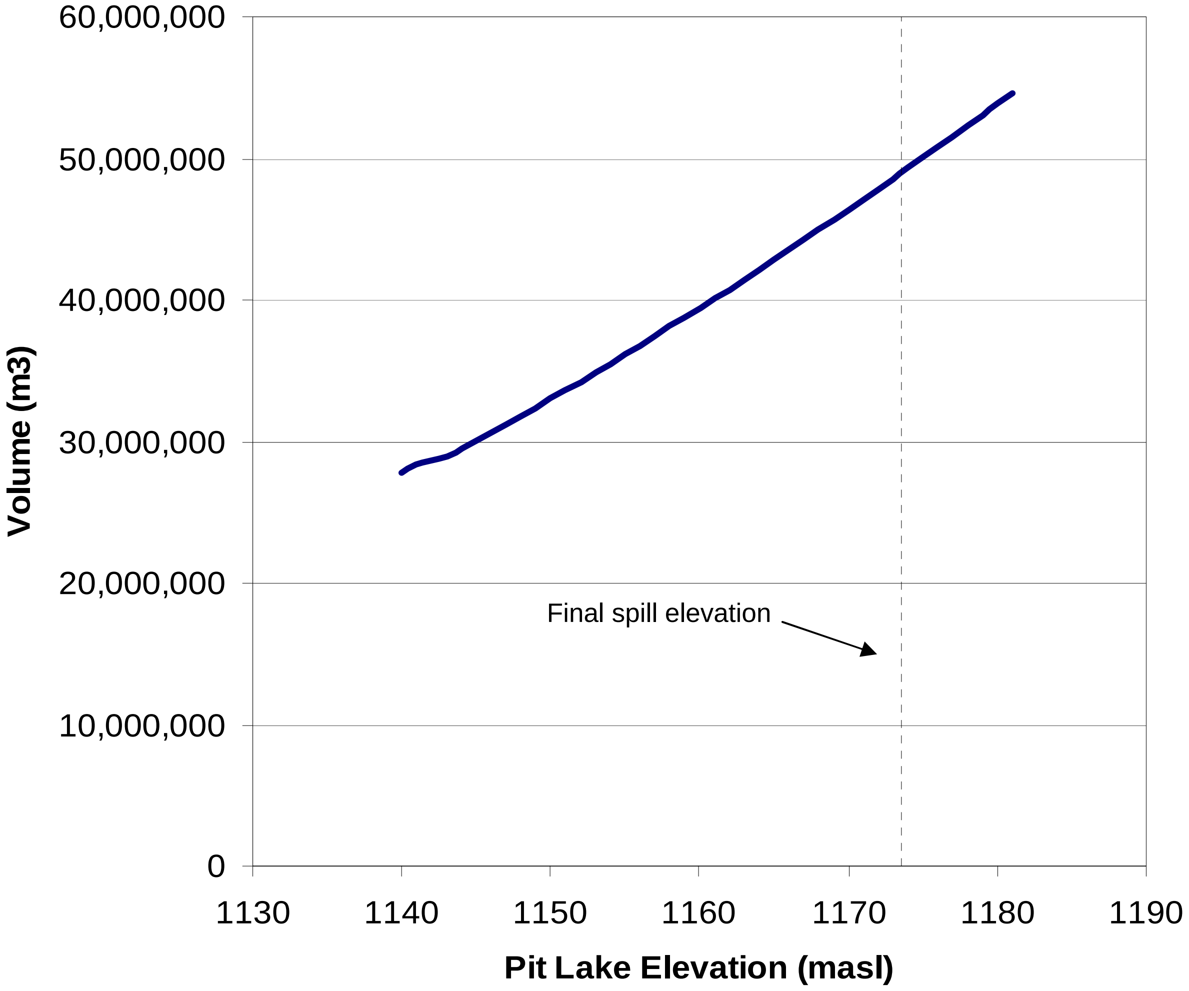
Updated Post-Closure Estimates of Water Quality in the Faro, Grum and Vangorda Pits

Trends in Temperature, Conductivity, Sulphate, Diss. Oxygen and Zinc - Vangorda Pit

| Project | Date | Approved | Figure |
|---|---|---|---|
| 1CD003.046 | Dec-04 | | **3.6** |



FILE REF: Figures 3-1_3-14.xls

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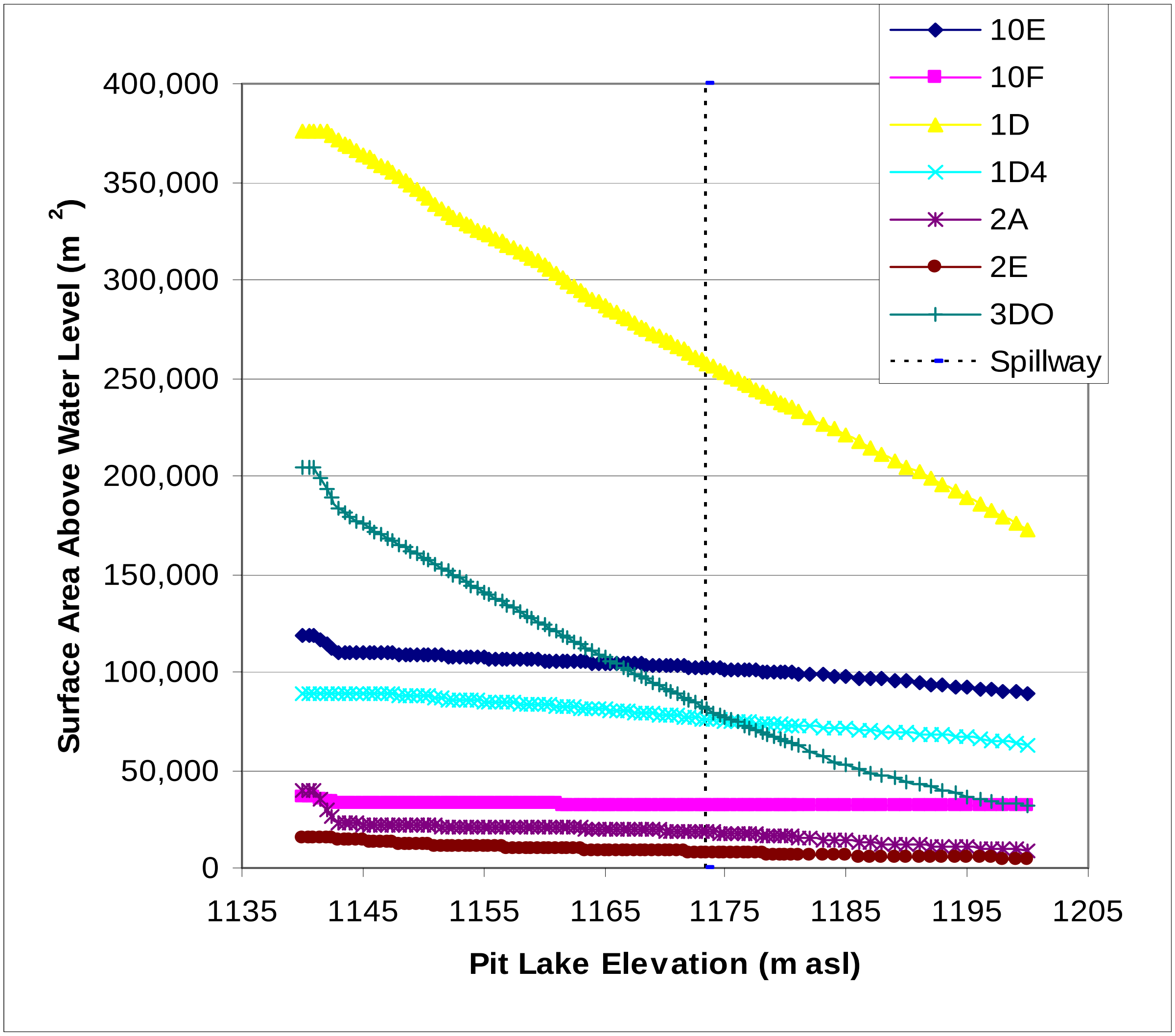
Anvil Range Pit Lakes
Assessment of Post Closure Conditions

**Faro Pit Height-Capacity Curve**

| PROJECT | DATE | APPROVED | FIGURE |
|---|---|---|---|
| 1CD003.46 | Nov. 2004 | | **4.1** |



FILE REF: Figures 3-1_3-14.xls

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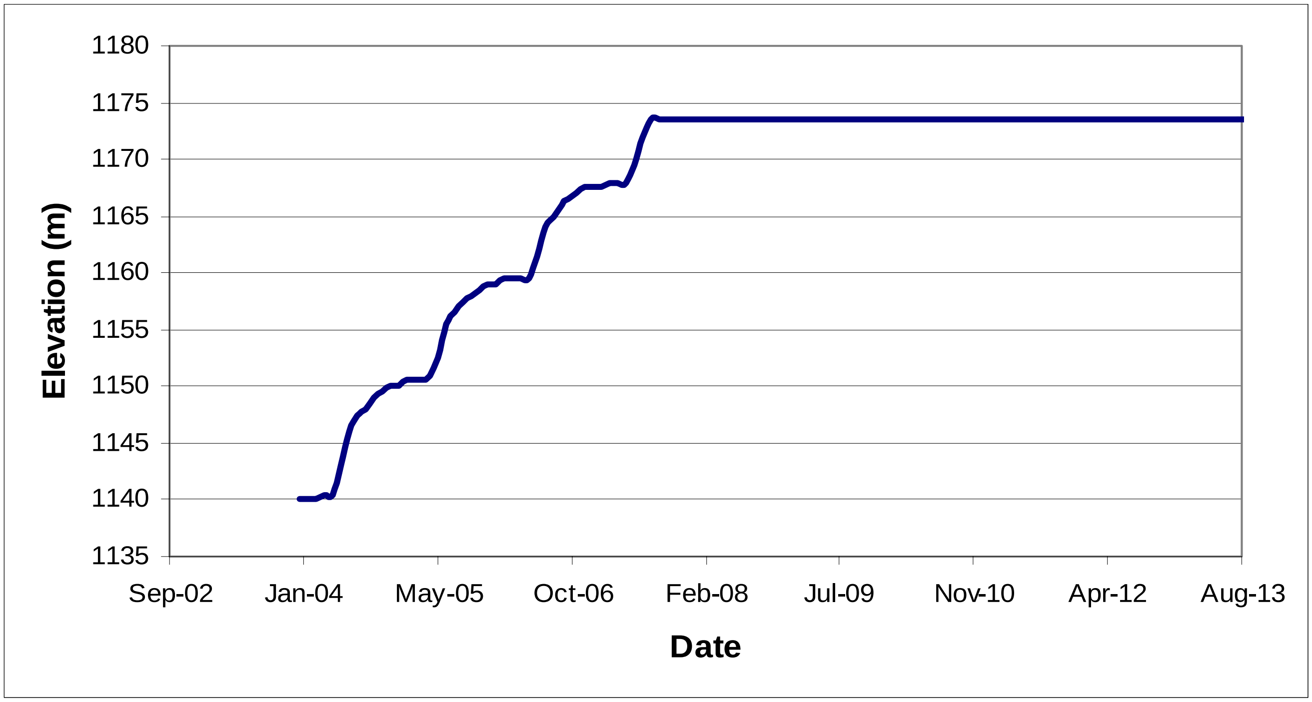
Anvil Range Pit Lakes
Assessment of Post Closure Conditions

**Faro Pit: Estimated Wall Rock Surface Exposure, 1140 - 1200 masl**

| PROJECT | DATE | APPROVED | FIGURE |
|---|---|---|---|
| 1CD003.46 | Nov. 2004 | | **4.2** |



FILE REF: Figures 3-1_3-14.xls

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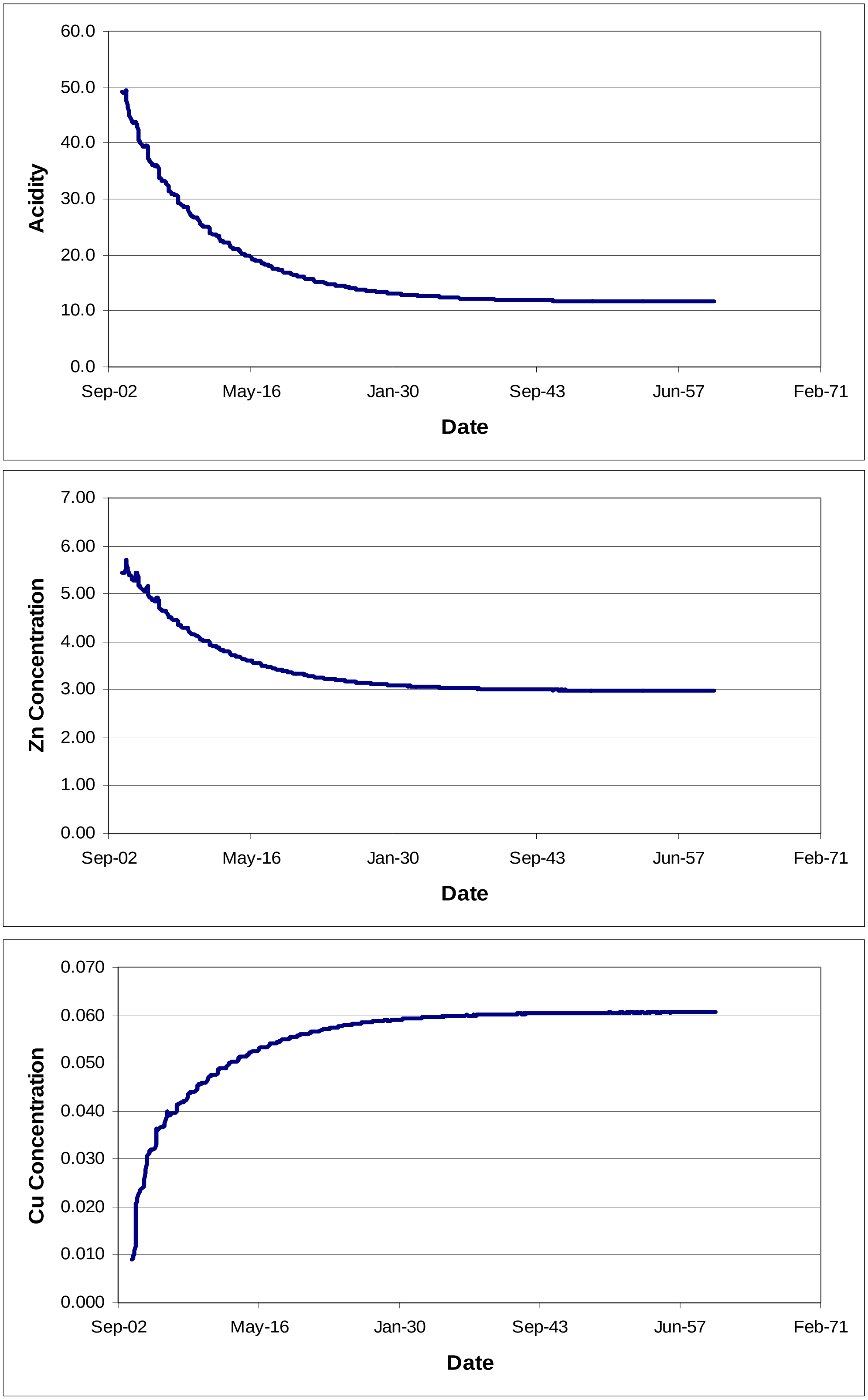
Anvil Range Pit Lakes
Assessment of Post Closure Conditions

## Faro Pit Filling Curve: Base Case

| PROJECT | DATE | APPROVED | FIGURE |
|---|---|---|---|
| 1CD003.46 | Nov. 2004 | | **4.3** |



FILE REF: Figures 3-1_3-14.xls

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Anvil Range Pit Lakes
Assessment of Post Closure Conditions

**Estimated Faro Pit Lake Water Quality**
**Base Case**

| PROJECT | DATE | APPROVED | FIGURE |
|---|---|---|---|
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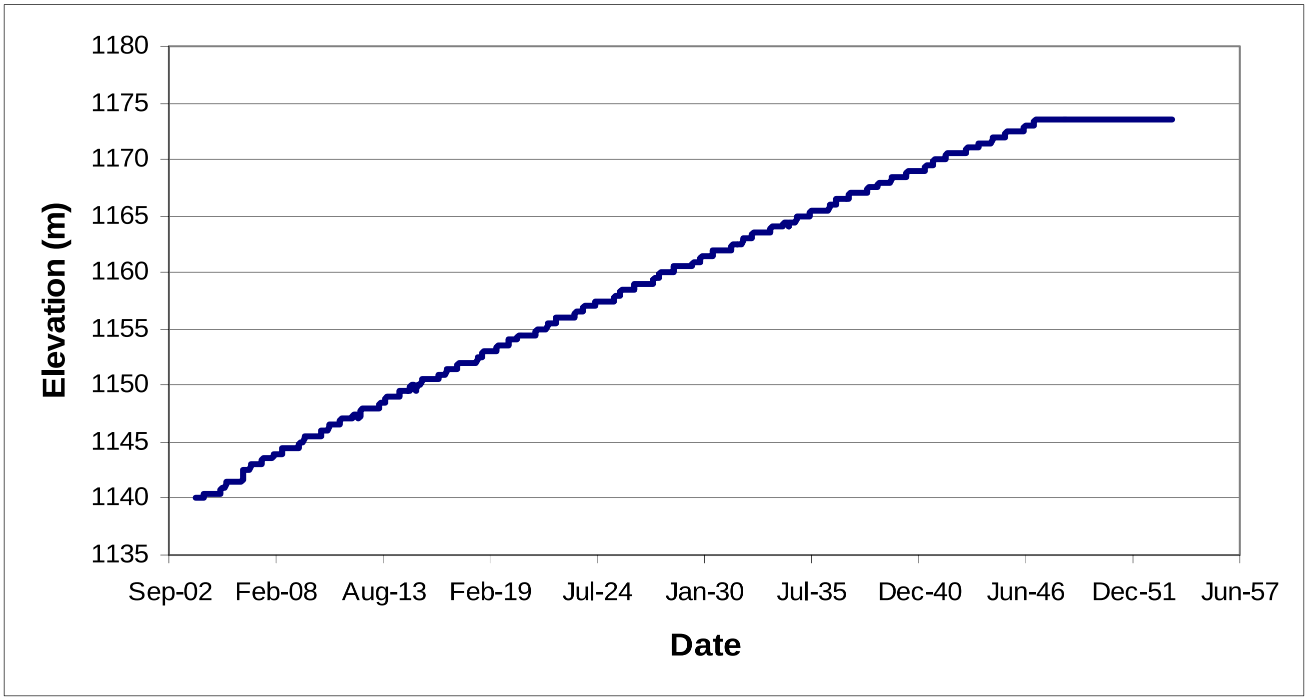

FILE REF: Figures 3-1_3-14.xls

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Anvil Range Pit Lakes
Assessment of Post Closure Conditions

## Faro Pit Filling Curve: Faro Creek Diversion in place

| PROJECT | DATE | APPROVED | FIGURE |
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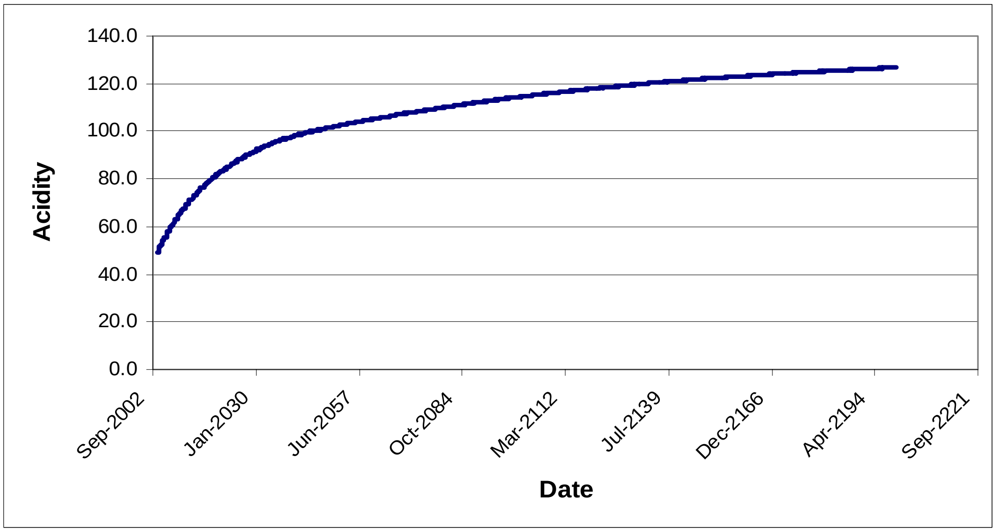

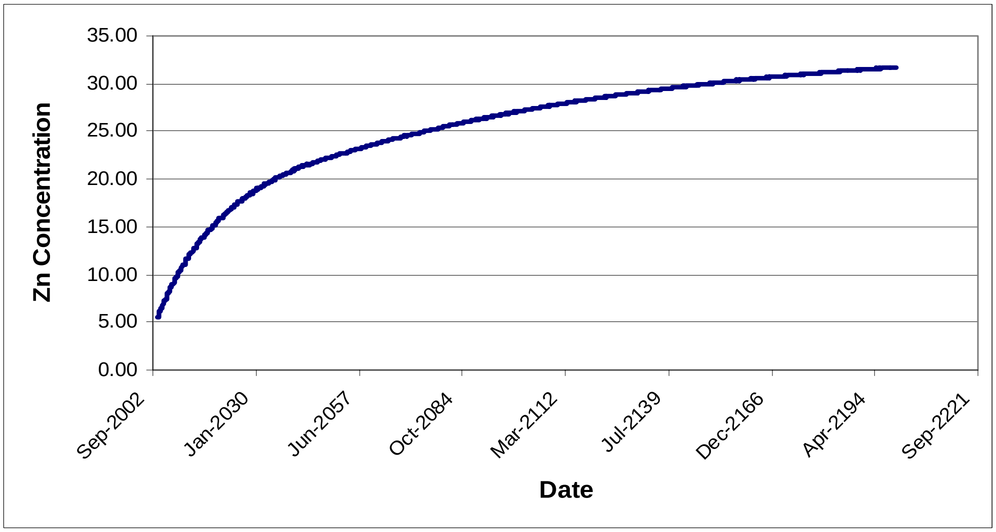

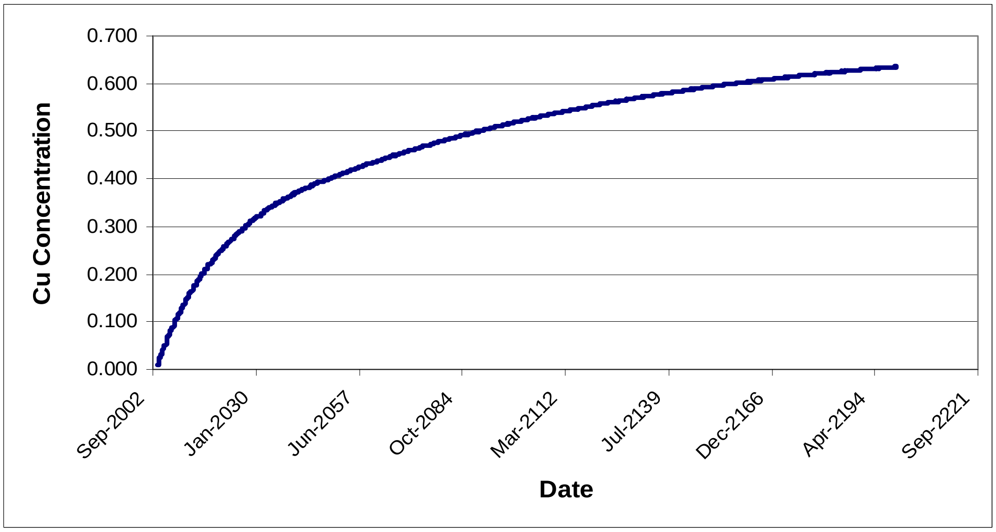

FILE REF: Figures 3-1_3-14.xls

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Anvil Range Pit Lakes
Assessment of Post Closure Conditions

**Estimated Faro Pit Lake Water Quality**
**Faro Creek diversion upgraded**

| PROJECT | DATE | APPROVED | FIGURE |
|---|---|---|---|
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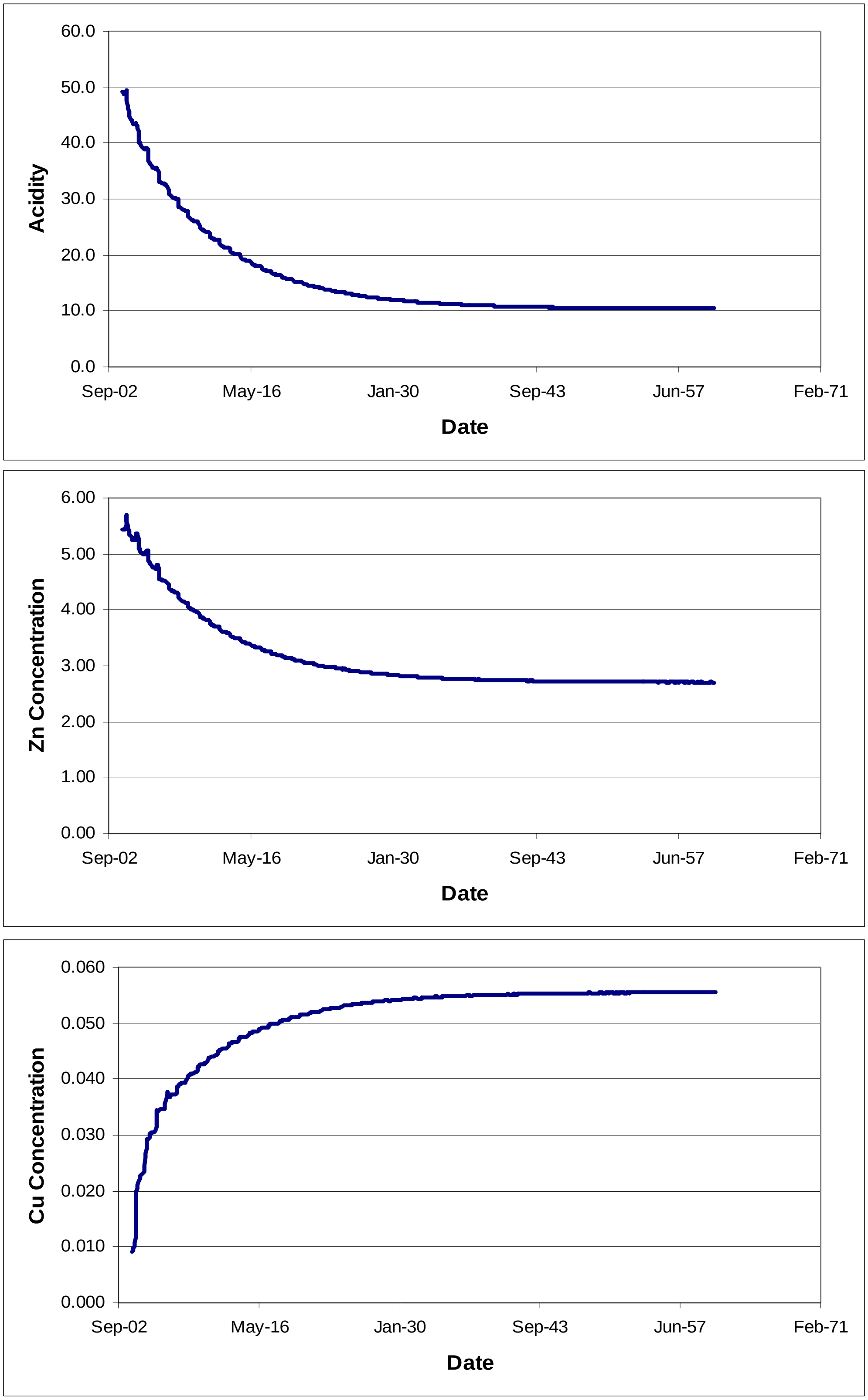

FILE REF: Figures 3-1_3-14.xls

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Anvil Range Pit Lakes
Assessment of Post Closure Conditions

## Estimated Faro Pit Lake Water Quality
## Faro Valley Dumps removed

| PROJECT | DATE | APPROVED | FIGURE |
|---|---|---|---|
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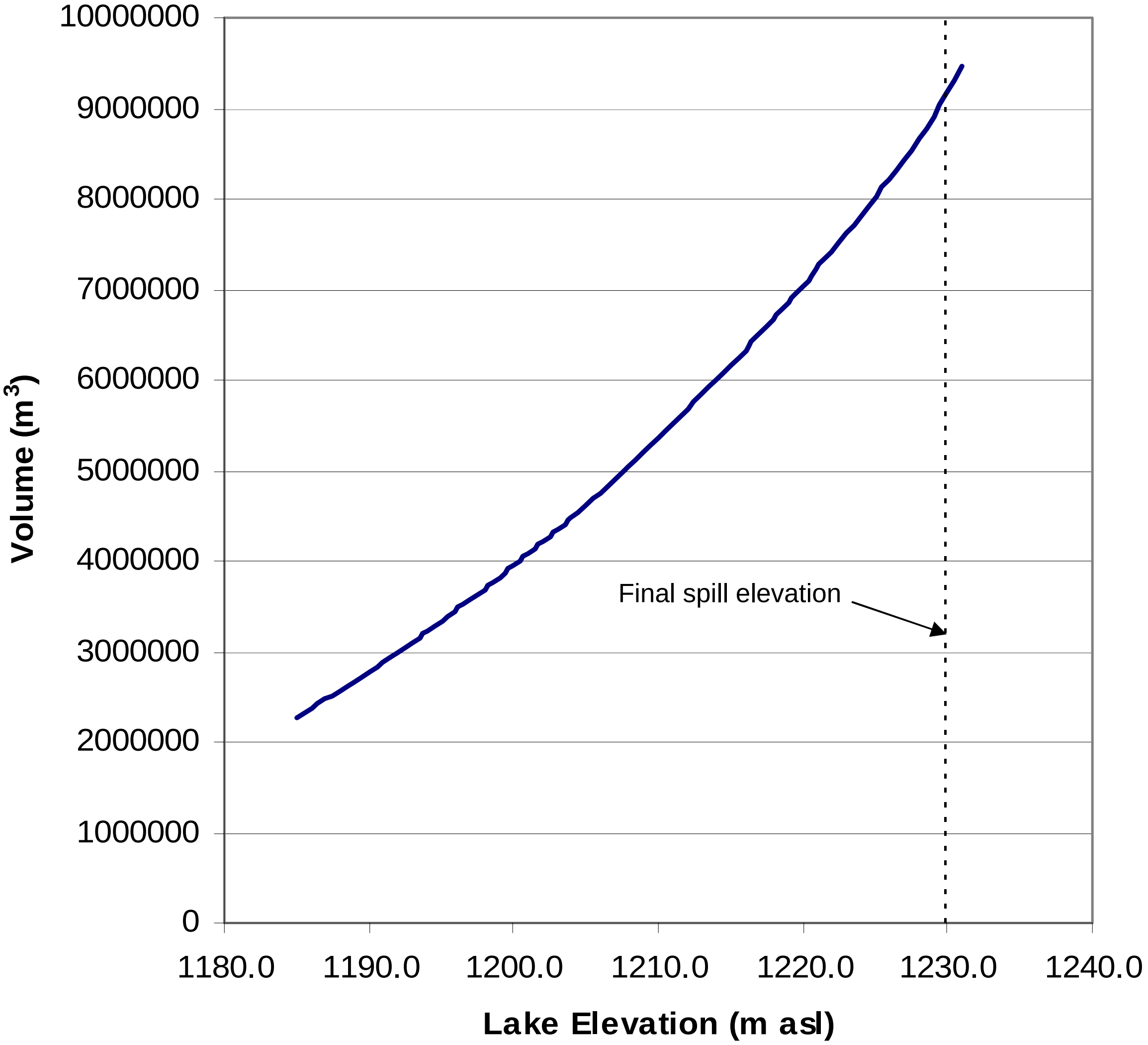

FILE REF: Figures 3-1_3-14.xls

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Anvil Range Pit Lakes
Assessment of Post Closure Conditions

## Grum Pit Volume Capacity Curve

| PROJECT | DATE | APPROVED | FIGURE |
|---|---|---|---|
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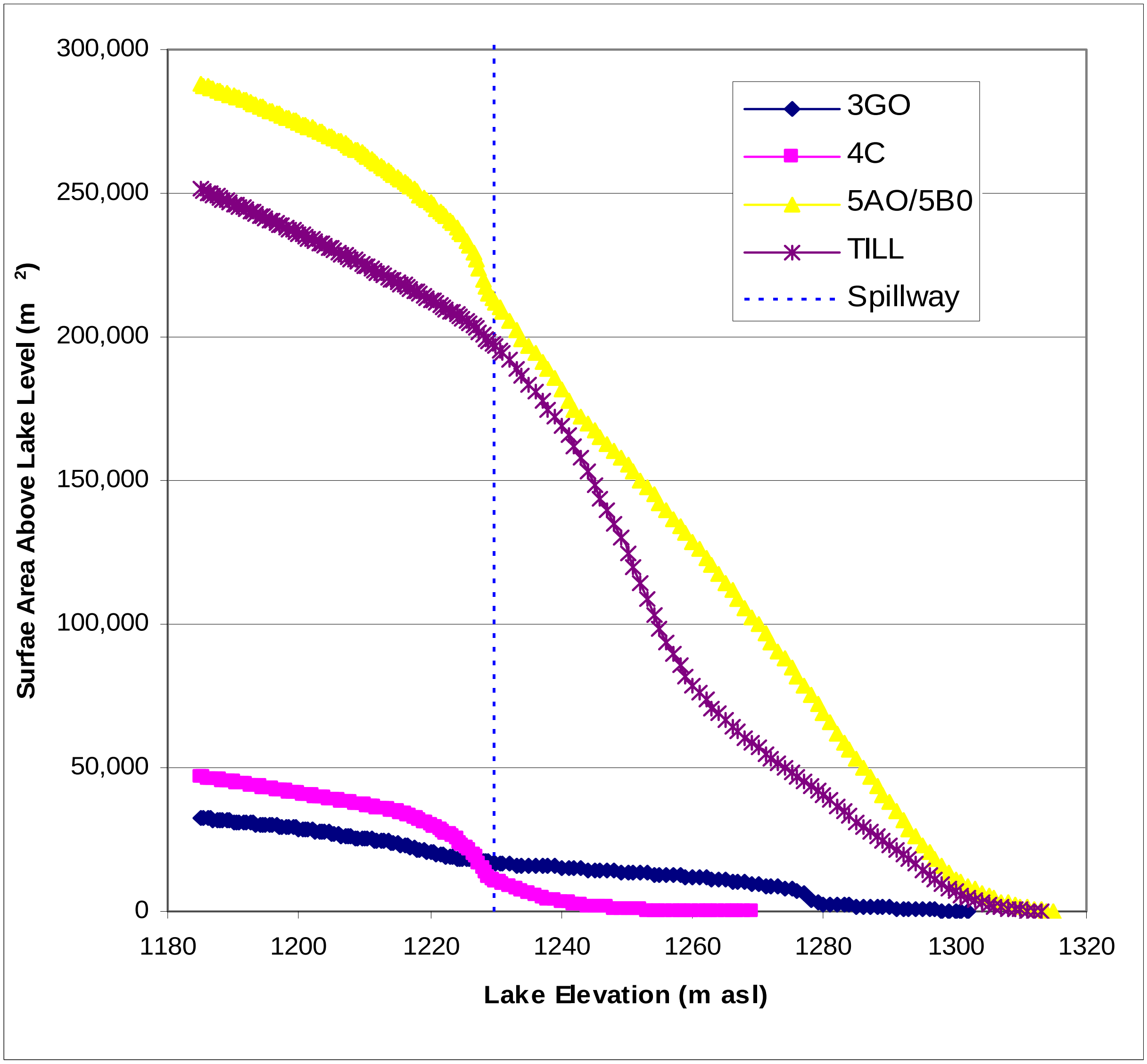

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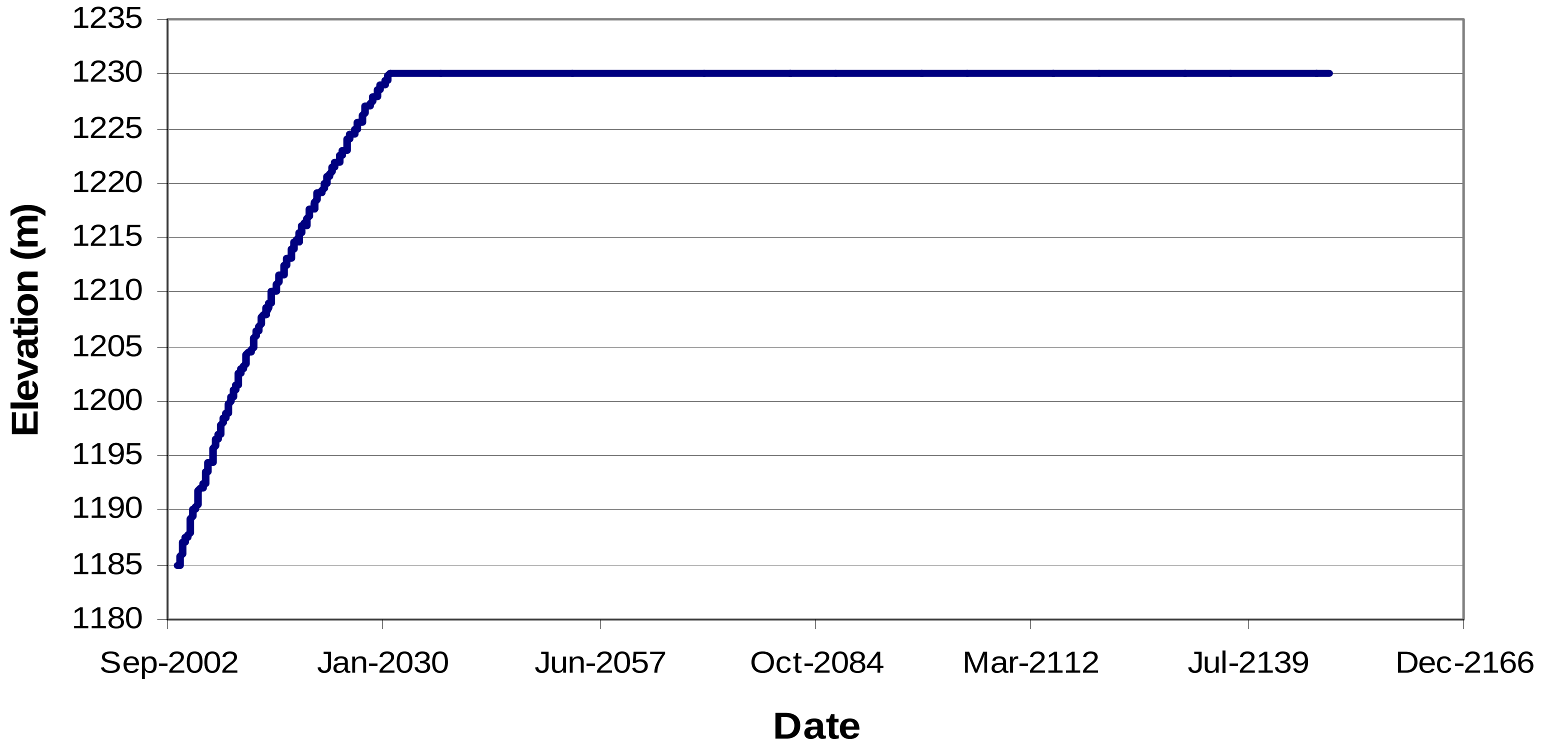
Anvil Range Pit Lakes
Assessment of Post Closure Conditions

## Estimated Grum Pit Wall Rock Exposure

| PROJECT | DATE | APPROVED | FIGURE |
|---|---|---|---|
| 1CD003.46 | Nov. 2004 |  | **4.9** |

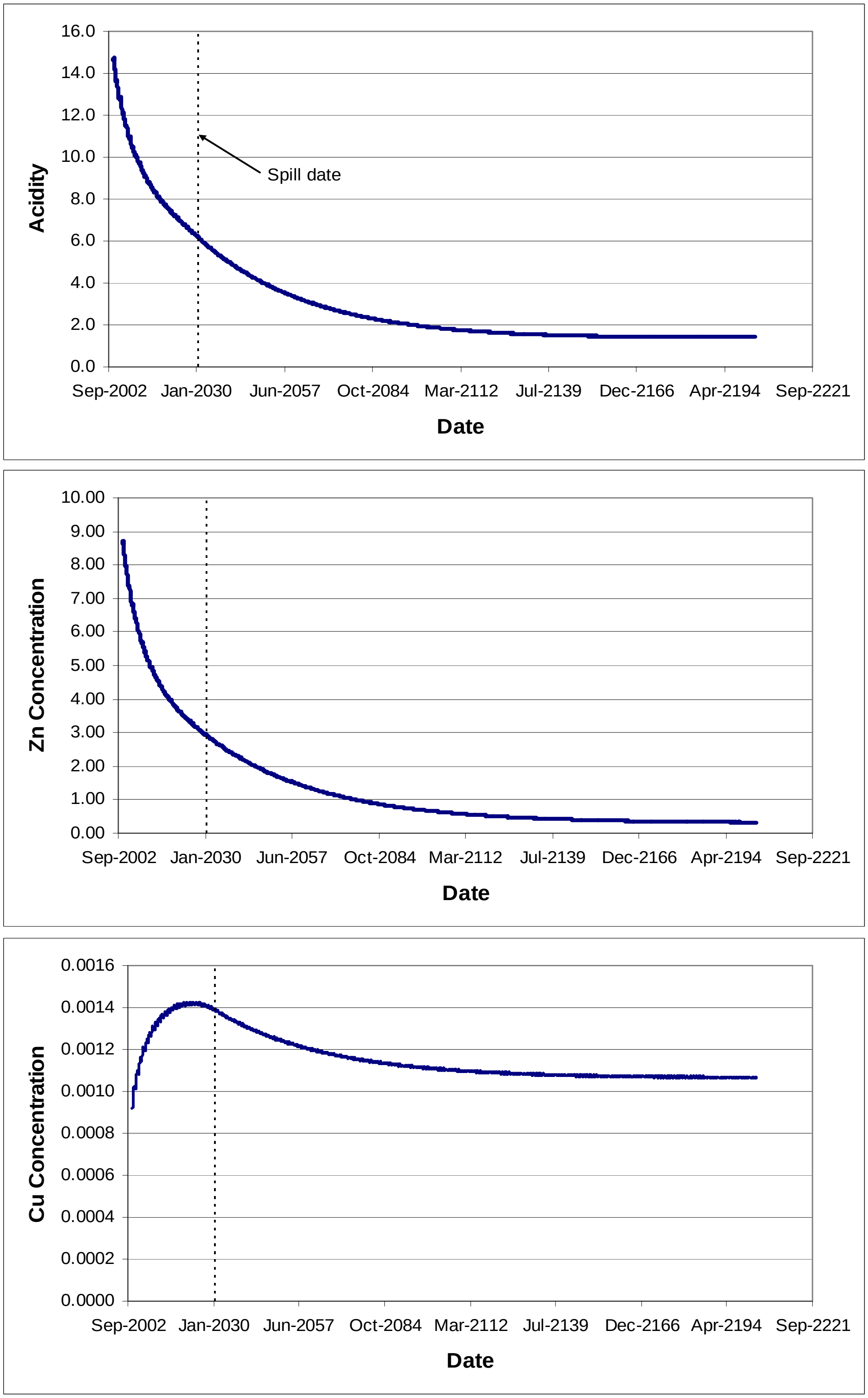
FILE REF: Figures 3-1_3-14.xls

FILE REF: Figures 3-1_3-14.xls



| | |
|---|---|
| SRK Consulting<br>*Engineers and Scientists* | Anvil Range Pit Lakes<br>Assessment of Post Closure Conditions |
| **Deloitte & Touche Inc.** | **Estimated Flooding Rate of the Grum Pit** |

| PROJECT | DATE | APPROVED | FIGURE |
|---|---|---|---|
| 1CD003.46 | Nov. 2004 | | **4.10** |



FILE REF: Figures 3-1_3-14.xls

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Anvil Range Pit Lakes
Assessment of Post Closure Conditions

## Estimated Future Grum Pit Lake Water Quality

| PROJECT | DATE | APPROVED | FIGURE |
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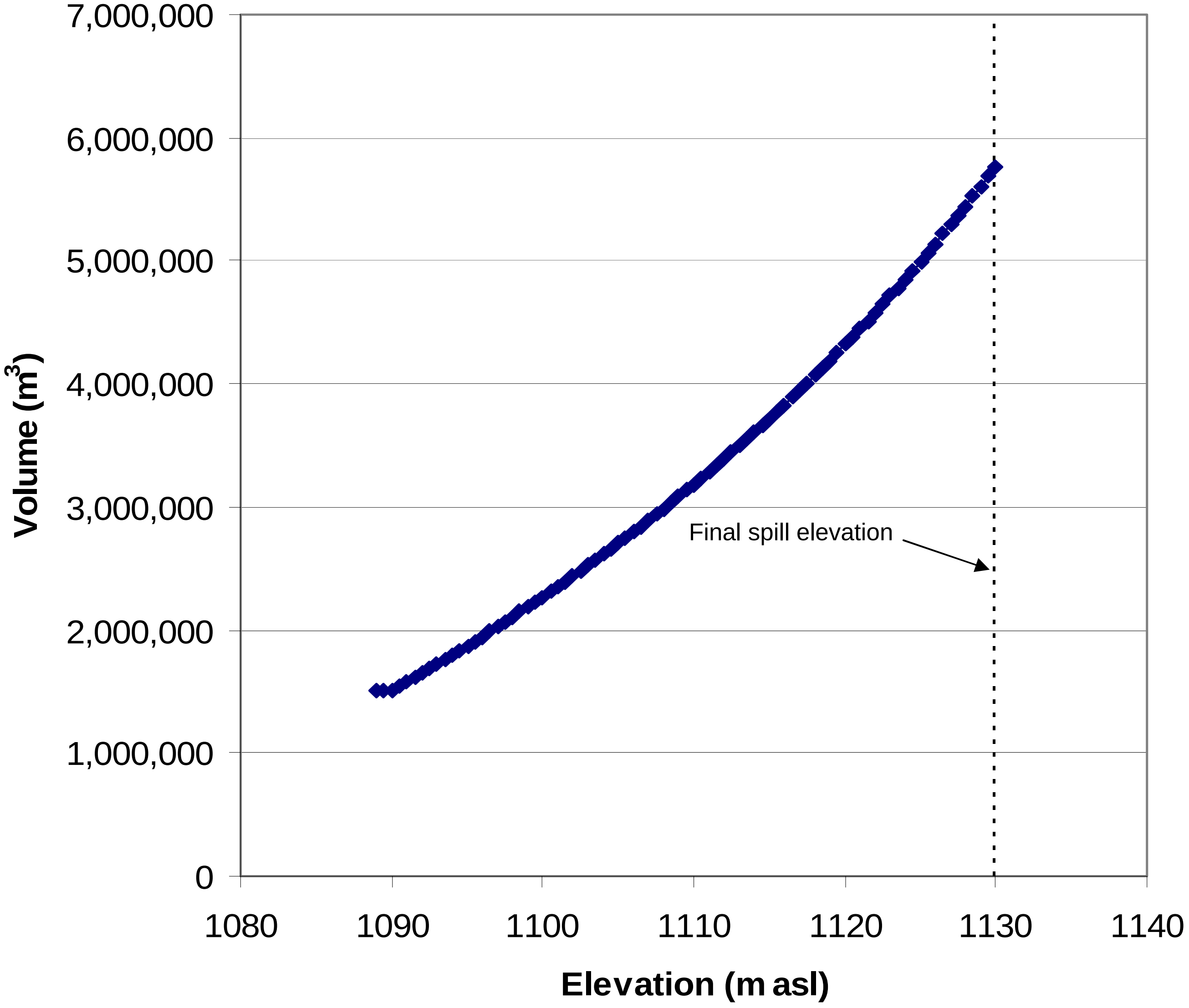

FILE REF: Figures 3-1_3-14.xls

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Anvil Range Pit Lakes
Assessment of Post Closure Conditions

## Vangorda Pit Volume Capacity Curve

| PROJECT | DATE | APPROVED | FIGURE |
|---|---|---|---|
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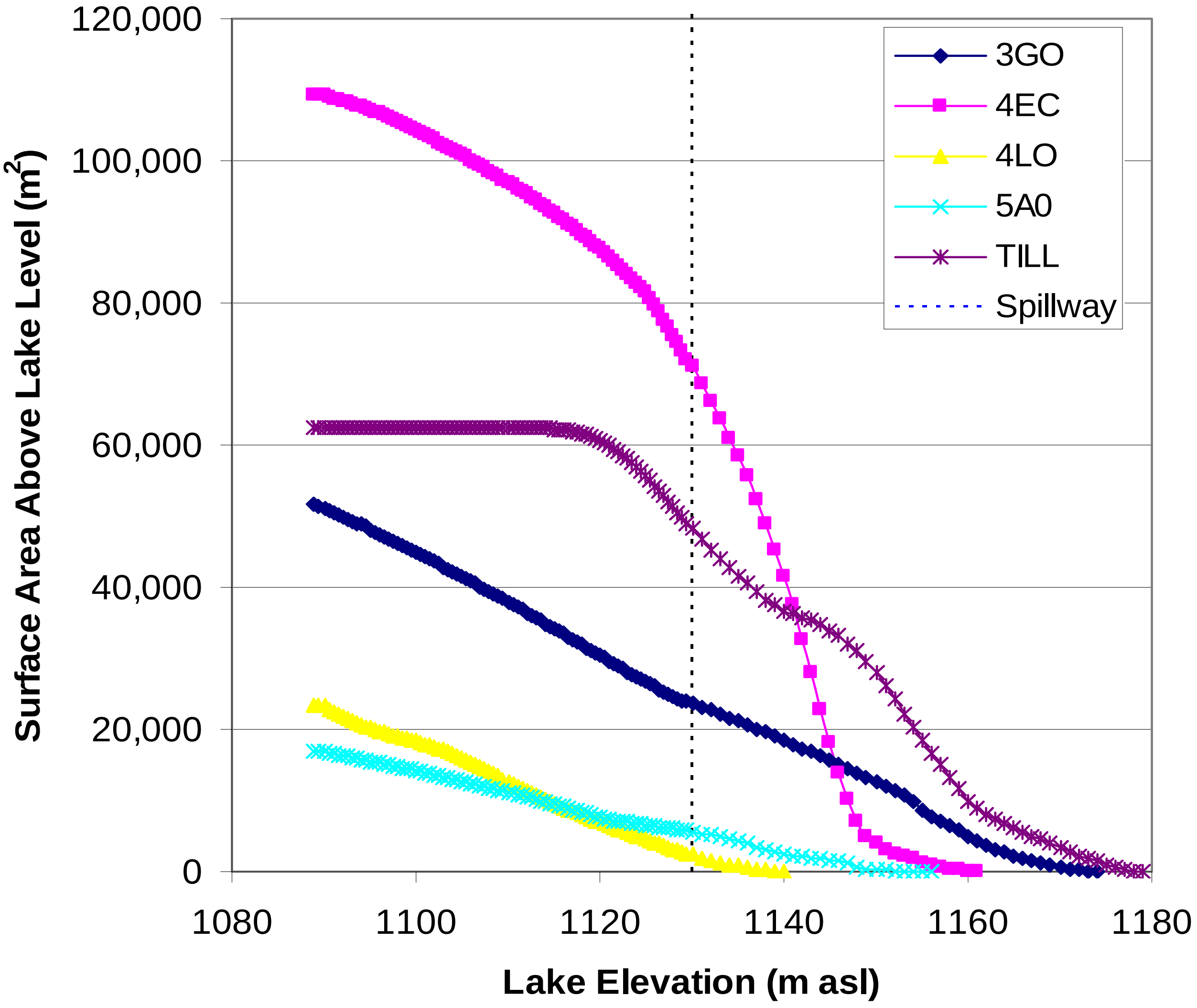

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Anvil Range Pit Lakes
Assessment of Post Closure Conditions

**Estimated Vangorda Pit Wall Rock Exposure**

| PROJECT | DATE | APPROVED | FIGURE |
|---|---|---|---|
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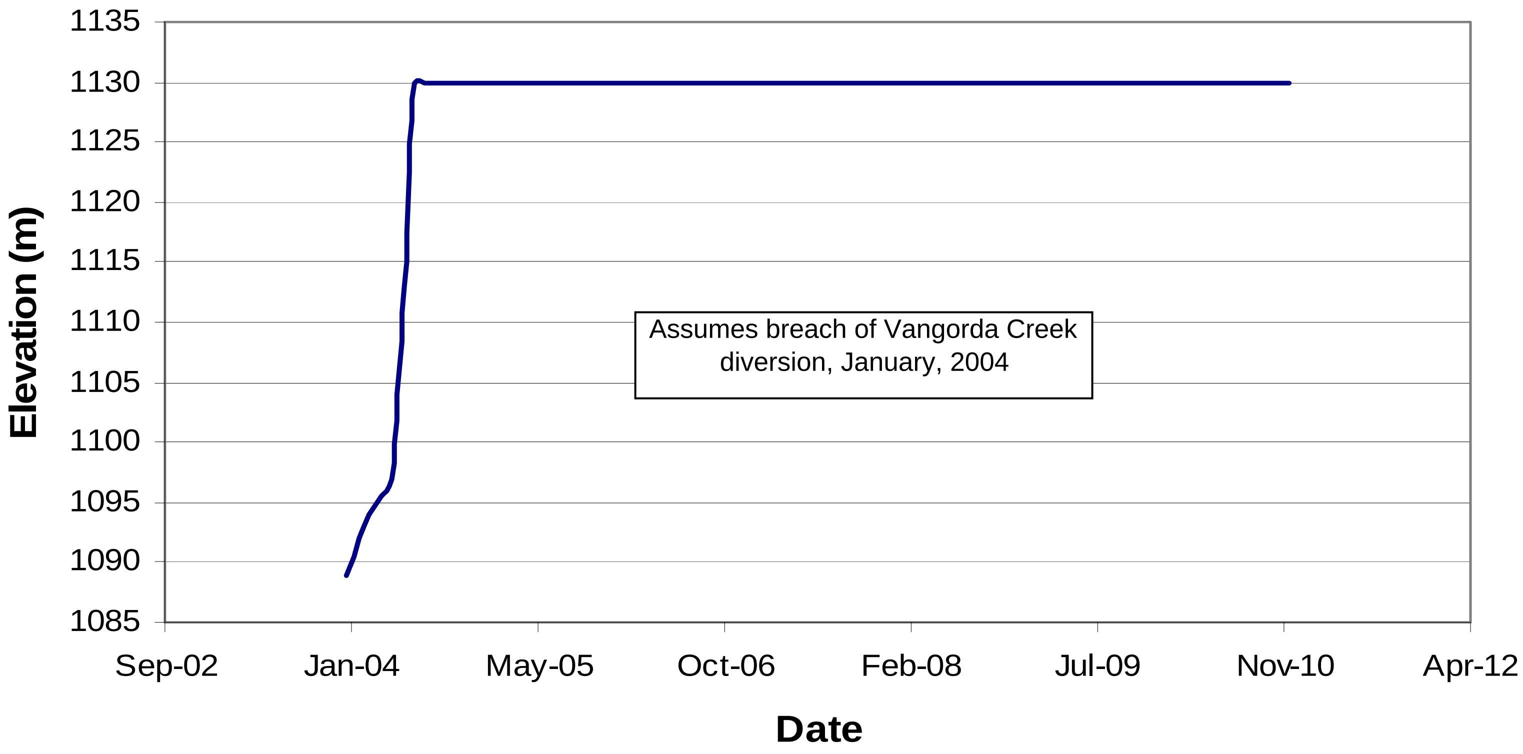
FILE REF: Figures 3-1_3-14.xls

FILE REF: Figures 3-1_3-14.xls



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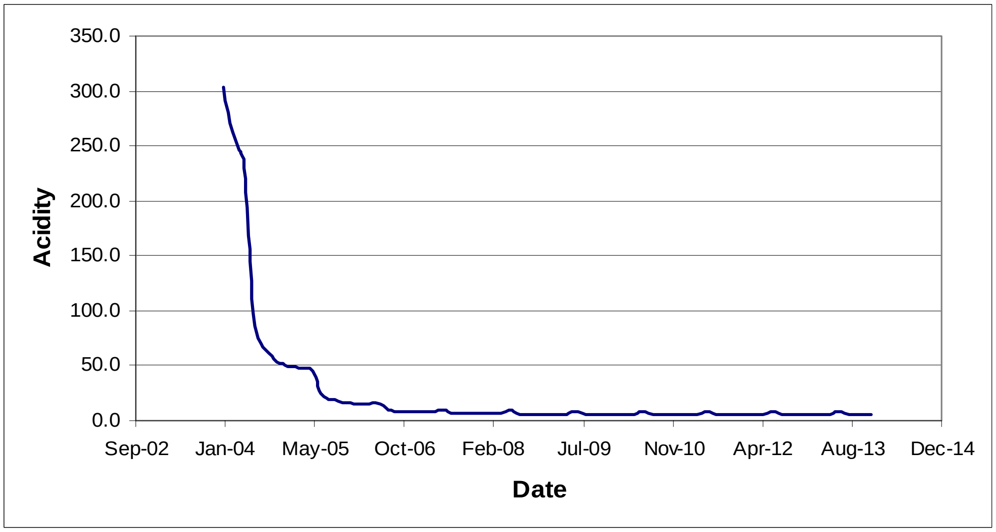
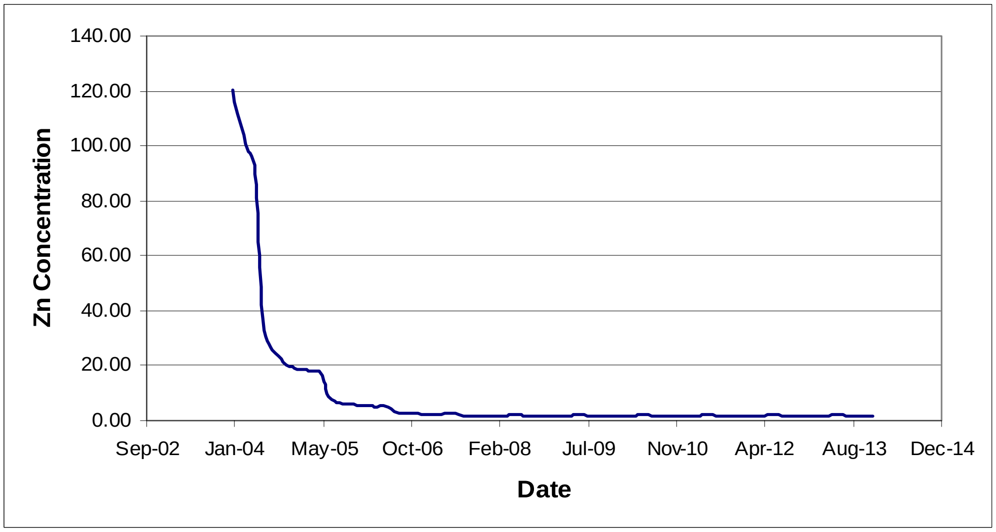
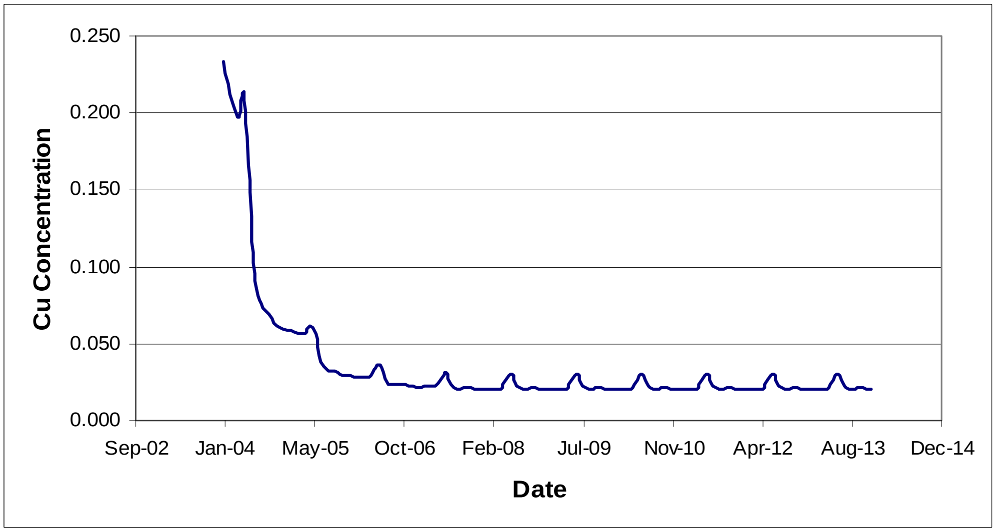
Anvil Range Pit Lakes
Assessment of Post Closure Conditions

**Estimated Filling Period for Vangorda Pit**

| PROJECT | DATE | APPROVED | FIGURE |
|---|---|---|---|
| 1CD003.046 | Nov 2004 | | **4.14** |







FILE REF: Figures 3-1_3-14.xls

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Anvil Range Pit Lakes
Assessment of Post Closure Conditions

## Estimated Vangorda Pit Lake Water Quality
## Base Case

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| PROJECT | DATE | APPROVED | FIGURE |
|---|---|---|---|
| 1CD003.46 | Nov. 2004 | | **4.15** |

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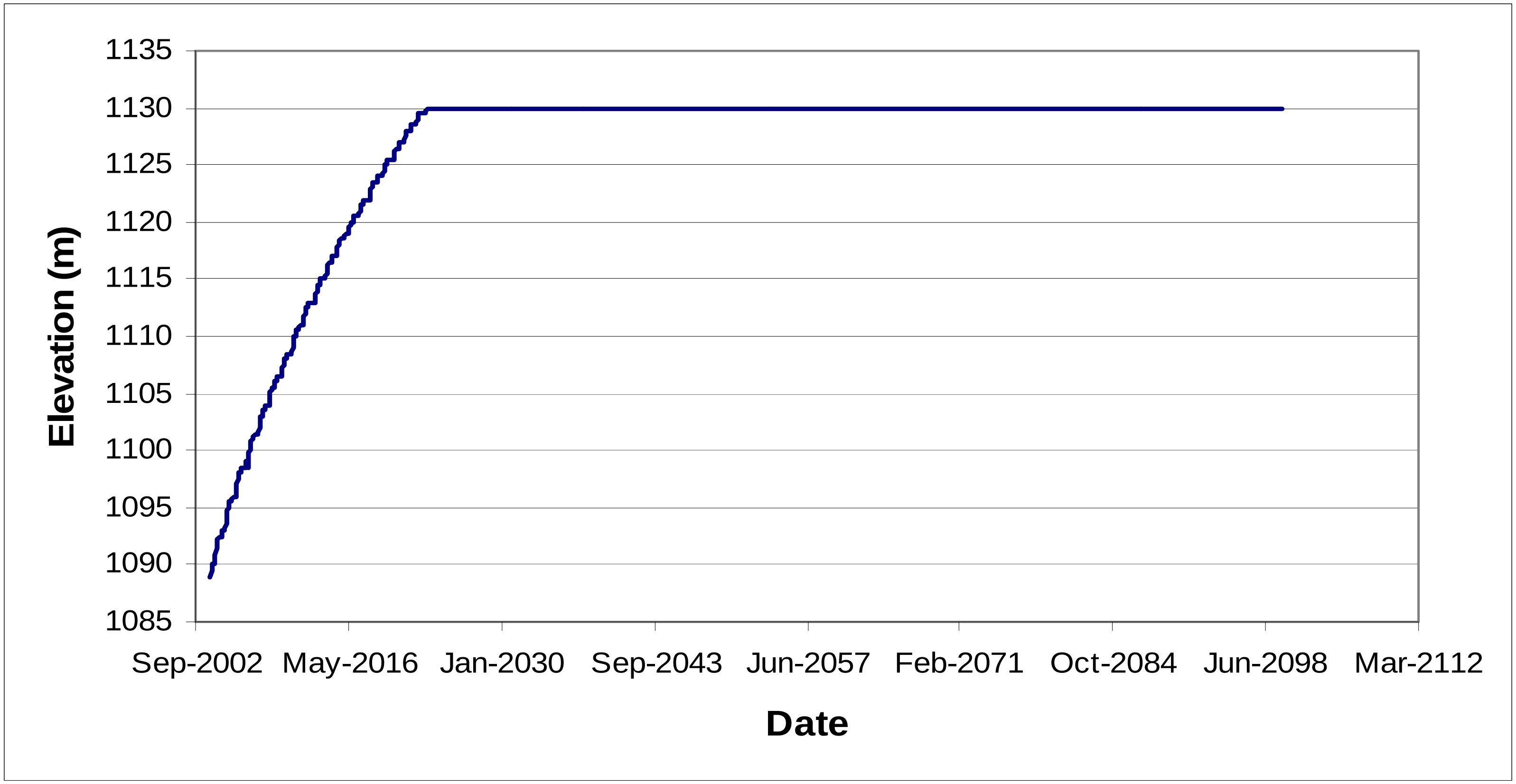

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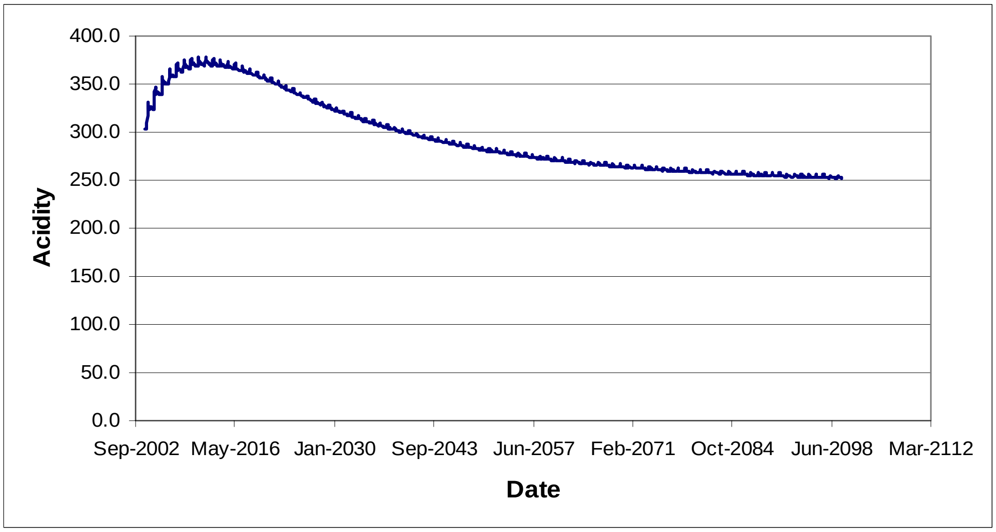
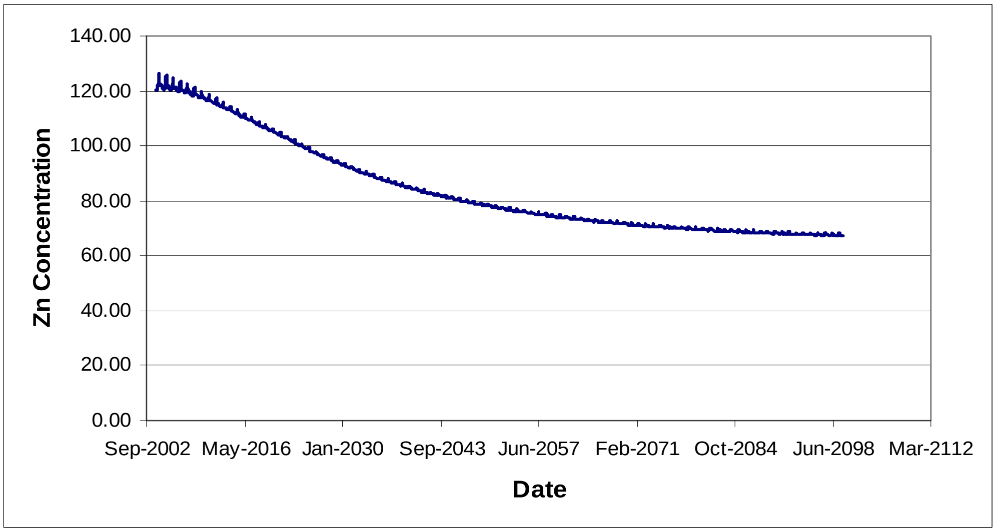
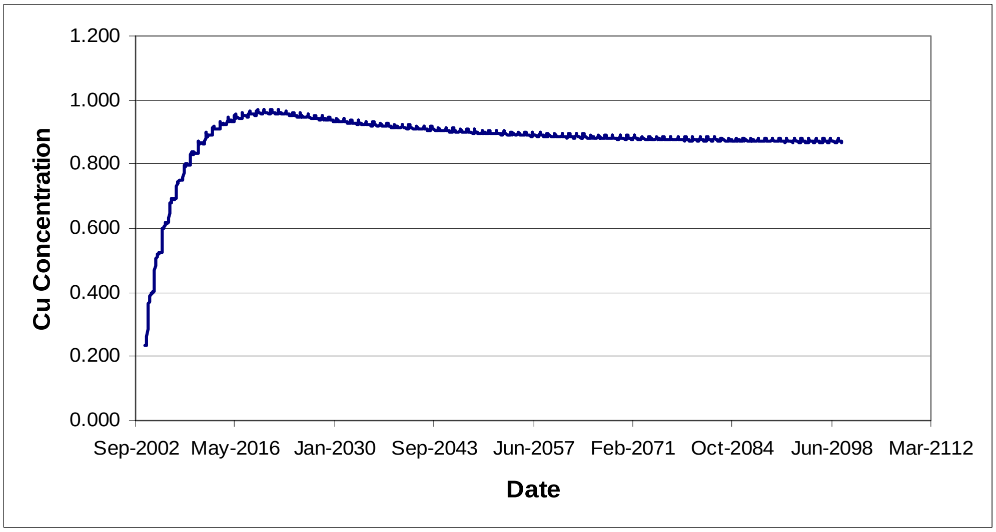
Anvil Range Pit Lakes
Assessment of Post Closure Conditions

**Estimated Filling Period for Vangorda Pit with Vangorda Creek diversion maintained**

| PROJECT | DATE | APPROVED | FIGURE |
|---|---|---|---|
| 1CD003.046 | Nov 2004 | | **4.16** |







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Anvil Range Pit Lakes
Assessment of Post Closure Conditions

**Estimated Vangorda Pit Lake Water Quality**
**Vangorda Creek diversion maintained**

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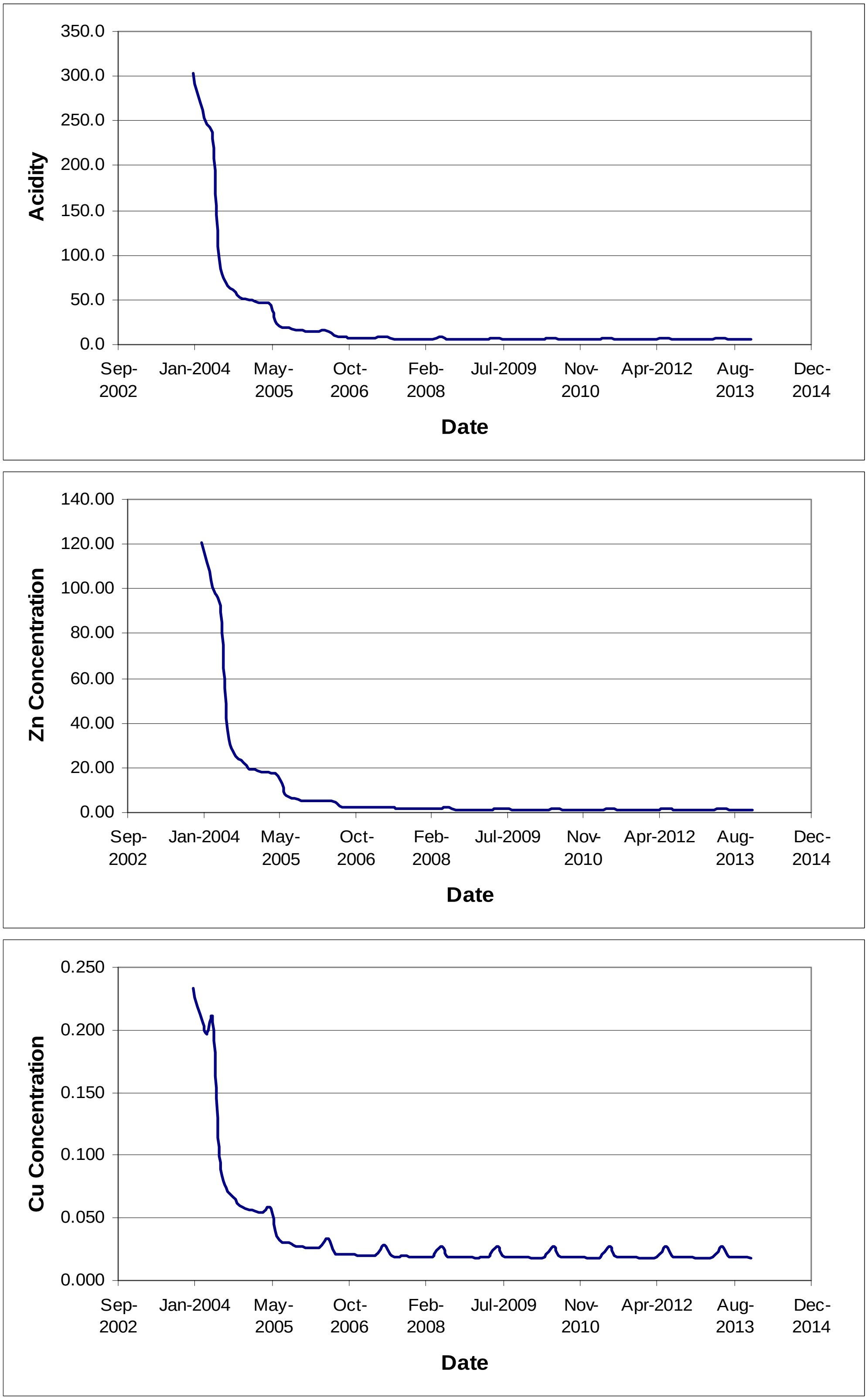
| PROJECT | DATE | APPROVED | FIGURE |
|---|---|---|---|
| 1CD003.46 | Nov. 2004 | | **4.17** |



FILE REF: Figures 3-1_3-14.xls

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Anvil Range Pit Lakes
Assessment of Post Closure Conditions

**Estimated Vangorda Pit Lake Water Quality**
**In-pit dumps removed**

| PROJECT | DATE | APPROVED | FIGURE |
|---|---|---|---|
| 1CD003.46 | Nov. 2004 | | **4.18** |

# Appendix A

## Description and Nomenclature of Anvil Range Rock Types

## Geochemical Studies Logging Guide

## Faro Area Rock Types

| | |
|---|---|
| 1D | Non-carbonaceous fine-grained schist containing muscovite, biotite and andalusite. Typically contains finely disseminated pyrite or pyrrhotite along foliations. May contain quartz veins with coarse grained pyrite and/or chalcopyrite. Occassionally contains calcite in fractures and along foliations. Often loose but sometimes cemented by white salts. May be blocky or fine-grained.<br>A variety of 1D is maroon-stained and typically contains more visible pyrite and calcite. Sometimes appears to be a transitional form between 1D and 1D4. |
| 1C6 | Same as above but with biotite and andalusite porphyroblasts along foliation |
| 1D2 | Carbonaceous fine-grained schist. Typically friable with abundant fines. |
| 1D4 | Quartz muscovite schist. In palest form, is extremely friable and decomposed. Fine-grained pyrite may be visible. Oxidized fines are pale yellow to orange brown. Quartz veins typically contain pyrite. Rinse pH is strongly acidic (pH<3). See comment about maroon stained variety of 1D. |
| 2 | Sulphide rock types. These include massive to semi-massive siliceous pyrite occurring as blocks (brown stained), massive crumbly pyrite occurring as blocks and fines (no stain), and massive sphalerite. Barite is common. |
| 3D0 | Amphibolite and calc-silicate schist. Distinctive centimetre-scale light and dark banding. Calcite is common both as a matrix component and as a fracture filling. Rare sulphides. Typically blocky. |
| 6 | Milky quartz. Informal name. |
| 10E | Hornblende biotite quartz diorite. Dark porphyritic rock type. Typically blocky and stable but also rapidly decomposing and fines forming. |
| 10F | Quartz feldspar porphyry. Distinctive white rock and 1 mm biotite and hornblende phenocrysts. Typically blocky and stable but also rapidly decomposing and fines forming. |
| 5 or T | Overburden. Till. |

## Grum and Vangorda Area

| Units | | Symbols Used on Field Maps |
|---|---|---|
| *Vangorda Formation* | | |
| 5C | Poorly foliated greenstone | |
| 5D | Chlorite phyllite, calcareous | 5D0, 5D4 |
| 5B0 | Calcareous phyllite, silver to dark grey | 5B |
| 5A0 | Carbonaceous phyllite, weakly calcareous | 5A |
| *Mount Mye Formation* | | |
| 3G0 | Non-calcareous phyllite | 3G |
| 4EC | Undifferentiated massive and disseminated sulphides | |
| 4E | Massive pyritic sulphides (60 to 100% pyrite) | |
| 4C | Pyritic quartzite (<30% pyrite) | |
| 4L0 | Bleached phyllite, commonly pyritic | 4L |

**Modifiers**

| | |
|---|---|
| ca | Calcareous |
| py | Pyritic |
| ox | Oxidized |
| st | Visible salts (describe type in notes) |
| gn | Galena |
| sl | Sphalerite |
| bl | Blocky (describe in notes) |
| sk | Slaking (describe in notes) |
| ms | Massive sulphide |

**Clast sizes**

| | |
|---|---|
| m>cm: | Coarse |
| cm/m: | Mixed metre and centimetre scale |
| mm>cm>>m | Fine Frained |

**Mapping Conventions**

| | |
|---|---|
| 3D0ox/10Fsk | About equal quantities. |
| 10% 3D0ox/90% 10Fsk | Proportions indicated |

**Symbols**

| | |
|---|---|
| — | Distinct contact |
| - - - | Indistinct contact |
| ☁ | FD – Free dumped area |
| * | Small cluster of sulphide boulders |
| • GUS-01 | Fine screened sample location for contact test |

# Appendix B

## Pit Wall Seep Sampling Results

# Appendix B.1

## Faro Pit Seeps

| **Yr-Sample ID** | **04FP01** | **04FP02** | **04FP03** | **04FP04** | **04FP05** | **04FP06** | **04FP07** |
|---|---|---|---|---|---|---|---|
| **Sample ID** | FP01 | FP02 | FP03 | FP04 | FP05 | FP06 | FP07 |
| **Source rock type** | Calc-silicate with WR/ LG ore influence | Calc-silicate | 4E (barren sulphides)/ 4C (white mica envelope) mix | HBL diorite w/ some sulphide influence | HBL Diorite | Till/ 1D4 (not a good 1D4 source) | Hbl Qtz Diorite |
| Date | 6/3/2004 | 6/3/2004 | 6/3/2004 | 6/3/2004 | 6/3/2004 | 6/3/2004 | 6/3/2004 |
| **Field Parameters** | | | | | | | |
| pH | 6.54 | 7.46 | 3.02 | 7.32 | 8.12 | 7.23 | 7.03 |
| Conductivity | 3630 | 1170 | 5180 | 616 | 1038 | 275 | 379 |
| Temp | 11.5 | 11.1 | 12.4 | 12.5 | 14.8 | 11.2 | 4.2 |
| Redox | 411 | 376 | 654 | 346 | 328 | 433 | 421 |
| Flow | 4 | 4 | 25 | 600 | 7.5 | not recorded | 400 |
| **Notes** | | | | | | | |
| Easting (NAD 27) | 584413 | 584173 | 584148 | 584193 | 584240 | 584871 | 584116 |
| Northing (NAD 27) | 6914558 | 6914915 | 6915209 | 6915282 | 6915303 | 6915031 | 6915428 |
| **Laboratory Parameters** | | | | | | | |
| pH | 7.29 | 8.01 | 2.94 | 8.05 | 8.11 | 7.84 | 7.99 |
| Conductivity | 3540 | 1150 | 5120 | 600 | 983 | 277 | 393 |
| **Dissolved Anions** | | | | | | | |
| Acidity pH 8.3 | 80.6 | 2.4 | 1960 | 4.2 | 3.9 | 1 | 4.1 |
| Alkalinity Total as CaCO3 | 280 | 139 | <1.0 | 239 | 293 | 119 | 193 |
| Chloride | 44.2 | 0.64 | 0.94 | <0.50 | <0.50 | <0.50 | <0.50 |
| Sulphate | 2310 | 428 | 4100 | 99.4 | 287 | 21.7 | 25.5 |
| **Dissolved Metals** | | | | | | | |
| Aluminum | <0.20 | <0.20 | 2.5 | <0.20 | <0.20 | <0.20 | <0.20 |
| Antimony | <0.20 | <0.20 | <1.0 | <0.20 | <0.20 | <0.20 | <0.20 |
| Arsenic | <0.20 | <0.20 | <1.0 | <0.20 | <0.20 | <0.20 | <0.20 |
| Barium | <0.010 | 0.014 | <0.050 | 0.036 | 0.031 | 0.016 | 0.062 |
| Beryllium | <0.0050 | <0.0050 | <0.025 | <0.0050 | <0.0050 | <0.0050 | <0.0050 |
| Bismuth | <0.20 | <0.20 | <1.0 | <0.20 | <0.20 | <0.20 | <0.20 |
| Boron | <0.10 | <0.10 | <0.70 | <0.10 | <0.10 | <0.10 | <0.10 |
| Cadmium | 0.022 | <0.010 | 0.904 | <0.010 | <0.010 | <0.010 | <0.010 |
| Calcium | 631 | 44.4 | 302 | 58.6 | 94.2 | 32.8 | 50.4 |
| Chromium | <0.010 | <0.010 | <0.050 | <0.010 | <0.010 | <0.010 | <0.010 |
| Cobalt | 0.047 | <0.010 | 1.55 | <0.010 | <0.010 | <0.010 | <0.010 |
| Copper | 0.014 | <0.010 | 2.55 | <0.010 | <0.010 | <0.010 | <0.010 |
| Iron | <0.030 | <0.030 | 192 | <0.030 | <0.030 | <0.030 | <0.030 |
| Lead | <0.050 | <0.050 | 0.95 | <0.050 | <0.050 | <0.050 | <0.050 |
| Lithium | 0.097 | 0.032 | 0.131 | 0.043 | 0.055 | 0.021 | <0.010 |
| Magnesium | 171 | 10.1 | 413 | 28.4 | 59.2 | 10.4 | 13.2 |
| Manganese | 6.01 | <0.0050 | 82 | 0.0928 | <0.0050 | <0.0050 | <0.0050 |
| Molybdenum | <0.030 | <0.030 | <0.15 | <0.030 | <0.030 | <0.030 | <0.030 |
| Nickel | 0.194 | <0.050 | 1.41 | <0.050 | <0.050 | <0.050 | <0.050 |
| Phosphorus | <0.30 | <0.30 | <1.5 | <0.30 | <0.30 | <0.30 | <0.30 |
| Potassium | 8.2 | <2.0 | <10 | 3.1 | 6.1 | 2.2 | <2.0 |
| Selenium | <0.20 | <0.20 | <1.0 | <0.20 | <0.20 | <0.20 | <0.20 |
| Silicon | 7 | 2.61 | 3.86 | 0.989 | 0.808 | 4.66 | 1.75 |
| Silver | <0.010 | <0.010 | <0.050 | <0.010 | <0.010 | <0.010 | <0.010 |
| Sodium | 58.3 | 150 | <10 | 14.9 | 35.6 | 3 | 2.6 |
| Strontium | 2.24 | 1.2 | 0.796 | 1.66 | 3.24 | 0.234 | 0.536 |
| Thallium | <0.20 | <0.20 | <1.0 | <0.20 | <0.20 | <0.20 | <0.20 |
| Tin | <0.030 | <0.030 | <0.15 | <0.030 | <0.030 | <0.030 | <0.030 |
| Titanium | 0.012 | <0.010 | <0.050 | <0.010 | <0.010 | <0.010 | <0.010 |
| Vanadium | <0.030 | <0.030 | <0.15 | <0.030 | <0.030 | <0.030 | <0.030 |
| Zinc | 45.2 | 0.0509 | 875 | 0.832 | <0.0050 | <0.0050 | <0.0050 |

# Appendix B.2

## Grum Pit Seeps

| **Yr-Sample ID** | **03GP01** | **03GP02** | **03GP04** | **03GP05** | **03GP06** | **04GP01** | **04GP02** | **04GP03** | **04GP04** |
|---|---|---|---|---|---|---|---|---|---|
| **Sample ID** | SRK-GP01 | SRK-GP02 | SRK-GP04 | SRK-GP05 | SRK-GP06 | GP01 | GP02 | GP03 | GP04 |
| **Source rock type** | ore/ undiff. sulphides | ore/ undiff. sulphides | Mixed phyllite | Mixed phyllite | Mixed phyllite | Mixed phyllite | Mixed phyllite | Mixed phyllite | Till/ deep groundwater |
| Date | 6/9/2003 | 6/9/2003 | 6/9/2003 | 6/9/2003 | 6/9/2003 | 5/31/2004 | 5/31/2004 | 5/31/2004 | 5/31/2004 |
| **Field Parameters** | | | | | | | | | |
| pH | 8.05 | 7.28 | 8.21 | 7.88 | 8.36 | 7.81 | 7.96 | 8 | 7.95 |
| Conductivity | 1928 | 1456 | 1896 | 1289 | 1755 | 946 | 1174 | 764 | 341 |
| Temp | 12.7 | 13.7 | 15.4 | 3.7 | 11.2 | 12 | 8.6 | 5.5 | 4.3 |
| Redox | 635 | 622 | 617 | 586 | 462 | 346 | 1357 | 334 | 351 |
| Flow | 2 | Trace | 1 | 3 | Trace | Trace | 15 | 15 | 60 |
| **Notes** | | | | | | | | | |
| Easting (NAD 27) | 592306 | 592241 | 592220 | 592123 | 592081 | 592057 | 592025 | 592009 | 592659 |
| Northing (NAD 27) | 6905309 | 6905243 | 6905228 | 6905120 | 6905001 | 6904872 | 6904962 | 6905010 | 6905112 |
| **Laboratory Parameters** | | | | | | | | | |
| pH | 7.8 | 7.51 | 8.08 | 7.65 | 8.13 | 8.29 | 8.29 | 8.31 | 8.28 |
| Conductivity | 1850 | 1550 | 1780 | 1240 | 1660 | 935 | 1190 | 757 | 346 |
| **Dissolved Anions** | | | | | | | | | |
| Acidity pH 8.3 | 37 | 51 | 20 | 36 | 11 | <1.0 | <1.0 | <1.0 | <1.0 |
| Alkalinity Total as CaCO3 | 373 | 189 | 266 | 223 | 264 | 139 | 210 | 187 | 145 |
| Chloride | -0.5 | -0.5 | -0.5 | -0.5 | 2.7 | 0.78 | 2.3 | 0.86 | <0.50 |
| Sulphate | 989 | 932 | 1050 | 627 | 995 | 359 | 456 | 225 | 34.7 |
| **Dissolved Metals** | | | | | | | | | |
| Aluminum | -0.2 | -0.2 | -0.2 | -0.2 | -0.2 | <0.20 | <0.20 | <0.20 | <0.20 |
| Antimony | -0.2 | -0.2 | -0.2 | -0.2 | -0.2 | <0.20 | <0.20 | <0.20 | <0.20 |
| Arsenic | -0.2 | -0.2 | -0.2 | -0.2 | -0.2 | <0.20 | <0.20 | <0.20 | <0.20 |
| Barium | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.014 | 0.011 | 0.017 | 0.109 |
| Beryllium | -0.005 | -0.005 | -0.005 | -0.005 | -0.005 | <0.0050 | <0.0050 | <0.0050 | <0.0050 |
| Bismuth | -0.2 | -0.2 | -0.2 | -0.2 | -0.2 | <0.20 | <0.20 | <0.20 | <0.20 |
| Boron | -0.1 | -0.1 | -0.1 | -0.1 | -0.1 | <0.10 | <0.10 | <0.10 | <0.10 |
| Cadmium | -0.01 | -0.01 | -0.01 | -0.01 | -0.01 | <0.010 | <0.010 | <0.010 | <0.010 |
| Calcium | 239 | 197 | 268 | 158 | 90 | 94.9 | 117 | 64.8 | 46 |
| Chromium | -0.01 | -0.01 | -0.01 | -0.01 | -0.01 | <0.010 | <0.010 | <0.010 | <0.010 |
| Cobalt | 0.01 | 0.1 | 0.02 | 0.02 | -0.01 | <0.010 | <0.010 | <0.010 | <0.010 |
| Copper | -0.01 | -0.01 | -0.01 | -0.01 | -0.01 | <0.010 | <0.010 | <0.010 | <0.010 |
| Iron | -0.03 | -0.03 | -0.03 | -0.03 | -0.03 | <0.030 | <0.030 | <0.030 | <0.030 |
| Lead | -0.05 | -0.05 | -0.05 | -0.05 | -0.05 | <0.050 | <0.050 | <0.050 | <0.050 |
| Lithium | 0.02 | 0.02 | 0.03 | 0.03 | 0.05 | 0.023 | 0.017 | 0.02 | <0.010 |
| Magnesium | 167 | 112 | 144 | 96.9 | 235 | 70.9 | 97.1 | 59.6 | 9.78 |
| Manganese | 0.015 | 0.224 | 0.013 | -0.005 | -0.005 | <0.0050 | <0.0050 | <0.0050 | <0.0050 |
| Molybdenum | -0.03 | -0.03 | 0.06 | -0.03 | -0.03 | <0.030 | <0.030 | <0.030 | <0.030 |
| Nickel | 0.51 | 1.03 | 0.17 | 0.07 | -0.05 | 0.092 | 0.108 | 0.08 | <0.050 |
| Phosphorus | -0.3 | -0.3 | -0.3 | -0.3 | -0.3 | <0.30 | <0.30 | <0.30 | <0.30 |
| Potassium | 3 | 3 | 5 | 3 | 4 | 2.9 | 3.9 | 3.6 | <2.0 |
| Selenium | -0.2 | -0.2 | -0.2 | -0.2 | -0.2 | <0.20 | <0.20 | <0.20 | <0.20 |
| Silicon | 2.37 | 3.46 | 1.94 | 1.78 | 1.21 | 0.949 | 0.879 | 1.11 | 5.72 |
| Silver | -0.01 | -0.01 | -0.01 | -0.01 | -0.01 | <0.010 | <0.010 | <0.010 | <0.010 |
| Sodium | 6 | 8 | 6 | 5 | 5 | <2.0 | 3 | <2.0 | 6.9 |
| Strontium | 1.14 | 1.41 | 1.78 | 1.47 | 0.403 | 0.465 | 0.498 | 0.289 | 0.314 |
| Thallium | -0.2 | -0.2 | -0.2 | -0.2 | -0.2 | <0.20 | <0.20 | <0.20 | <0.20 |
| Tin | -0.03 | -0.03 | -0.03 | -0.03 | -0.03 | <0.030 | <0.030 | <0.030 | <0.030 |
| Titanium | -0.01 | -0.01 | -0.01 | -0.01 | -0.01 | <0.010 | <0.010 | <0.010 | <0.010 |
| Vanadium | -0.03 | -0.03 | -0.03 | -0.03 | -0.03 | <0.030 | <0.030 | <0.030 | <0.030 |
| Zinc | 6.69 | 14.3 | 0.073 | 0.03 | -0.005 | 0.0188 | 0.0238 | <0.0050 | <0.0050 |

| **Yr-Sample ID** | **04GP05** | **04GP06** | **04GP07** | **04GP08** | **04GP10** | **04GP11** | **04GP12** | **04GP13** | **04GP14** |
|---|---|---|---|---|---|---|---|---|---|
| **Sample ID** | GP05 | GP06 | GP07 | GP08 | GP10 | GP11 | GP12 | GP13 | GP14 |
| **Source rock type** | Till | Mixed phyllite | Mixed phyllite | Mixed phyllite | ore/ undiff. sulphides | ore/ undiff. sulphides | Mixed phyllite | Till (lake in sot) | Pyritic quartzite |
| Date | 5/31/2004 | 6/1/2004 | 6/1/2004 | 6/1/2004 | 6/1/2004 | 6/1/2004 | 6/1/2004 | 6/1/2004 | 6/1/2004 |
| **Field Parameters** | | | | | | | | | |
| pH | 7.87 | 7.41 | 8.09 | 8.34 | 8.45 | 7.5 | 7.94 | 8.28 | 6.78 |
| Conductivity | 1097 | 1744 | 1059 | 1206 | 1518 | 1442 | 1709 | 789 | 1371 |
| Temp | 17.4 | 12.4 | 8 | 7.9 | 7.3 | 10.8 | 14.6 | 12.8 | 3.9 |
| Redox | not recorded | 293 | 307 | 291 | not recorded | 321 | 303 | 303 | 256 |
| Flow | Trace | 0.1 | 5 | Trace | 9 | 0.25 | 0.1 | 0 | 15 |
| **Notes** | | | | | | | | | |
| Easting (NAD 27) | 592765 | 592123 | 592146 | 592169 | 592301 | 592236 | 592222 | 592611 | 592480 |
| Northing (NAD 27) | 6904941 | 6905120 | 6905136 | 6905153 | 6905303 | 6905238 | 6905215 | 6904459 | 6904642 |
| **Laboratory Parameters** | | | | | | | | | |
| pH | 7.87 | 7.96 | 8.14 | 8.04 | 7.92 | 7.61 | 8.05 | 8.29 | 6.67 |
| Conductivity | 1190 | 1770 | 1090 | 1280 | 1520 | 1480 | 1680 | 775 | 1340 |
| **Dissolved Anions** | | | | | | | | | |
| Acidity pH 8.3 | 3.3 | 2.3 | <1.0 | 3.7 | 5.8 | 13.4 | 4 | <1.0 | 173 |
| Alkalinity Total as CaCO3 | 99.2 | 297 | 245 | 268 | 273 | 217 | 280 | 91.8 | 28.5 |
| Chloride | 0.76 | 1.5 | 0.84 | 0.61 | <0.50 | <0.50 | 0.63 | 0.74 | 1.18 |
| Sulphate | 590 | 853 | 403 | 513 | 716 | 733 | 849 | 350 | 782 |
| **Dissolved Metals** | | | | | | | | | |
| Aluminum | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 |
| Antimony | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 |
| Arsenic | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | 0.34 |
| Barium | 0.342 | 0.011 | 0.024 | 0.015 | 0.011 | 0.014 | 0.018 | 0.043 | 0.03 |
| Beryllium | <0.0050 | <0.0050 | <0.0050 | <0.0050 | <0.0050 | <0.0050 | <0.0050 | <0.0050 | <0.0050 |
| Bismuth | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 |
| Boron | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 |
| Cadmium | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | 0.098 |
| Calcium | 185 | 103 | 83.9 | 144 | 173 | 176 | 216 | 103 | 113 |
| Chromium | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 |
| Cobalt | <0.010 | <0.010 | <0.010 | 0.011 | 0.022 | 0.101 | 0.018 | <0.010 | 0.529 |
| Copper | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | 1.73 |
| Iron | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | 72 |
| Lead | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | 0.074 |
| Lithium | <0.010 | 0.036 | 0.03 | 0.022 | <0.010 | 0.022 | 0.019 | 0.011 | 0.025 |
| Magnesium | 34.8 | 206 | 98.2 | 89.3 | 109 | 99.6 | 121 | 34.3 | 66.9 |
| Manganese | 0.0252 | 0.0149 | 0.0083 | 0.0168 | 0.0216 | 0.158 | 0.0102 | 0.558 | 17.4 |
| Molybdenum | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | 0.046 | <0.030 | <0.030 |
| Nickel | <0.050 | 0.056 | <0.050 | 0.052 | 0.418 | 1.03 | 0.13 | <0.050 | 0.65 |
| Phosphorus | <0.30 | <0.30 | <0.30 | <0.30 | <0.30 | <0.30 | <0.30 | <0.30 | <0.30 |
| Potassium | 5.2 | 3.8 | 2.5 | 2.9 | 2.7 | 3 | 4.8 | 2.9 | <2.0 |
| Selenium | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 |
| Silicon | 1.4 | 1.33 | 0.887 | 1.58 | 1.44 | 3.06 | 1.74 | 0.726 | 5.57 |
| Silver | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 |
| Sodium | 14.7 | 4.1 | <2.0 | 4 | 2.7 | 5.8 | 4.8 | 8.3 | 16 |
| Strontium | 0.745 | 0.516 | 0.418 | 1.37 | 0.805 | 1.25 | 1.45 | 0.35 | 0.552 |
| Thallium | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 |
| Tin | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 |
| Titanium | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 |
| Vanadium | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 |
| Zinc | <0.0050 | <0.0050 | <0.0050 | 0.0133 | 7.5 | 12 | 0.0326 | 0.0307 | 97.5 |

# Appendix B.3

## Vangorda Pit Seeps

| **Yr-Sample ID** | **04VP01** | **04VP02** | **04VP03** | **04VP04** | **04VP05** | **04VP06** | **04VP07** | **04VP08** | **04VP09** |
|---|---|---|---|---|---|---|---|---|---|
| **Sample ID** | VP01 | VP02 | VP03 | VP04 | VP05 | VP06 | VP07 | VP08 | VP09 |
| **Source rock type** | Mt Mye Fm non-calc phyllite | Massive pyritic sulphides | Till | Massive pyritic sulphides | Massive pyritic sulphides | Bleached phyllite/ massive sulphides | Bleached phyllite/ massive sulphides | Massive pyritic sulphides | Massive pyritic sulphides |
| Date | 5/31/2004 | 6/1/2004 | 6/1/2004 | 6/1/2004 | 6/1/2004 | 6/1/2004 | 6/1/2004 | 6/2/2004 | 6/2/2004 |
| **Field Parameters** | | | | | | | | | |
| pH | 7.27 | 2.95 | 7.57 | 3.96 | 5.58 | 2.7 | 3.15 | 2.84 | 5.62 |
| Conductivity | 181 | 1261 | 405 | 7390 | 2810 | 12.9 | 5750 | 9110 | 1033 |
| Temp | 8.4 | 14.5 | 20.5 | 17.8 | 8.3 | 10210 | 11.3 | 6.9 | 4.4 |
| Redox | 382 | 672 | not recorded | 480 | 254 | 712 | 616 | 607 | 326 |
| Flow | 6 | 15 | 0.25 | 2 | Trace | Trace | 1 | Trace | 2 |
| **Notes** | | | | | | | | | |
| Easting (NAD 27) | 594111 | 594513 | 594386 | 594419 | 594237 | 594269 | 594297 | 594208 | 594186 |
| Northing (NAD 27) | 6903499 | 6902916 | 6903000 | 6902875 | 6903066 | 6903035 | 6902993 | 6903111 | 6903176 |
| **Laboratory Parameters** | | | | | | | | | |
| pH | 8.04 | 2.83 | 8.17 | 3.61 | 5.14 | 2.74 | 2.89 | 3.08 | 6.55 |
| Conductivity | 174 | 1240 | 405 | 7410 | 2750 | 10100 | 5830 | 8350 | 940 |
| **Dissolved Anions** | | | | | | | | | |
| Acidity pH 8.3 | 1.3 | 408 | <1.0 | 4370 | 643 | 3270 | 2070 | 3570 | 115 |
| Alkalinity Total as CaCO3 | 59.5 | <1.0 | 201 | <1.0 | 10.6 | <1.0 | <1.0 | <1.0 | 24.1 |
| Chloride | <0.50 | 0.57 | 0.62 | <0.50 | 0.75 | <0.50 | 1.02 | 1.19 | <0.50 |
| Sulphate | 23.3 | 582 | 25.1 | 7070 | 1930 | 11139 | 5110 | 8080 | 485 |
| **Dissolved Metals** | | | | | | | | | |
| Aluminum | <0.20 | 7.38 | <0.20 | 45.6 | <0.40 | 19.1 | 54.6 | 12.1 | <0.20 |
| Antimony | <0.20 | <0.20 | <0.20 | <2.0 | <0.40 | <2.0 | <0.60 | <2.0 | <0.20 |
| Arsenic | <0.20 | <0.20 | <0.20 | <2.0 | <0.40 | <2.0 | <0.60 | <2.0 | <0.20 |
| Barium | 0.025 | 0.014 | 0.034 | <0.10 | 0.021 | <0.10 | <0.030 | <0.10 | 0.018 |
| Beryllium | <0.0050 | <0.0050 | <0.0050 | <0.050 | <0.010 | <0.050 | <0.015 | <0.050 | <0.0050 |
| Bismuth | <0.20 | <0.20 | <0.20 | <2.0 | <0.40 | <2.0 | <0.60 | <2.0 | <0.20 |
| Boron | <0.10 | <0.10 | <0.10 | <1.0 | <0.20 | <1.0 | <0.30 | <1.0 | <0.10 |
| Cadmium | <0.010 | 0.025 | <0.010 | 3.21 | 0.059 | 1.08 | 0.823 | 1.13 | 0.045 |
| Calcium | 27 | 28.1 | 52.8 | 221 | 232 | 404 | 363 | 455 | 98.6 |
| Chromium | <0.010 | <0.010 | <0.010 | <0.10 | <0.020 | <0.10 | <0.030 | <0.10 | <0.010 |
| Cobalt | <0.010 | 0.345 | <0.010 | 4.65 | 0.844 | 9.14 | 3.34 | 4.25 | 0.187 |
| Copper | <0.010 | 4.75 | <0.010 | 41.3 | 0.025 | 11.9 | 8.64 | 1.77 | <0.010 |
| Iron | <0.030 | 129 | <0.030 | 1410 | 166 | 421 | 492 | 860 | 50 |
| Lead | <0.050 | 0.436 | <0.050 | 2.49 | <0.10 | <0.50 | 0.91 | <0.50 | <0.050 |
| Lithium | <0.010 | 0.011 | <0.010 | <0.10 | 0.103 | 0.33 | 0.2 | 0.35 | 0.03 |
| Magnesium | 2.33 | 13.3 | 14.7 | 226 | 131 | 918 | 326 | 675 | 32.7 |
| Manganese | <0.0050 | 7.34 | 0.0084 | 168 | 90 | 924 | 312 | 559 | 21.4 |
| Molybdenum | <0.030 | <0.030 | <0.030 | <0.30 | <0.060 | <0.30 | <0.090 | <0.30 | <0.030 |
| Nickel | <0.050 | 0.075 | <0.050 | 2.11 | 0.65 | 3.77 | 1.69 | 3.34 | 0.076 |
| Phosphorus | <0.30 | <0.30 | <0.30 | <3.0 | <0.60 | <3.0 | <0.90 | <3.0 | <0.30 |
| Potassium | <2.0 | <2.0 | <2.0 | <20 | 7.9 | <20 | 9.5 | <20 | 2.2 |
| Selenium | <0.20 | <0.20 | <0.20 | <2.0 | <0.40 | <2.0 | <0.60 | <2.0 | <0.20 |
| Silicon | 3.92 | 8.53 | 5.89 | 15.7 | 5.88 | 13.5 | 19.7 | 24 | 5.08 |
| Silver | <0.010 | <0.010 | <0.010 | <0.10 | <0.020 | <0.10 | <0.030 | <0.10 | <0.010 |
| Sodium | <2.0 | 2.1 | 6 | <20 | 5.1 | <20 | <6.0 | <20 | 4.9 |
| Strontium | 0.087 | 0.145 | 0.304 | 0.258 | 0.807 | 1.11 | 0.946 | 1.52 | 0.488 |
| Thallium | <0.20 | <0.20 | <0.20 | <2.0 | <0.40 | <2.0 | <0.60 | <2.0 | <0.20 |
| Tin | <0.030 | <0.030 | <0.030 | <0.30 | <0.060 | <0.30 | <0.090 | <0.30 | <0.030 |
| Titanium | <0.010 | <0.010 | <0.010 | <0.10 | <0.020 | <0.10 | <0.030 | <0.10 | <0.010 |
| Vanadium | <0.030 | <0.030 | <0.030 | <0.30 | <0.060 | <1.0 | <0.30 | <1.0 | <0.030 |
| Zinc | 0.0074 | 12.1 | <0.0050 | 1530 | 229 | 1550 | 558 | 1550 | 48.1 |

| **Yr-Sample ID** | **04VP10** | **04VP11** | **04VP12** | **04VP13** | **04VP14** | **04VP15** | **04VP16** |
|---|---|---|---|---|---|---|---|
| **Sample ID** | VP10 | VP11 | VP12 | VP13 | VP14 | VP15 | VP16 |
| **Source rock type** | Vangorda Fm Non-calc phyllite | Mt Mye Fm Non-calc phyllite + sx | Mt Mye Fm Non-calc phyllite | Mt Mye Fm Non-calc phyllite | Pyritic quartzite | Pyritic quartzite | Pyritic Quartzite |
| Date | 6/2/2004 | 6/2/2004 | 6/2/2004 | 6/2/2004 | 6/2/2004 | 6/2/2004 | 6/2/2004 |
| **Field Parameters** | | | | | | | |
| pH | 6.33 | 3.44 | 7.18 | 6.82 | 7.18 | 7.1 | 3.71 |
| Conductivity | 809 | 1465 | 1372 | 2080 | 583 | 1243 | 2980 |
| Temp | 13.3 | 11.9 | 12.6 | 12 | 12.6 | 12.8 | 15.1 |
| Redox | 354 | 666 | 431 | 455 | 443 | 458 | 634 |
| Flow | Trace | 90 | Trace | Trace | 0.25 | Trace | 0.1 |
| **Notes** | | | | | | | |
| Easting (NAD 27) | 593847 | 593924 | 593906 | 593975 | 594094 | 594083 | 594100 |
| Northing (NAD 27) | 6903325 | 6903483 | 6903462 | 6903479 | 6903329 | 6903341 | 6903312 |
| **Laboratory Parameters** | | | | | | | |
| pH | 3.67 | 7.32 | 8 | 7.24 | 7.46 | 7.4 | 4.08 |
| Conductivity | 1400 | 773 | 1330 | 2020 | 568 | 1230 | 2920 |
| **Dissolved Anions** | | | | | | | |
| Acidity pH 8.3 | 356 | 17.4 | 8.4 | 87.5 | 35 | 75 | 766 |
| Alkalinity Total as CaCO3 | <1.0 | 150 | 216 | 14 | 90 | 15.5 | <1.0 |
| Chloride | <0.50 | <0.50 | <0.50 | 1.37 | <0.50 | <0.50 | 1.08 |
| Sulphate | 797 | 286 | 600 | 1370 | 212 | 684 | 2200 |
| **Dissolved Metals** | | | | | | | |
| Aluminum | 4 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | 49.3 |
| Antimony | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 |
| Arsenic | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | 0.2 |
| Barium | 0.017 | 0.018 | 0.015 | 0.011 | 0.041 | 0.011 | <0.010 |
| Beryllium | <0.0050 | <0.0050 | <0.0050 | <0.0050 | <0.0050 | <0.0050 | 0.0132 |
| Bismuth | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 |
| Boron | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 |
| Cadmium | 0.322 | <0.010 | <0.010 | <0.010 | 0.036 | 0.036 | 0.284 |
| Calcium | 105 | 129 | 199 | 324 | 70.2 | 166 | 298 |
| Chromium | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 |
| Cobalt | 0.355 | 0.05 | <0.010 | 0.113 | 0.072 | 0.144 | 1.41 |
| Copper | 1.54 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | 2.37 |
| Iron | 6.14 | 1.4 | <0.030 | <0.030 | <0.030 | <0.030 | 4.17 |
| Lead | 0.685 | <0.050 | <0.050 | <0.050 | <0.050 | 0.101 | 1.85 |
| Lithium | 0.048 | <0.010 | 0.045 | 0.157 | 0.01 | 0.072 | 0.309 |
| Magnesium | 55.6 | 29 | 77.2 | 91.8 | 21.6 | 44.5 | 147 |
| Manganese | 16.1 | 0.698 | 0.245 | 31.7 | 4.13 | 15 | 51.9 |
| Molybdenum | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 |
| Nickel | 0.603 | 0.125 | 0.087 | 0.646 | 0.183 | 0.745 | 2.51 |
| Phosphorus | <0.30 | <0.30 | <0.30 | <0.30 | <0.30 | <0.30 | <0.30 |
| Potassium | <2.0 | <2.0 | 2.4 | 3.1 | <2.0 | <2.0 | 4.2 |
| Selenium | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 |
| Silicon | 8.99 | 5.76 | 2.02 | 3.14 | 4.39 | 3.52 | 20.9 |
| Silver | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 |
| Sodium | <2.0 | 3 | 2.3 | 2.4 | 2.1 | 2.3 | 5.2 |
| Strontium | 0.447 | 1.38 | 1.05 | 1.18 | 0.334 | 0.794 | 1.23 |
| Thallium | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | <0.20 | 0.2 |
| Tin | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 |
| Titanium | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 |
| Vanadium | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 | <0.030 |
| Zinc | 180 | 5.19 | 2.86 | 42 | 19.9 | 37.7 | 238 |

# Appendix C

## Pit Lake Routine Monitoring Results

# Appendix C.1

## Faro Pit

X22B, Faro Pit water

| Date | pH Field s.u. | pH Lab s.u. | ALK-T mg/L | SO4-D mg/L | SO4-T mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Al mg/L | Cd mg/L | Co mg/L | Cu mg/L | Fe mg/L | Pb mg/L | Mn mg/L | Ni mg/L | Zn - D mg/L | Zn - T mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 21-Jun-96 | 7.72 | | 123 | | 731 | 135.2 | 50.3 | | 27 | -0.05 | 0.012 | 0.041 | 0.009 | 0.18 | 0.11 | 4.19 | 0.155 | | 7.80 |
| 17-Jul-96 | 7.3 | | | | 686 | | | | | | | | | | | | | 8.56 | |
| 15-Aug-96 | 7.78 | | 122 | | 678 | 130.2 | 46.0 | | 27 | 0.05 | 0.012 | 0.040 | 0.045 | 0.15 | 0.22 | 3.77 | 0.111 | | 4.08 |
| 12-Sep-96 | | | | | 741 | 163.8 | 56.5 | | 43 | 0.13 | 0.013 | 0.049 | 0.045 | 0.96 | 0.03 | 5.05 | 0.059 | | 4.01 |
| 21-Oct-96 | 6.50 | | 126 | | 531 | 128.9 | 45.1 | | 37 | 0.05 | 0.010 | 0.043 | 0.047 | 0.24 | -0.02 | 3.28 | 0.077 | | 3.33 |
| 21-Nov-96 | 7.51 | | | | 636 | 130.3 | 45.3 | | 40 | -0.05 | 0.006 | 0.032 | 0.023 | 0.16 | 0.02 | 3.23 | 0.094 | | 3.70 |
| 19-Dec-96 | 7.51 | | | | 679 | 153.0 | 52.9 | | 37 | 0.40 | 0.006 | 0.029 | 0.032 | 2.33 | 0.27 | 3.78 | 0.108 | | 4.26 |
| 20-Jan-97 | | | 102 | | 709 | 144.4 | 49.0 | | 36 | 0.40 | 0.008 | 0.028 | 0.019 | 0.37 | -0.02 | 4.05 | 0.087 | | 4.20 |
| 11-Mar-97 | | | | | 493 | 138.8 | 44.6 | | 28 | 0.93 | 0.006 | 0.037 | 0.161 | 0.51 | 0.05 | 3.33 | 0.074 | | 1.57 |
| 15-Apr-97 | 7.12 | | | | 232 | 58.8 | 21.8 | 1.2 | 4 | 0.07 | 0.003 | 0.009 | 0.028 | 0.80 | 0.10 | 0.86 | 0.054 | | 5.82 |
| 4-May-97 | | 6.5 | | | 72 | 20.3 | 5.5 | 3 | 3 | -0.05 | 0.002 | 0.006 | 0.006 | 0.03 | -0.02 | 0.40 | -0.005 | 0.81 | 1.57 |
| 12-May-97 | 7.39 | | | | 190 | 53.1 | 17.9 | -1 | 11 | -0.05 | 0.003 | -0.005 | 0.055 | 0.04 | -0.02 | 1.23 | 0.025 | | 1.28 |
| 23-Jun-97 | 7.93 | | | | 549 | 140.8 | 44.1 | 5 | 25 | -0.05 | 0.003 | 0.017 | 0.081 | 0.22 | -0.02 | 2.81 | 0.063 | | 1.85 |
| 15-Jul-97 | 7.7 | | | | 105 | 166.5 | 53.9 | 13 | 33 | 0.24 | 0.006 | 0.033 | 0.107 | 0.27 | 0.05 | 3.58 | 0.073 | | 2.51 |
| 12-Aug-97 | 7.74 | | | | 208 | 135.3 | 46.5 | 13 | 29 | 0.10 | 0.007 | 0.034 | 0.059 | -0.01 | -0.02 | 3.16 | 0.061 | | 2.85 |
| 22-Sep-97 | 7.53 | | | | 206 | 152.6 | 49.7 | 12 | 29 | 0.10 | 0.005 | 0.038 | 0.113 | 0.21 | -0.02 | 3.14 | 0.073 | | 2.70 |
| 20-Oct-97 | 7.68 | | | | 541 | 144.0 | 47.2 | 11 | 27 | -0.05 | 0.003 | 0.024 | 0.053 | 0.13 | 0.04 | 2.76 | 0.057 | | 2.25 |
| 18-Nov-97 | 7.5 | | | | 591 | 157.9 | 47.3 | 15 | 28 | -0.05 | 0.010 | -0.005 | 0.165 | 0.50 | 0.09 | 3.46 | 0.065 | | 2.04 |
| 8-Dec-97 | 7.65 | | | | 548 | 154.6 | 47.1 | 15 | 28 | -0.05 | -0.002 | -0.005 | 0.158 | 0.11 | 0.09 | 3.11 | 0.065 | | 1.95 |
| 13-Jan-98 | 8.33 | | | | 529 | 144.6 | 42.3 | 9 | 27 | -0.05 | -0.002 | 0.014 | 0.152 | 0.13 | 0.07 | 2.73 | 0.055 | | 1.11 |
| 18-May-98 | 7.68 | | | | 195 | 25.8 | 8.2 | 2 | 7 | 0.11 | -0.002 | -0.005 | 0.038 | -0.01 | 0.03 | 0.38 | 0.015 | | 1.58 |
| 16-Jun-98 | 7.49 | | 111 | | 345 | 153.1 | 45.6 | 12 | 27 | 0.42 | 0.008 | 0.021 | 0.137 | 1.18 | 0.04 | 2.58 | 0.052 | | 2.85 |
| 20-Jun-98 | | | | | | 139.7 | 44.4 | 13 | 28 | 0.12 | 0.003 | 0.020 | 0.107 | 0.12 | -0.02 | 2.37 | 0.050 | | 2.11 |
| 21-Jul-98 | 7.31 | | | | 202 | 164.9 | 54.0 | 14 | 31 | 0.12 | 0.007 | 0.037 | 0.108 | 0.09 | -0.02 | 2.72 | 0.071 | | 2.67 |
| 10-Aug-98 | 7.23 | | | | 342 | 168.9 | 52.7 | 14 | 31 | 0.25 | 0.007 | 0.022 | 0.111 | 0.12 | 0.05 | 2.88 | 0.062 | 0.83 | 2.51 |
| 25-Sep-98 | | 8.03 | | | 623 | 172.4 | 55.1 | 14 | 33 | 0.17 | 0.003 | 0.029 | 0.082 | 0.06 | -0.02 | 2.87 | 0.064 | | 2.46 |
| 19-Oct-98 | 7.15 | | | 494 | 693 | 163.1 | 53.6 | 15 | 34 | 0.29 | -0.002 | 0.032 | 0.075 | 0.27 | 0.04 | 2.74 | 0.067 | 1.02 | 2.16 |
| 17-Nov-98 | 7.25 | | | | 614 | 194.9 | 60.1 | 19 | 35 | 0.19 | 0.008 | 0.025 | 0.099 | 0.20 | 0.02 | 2.78 | 0.061 | | 2.20 |
| 19-Jan-99 | 6.87 | | | | 574 | 119.7 | 58.4 | 7 | 16 | 0.13 | 0.030 | 0.013 | 0.050 | 0.08 | 0.08 | 1.42 | 0.090 | 9.79 | 16.95 |
| 22-Feb-99 | 7.42 | | | | 692 | 188.0 | 60.7 | 15 | 34 | 0.41 | 0.010 | 0.035 | 0.066 | 0.02 | -0.01 | 2.95 | 0.062 | 0.65 | 3.92 |
| 22-Mar-99 | | 7.11 | | | 546 | 130.7 | 50.8 | 9 | 20 | 0.30 | 0.025 | 0.037 | 0.062 | 0.17 | 0.04 | 2.80 | 0.056 | 8.35 | 14.98 |
| 17-May-99 | 6.91 | | | | 190 | 19.3 | 7.4 | 2 | 3 | -0.05 | -0.001 | -0.005 | 0.020 | 0.03 | -0.01 | 0.31 | 0.020 | 0.52 | 2.56 |
| 3-Jul-99 | 7.26 | | | | 478 | 125.2 | 46.1 | 11 | 20 | 0.37 | 0.009 | 0.042 | 0.040 | 0.95 | -0.01 | 2.55 | 0.073 | 5.67 | 8.50 |
| 27-Jul-99 | 7.74 | | | 571 | 581 | 120.5 | 46.6 | 10 | 19 | 0.25 | 0.005 | 0.051 | 0.033 | 0.24 | 0.05 | 2.52 | 0.069 | 2.28 | 5.56 |
| 12-Aug-99 | 7.72 | | | | 567 | 155.2 | 50.1 | 12 | 27 | -0.05 | -0.001 | 0.048 | 0.018 | 0.11 | -0.01 | 2.26 | 0.041 | 1.03 | 4.19 |
| 10-Sep-99 | 7.58 | | 98 | | 507 | 123.3 | 42.6 | 10 | 19 | 0.20 | 0.008 | 0.019 | 0.027 | 0.13 | -0.01 | 2.25 | 0.060 | 0.54 | 4.11 |
| 30-Oct-99 | 6.85 | | | | 638 | 131.0 | 43.8 | 6 | 25 | 0.12 | -0.001 | -0.005 | 0.013 | 0.29 | -0.01 | 2.56 | 0.039 | 2.26 | 4.31 |

| Date | pH Field s.u. | pH Lab s.u. | ALK-T mg/L | SO4-D mg/L | SO4-T mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Al mg/L | Cd mg/L | Co mg/L | Cu mg/L | Fe mg/L | Pb mg/L | Mn mg/L | Ni mg/L | Zn - D mg/L | Zn - T mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 23-Mar-00 |  | 7.96 | 105 |  | 548 | 151.0 | 53.6 | 15 | 20 | 0.36 | 0.008 | 0.069 | 0.018 | 0.07 | -0.01 | 2.72 | 0.059 | 2.58 | 7.49 |
| 15-May-00 | 7.29 |  |  |  | 620 | 153.8 | 54.6 | 12 | 23 | 0.52 | 0.010 | 0.041 | 0.026 | 0.79 | 0.04 | 2.53 | 0.058 | 1.17 | 5.51 |
| 26-Jun-00 | 7.58 |  |  |  | 457 | 136.3 | 48.4 | 12 | 22 | 0.26 | 0.008 | 0.042 | 0.037 | 0.16 | -0.01 | 2.36 | 0.081 | 1.34 | 7.64 |
| 25-Jul-00 | 6.93 |  |  |  | 536 | 130.8 | 47.2 | 11 | 25 | 0.13 | 0.017 | 0.062 | 0.033 | 0.55 | -0.01 | 2.40 | 0.101 | 0.54 | 8.09 |
| 29-Aug-00 | 7.37 |  |  |  | 545 | 153.3 | 53.7 | 13 | 25 | 0.31 | 0.016 | 0.039 | 0.030 | 0.28 | -0.01 | 2.47 | 0.102 | 7.06 | 8.56 |
| 25-Sep-00 | 7.47 |  |  |  | 597 | 142 | 53.9 | 10 | 24 | 0.09 | 0.009 | 0.04 | -0.01 | 0.2 | -0.05 | 2.51 | 0.07 | 9.09 | 9.02 |
| 29-Oct-00 |  |  |  |  | 779 | 135.6 | 50.6 | 12 | 28 | 0.42 | 0.016 | 0.031 | 0.051 | 0.43 | -0.01 | 2.69 | 0.071 | 1.87 | 9.83 |
| 13-Nov-00 | 7.4 |  |  |  | 620 | 152.3 | 56.9 | 13 | 29 | 0.06 | 0.012 | 0.051 | 0.008 | 0.12 | 0.01 | 3.63 | 0.089 | 10.75 | 11.29 |
| 18-Nov-00 |  |  |  |  | 1735 | 540 | 229 | 42 | 98 | 0.1 | 0.055 | 0.16 | 0.09 | 0.15 | -0.05 | 9.84 | 0.3 | 44.7 | 46.5 |
| 14-Dec-00 | 7.02 |  |  |  | 572 | 134 | 61.9 | 7 | 15 | -0.05 | 0.027 | 0.04 | 0.04 | 0.05 | -0.05 | 2.21 | 0.10 | 26.2 | 26.2 |
| 13-Jan-01 |  | 7.03 |  |  | 404 | 127.0 | 52.8 | 10 | 21 | 0.14 | 0.025 | -0.005 | 0.057 | 0.30 | 0.10 | 2.32 | 0.088 | 17.40 | 17.70 |
| 10-Feb-01 |  | 7.03 |  |  | 396 | 124.9 | 48.8 | 9 | 21 | 0.16 | 0.006 | -0.005 | 0.030 | 0.07 | 0.05 | 2.32 | 0.138 | 14.40 | 14.50 |
| 10-Mar-01 | 7.3 |  |  |  | 598 | 130 | 53.25 | 1.15 | 22.76 | 0.47 | 0.014 | -0.005 | 0.03 | 0.06 | -0.01 | 2.71 | 0.072 | 16 | 16 |
| 16-Apr-01 | 7.9 |  |  |  | 526 | 146.4 | 55.3 | -1 | 23 | -0.05 | 0.009 | -0.005 | 0.023 | 0.09 | -0.01 | 3.36 | 0.079 | 6.07 | 12.17 |
| 14-May-01 | 7.9 |  |  |  | 532 | 146.2 | 50.4 | 9 | 22 | 0.30 | 0.011 | 0.015 | 0.022 | 0.56 | -0.01 | 2.31 | 0.074 | 6.35 | 8.42 |
| 17-Jun-01 | 7.8 |  |  |  | 565 | 152.6 | 56.0 | 11 | 26 | 0.12 | 0.014 | 0.046 | 0.022 | 0.18 | -0.01 | 1.92 | 0.096 | 2.91 | 11.60 |
| 14-Jul-01 | 7.6 |  |  |  | 569 | 150.7 | 56.1 | 11 | 24 | 0.12 | 0.011 | 0.048 | 0.014 | 0.38 | -0.01 | 3.25 | 0.102 | 3.39 | 13.18 |
| 14-Aug-01 | 7.6 |  |  |  | 582 | 160.8 | 67.3 | 10 | 25 | 0.10 | 0.013 | 0.053 | 0.014 | 0.10 | -0.01 | 3.19 | 0.119 | 4.22 | 16.53 |
| 17-Sep-01 | 7.6 |  |  |  | 546 | 125.6 | 52.5 | 9 | 25 | 0.06 | 0.012 | 0.045 | 0.009 | 0.04 | 0.01 | 3.14 | 0.091 | 7.67 | 12.21 |
| 15-Oct-01 | 7.6 |  |  |  | 586 | 141.2 | 55.1 | 12 | 23 | -0.05 | 0.010 | 0.043 | 0.010 | -0.01 | -0.01 | 3.31 | 0.091 | 11.58 | 11.89 |
| 13-Nov-01 | 7.4 |  |  |  | 620 | 152.3 | 56.9 | 13 | 29 | 0.06 | 0.012 | 0.051 | 0.008 | 0.12 | 0.01 | 3.63 | 0.089 | 10.75 | 11.29 |
| 15-Dec-01 | 7.5 |  |  |  | 534 | 156.1 | 60.7 | 10 | 22 | -0.05 | 0.01 | 0.057 | 0.015 | 0.06 | 0.01 | 3.02 | 0.085 | 11.2 | 11.93 |
| 15-Jan-02 |  |  |  |  | 640 | 153.0 | 62.9 | 15 | 28 | 0.06 | 0.011 | 0.049 | 0.012 | 0.05 | -0.01 | 2.93 | 0.085 | 11.50 | 12.14 |
| 12-Feb-02 |  |  |  |  | 562 | 154.7 | 62.4 | 13 | 28 | -0.05 | 0.012 | 0.045 | 0.021 | 0.02 | 0.03 | 2.77 | 0.084 | 13.40 | 12.81 |
| 12-Mar-02 |  |  |  |  | 597 | 149.2 | 60.8 | 13 | 25 | -0.05 | 0.012 | 0.044 | 0.026 | 0.05 | -0.01 | 2.67 | 0.086 | 15.90 | 14.06 |
| 15-Apr-02 | 7.7 |  |  |  | 600 | 145.8 | 56.7 | 14 | 25 | -0.05 | 0.007 | 0.044 | 0.012 | -0.01 | -0.01 | 2.57 | 0.080 | 12.99 | 12.21 |
| 13-May-02 |  |  |  |  | 606 | 149.5 | 57.6 | 12 | 25 | 0.15 | 0.012 | 0.042 | 0.012 | 0.45 | 0.04 | 2.57 | 0.078 | 12.05 | 11.22 |
| 16-Jun-02 |  |  |  | 575 | 575 | 157.5 | 56.5 | 11.3 | 23.8 | 0.095 | 9.5 | 0.045 | 0.027 | 0.097 | 0.011 | 2.693 | 0.081 | 13.084 | 12.659 |
| 16-Jul-02 |  |  |  | 591 | 591 | 147.9 | 54.9 | 10.4 | 20.0 | 0.079 | 15.7 | 0.047 | 0.029 | 0.068 | 0.006 | 2.442 | 0.082 | 12.784 | 11.924 |
| 12-Aug-02 |  |  |  | 578 | 578 | 145.4 | 53.4 | 11.0 | 24.6 | 0.058 | 11.2 | 0.044 | 0.013 | 0.055 | 0.012 | 2.479 | 0.087 | 12.550 | 12.273 |
| 16-Sep-02 |  |  |  | 598 | 598 | 154.5 | 60.8 | 13.6 | 23.4 | 0.040 | 12.2 | 0.049 | 0.021 | 0.179 | 0.003 | 2.749 | 0.087 | 13.312 | 13.202 |
| 15-Oct-02 |  |  |  | 617 | 617 | 148.5 | 59.4 | 13.1 | 24.5 | 0.067 | 11.3 | 0.046 | 0.024 | 0.112 | -0.002 | 2.730 | 0.082 | 13.043 | 11.892 |
| 12-Nov-02 | 7.7 |  |  | 627 | 627 | 160.0 | 61.7 | 14.6 | 27.2 | 0.055 | 11.1 | 0.049 | 0.028 | 0.146 | -0.002 | 2.984 | 0.085 | 11.942 | 11.994 |
| 10-Dec-02 | 7.7 |  |  | 621 | 621 | 151.1 | 61.8 | 14.2 | 24.3 | 0.036 | 11.9 | 0.045 | 0.033 | 0.075 | 0.017 | 2.764 | 0.090 | 13.011 | 13.364 |

| Date | pH Field s.u. | pH Lab s.u. | ALK-T mg/L | SO4-D mg/L | SO4-T mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Al mg/L | Cd mg/L | Co mg/L | Cu mg/L | Fe mg/L | Pb mg/L | Mn mg/L | Ni mg/L | Zn - D mg/L | Zn - T mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 14-Jan-03 | 7.50 | | | 616 | | 144.2 | 64.7 | 11.5 | 22.6 | 0.069 | 0.0179 | 0.041 | 0.050 | 0.065 | -0.002 | 2.379 | 0.098 | 20.603 | 20.288 |
| 15-Feb-03 | 7.5 | | | 622 | | 144.2 | 60.1 | 11.4 | 21.6 | 0.047 | 0.0168 | 0.043 | 0.035 | 0.047 | 0.008 | 2.437 | 0.095 | 18.082 | 17.692 |
| 15-Mar-03 | 7.5 | | | 501 | | 122.9 | 62.6 | 8.2 | 15.9 | 0.077 | 0.0292 | 0.045 | 0.056 | 0.042 | 0.004 | 2.161 | 0.099 | 28.380 | 28.520 |
| 15-Apr-03 | 7.5 | | | 465 | | 108.9 | 52.0 | 6.8 | 13.9 | 0.121 | 0.021 | 0.035 | 0.031 | 0.087 | 0.008 | 1.754 | 0.109 | 22.220 | 21.585 |
| 13-May-03 | 7.8 | | | 132 | | 34 | 13.4 | 1.9 | 3.5 | 0.109 | 0.0062 | 0.009 | 0.007 | 0.058 | 0.013 | 0.465 | 0.023 | 6.057 | 6.273 |
| 14-Jun-03 | 7.4 | | | 647 | | 160.2 | 60.2 | 14.9 | 24.6 | 0.007 | 0.0109 | 0.047 | 0.029 | 0.139 | 0.019 | 2.807 | 0.090 | 11.372 | 11.980 |
| 14-Jul-03 | | | | 657 | | 159.6 | 60.1 | 14.3 | 23.1 | 0.022 | 0.0115 | 0.043 | 0.020 | 0.103 | 0.007 | 2.717 | 0.086 | 10.441 | 10.379 |
| 11-Aug-03 | 7.6 | | | 574 | | 144.5 | 56.6 | 11.7 | 19.6 | 0.024 | 0.0127 | 0.046 | 0.029 | 0.226 | -0.002 | 2.508 | 0.085 | 10.746 | 10.873 |
| 8-Sep-03 | 7.7 | | | 588 | | 147.2 | 60.5 | 12.1 | 20.1 | 0.06 | 0.0115 | 0.046 | 0.056 | 0.265 | -0.002 | 2.617 | 0.084 | 10.238 | 13.751 |
| 14-Oct-03 | 7.3 | | | 606 | | 156.9 | 58.6 | 12.8 | 20.7 | 0.042 | 0.0105 | 0.044 | 0.021 | 0.286 | 0.004 | 2.605 | 0.082 | 10.07 | 9.919 |
| 15-Nov-03 | 7.1 | | | 597 | | 159.8 | 62.5 | 14.5 | 24 | 0.006 | 0.0101 | 0.045 | 0.014 | 0.044 | 0.004 | 2.79 | 0.083 | 7.985 | 8.139 |
| 15-Dec-03 | 7.3 | | | 564 | | 157.7 | 58.8 | 14.0 | 23.2 | 0.004 | 0.0106 | 0.042 | 0.014 | 0.060 | 0.005 | 2.690 | 0.088 | 8.838 | 9.228 |
| 12-Jan-04 | | | | 557 | | 157.3 | 62.6 | 12.3 | 21.5 | 0.021 | 0.0135 | 0.047 | 0.060 | 0.085 | -0.002 | 2.615 | 0.080 | 12.057 | 12.052 |
| 16-Feb-04 | 6.7 | | | 470 | | 111.2 | 51.7 | 7.9 | 13.2 | 0.025 | 0.0166 | 0.039 | 0.100 | 0.038 | 0.003 | 1.693 | 0.069 | 14.473 | 13.686 |
| 15-Mar-04 | 6.9 | | | 500 | | 121 | 56.3 | 6 | 14.5 | 0.032 | 0.021 | 0.039 | 0.094 | 0.02 | -0.001 | 2.28 | 0.085 | 18.1 | 19.8 |
| 14-Apr-04 | 6.7 | | | 500 | | 121 | 52.9 | 6.0 | 15.3 | 0.06 | 0.02 | 0.03 | 0.05 | 0.13 | -0.03 | 1.97 | 0.08 | 14.3 | 16 |
| 14-May-04 | 7.2 | | 60 | 146 | | 36.7 | 14.2 | 2.4 | 5.06 | 0.017 | 0.0042 | 0.011 | 0.005 | -0.05 | 0.008 | 0.62 | 0.028 | 4.18 | 4.71 |
| 14-Jun-04 | 7.0 | | | 506 | | 126 | 55.3 | 8.6 | 21.2 | 0.03 | 0.0082 | 0.035 | 0.014 | 0.16 | 0.002 | 2.19 | 0.084 | 7.74 | 10.6 |
| 12-Jul-04 | 7.7 | | | 559 | | 135 | 50.1 | 9 | 17.8 | 0.008 | 0.0086 | 0.039 | 0.008 | 0.18 | 0.001 | 2.47 | 0.092 | 9.55 | 11.7 |
| 9-Aug-04 | 7.6 | | | 611 | | 137 | 54.4 | 8.7 | 19.6 | 0.006 | 0.01 | 0.04 | 0.007 | 0.13 | -0.001 | 2.47 | 0.092 | 8.78 | 10.6 |
| 13-Sep-04 | 7.1 | | | 946 | | 133 | 57.2 | 8.3 | 20.4 | 0.006 | 0.0093 | 0.045 | 0.009 | 0.41 | 0.004 | 2.5 | 0.1 | 12 | 12.9 |
| 2004 Avg. | 7.1 | | 60 | 533 | | 120 | 51 | 7.7 | 17 | 0.023 | 0.012 | 0.036 | 0.039 | 0.12 | -0.002 | 2.1 | 0.079 | 11 | 12 |

Notes:

metals are total metal values unless indicated otherwise

# Appendix C.2

## Grum Pit

V23, Grum Pit Water

| Date | pH Field s.u. | pH Lab s.u. | ALK-T mg/L | SO4-D mg/L | SO4-T mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Al mg/L | Cd mg/L | Co mg/L | Cu mg/L | Fe mg/L | Pb mg/L | Mn mg/L | Ni mg/L | Zn mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 14-Jan-97 | | | 158 | | 87 | 75.3 | 38.2 | | 15 | 0.17 | -0.002 | 0.007 | 0.008 | 0.07 | -0.02 | 0.07 | 0.177 | 0.01 |
| 26-May-97 | | | | | 51 | 49.4 | 23.8 | -1 | 8 | 0.05 | 0.011 | -0.005 | -0.002 | 0.2 | 0.03 | 0.31 | 0.192 | 7.79 |
| 22-Jul-97 | 8.3 | | 24 | | 49 | 61.1 | 31.4 | 4 | 13 | 0.15 | -0.002 | 0.042 | 0.021 | 0.11 | -0.02 | 0.05 | 0.188 | 2.53 |
| 14-Sep-98 | 7.65 | | | | 201 | 78.0 | 45.8 | 4 | 15 | 0.16 | -0.002 | 0.026 | 0.024 | 0.09 | 0.04 | 0.10 | 0.134 | 1.03 |
| 10-Sep-99 | 7.64 | | 190 | | 266 | 82.4 | 46.0 | 4 | 12 | 0.22 | 0.010 | 0.057 | 0.017 | 0.18 | -0.01 | 0.37 | 0.177 | 3.42 |
| 12-Oct-99 | 7.12 | | 190 | | 344 | 73.8 | 41.7 | 4 | 11 | 0.16 | 0.019 | 0.044 | 0.029 | 0.14 | 0.04 | 0.46 | 0.174 | 5.91 |
| 22-Mar-00 | | 7.55 | 216 | | 292 | 101.4 | 56.1 | 8 | 7 | 0.39 | 0.018 | 0.114 | 0.013 | 0.08 | -0.01 | 0.66 | 0.176 | 7.19 |
| 20-Jun-00 | | | 59 | | 192 | 63.7 | 22.5 | 5 | 9 | 0.46 | -0.001 | -0.005 | 0.013 | 0.43 | -0.01 | 0.02 | 0.013 | 0.02 |
| 26-Jun-00 | 7.71 | | 161 | | 335 | 91.2 | 49.6 | 5 | 10 | 0.23 | 0.029 | 0.073 | 0.021 | 0.16 | -0.01 | 0.59 | 0.221 | 5.92 |
| 12-Sep-00 | 7.63 | | 249 | | 488 | 112.2 | 60.1 | 2 | 14 | 0.29 | 0.049 | 0.076 | 0.051 | 0.18 | -0.01 | 0.86 | 0.275 | 11.94 |
| 5-Mar-01 | 8.1 | | | | 154 | 93 | 41 | -1 | 9 | 0.327 | -0.001 | -0.005 | -0.002 | 0.050 | -0.01 | 0.07 | -0.005 | -0.01 |
| 13-Jun-01 | 7.9 | | 141 | | 435 | 105.0 | 64.3 | 3 | 12 | 0.24 | 0.030 | 0.091 | 0.014 | 0.49 | -0.01 | 1.73 | 0.181 | 13.80 |
| 8-Sep-01 | 7.9 | | 148 | | 456 | 119.9 | 66.4 | 4 | 12 | 0.11 | 0.025 | 0.079 | 0.006 | 0.14 | -0.01 | 1.01 | 0.263 | 12.27 |
| 21-Mar-02 | | | 236 | | 133 | 89.0 | 30.4 | 4 | 13 | 0.06 | 0.002 | 0.010 | -0.002 | 0.02 | -0.01 | 0.18 | 0.042 | 1.81 |
| 25-Jun-02 | | | 123 | 419 | 419 | 107.1 | 60.2 | 3.5 | 10.5 | 0.128 | 0.0142 | 0.053 | 0.030 | 0.069 | 0.004 | 0.630 | 0.191 | 7.822 |
| 27-Sep-02 | 7.9 | | 136 | 459 | 459 | 122.7 | 67.6 | 4.3 | 11.9 | 0.065 | 0.0155 | 0.051 | 0.020 | 0.077 | 0.002 | 0.577 | 0.179 | 5.923 |
| 14-Jan-03 | 7.8 | | 270 | 313 | | 136.5 | 57.9 | 5.2 | 15.9 | 0.064 | 0.0087 | 0.030 | 0.013 | 0.033 | -0.002 | 0.373 | 0.121 | 6.198 |
| 6-Mar-03 | 7.8 | | 168 | 537 | | 144.9 | 85.8 | 6.1 | 16.8 | 0.070 | 0.0214 | 0.066 | 0.015 | 0.093 | 0.007 | 0.786 | 0.264 | 10.043 |
| 17-Jun-03 | | | 130 | 427 | | 121.7 | 66.7 | 4.2 | 10.2 | 0.023 | 0.0104 | 0.040 | 0.069 | 0.229 | 0.003 | 0.636 | 0.186 | 3.654 |
| 15-Sep-03 | 7.9 | | 147 | 425 | | 122.7 | 66 | 4.3 | 9.9 | 0.051 | 0.0104 | 0.038 | 0.012 | 0.128 | 0.004 | 0.509 | 0.17 | 5.507 |
| 13-Dec-03 | 7.6 | | 178 | 450 | | 137.3 | 65.7 | 5.1 | 13.1 | 0.018 | 0.0111 | 0.035 | 0.010 | 0.036 | 0.007 | 0.560 | 0.183 | 8.216 |
| 14-Mar-04 | 7.6 | | 175 | 411 | | 133.9 | 69.7 | 4.5 | 10.9 | 0.026 | 0.0106 | 0.034 | 0.009 | 0.006 | -0.002 | 0.555 | 0.205 | 8.495 |
| 7-Sep-04 | | | | 422 | | 106 | 62 | 3.17 | 10.4 | 0.11 | 0.0021 | 0.016 | 0.0029 | 0.22 | 0.0038 | 0.22 | 0.127 | 2 |
| 2003/2004 Avg. | 7.7 | | 178 | 427 | | 133 | 69 | 4.9 | 13 | 0.042 | 0.012 | 0.041 | 0.021 | 0.088 | 0.0028 | 0.57 | 0.19 | 7.0 |

Notes: * excludes the September 2004 data which was likely influenced by the biological treatment studies.
metals are total metal values unless indicated otherwise

# Appendix C.3

## Vangorda Pit

V22 - Vangorda pit water

| Date | pH Field s.u. | pH Lab s.u. | ALK-T mg/L | SO4-D mg/L | SO4-T mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Al mg/L | Cd mg/L | Co mg/L | Cu mg/L | Fe mg/L | Pb mg/L | Mn mg/L | Ni mg/L | Zn mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13-Jan-98 | 7.42 | | | | 417 | 144.8 | 43.9 | 8 | 14 | 0.19 | -0.002 | 0.065 | 0.020 | 2.78 | 0.40 | 2.79 | 0.048 | 4.88 |
| 14-Sep-98 | | 7.83 | | | 872 | 217.9 | 79.0 | 4 | 10 | 0.17 | 0.099 | 0.467 | 0.032 | 0.20 | 0.24 | 19.37 | 0.487 | 42.75 |
| 18-Jun-99 | 7.48 | | | | 247 | 68.7 | 25.8 | 3 | 5 | 0.54 | 0.017 | 0.052 | 0.095 | 1.15 | 0.04 | 3.13 | 0.110 | 11.21 |
| 10-Sep-99 | 7.43 | | 66 | | 513 | 119.6 | 45.4 | 3 | 5 | 0.19 | 0.058 | 0.216 | 0.022 | 0.28 | 0.13 | 9.94 | 0.261 | 22.59 |
| 12-Oct-99 | 6.48 | | 85 | | 635 | 135.9 | 52.1 | 4 | 6 | 0.23 | 0.061 | 0.199 | 0.034 | 0.39 | 0.17 | 10.77 | 0.278 | 37.36 |
| 22-Mar-00 | | 6.80 | 118 | | 589 | 163.4 | 59.1 | 4 | 9 | 0.53 | 0.044 | 0.273 | 0.017 | 0.09 | 0.05 | 14.53 | 0.234 | 43.76 |
| 20-Jun-00 | | | 62 | | 107 | 40.8 | 13.6 | 2 | 3 | 0.82 | 0.016 | 0.011 | 0.069 | 1.26 | 0.03 | 1.02 | 0.056 | 4.62 |
| 12-Sep-00 | 7.1 | | 184 | | 357 | 92.5 | 30.5 | -1 | 5 | 0.26 | 0.047 | 0.143 | 0.030 | 0.42 | 0.11 | 6.21 | 0.175 | 21.84 |
| 5-Mar-01 | 7.0 | | | | 177 | 112 | 52 | -1 | 10 | 0.461 | -0.001 | -0.005 | 0.003 | 0.095 | -0.01 | -0.01 | -0.005 | -0.01 |
| 13-Jun-01 | 7.5 | | 45 | | 430 | 90.8 | 38.5 | 2 | 4 | 0.22 | 0.056 | 0.258 | 0.028 | 0.70 | 0.02 | 13.65 | 0.172 | 45.90 |
| 8-Sep-01 | 7.4 | | 17 | | 591 | 116.6 | 49.3 | 3 | 4 | 0.07 | 0.086 | 0.381 | 0.018 | 2.02 | 0.16 | 21.80 | 0.349 | 78.29 |
| 21-Mar-02 | | | 31 | | 734 | 142.0 | 59.4 | 4 | 6 | -0.05 | 0.101 | 0.446 | 0.003 | 0.08 | -0.01 | 19.57 | 0.348 | 74.09 |
| 25-Jun-02 | | | 30 | 798 | 798 | 165.6 | 59.9 | 3.0 | 5.6 | 0.091 | 0.1099 | 0.475 | 0.018 | 0.566 | 0.014 | 19.965 | 0.345 | 86.758 |
| 27-Sep-02 | 7.1 | | 43 | 862 | 862 | 176.4 | 67.0 | 3.8 | 6.1 | 0.040 | 0.0988 | 0.494 | 0.059 | 0.107 | 0.020 | 22.259 | 0.397 | 106.1 |
| 15-Dec-02 | 7.2 | | | 869 | 869 | 189.4 | 72.7 | 4.1 | 6.6 | 0.035 | 0.0997 | 0.510 | 0.047 | 1.006 | 0.014 | 23.433 | 0.426 | 81.243 |
| 6-Mar-03 | 7.4 | | 71 | 808 | | 178.7 | 71.6 | 4.9 | 10.1 | 0.029 | 0.0922 | 0.456 | 0.029 | 0.116 | 0.004 | 20.418 | 0.406 | 73.314 |
| 17-Jun-03 | | | 37 | 635 | | 145.9 | 52.3 | 3.0 | 3.5 | -0.001 | 0.0720 | 0.358 | 0.095 | 0.334 | 0.017 | 16.509 | 0.325 | 51.333 |
| 15-Sep-03 | 6.9 | | 46 | 1041 | | 261.7 | 82.8 | 4.7 | 6.1 | 0.019 | 0.0941 | 0.664 | 0.049 | 1.546 | 0.004 | 29.179 | 0.449 | 72.472 |
| 13-Dec-03 | 6.6 | | 59 | 1088 | | 234.6 | 81.8 | 5.7 | 8.6 | 0.015 | 0.0619 | 0.461 | 0.049 | 1.155 | 0.011 | 24.332 | 0.384 | 57.246 |
| 14-Mar-04 | 6.7 | | 127 | 626 | | 192.4 | 63.3 | 4.2 | 7.4 | 0.021 | 0.0348 | 0.182 | 0.015 | 0.406 | 0.002 | 9.256 | 0.226 | 48.557 |
| 7-Sep-04 | | | | 1090 | | 233 | 82.5 | 3.36 | 5.28 | 0.08 | 0.0561 | 0.497 | 0.033 | 1.28 | 0.021 | 31.1 | 0.465 | 92.2 |
| 2003/2004 Avg. | 6.9 | | 68 | 881 | | 208 | 72.4 | 4.3 | 6.8 | 0.027 | 0.069 | 0.44 | 0.045 | 0.81 | 0.0098 | 22 | 0.38 | 66 |

Notes: values shown in red were divided by 1000, due to a likely unit error in the database
metals are total metal values unless indicated otherwise

# Appendix D

## Pit Lake Vertical Profiling Results

# Appendix D.1

## Faro Pit

| Pit Lake | Date Sampled | Depth | Sample ID | Field Cond. | Field Water Temperature | Field pH | Field Dissolved Oxygen | Field ORP | Field TDS | Lab Cond. | Hardness | pH | TDS | TSS | Alkalinity Total | Acidity (to pH 8.3) | Chloride - Cl | Sulphate - SO4 | Ammonia Nitrogen - N | Nitrate Nitrogen N | Nitrite Nitrogen N | Total Phosphate P | Total Cyanide CN | Chlorophyll a (a) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | mm/dd/yyyy | m |  | µS/cm | ºC |  | mg/L - Faro & Grum<br>% Saturation - Vangorda | mV | mg/L | µS/cm | CaCO3 mg/l |  | mg/L | mg/L | CaCO3 mg/l | CaCO3 mg/l | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L |
| Faro | 8/9/2003 | 0 | FP1 | 1113 | 12.37 | 7.42 | 9.68 | 52.8 | 0.35 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 8/9/2003 | 2.5 | FP1 | 1111 | 12.33 | 7.31 | 9.5 | 51.8 | 0.72 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 8/9/2003 | 5 | FP1-5 | 1114 | 12.2 | 7.18 | 8.45 | 60.6 | 0.71 | 1070 | 570 | 7.6 |  |  | 98 | 39 |  | 486 | 0.93 |  |  |  |  |  |
|  | 8/9/2003 | 7.5 | FP1 | 1237 | 6.35 | 7.16 | 8.22 | 61.5 | 0.8 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 8/9/2003 | 10 | FP1-10 | 1244 | 5.27 | 7.15 | 7.56 | 43 | 0.8 | 1200 | 644 | 7.84 |  |  | 108 | 27 |  | 707 | 1.25 |  |  |  |  |  |
|  | 8/9/2003 | 10 | FP1-10R |  |  |  |  |  |  | 1210 | 625 | 7.38 |  |  | 103 | 23 |  | 663 | 1.12 |  |  |  |  |  |
|  | 8/9/2003 | 12.5 | FP1 | 1255 | 4.81 | 7.13 | 5.33 | 16.3 | 0.81 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 8/9/2003 | 15 | FP1-15 | 1281 | 4.67 | 7.14 | 1.42 | -16 | 0.82 | 1240 | 640 | 7.52 |  |  | 108 | 25 |  | 694 | 1.28 |  |  |  |  |  |
|  | 8/9/2003 | 17.5 | FP1 | 1360 | 4.3 | 7.27 | 0.15 | -55 | 0.8 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 8/9/2003 | 20 | FP1 | 1388 | 4.2 | 7.32 | 0.14 | -61.3 | 0.89 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 8/9/2003 | 25 | FP1 | 1404 | 4.06 | 7.36 | 0.15 | -63 | 0.91 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 8/9/2003 | 30 | FP1 | 1417 | 4.07 | 7.39 | 0.16 | -64 | 0.92 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 8/9/2003 | 35 | FP1 | 1423 | 4.07 | 7.39 | 0.18 | -63 | 0.92 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 8/9/2003 | 40 | FP1 | 1426 | 4.08 | 7.42 | 0.18 | -63.7 | 0.92 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 8/9/2003 | 45 | FP1 | 1430 | 4.11 | 7.48 | 0.21 | -64.5 | 0.92 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 8/9/2003 | 58 | FP1-58 | 1486 | *5.18 | 7.86 | 6.65* | -119 | 0.97 | 1370 | 726 | 7.17 |  |  | 96 | 42 |  | 793 | 1.45 |  |  |  |  |  |
|  | 8/9/2003 | 0 | FP2-S | 1119 | 12.4 | 7.4 | 10.3 | -45.5 | 0.72 | 1070 | 554 | 7.89 |  |  | 97 | 18 |  | 606 | 0.89 |  |  |  |  |  |
|  | 8/9/2003 | 2.5 | FP2 | 1118 | 12.3 | 7.5 | 9.8 | -26 | 0.72 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 8/9/2003 | 5 | FP2 | 1120 | 12.1 | 7.5 | 9.7 | -11 | 0.72 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 8/9/2003 | 7.5 | FP2 | 1244 | 6.3 | 7.6 | 10.07 | 15.5 | 0.82 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 8/9/2003 | 10 | FP2-10 | 1251 | 5.4 | 7.6 | 9.2 | 35.6 | 0.81 | 1200 | 636 | 7.86 |  |  | 97 | 26 |  | 655 | 1.13 |  |  |  |  |  |
|  | 8/9/2003 | 12.5 | FP2 | 1257 | 5.13 | 7.6 | 8.67 | 50 | 0.82 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 8/9/2003 | 15 | FP2 | 1277 | 4.65 | 7.6 | 7.97 | 55.5 | 0.84 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 8/9/2003 | 17.5 | FP2 | 1362 | 4.25 | 7.6 | 4.32 | -37.5 | 0.88 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 8/9/2003 | 20 | FP2 | 1381 | 4.13 | 7.6 | 2.07 | -50 | 0.9 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 8/9/2003 | 25 | FP2-25 | 1404 | 4.05 | 7.5 | 0.91 | -51.3 | 0.92 | 1330 | 684 | 7.36 |  |  | 100 | 35 |  | 775 | 1.6 |  |  |  |  |  |
|  | 8/9/2003 | 30 | FP2 | 1422 | 4.07 | 7.5 | 0.49 | -58 | 0.93 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 8/9/2003 | 35 | FP2 | 1426 | 4.08 | 7.4 | 0.35 | -58 | 0.93 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 8/9/2003 | 40 | FP2 | 1429 | 4.09 | 7.35 | 0.28 | -58.6 | 0.93 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 8/9/2003 | 45 | FP2 | 1432 | 4.11 | 7.3 | 0.24 | -59 | 0.93 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 8/9/2003 | 60 | FP2-60 | 1563 | *5.29 | 7.5 | *5.2 | -135 | 1.02 | 1390 | 719 | 6.87 |  |  | 100 | 65 |  | 793 | 1.4 |  |  |  |  |  |
|  | 6/30/2004 | 1 | FARO-1 |  |  |  |  |  |  |  |  |  | 874 | 3 | 105 |  | 1.07 | 524 | 0.934 | 0.206 | 0.0055 | 0.0068 |  |  |
|  | 6/30/2004 | 5 | FARO-5 |  |  |  |  |  |  |  |  |  | 892 | <3.0 | 99.9 |  | 1.08 | 528 | 1.06 | 0.184 | 0.0059 | 0.005 | 0.0528 |  |
|  | 6/30/2004 | 10 | FARO-10 |  |  |  |  |  |  |  |  |  | 982 | <3.0 | 103 |  | 1.21 | 582 | 1.14 | 0.151 | 0.0058 | 0.004 | 0.0706 |  |
|  | 6/30/2004 | 15 | FARO-15 |  |  |  |  |  |  |  |  |  | 983 | <3.0 | 100 |  | 1.22 | 593 | 1.22 | 0.158 | 0.0053 | 0.0062 |  |  |
|  | 6/30/2004 | 20 | FARO-20 |  |  |  |  |  |  |  |  |  | 1050 | 7.5 | 98.8 |  | 1.35 | 643 | 1.29 | 0.0344 | 0.0037 | 0.0046 |  |  |
|  | 6/30/2004 | 25 | FARO-25 |  |  |  |  |  |  |  |  |  | 1110 | 6.5 | 98.2 |  | 1.41 | 668 | 1.39 | <0.0050 | 0.0019 | 0.0051 |  |  |
|  | 6/30/2004 | 30 | FARO-30 |  |  |  |  |  |  |  |  |  | 1120 | 11 | 94.5 |  | 1.41 | 677 | 1.46 | <0.0050 | 0.0013 | 0.0047 | 0.136 |  |
|  | 6/30/2004 | 40 | FARO-40 |  |  |  |  |  |  |  |  |  | 1120 | 12.5 | 95.8 |  | 1.42 | 689 | 1.46 | <0.0050 | 0.0023 | 0.0049 | 0.145 |  |

| Pit Lake | Date Sampled | Depth | Sample ID | T-Al | T-Sb | T-As | T-Ba | T-Be | T-Bi | T-B | T-Cd | T-Ca | T-Cr | T-Co | T-Cu | T-Fe | T-Pb | T-Li | T-Mg | T-Mn | T-Hg | T-Mo | T-Ni | T-P | T-K | T-Se | T-Si | T-Ag | T-Na | T-Sr | T-Tl | T-Sn | T-Ti | T-U | T-V | T-Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mm/dd/yyyy | m | | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L |
| Faro | 8/9/2003 | 0 | FP1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 2.5 | FP1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 5 | FP1-5 | <0.03 | 0.004 | <0.003 | 0.02 | <0.005 | | <0.1 | 0.0129 | 133 | <0.005 | 0.041 | 0.008 | 0.04 | <0.003 | 0.05 | 57.9 | 2.24 | <0.00005 | <0.005 | 0.092 | | 9 | <0.005 | | <0.0001 | 21 | | <0.001 | <0.003 | <0.01 | 0.003 | <0.03 | 11 |
| | 8/9/2003 | 7.5 | FP1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 10 | FP1-10 | 0.04 | 0.004 | <0.003 | <0.02 | <0.005 | | <0.1 | 0.0111 | 156 | <0.005 | 0.045 | 0.008 | 0.04 | <0.003 | 0.05 | 63.5 | 2.62 | <0.00005 | <0.005 | 0.095 | | 11 | <0.005 | | <0.0001 | 26 | | <0.001 | <0.003 | <0.01 | 0.003 | <0.03 | 10.3 |
| | 8/9/2003 | 10 | FP1-10R | <0.03 | 0.004 | <0.003 | <0.02 | <0.005 | | <0.1 | 0.0115 | 152 | <0.005 | 0.045 | 0.008 | 0.04 | <0.003 | 0.05 | 62.4 | 2.63 | <0.00005 | 0.005 | 0.096 | | 12 | <0.005 | | <0.0001 | 26 | | <0.001 | <0.003 | <0.01 | 0.003 | <0.03 | 10.3 |
| | 8/9/2003 | 12.5 | FP1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 15 | FP1-15 | <0.03 | <0.003 | <0.003 | <0.02 | <0.005 | | <0.1 | 0.0087 | 163 | <0.005 | 0.043 | 0.007 | 0.15 | <0.003 | 0.06 | 63.9 | 2.75 | <0.00005 | <0.005 | 0.09 | | 13 | <0.005 | | <0.0001 | 28 | | <0.001 | <0.003 | <0.01 | 0.003 | <0.03 | 8.39 |
| | 8/9/2003 | 17.5 | FP1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 20 | FP1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 25 | FP1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 30 | FP1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 35 | FP1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 40 | FP1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 45 | FP1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 58 | FP1-58 | <0.03 | <0.003 | <0.003 | <0.02 | <0.005 | | <0.1 | <0.0003 | 180 | <0.005 | 0.031 | <0.005 | 20.4 | 0.003 | 0.06 | 63.7 | 3.38 | <0.00005 | 0.005 | 0.06 | | 15 | <0.005 | | <0.0001 | 34 | | <0.001 | <0.003 | <0.01 | 0.003 | <0.03 | 1.42 |
| | 8/9/2003 | 0 | FP2-S | <0.03 | 0.003 | <0.003 | <0.02 | <0.005 | | <0.1 | 0.0129 | 133 | <0.005 | 0.041 | 0.008 | 0.05 | <0.003 | 0.05 | 57.8 | 2.23 | <0.00005 | <0.005 | 0.093 | | 9 | <0.005 | | <0.0001 | 21 | | <0.001 | <0.003 | <0.01 | 0.003 | <0.03 | 11 |
| | 8/9/2003 | 2.5 | FP2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 5 | FP2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 7.5 | FP2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 10 | FP2-10 | <0.03 | 0.004 | <0.003 | <0.02 | <0.005 | | <0.1 | 0.0111 | 157 | <0.005 | 0.044 | 0.008 | 0.06 | <0.003 | 0.05 | 64.2 | 2.58 | <0.00005 | <0.005 | 0.094 | | 12 | <0.005 | | <0.0001 | 26 | | <0.001 | <0.003 | <0.01 | 0.003 | <0.03 | 10.2 |
| | 8/9/2003 | 12.5 | FP2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 15 | FP2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 17.5 | FP2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 20 | FP2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 25 | FP2-25 | <0.03 | <0.003 | <0.003 | <0.02 | <0.005 | | <0.1 | 0.0003 | 178 | <0.005 | 0.034 | <0.005 | 11.8 | <0.003 | 0.06 | 63.9 | 3.27 | <0.00005 | 0.005 | 0.073 | | 15 | <0.005 | | <0.0001 | 33 | | <0.001 | <0.003 | <0.01 | 0.003 | <0.03 | 3.04 |
| | 8/9/2003 | 30 | FP2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 35 | FP2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 40 | FP2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 45 | FP2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 60 | FP2-60 | <0.03 | <0.003 | <0.003 | <0.02 | <0.005 | | <0.1 | <0.0003 | 185 | <0.005 | 0.032 | <0.005 | 21.8 | <0.003 | 0.06 | 65.8 | 3.38 | <0.00005 | 0.005 | 0.062 | | 15 | <0.005 | | <0.0001 | 35 | | <0.001 | <0.003 | <0.01 | 0.003 | <0.03 | 1.4 |
| | 6/30/2004 | 1 | FARO-1 | 0.771 | 0.002 | <0.00050 | 0.0155 | <0.0025 | <0.0025 | <0.050 | 0.0111 | 134 | <0.0025 | 0.0412 | 0.00975 | 0.174 | 0.00156 | 0.057 | 57.5 | 2.66 | | 0.00303 | 0.095 | <0.30 | 8.9 | <0.0050 | 3.21 | <0.000050 | 22.3 | 0.51 | 0.00068 | <0.00050 | <0.010 | 0.00308 | <0.0050 | 11.4 |
| | 6/30/2004 | 5 | FARO-5 | 0.007 | 0.00201 | <0.00050 | 0.0157 | <0.0025 | <0.0025 | <0.050 | 0.0109 | 141 | <0.0025 | 0.0399 | 0.00958 | 0.202 | 0.00138 | 0.052 | 60.7 | 2.62 | | 0.00301 | 0.0915 | <0.30 | 9.4 | <0.0050 | 3.4 | <0.000050 | 23.2 | 0.5 | 0.00064 | <0.00050 | <0.010 | 0.00295 | <0.0050 | 11.1 |
| | 6/30/2004 | 10 | FARO-10 | 0.0132 | 0.00215 | <0.00050 | 0.0152 | <0.0025 | <0.0025 | <0.050 | 0.0116 | 155 | <0.0025 | 0.041 | 0.0144 | 0.094 | 0.001 | 0.054 | 64.6 | 2.78 | | 0.00324 | 0.0889 | <0.30 | 11.7 | <0.0050 | 3.51 | <0.000050 | 25.9 | 0.498 | 0.00072 | <0.00050 | <0.010 | 0.00278 | <0.0050 | 11.6 |
| | 6/30/2004 | 15 | FARO-15 | 0.0188 | 0.00206 | <0.00050 | 0.0152 | <0.0025 | <0.0025 | <0.050 | 0.0125 | 150 | <0.0025 | 0.0444 | 0.0175 | 0.362 | 0.00142 | 0.056 | 63.6 | 2.94 | | 0.00328 | 0.0924 | <0.30 | 12.1 | <0.0050 | 3.4 | <0.000050 | 26.1 | 0.513 | 0.00072 | <0.00050 | <0.010 | 0.00266 | <0.0050 | 12.7 |
| | 6/30/2004 | 20 | FARO-20 | 0.0131 | 0.00076 | 0.00028 | 0.014 | <0.0010 | <0.0010 | <0.020 | 0.00482 | 167 | <0.0010 | 0.0352 | 0.016 | 6.54 | 0.00114 | 0.064 | 62.9 | 3.51 | | 0.0033 | 0.074 | <0.30 | 13.1 | <0.0020 | 2.88 | <0.000020 | 31.5 | 0.533 | 0.00037 | <0.00020 | <0.010 | 0.00242 | <0.0020 | 6.28 |
| | 6/30/2004 | 25 | FARO-25 | 0.0125 | <0.00050 | 0.00055 | 0.013 | <0.0025 | <0.0025 | <0.050 | 0.00053 | 164 | <0.0025 | 0.0337 | 0.0191 | 14.6 | 0.0008 | 0.071 | 60.1 | 3.94 | | 0.00476 | 0.0729 | <0.30 | 13.2 | <0.0050 | 2.63 | <0.000050 | 31.7 | 0.574 | <0.00050 | <0.00050 | <0.010 | 0.00272 | <0.0050 | 2.88 |
| | 6/30/2004 | 30 | FARO-30 | 0.0189 | <0.00050 | 0.00108 | 0.0134 | <0.0025 | <0.0025 | <0.050 | 0.00027 | 178 | <0.0025 | 0.0341 | 0.00783 | 18.3 | 0.00086 | 0.073 | 64.7 | 4.08 | | 0.00473 | 0.0686 | <0.30 | 14.3 | <0.0050 | 2.83 | <0.000050 | 34.5 | 0.604 | <0.00050 | <0.00050 | <0.010 | 0.00305 | <0.0050 | 2.44 |
| | 6/30/2004 | 40 | FARO-40 | 0.0171 | <0.00050 | 0.00153 | 0.0171 | <0.0025 | <0.0025 | <0.050 | 0.00025 | 179 | <0.0025 | 0.0321 | 0.0029 | 20.1 | 0.00078 | 0.072 | 64.6 | 3.98 | | 0.00366 | 0.0662 | <0.30 | 15.1 | <0.0050 | 2.82 | <0.000050 | 34.1 | 0.597 | <0.00050 | <0.00050 | <0.010 | 0.00318 | <0.0050 | 2.33 |

| Pit Lake | Date Sampled | Depth | Sample ID | D-Al | D-Sb | D-As | D-Ba | D-Be | D-Bi | D-B | D-Cd | D-Ca | D-Cr | D-Co | D-Cu | D-Fe | D-Pb | D-Li | D-Mg | D-Mn | D-Hg | D-Mo | D-Ni | D-P | D-K | D-Se | D-Si | D-Ag | D-Na | D-Sr | D-Tl | D-Sn | D-Ti | D-U | D-V | D-Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mm/dd/yyyy | m | | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L |
| Faro | 8/9/2003 | 0 | FP1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 2.5 | FP1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 5 | FP1-5 | <0.03 | 0.004 | <0.003 | <0.02 | <0.005 | | <0.1 | 0.0125 | 133 | <0.005 | 0.04 | 0.007 | <0.03 | <0.003 | 0.05 | 57.7 | 2.22 | <0.00005 | <0.005 | 0.09 | | 10 | <0.005 | | <0.0001 | 21 | | <0.001 | <0.003 | <0.01 | 0.003 | <0.03 | 10.7 |
| | 8/9/2003 | 7.5 | FP1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 10 | FP1-10 | <0.03 | 0.004 | <0.003 | <0.02 | <0.005 | | <0.1 | 0.0114 | 154 | <0.005 | 0.045 | 0.007 | <0.03 | <0.003 | 0.06 | 62.6 | 2.68 | <0.00005 | 0.005 | 0.095 | | 11 | <0.005 | | <0.0001 | 25 | | 0.001 | <0.003 | <0.01 | 0.003 | <0.03 | 10.4 |
| | 8/9/2003 | 10 | FP1-10R | <0.03 | 0.004 | <0.003 | 0.02 | <0.005 | | <0.1 | 0.011 | 149 | <0.005 | 0.044 | 0.006 | <0.03 | <0.003 | 0.05 | 61.7 | 2.58 | <0.00005 | 0.005 | 0.092 | | 11 | <0.005 | | <0.0001 | 26 | | <0.001 | <0.003 | <0.01 | 0.003 | <0.03 | 10.1 |
| | 8/9/2003 | 12.5 | FP1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 15 | FP1-15 | <0.03 | <0.003 | <0.003 | <0.02 | <0.005 | | <0.1 | 0.0089 | 155 | <0.005 | 0.044 | 0.005 | <0.03 | <0.003 | 0.06 | 61.3 | 2.83 | <0.00005 | <0.005 | 0.093 | | 12 | <0.005 | | <0.0001 | 27 | | <0.001 | <0.003 | <0.01 | 0.003 | <0.03 | 8.53 |
| | 8/9/2003 | 17.5 | FP1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 20 | FP1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 25 | FP1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 30 | FP1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 35 | FP1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 40 | FP1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 45 | FP1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 58 | FP1-58 | <0.03 | <0.003 | <0.003 | <0.02 | <0.005 | | <0.1 | <0.0003 | 183 | <0.005 | 0.033 | <0.005 | 20.5 | <0.003 | 0.07 | 65.1 | 3.59 | <0.00005 | 0.006 | 0.064 | | 15 | <0.005 | | <0.0001 | 34 | | <0.001 | <0.003 | <0.01 | 0.004 | <0.03 | 1.49 |
| | 8/9/2003 | 0 | FP2-S | <0.03 | 0.003 | <0.003 | <0.02 | <0.005 | | <0.1 | 0.0126 | 130 | <0.005 | 0.041 | 0.007 | <0.03 | <0.003 | 0.05 | 56 | 2.25 | <0.00005 | <0.005 | 0.091 | | 10 | <0.005 | | <0.0001 | 21 | | <0.001 | <0.003 | <0.01 | 0.003 | <0.03 | 10.9 |
| | 8/9/2003 | 2.5 | FP2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 5 | FP2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 7.5 | FP2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 10 | FP2-10 | <0.03 | 0.004 | <0.003 | 0.02 | <0.005 | | <0.1 | 0.0109 | 152 | <0.005 | 0.044 | 0.006 | <0.03 | <0.003 | 0.05 | 62.3 | 2.55 | <0.00005 | <0.005 | 0.093 | | 10 | <0.005 | | <0.0001 | 26 | | <0.001 | <0.003 | <0.01 | 0.003 | <0.03 | 9.97 |
| | 8/9/2003 | 12.5 | FP2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 15 | FP2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 17.5 | FP2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 20 | FP2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 25 | FP2-25 | <0.03 | <0.003 | <0.003 | <0.02 | <0.005 | | <0.1 | <0.0003 | 171 | <0.005 | 0.034 | <0.005 | 11.1 | <0.003 | 0.06 | 62.2 | 3.26 | <0.00005 | 0.005 | 0.072 | | 15 | <0.005 | | <0.0001 | 33 | | <0.001 | <0.003 | <0.01 | 0.003 | <0.03 | 3.02 |
| | 8/9/2003 | 30 | FP2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 35 | FP2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 40 | FP2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 45 | FP2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/9/2003 | 60 | FP2-60 | <0.03 | <0.003 | <0.003 | <0.02 | <0.005 | | <0.1 | <0.0003 | 181 | <0.005 | 0.033 | <0.005 | 21.2 | <0.003 | 0.07 | 64.5 | 3.47 | <0.00005 | 0.006 | 0.063 | | 15 | <0.005 | | <0.0001 | 34 | | <0.001 | <0.003 | <0.01 | 0.003 | <0.03 | 1.35 |
| | 6/30/2004 | 1 | FARO-1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 6/30/2004 | 5 | FARO-5 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 6/30/2004 | 10 | FARO-10 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 6/30/2004 | 15 | FARO-15 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 6/30/2004 | 20 | FARO-20 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 6/30/2004 | 25 | FARO-25 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 6/30/2004 | 30 | FARO-30 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 6/30/2004 | 40 | FARO-40 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

# Appendix D.2

## Grum Pit

| Pit Lake | Date Sampled | Depth | Sample ID | Field Cond. | Field Water Temperature | Field pH | Field Dissolved Oxygen | Field ORP | Field TDS | Lab Cond. | Hardness | pH | TDS | TSS | Alkalinity Total | Acidity (to pH 8.3) | Chloride - Cl | Sulphate - SO4 | Ammonia Nitrogen - N | Nitrate Nitrogen N | Nitrite Nitrogen N | Total Phosphate P | Total Cyanide CN | Chlorophyll a (a) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mm/dd/yyyy | m | | µS/cm | ºC | | mg/L - Faro & Grum<br>% Saturation - Vangorda | mV | mg/L | µS/cm | CaCO3 mg/l | | mg/L | mg/L | CaCO3 mg/l | CaCO3 mg/l | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L |
| Grum | 8/8/2003 | 0 | GP1-S | 1002 | 12.91 | 7.9 | 9.32 | 139.6 | 0.65 | 955 | 522 | 8.08 | | | 149 | 2 | | 424 | 0.03 | | | | | |
| | 8/8/2003 | 5 | GP1 | 1099 | 5.31 | 7.79 | 10.8 | 163.2 | 0.71 | | | | | | | | | | | | | | | |
| | 8/8/2003 | 7.5 | GP1 | 1097 | 4.93 | 7.8 | 9.9 | 164.6 | 0.71 | | | | | | | | | | | | | | | |
| | 8/8/2003 | 10 | GP1-10 | 1097 | 4.93 | 7.7 | 9.43 | 166.5 | 0.71 | 1020 | 563 | 7.7 | | | 164 | 28 | | 461 | 0.02 | | | | | |
| | 8/8/2003 | 12.5 | GP1 | 1096 | 4.92 | 7.7 | 9.37 | 168.1 | 0.71 | | | | | | | | | | | | | | | |
| | 8/8/2003 | 15 | GP1 | 1096 | 4.93 | 7.7 | 9.36 | 167.7 | 0.71 | | | | | | | | | | | | | | | |
| | 8/8/2003 | 17.5 | GP1 | 1096 | 4.93 | 7.6 | 9.3 | 168 | 0.71 | | | | | | | | | | | | | | | |
| | 8/8/2003 | 20 | GP1-20 | 1096 | 4.93 | 7.6 | 9.3 | 168.3 | 0.71 | 1050 | 510 | 7.79 | | | 165 | 27 | | 452 | <0.02 | | | | | |
| | 8/8/2003 | 22.5 | GP1 | 1096 | 4.93 | 7.6 | 9.36 | 169 | 0.71 | | | | | | | | | | | | | | | |
| | 8/8/2003 | 25 | GP1 | 1096 | 4.93 | 7.57 | 9.36 | 168.5 | 0.71 | | | | | | | | | | | | | | | |
| | 8/8/2003 | 30 | GP1-30 | 1097 | 4.94 | 7.55 | 9.37 | 164 | 0.71 | 1040 | 505 | 7.49 | | | 166 | 26 | | 460 | <0.02 | | | | | |
| | 8/8/2003 | 35 | GP1 | 1097 | 4.94 | 7.5 | 9.3 | 161 | 0.71 | | | | | | | | | | | | | | | |
| | 8/8/2003 | 40 | GP1-40 | 981 | 4.95 | 7.52 | 7.2 | 161 | 0.71 | 1060 | 460 | 7.83 | | | 166 | 23 | | 454 | 0.08 | | | | | |
| | 8/8/2003 | 0 | GP2-S | 1002 | 13.05 | 8.26 | 10.36 | 219.9 | 0.65 | 961 | 520 | 8.22 | | | 150 | <1 | | 429 | 0.05 | | | | | |
| | 8/8/2003 | 5 | GP2 | 1098 | 4.96 | 8.1 | 11.23 | 233.6 | 0.71 | | | | | | | | | | | | | | | |
| | 8/8/2003 | 10 | GP2-10 | 1097 | 4.94 | 8.03 | 9.72 | 239.2 | 0.71 | 1050 | 558 | 7.76 | | | 166 | 26 | | 464 | <0.02 | | | | | |
| | 8/8/2003 | 15 | GP2 | 1097 | 4.94 | 7.97 | 9.59 | 240.9 | 0.71 | | | | | | | | | | | | | | | |
| | 8/8/2003 | 20 | GP2-20 | 1097 | 4.94 | 7.93 | 9.53 | 241.4 | 0.71 | 1050 | 566 | 7.76 | | | 166 | 26 | | 455 | <0.02 | | | | | |
| | 8/8/2003 | 25 | GP2 | 1096 | 4.94 | 7.89 | 9.52 | 241.3 | 0.71 | | | | | | | | | | | | | | | |
| | 8/8/2003 | 30 | GP2-30 | 1096 | 4.94 | 7.85 | 9.52 | 240.8 | 0.71 | 1060 | 567 | 7.77 | | | 166 | 26 | | 453 | <0.02 | | | | | |
| | 8/8/2003 | 35 | GP2 | 1097 | 4.94 | 7.83 | 9.52 | 235 | 0.71 | | | | | | | | | | | | | | | |
| | 8/8/2003 | 40 | GP2-40 | 1097 | 4.94 | 7.8 | 9.53 | 152 | 0.71 | 1040 | 569 | 7.77 | | | 161 | 26 | | 455 | 0.1 | | | | | |
| | 6/29/2004 | 1 | GL-1 | | | | | | | | | | 755 | <3.0 | 152 | | <0.5 | 408 | 0.025 | 0.904 | 0.0112 | <0.0020 | | <0.060 |
| | 6/29/2004 | 3 | GL-3 | | | | | | | | | | 816 | <3.0 | 168 | | <0.5 | 437 | 0.024 | 0.848 | 0.0024 | <0.0020 | | 0.477 |
| | 6/29/2004 | 5 | GL-5 | | | | | | | | | | 814 | <3.0 | 166 | | <0.5 | 438 | 0.023 | 0.811 | 0.002 | <0.0020 | | 0.89 |
| | 6/29/2004 | 7 | GL-7 | | | | | | | | | | 832 | <3.0 | 169 | | <0.5 | 438 | 0.025 | 0.864 | 0.0025 | <0.0020 | | 1.5 |
| | 6/29/2004 | 10 | GL-10 | | | | | | | | | | 820 | <3.0 | 170 | | <0.5 | 439 | 0.026 | 0.978 | 0.0025 | <0.0020 | | 0.773 |
| | 6/29/2004 | 15 | GL-15 | | | | | | | | | | - | - | | | | | | | | | | 0.549 |
| | 6/29/2004 | 20 | GL-20 | | | | | | | | | | 802 | <3.0 | 167 | | <0.5 | 439 | 0.03 | 0.967 | 0.0023 | <0.0020 | | |
| | 6/29/2004 | 30 | GL-30 | | | | | | | | | | 820 | <3.0 | 167 | | <0.5 | 439 | 0.03 | 0.962 | 0.0028 | <0.0020 | | |
| | 6/29/2004 | 40 | GL-40 | | | | | | | | | | 826 | <3.0 | 168 | | <0.5 | 440 | 0.026 | 0.963 | 0.0029 | <0.0020 | | |

| Pit Lake | Date Sampled | Depth | Sample ID | T-Al | T-Sb | T-As | T-Ba | T-Be | T-Bi | T-B | T-Cd | T-Ca | T-Cr | T-Co | T-Cu | T-Fe | T-Pb | T-Li | T-Mg | T-Mn | T-Hg | T-Mo | T-Ni | T-P | T-K | T-Se | T-Si | T-Ag | T-Na | T-Sr | T-Tl | T-Sn | T-Ti | T-U | T-V | T-Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mm/dd/yyyy | m | | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L |
| Grum | 8/8/2003 | 0 | GP1-S | 0.07 | 0.008 | <0.001 | 0.06 | <0.002 | | <0.1 | 0.0097 | 107 | <0.002 | 0.0349 | <0.002 | 0.09 | 0.002 | 0.03 | 64.6 | 0.451 | <0.00005 | 0.004 | 0.187 | | 4 | <0.002 | | <0.00004 | 11 | | 0.0012 | <0.001 | <0.01 | 0.0029 | <0.03 | 4.4 |
| | 8/8/2003 | 5 | GP1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/8/2003 | 7.5 | GP1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/8/2003 | 10 | GP1-10 | 0.05 | 0.01 | <0.003 | 0.06 | <0.005 | | <0.1 | 0.0159 | 113 | <0.005 | 0.046 | <0.005 | 0.08 | <0.003 | <0.03 | 67 | 0.658 | <0.00005 | <0.005 | 0.263 | | 3 | <0.005 | | <0.0001 | 11 | | 0.001 | <0.003 | <0.01 | 0.01 | <0.03 | 12 |
| | 8/8/2003 | 12.5 | GP1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/8/2003 | 15 | GP1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/8/2003 | 17.5 | GP1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/8/2003 | 20 | GP1-20 | 0.04 | 0.01 | <0.003 | 0.05 | <0.005 | | <0.1 | 0.0159 | 109 | <0.005 | 0.046 | <0.005 | 0.06 | <0.003 | <0.03 | 65.2 | 0.66 | <0.00005 | <0.005 | 0.269 | | 4 | <0.005 | | <0.0001 | 11 | | 0.001 | <0.003 | <0.01 | 0.01 | <0.03 | 12.3 |
| | 8/8/2003 | 22.5 | GP1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/8/2003 | 25 | GP1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/8/2003 | 30 | GP1-30 | 0.06 | 0.011 | <0.003 | 0.04 | <0.005 | | <0.1 | 0.0159 | 106 | <0.005 | 0.047 | <0.005 | <0.03 | <0.003 | <0.03 | 62.9 | 0.659 | <0.00005 | <0.005 | 0.27 | | 3 | <0.005 | | <0.0001 | 11 | | 0.001 | <0.003 | <0.01 | 0.01 | <0.03 | 12.3 |
| | 8/8/2003 | 35 | GP1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/8/2003 | 40 | GP1-40 | 0.1 | 0.01 | <0.003 | 0.05 | <0.005 | | <0.1 | 0.0159 | 93.7 | <0.005 | 0.045 | <0.005 | 0.17 | <0.003 | <0.03 | 55.6 | 0.659 | <0.00005 | <0.005 | 0.265 | | 3 | <0.005 | | <0.0001 | 9 | | 0.001 | <0.003 | <0.01 | 0.01 | <0.03 | 12 |
| | 8/8/2003 | 0 | GP2-S | 0.08 | 0.009 | <0.001 | 0.05 | <0.002 | | <0.1 | 0.0099 | 102 | <0.002 | 0.0362 | <0.002 | 0.09 | 0.002 | 0.03 | 61.5 | 0.468 | <0.00005 | 0.004 | 0.195 | | 3 | <0.002 | | <0.00004 | 10 | | 0.0012 | <0.001 | <0.01 | 0.003 | <0.03 | 4.43 |
| | 8/8/2003 | 5 | GP2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/8/2003 | 10 | GP2-10 | 0.04 | 0.01 | <0.003 | 0.06 | <0.005 | | <0.1 | 0.0155 | 114 | <0.005 | 0.045 | <0.005 | 0.06 | <0.003 | <0.03 | 67.6 | 0.65 | <0.00005 | <0.005 | 0.262 | | 4 | <0.005 | | <0.0001 | 11 | | 0.001 | <0.003 | <0.01 | 0.01 | <0.03 | 11.8 |
| | 8/8/2003 | 15 | GP2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/8/2003 | 20 | GP2-20 | 0.05 | 0.011 | <0.003 | 0.05 | <0.005 | | <0.1 | 0.0165 | 111 | <0.005 | 0.047 | <0.005 | 0.09 | <0.003 | <0.03 | 66.3 | 0.676 | <0.00005 | <0.005 | 0.273 | | 4 | <0.005 | | <0.0001 | 11 | | 0.001 | <0.003 | <0.01 | 0.01 | <0.03 | 12.4 |
| | 8/8/2003 | 25 | GP2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/8/2003 | 30 | GP2-30 | 0.06 | 0.011 | <0.003 | 0.05 | <0.005 | | <0.1 | 0.0157 | 117 | <0.005 | 0.046 | <0.005 | 0.14 | <0.003 | <0.03 | 69.3 | 0.67 | <0.00005 | <0.005 | 0.272 | | 4 | <0.005 | | <0.0001 | 12 | | 0.001 | <0.003 | <0.01 | 0.01 | <0.03 | 12 |
| | 8/8/2003 | 35 | GP2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8/8/2003 | 40 | GP2-40 | 0.06 | 0.01 | <0.003 | 0.05 | <0.005 | | <0.1 | 0.0161 | 115 | <0.005 | 0.046 | <0.005 | 0.13 | <0.003 | <0.03 | 68.9 | 0.659 | <0.00005 | <0.005 | 0.271 | | 4 | <0.005 | | <0.0001 | 12 | | 0.001 | <0.003 | <0.01 | 0.01 | <0.03 | 12 |
| | 6/29/2004 | 1 | GL-1 | 0.0205 | 0.00668 | 0.00062 | 0.0497 | <0.0010 | <0.0010 | <0.020 | 0.00849 | 109 | <0.0010 | 0.0261 | 0.00087 | <0.03 | 0.00069 | 0.025 | 64.4 | 0.42 | | 0.00357 | 0.178 | <0.30 | 3 | <0.0020 | 3.07 | <0.000020 | 10.1 | 0.821 | 0.00073 | <0.00020 | <0.010 | 0.00275 | <0.0020 | 3.34 |
| | 6/29/2004 | 3 | GL-3 | 0.0281 | 0.00837 | 0.00085 | 0.0498 | <0.0010 | <0.0010 | <0.020 | 0.011 | 117 | <0.0010 | 0.0329 | 0.00115 | <0.03 | 0.00086 | 0.027 | 68.5 | 0.658 | | 0.00366 | 0.244 | <0.30 | 3.5 | 0.0021 | 3.37 | <0.000020 | 10.9 | 0.926 | 0.00077 | <0.00020 | <0.010 | 0.00314 | <0.0020 | 12.1 |
| | 6/29/2004 | 5 | GL-5 | 0.0224 | 0.00795 | 0.00104 | 0.0491 | <0.0010 | <0.0010 | <0.020 | 0.00991 | 126 | <0.0010 | 0.027 | 0.00088 | 0.041 | 0.00072 | 0.027 | 73.3 | 0.521 | | 0.00337 | 0.205 | <0.30 | 3.6 | 0.002 | 3.55 | <0.000020 | 11.5 | 0.823 | 0.00068 | <0.00020 | <0.010 | 0.00668 | <0.0020 | 9.6 |
| | 6/29/2004 | 7 | GL-7 | 0.0336 | 0.00801 | 0.00126 | 0.0487 | <0.0010 | <0.0010 | <0.020 | 0.00981 | 118 | <0.0010 | 0.027 | 0.00093 | 0.042 | 0.00069 | 0.027 | 69.3 | 0.518 | | 0.0033 | 0.202 | <0.30 | 3.4 | 0.002 | 3.33 | <0.000020 | 10.9 | 0.825 | 0.00066 | <0.00020 | <0.010 | 0.00568 | <0.0020 | 9.85 |
| | 6/29/2004 | 10 | GL-10 | 0.0275 | 0.00804 | 0.00148 | 0.0496 | <0.0010 | <0.0010 | <0.020 | 0.0101 | 119 | <0.0010 | 0.0285 | 0.00098 | 0.041 | 0.00088 | 0.026 | 69.4 | 0.562 | | 0.00341 | 0.214 | <0.30 | 4 | <0.0020 | 3.31 | <0.000020 | 10.9 | 0.849 | 0.00067 | <0.00020 | <0.010 | 0.00938 | <0.0020 | 10.1 |
| | 6/29/2004 | 15 | GL-15 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 6/29/2004 | 20 | GL-20 | 0.0472 | 0.00777 | 0.00151 | 0.0484 | <0.0010 | <0.0010 | <0.020 | 0.00952 | 117 | <0.0010 | 0.0277 | 0.00102 | 0.082 | 0.00069 | 0.025 | 69 | 0.533 | | 0.00333 | 0.209 | <0.30 | 4 | 0.002 | 3.34 | <0.000020 | 10.9 | 0.797 | 0.00066 | <0.00020 | <0.010 | 0.00784 | <0.0020 | 9.53 |
| | 6/29/2004 | 30 | GL-30 | 0.0784 | 0.00793 | 0.00158 | 0.05 | <0.0010 | <0.0010 | <0.020 | 0.00996 | 124 | <0.0010 | 0.0285 | 0.001 | 0.122 | 0.00085 | 0.026 | 72.2 | 0.562 | | 0.00345 | 0.214 | <0.30 | 4.9 | <0.0020 | 3.54 | <0.000020 | 11.6 | 0.837 | 0.00068 | <0.00020 | <0.010 | 0.00815 | <0.0020 | 9.87 |
| | 6/29/2004 | 40 | GL-40 | 0.0855 | 0.00799 | 0.00184 | 0.05 | <0.0010 | <0.0010 | <0.020 | 0.01 | 118 | <0.0010 | 0.0292 | 0.00112 | 0.23 | 0.00104 | 0.025 | 70 | 0.573 | | 0.00337 | 0.217 | <0.30 | 3 | <0.0020 | 3.5 | <0.000020 | 11.1 | 0.841 | 0.0007 | <0.00020 | <0.010 | 0.00828 | <0.0020 | 10 |

| Pit Lake | Date Sampled | Depth | Sample ID | D-Al | D-Sb | D-As | D-Ba | D-Be | D-Bi | D-B | D-Cd | D-Ca | D-Cr | D-Co | D-Cu | D-Fe | D-Pb | D-Li | D-Mg | D-Mn | D-Hg | D-Mo | D-Ni | D-P | D-K | D-Se | D-Si | D-Ag | D-Na | D-Sr | D-Tl | D-Sn | D-Ti | D-U | D-V | D-Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | mm/dd/yyyy | m |  | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L |
| Grum | 8/8/2003 | 0 | GP1-S | <0.01 | 0.008 | <0.001 | 0.06 | <0.002 |  | <0.1 | 0.0086 | 105 | <0.002 | 0.0329 | <0.002 | <0.03 | <0.001 | 0.02 | 63 | 0.407 | <0.00005 | 0.004 | 0.176 |  | 3 | <0.002 |  | <0.00004 | 11 |  | 0.0011 | <0.001 | <0.01 | 0.0028 | <0.03 | 3.79 |
|  | 8/8/2003 | 5 | GP1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 8/8/2003 | 7.5 | GP1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 8/8/2003 | 10 | GP1-10 | <0.03 | 0.01 | <0.003 | 0.05 | <0.005 |  | <0.1 | 0.0151 | 113 | <0.005 | 0.044 | <0.005 | <0.03 | <0.003 | <0.03 | 68.2 | 0.632 | <0.00005 | <0.005 | 0.255 |  | 3 | <0.005 |  | <0.0001 | 12 |  | 0.001 | <0.003 | <0.01 | 0.01 | <0.03 | 11.5 |
|  | 8/8/2003 | 12.5 | GP1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 8/8/2003 | 15 | GP1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 8/8/2003 | 17.5 | GP1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 8/8/2003 | 20 | GP1-20 | <0.03 | 0.011 | <0.003 | 0.04 | <0.005 |  | <0.1 | 0.0156 | 103 | <0.005 | 0.046 | <0.005 | <0.03 | <0.003 | <0.03 | 61.2 | 0.666 | <0.00005 | <0.005 | 0.266 |  | 4 | <0.005 |  | <0.0001 | 11 |  | 0.001 | <0.003 | <0.01 | 0.01 | <0.03 | 12 |
|  | 8/8/2003 | 22.5 | GP1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 8/8/2003 | 25 | GP1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 8/8/2003 | 30 | GP1-30 | <0.03 | 0.01 | <0.003 | 0.05 | <0.005 |  | <0.1 | 0.0151 | 103 | <0.005 | 0.044 | <0.005 | <0.03 | <0.003 | <0.03 | 60.4 | 0.639 | <0.00005 | <0.005 | 0.256 |  | 3 | <0.005 |  | <0.0001 | 11 |  | 0.001 | <0.003 | <0.01 | 0.01 | <0.03 | 11.6 |
|  | 8/8/2003 | 35 | GP1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 8/8/2003 | 40 | GP1-40 | <0.03 | 0.01 | <0.003 | 0.04 | <0.005 |  | <0.1 | 0.0149 | 92.6 | <0.005 | 0.043 | <0.005 | <0.03 | <0.003 | <0.03 | 55.5 | 0.633 | <0.00005 | <0.005 | 0.254 |  | 2 | <0.005 |  | <0.0001 | 10 |  | 0.001 | <0.003 | <0.01 | 0.01 | <0.03 | 11.4 |
|  | 8/8/2003 | 0 | GP2-S | <0.01 | 0.008 | <0.001 | 0.06 | <0.002 |  | <0.1 | 0.0088 | 105 | <0.002 | 0.034 | <0.002 | <0.03 | <0.001 | 0.02 | 62.9 | 0.422 | <0.00005 | 0.004 | 0.181 |  | 3 | <0.002 |  | <0.00004 | 11 |  | 0.0011 | <0.001 | <0.01 | 0.0028 | <0.03 | 3.85 |
|  | 8/8/2003 | 5 | GP2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 8/8/2003 | 10 | GP2-10 | <0.03 | 0.01 | <0.003 | 0.05 | <0.005 |  | <0.1 | 0.0148 | 113 | <0.005 | 0.045 | <0.005 | <0.03 | <0.003 | <0.03 | 67.1 | 0.634 | <0.00005 | <0.005 | 0.256 |  | 4 | <0.005 |  | <0.0001 | 12 |  | 0.001 | <0.003 | <0.01 | 0.009 | <0.03 | 11.4 |
|  | 8/8/2003 | 15 | GP2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 8/8/2003 | 20 | GP2-20 | <0.03 | 0.01 | <0.003 | 0.05 | <0.005 |  | <0.1 | 0.0147 | 114 | <0.005 | 0.043 | <0.005 | <0.03 | <0.003 | <0.03 | 68.1 | 0.626 | <0.00005 | <0.005 | 0.255 |  | 3 | <0.005 |  | <0.0001 | 12 |  | 0.001 | <0.003 | <0.01 | 0.01 | <0.03 | 11.3 |
|  | 8/8/2003 | 25 | GP2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 8/8/2003 | 30 | GP2-30 | <0.03 | 0.01 | <0.003 | 0.05 | <0.005 |  | <0.1 | 0.0148 | 115 | <0.005 | 0.044 | <0.005 | <0.03 | <0.003 | <0.03 | 67.9 | 0.637 | <0.00005 | <0.005 | 0.255 |  | 3 | <0.005 |  | <0.0001 | 12 |  | 0.001 | <0.003 | <0.01 | 0.01 | <0.03 | 11.4 |
|  | 8/8/2003 | 35 | GP2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 8/8/2003 | 40 | GP2-40 | <0.03 | 0.01 | <0.003 | 0.06 | <0.005 |  | <0.1 | 0.015 | 115 | <0.005 | 0.043 | <0.005 | <0.03 | <0.003 | <0.03 | 68.5 | 0.635 | <0.00005 | <0.005 | 0.257 |  | 3 | <0.005 |  | <0.0001 | 12 |  | 0.001 | <0.003 | <0.01 | 0.01 | <0.03 | 11.4 |
|  | 6/29/2004 | 1 | GL-1 | <0.0020 | 0.00671 | 0.00055 | 0.05 | <0.0010 | <0.0010 | <0.020 | 0.00838 | 111 | <0.0010 | 0.0267 | 0.00081 | <0.030 | 0.00034 | 0.025 | 66.1 | 0.419 |  | 0.00367 | 0.187 | <0.30 | 3.1 | <0.0020 | 3.09 | <0.000020 | 10.6 | 0.848 | 0.00076 | <0.00020 | <0.010 | 0.00281 | <0.0020 | 3.33 |
|  | 6/29/2004 | 3 | GL-3 | <0.0020 | 0.00794 | 0.00064 | 0.048 | <0.0010 | <0.0010 | <0.020 | 0.00995 | 119 | <0.0010 | 0.027 | 0.00077 | <0.030 | 0.00037 | 0.028 | 69.6 | 0.506 |  | 0.00334 | 0.201 | <0.30 | 2.7 | <0.0020 | 3.32 | <0.000020 | 11.3 | 0.835 | 0.00078 | <0.00020 | <0.010 | 0.00268 | <0.0020 | 9.55 |
|  | 6/29/2004 | 5 | GL-5 | <0.0020 | 0.00807 | 0.00082 | 0.0491 | <0.0010 | <0.0010 | <0.020 | 0.0101 | 129 | <0.0010 | 0.0271 | 0.00064 | <0.030 | 0.00034 | 0.028 | 75 | 0.522 |  | 0.00338 | 0.205 | <0.30 | 3.6 | <0.0020 | 3.56 | <0.000020 | 11.7 | 0.848 | 0.00068 | <0.00020 | <0.010 | 0.00666 | <0.0020 | 9.64 |
|  | 6/29/2004 | 7 | GL-7 | <0.0020 | 0.00819 | 0.00113 | 0.0494 | <0.0010 | <0.0010 | <0.020 | 0.01 | 116 | <0.0010 | 0.0288 | 0.00068 | <0.030 | 0.00032 | 0.028 | 67.9 | 0.553 |  | 0.00346 | 0.213 | <0.30 | 3.1 | 0.0021 | 3.21 | <0.000020 | 10.8 | 0.861 | 0.00068 | <0.00020 | <0.010 | 0.00574 | <0.0020 | 10.1 |
|  | 6/29/2004 | 10 | GL-10 | <0.0020 | 0.00824 | 0.00108 | 0.0499 | <0.0010 | <0.0010 | <0.020 | 0.0101 | 118 | <0.0010 | 0.0291 | 0.00078 | <0.030 | 0.00032 | 0.026 | 69.8 | 0.567 |  | 0.0035 | 0.219 | <0.30 | 3.5 | 0.0022 | 3.3 | <0.000020 | 10.7 | 0.875 | 0.00066 | <0.00020 | <0.010 | 0.00855 | <0.0020 | 10.2 |
|  | 6/29/2004 | 15 | GL-15 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 6/29/2004 | 20 | GL-20 | <0.0020 | 0.00799 | 0.00105 | 0.0479 | <0.0010 | <0.0010 | <0.020 | 0.00968 | 127 | <0.0010 | 0.0275 | 0.0007 | <0.030 | 0.00019 | 0.025 | 73.8 | 0.534 |  | 0.00336 | 0.209 | <0.30 | 3.5 | <0.0020 | 3.49 | <0.000020 | 11.6 | 0.801 | 0.00066 | <0.00020 | <0.010 | 0.00788 | <0.0020 | 9.54 |
|  | 6/29/2004 | 30 | GL-30 | <0.0020 | 0.00802 | 0.00109 | 0.0484 | <0.0010 | <0.0010 | <0.020 | 0.0101 | 127 | <0.0010 | 0.029 | 0.00066 | <0.030 | 0.00014 | 0.027 | 74.6 | 0.573 |  | 0.00344 | 0.216 | <0.30 | 4.6 | <0.0020 | 3.57 | <0.000020 | 11.9 | 0.842 | 0.00069 | <0.00020 | <0.010 | 0.00816 | <0.0020 | 10.1 |
|  | 6/29/2004 | 40 | GL-40 | <0.0020 | 0.00808 | 0.00119 | 0.0483 | <0.0010 | <0.0010 | <0.020 | 0.0102 | 119 | <0.0010 | 0.0296 | 0.00073 | <0.030 | 0.00011 | 0.026 | 69.9 | 0.598 |  | 0.00348 | 0.221 | <0.30 | 4.1 | 0.0021 | 3.32 | <0.000020 | 11.1 | 0.865 | 0.00068 | <0.00020 | <0.010 | 0.00835 | <0.0020 | 10.3 |

# Appendix D.3

## Vangorda Pit

| Pit Lake | Date Sampled | Depth | Sample ID | Field Cond. | Field Water Temperature | Field pH | Field Dissolved Oxygen | Field ORP | Field TDS | Lab Cond. | Hardness | pH | TDS | TSS | Alkalinity Total | Acidity (to pH 8.3) | Chloride - Cl | Sulphate - SO4 | Ammonia Nitrogen - N | Nitrate Nitrogen N | Nitrite Nitrogen N | Total Phosphate P | Total Cyanide CN | Chlorophyll a (a) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mm/dd/yyyy | m | | µS/cm | ºC | | mg/L - Faro & Grum<br>% Saturation - Vangorda | mV | mg/L | µS/cm | CaCO3 mg/l | | mg/L | mg/L | CaCO3 mg/l | CaCO3 mg/l | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L |
| Vangorda | 6/7/2000 | 0 | Center of Pit | 325 | 17.2 | 7.8 | 92 | | | | | | | | | | | | | | | | | |
| | 6/7/2000 | 2.5 | Seep 11 | 416 | 14.5 | 7.64 | 79 | | | 444 | | 7.89 | | 15 | 66 | 12 | | 166 | | | | | | |
| | 6/7/2000 | 5 | Center of Pit | 988 | 8.9 | 7.42 | 59 | | | | | | | | | | | | | | | | | |
| | 6/7/2000 | 7.5 | Center of Pit | 1072 | 6.7 | 7.39 | 44 | | | | | | | | | | | | | | | | | |
| | 6/7/2000 | 10 | Center of Pit | 1115 | 6 | 7.17 | 34 | | | | | | | | | | | | | | | | | |
| | 6/7/2000 | 12.5 | Seep 12 | 1127 | 5.6 | 7.06 | 20 | | | 1440 | | 7.28 | | 4 | 82 | 118 | | 830 | | | | | | |
| | 6/7/2000 | 15 | Center of Pit | 1242 | 5.5 | 7.04 | 17 | | | | | | | | | | | | | | | | | |
| | 6/7/2000 | 17.5 | Center of Pit | 1310 | 5.5 | 7.02 | 12 | | | | | | | | | | | | | | | | | |
| | 6/7/2000 | 20 | Center of Pit | 1340 | 5.4 | 6.99 | 9 | | | | | | | | | | | | | | | | | |
| | 6/7/2000 | 22 | Center of Pit | 1430 | 5.1 | 6.95 | 6 | | | | | | | | | | | | | | | | | |
| | 6/7/2000 | 0 | South End of Pit | 355 | 15.9 | 7.8 | 93 | | | | | | | | | | | | | | | | | |
| | 6/7/2000 | 2.5 | South End of Pit | 391 | 13.1 | 7.87 | 81 | | | | | | | | | | | | | | | | | |
| | 6/7/2000 | 5 | South End of Pit | 981 | 7.8 | 7.39 | 61 | | | | | | | | | | | | | | | | | |
| | 6/7/2000 | 7.5 | South End of Pit | 1079 | 6 | 7.19 | 45 | | | | | | | | | | | | | | | | | |
| | 6/7/2000 | 10 | South End of Pit | 1108 | 5.4 | 7.03 | 33 | | | | | | | | | | | | | | | | | |
| | 6/7/2000 | 12.5 | South End of Pit | 1134 | 5.2 | 6.91 | 28 | | | | | | | | | | | | | | | | | |
| | 6/7/2000 | 15 | South End of Pit | 1218 | 5 | 6.88 | 20 | | | | | | | | | | | | | | | | | |
| | 6/7/2000 | 17.5 | South End of Pit | 1319 | 5.1 | 6.91 | 14 | | | | | | | | | | | | | | | | | |
| | 6/7/2000 | 20 | South End of Pit | 1350 | 5 | 6.92 | 10 | | | | | | | | | | | | | | | | | |
| | 6/7/2000 | 22.5 | South End of Pit | 1430 | 4.9 | 6.9 | 7 | | | | | | | | | | | | | | | | | |
| | 6/7/2000 | 25 | South End of Pit | 1430 | 4.8 | 6.92 | 5 | | | | | | | | | | | | | | | | | |
| | 09/15/2003 | 1 | VGPW | 1776 | 5.1 | 6.99 | | 139 | | 1710 | | 7.03 | | | 57 | 151 | 0.7 | 1080 | | | | | | |
| | 09/15/2003 | 3 | VGPW | 1781 | 6.1 | 6.86 | | 102 | | 1760 | | 7.35 | | | 50 | 162 | 1 | 1100 | | | | | | |
| | 09/15/2003 | 5 | VGPW | 1990 | 6 | 6.65 | | 48 | | 1930 | | 7.31 | | | 48 | 194 | 0.9 | 1250 | | | | | | |
| | 09/15/2003 | 10 | VGPW | 2110 | 5.2 | 6.58 | | 25 | | 1980 | | 7.3 | | | 49 | 210 | 1 | 1280 | | | | | | |
| | 09/15/2003 | 20 | VGPW | 2070 | 5.4 | 6.57 | | 30 | | 1980 | | 7.28 | | | 49 | 212 | 0.9 | 1280 | | | | | | |
| | 09/15/2003 | 30 | VGPW | 2090 | 6.1 | 6.7 | | 35 | | 1940 | | 6.54 | | | 48 | 217 | 1 | 1250 | | | | | | |
| | 09/15/2003 | 40 | VGPW | 1865 | 5.4 | 6.82 | | 68 | | 1990 | | 7.03 | | | 49 | 221 | 0.6 | 1280 | | | | | | |
| | 7/7/2004 | 1 | VAN 1 | | | | | | | | | | 986 | <3.0 | 26.6 | | <0.5 | 619 | 0.257 | 0.0866 | 0.0045 | 0.0041 | | <0.060 |
| | 7/7/2004 | 3 | VAN 3 | 1800 | 5 | | | | | | | | 1770 | 4.7 | 31.6 | | <0.5 | 1140 | 0.766 | 0.0444 | 0.002 | <0.0020 | | <0.060 |
| | 7/7/2004 | 5 | VAN 5 | | | | | | | | | | 1810 | 18.7 | 31.5 | | <0.5 | 1210 | 0.603 | 0.0358 | 0.0025 | 0.002 | | <0.060 |
| | 7/7/2004 | 10 | VAN 10 | | | | | | | | | | 1910 | 28 | 27.7 | | <0.5 | 1240 | 0.576 | 0.0226 | 0.0021 | 0.002 | | <0.060 |
| | 7/7/2004 | 20 | VAN 20 | | | | | | | | | | 1970 | 32.7 | 20.7 | | <0.5 | 1280 | 0.608 | 0.0178 | 0.0022 | <0.0020 | | |
| | 7/7/2004 | 30 | VAN 30 | | | | | | | | | | 1960 | 36.7 | 13.6 | | <0.5 | 1300 | 0.599 | 0.0408 | 0.0026 | 0.0027 | | |
| | 7/7/2004 | 40 | VAN 40 | | | | | | | | | | 1930 | 38 | 14.5 | | <0.5 | 1280 | 0.636 | 0.013 | 0.0033 | <0.0020 | | |

| Pit Lake | Date Sampled | Depth | Sample ID | T-Al | T-Sb | T-As | T-Ba | T-Be | T-Bi | T-B | T-Cd | T-Ca | T-Cr | T-Co | T-Cu | T-Fe | T-Pb | T-Li | T-Mg | T-Mn | T-Hg | T-Mo | T-Ni | T-P | T-K | T-Se | T-Si | T-Ag | T-Na | T-Sr | T-Tl | T-Sn | T-Ti | T-U | T-V | T-Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | mm/dd/yyyy | m |  | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L |
| Vangorda | 6/7/2000 | 0 | Center of Pit |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 6/7/2000 | 2.5 | Seep 11 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 6/7/2000 | 5 | Center of Pit |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 6/7/2000 | 7.5 | Center of Pit |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 6/7/2000 | 10 | Center of Pit |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 6/7/2000 | 12.5 | Seep 12 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 6/7/2000 | 15 | Center of Pit |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 6/7/2000 | 17.5 | Center of Pit |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 6/7/2000 | 20 | Center of Pit |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 6/7/2000 | 22 | Center of Pit |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 6/7/2000 | 0 | South End of Pit |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 6/7/2000 | 2.5 | South End of Pit |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 6/7/2000 | 5 | South End of Pit |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 6/7/2000 | 7.5 | South End of Pit |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 6/7/2000 | 10 | South End of Pit |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 6/7/2000 | 12.5 | South End of Pit |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 6/7/2000 | 15 | South End of Pit |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 6/7/2000 | 17.5 | South End of Pit |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 6/7/2000 | 20 | South End of Pit |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 6/7/2000 | 22.5 | South End of Pit |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 6/7/2000 | 25 | South End of Pit |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 09/15/2003 | 1 | VGPW |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 09/15/2003 | 3 | VGPW |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 09/15/2003 | 5 | VGPW |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 09/15/2003 | 10 | VGPW |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 09/15/2003 | 20 | VGPW |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 09/15/2003 | 30 | VGPW |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 09/15/2003 | 40 | VGPW |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 7/7/2004 | 1 | VAN 1 | 0.043 | <0.0020 | <0.0020 | 0.0476 | <0.010 | <0.010 | <0.20 | 0.0619 | 129 | <0.010 | 0.307 | 0.121 | 0.144 | 0.0168 | <0.10 | 49.2 | 16.9 |  | <0.0010 | 0.325 | <0.30 | <2 | <0.020 | 2.96 | <0.00020 | 3.2 | 0.746 | <0.0020 | <0.0020 | <0.010 | 0.00054 | <0.020 | 56.1 |
|  | 7/7/2004 | 3 | VAN 3 | <0.05 | <0.0050 | <0.0050 | 0.0341 | <0.025 | <0.025 | <0.50 | 0.0913 | 234 | <0.025 | 0.658 | 0.321 | 1.65 | 0.008 | <0.25 | 92.4 | 37.2 |  | <0.0025 | 0.622 | <0.30 | 4.8 | <0.050 | 3.14 | <0.00050 | 5.6 | 1.34 | <0.0050 | <0.0050 | 0.01 | <0.00050 | <0.050 | 112 |
|  | 7/7/2004 | 5 | VAN 5 | <0.05 | <0.0050 | <0.0050 | 0.0272 | <0.025 | <0.025 | <0.50 | 0.0862 | 244 | <0.025 | 0.707 | 0.243 | 12.4 | 0.0027 | <0.25 | 96.6 | 40.2 |  | <0.0025 | 0.668 | <0.30 | 3.5 | <0.050 | 3.2 | <0.00050 | 5.6 | 1.37 | <0.0050 | <0.0050 | 0.011 | <0.00050 | <0.050 | 119 |
|  | 7/7/2004 | 10 | VAN 10 | <0.05 | <0.0050 | <0.0050 | 0.0242 | <0.025 | <0.025 | <0.50 | 0.0976 | 244 | <0.025 | 0.737 | 0.258 | 16 | 0.0026 | <0.25 | 97.3 | 42.3 |  | <0.0025 | 0.699 | <0.30 | 3.6 | <0.050 | 3.23 | <0.00050 | 5.6 | 1.41 | <0.0050 | <0.0050 | <0.010 | <0.00050 | <0.050 | 126 |
|  | 7/7/2004 | 20 | VAN 20 | <0.05 | <0.0050 | <0.0050 | 0.0236 | <0.025 | <0.025 | <0.50 | 0.111 | 253 | <0.025 | 0.773 | 0.226 | 21.1 | 0.006 | <0.25 | 100 | 44.4 |  | <0.0025 | 0.718 | <0.30 | 4 | <0.050 | 3.36 | <0.00050 | 5.9 | 1.45 | <0.0050 | <0.0050 | <0.010 | <0.00050 | <0.050 | 132 |
|  | 7/7/2004 | 30 | VAN 30 | <0.05 | <0.0050 | <0.0050 | 0.022 | <0.025 | <0.025 | <0.50 | 0.11 | 247 | <0.025 | 0.747 | 0.211 | 23.5 | 0.016 | <0.25 | 99.1 | 42.5 |  | <0.0025 | 0.699 | <0.30 | 3.2 | <0.050 | 3.33 | <0.00050 | 5.6 | 1.42 | <0.0050 | <0.0050 | 0.012 | <0.00050 | <0.050 | 129 |
|  | 7/7/2004 | 40 | VAN 40 | <0.05 | <0.0050 | <0.0050 | 0.021 | <0.025 | <0.025 | <0.50 | 0.107 | 259 | <0.025 | 0.7 | 0.207 | 25.6 | 0.0172 | <0.25 | 104 | 41.9 |  | <0.0025 | 0.65 | <0.30 | 3.9 | <0.050 | 3.51 | <0.00050 | 5.9 | 1.36 | <0.0050 | <0.0050 | <0.010 | <0.00050 | <0.050 | 127 |

| Pit Lake | Date Sampled | Depth | Sample ID | D-Al | D-Sb | D-As | D-Ba | D-Be | D-Bi | D-B | D-Cd | D-Ca | D-Cr | D-Co | D-Cu | D-Fe | D-Pb | D-Li | D-Mg | D-Mn | D-Hg | D-Mo | D-Ni | D-P | D-K | D-Se | D-Si | D-Ag | D-Na | D-Sr | D-Tl | D-Sn | D-Ti | D-U | D-V | D-Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mm/dd/yyyy | m | | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L |
| Vangorda | 6/7/2000 | 0 | Center of Pit | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 6/7/2000 | 2.5 | Seep 11 | <0.2 | <0.2 | <0.2 | 0.04 | <0.005 | <0.1 | <0.1 | 0.01 | 54 | <0.01 | 0.03 | 0.02 | 0.06 | <0.05 | 0.02 | 16.5 | 1.5 | | <0.03 | 0.07 | <0.3 | <2 | <0.2 | 2.79 | <0.01 | 2 | 0.51 | <0.2 | <0.03 | <0.01 | | <0.03 | 6.27 |
| | 6/7/2000 | 5 | Center of Pit | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 6/7/2000 | 7.5 | Center of Pit | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 6/7/2000 | 10 | Center of Pit | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 6/7/2000 | 12.5 | Seep 12 | <0.2 | <0.2 | <0.2 | 0.02 | <0.005 | <0.1 | <0.1 | 0.08 | 181 | <0.01 | 0.41 | 0.02 | 0.11 | <0.05 | 0.03 | 69.7 | 19.7 | | <0.03 | 0.41 | <0.3 | 4 | <0.2 | 2.63 | <0.01 | 6 | 1.4 | <0.2 | <0.03 | <0.01 | | <0.03 | 70.1 |
| | 6/7/2000 | 15 | Center of Pit | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 6/7/2000 | 17.5 | Center of Pit | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 6/7/2000 | 20 | Center of Pit | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 6/7/2000 | 22 | Center of Pit | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 6/7/2000 | 0 | South End of Pit | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 6/7/2000 | 2.5 | South End of Pit | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 6/7/2000 | 5 | South End of Pit | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 6/7/2000 | 7.5 | South End of Pit | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 6/7/2000 | 10 | South End of Pit | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 6/7/2000 | 12.5 | South End of Pit | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 6/7/2000 | 15 | South End of Pit | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 6/7/2000 | 17.5 | South End of Pit | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 6/7/2000 | 20 | South End of Pit | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 6/7/2000 | 22.5 | South End of Pit | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 6/7/2000 | 25 | South End of Pit | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 09/15/2003 | 1 | VGPW | <0.2 | <0.2 | <0.2 | 0.01 | <0.005 | <0.2 | <0.1 | 0.08 | 213 | <0.01 | 0.53 | 0.1 | 0.15 | <0.05 | 0.04 | 85.1 | 30.4 | <0.03 | 0.5 | <0.3 | | 4 | <0.2 | 2.97 | <0.01 | 5 | 1.22 | <0.2 | <0.03 | <0.01 | | <0.03 | 91.5 |
| | 09/15/2003 | 3 | VGPW | <0.2 | <0.2 | <0.2 | 0.01 | <0.005 | <0.2 | <0.1 | 0.08 | 208 | <0.01 | 0.53 | <0.01 | 1.74 | <0.05 | 0.04 | 84.4 | 30.3 | <0.03 | 0.51 | <0.3 | | 3 | <0.2 | 2.91 | <0.01 | 6 | 1.19 | <0.2 | <0.03 | <0.01 | | <0.03 | 91.4 |
| | 09/15/2003 | 5 | VGPW | <0.2 | <0.2 | <0.2 | 0.01 | <0.005 | <0.2 | <0.1 | 0.08 | 226 | <0.01 | 0.59 | 0.01 | 11.3 | <0.05 | 0.04 | 92.6 | 34.3 | <0.03 | 0.57 | <0.3 | | 3 | <0.2 | 3.04 | <0.01 | 6 | 1.24 | <0.2 | <0.03 | <0.01 | | <0.03 | 102 |
| | 09/15/2003 | 10 | VGPW | <0.2 | <0.2 | <0.2 | 0.01 | <0.005 | <0.2 | <0.1 | 0.08 | 248 | <0.01 | 0.65 | <0.01 | 17.6 | <0.05 | 0.05 | 103 | 38.5 | <0.03 | 0.62 | <0.3 | | 3 | <0.2 | 3.37 | <0.01 | 6 | 1.35 | <0.2 | <0.03 | <0.01 | | <0.03 | 114 |
| | 09/15/2003 | 20 | VGPW | <0.2 | <0.2 | <0.2 | <0.01 | <0.005 | <0.2 | <0.1 | 0.07 | 237 | <0.01 | 0.63 | <0.01 | 21.7 | <0.05 | 0.05 | 98.2 | 37.2 | <0.03 | 0.59 | <0.3 | | 3 | <0.2 | 3.19 | <0.01 | 5 | 1.26 | <0.2 | <0.03 | <0.01 | | <0.03 | 111 |
| | 09/15/2003 | 30 | VGPW | <0.2 | <0.2 | <0.2 | 0.01 | <0.005 | <0.2 | <0.1 | 0.08 | 267 | <0.01 | 0.72 | <0.01 | 27.9 | <0.05 | 0.05 | 112 | 43 | <0.03 | 0.66 | <0.3 | | 3 | <0.2 | 3.58 | <0.01 | 6 | 1.43 | <0.2 | <0.03 | <0.01 | | <0.03 | 124 |
| | 09/15/2003 | 40 | VGPW | <0.2 | <0.2 | <0.2 | 0.01 | <0.005 | <0.2 | <0.1 | 0.08 | 243 | <0.01 | 0.64 | 0.01 | 16.5 | <0.05 | 0.05 | 100 | 37.6 | <0.03 | 0.62 | <0.3 | | 3 | <0.2 | 3.23 | <0.01 | 6 | 1.33 | 0.2 | <0.03 | <0.01 | | <0.03 | 111 |
| | 7/7/2004 | 1 | VAN 1 | 0.034 | <0.0020 | <0.0020 | 0.0506 | <0.010 | <0.010 | <0.20 | 0.0627 | 125 | <0.010 | 0.307 | 0.122 | 0.144 | 0.0164 | <0.10 | 47.4 | 16.8 | | <0.0010 | 0.318 | <0.30 | 2.7 | <0.020 | 2.85 | <0.00020 | 3 | 0.745 | <0.0020 | <0.0020 | <0.010 | 0.00056 | <0.020 | 55.8 |
| | 7/7/2004 | 3 | VAN 3 | <0.050 | <0.0050 | <0.0050 | 0.0346 | <0.025 | <0.025 | <0.50 | 0.0914 | 212 | <0.025 | 0.657 | 0.317 | 1.13 | 0.0026 | <0.25 | 84.4 | 37.1 | | <0.0025 | 0.638 | <0.30 | 3.5 | <0.050 | 2.85 | <0.00050 | 5.1 | 1.31 | <0.0050 | <0.0050 | <0.010 | <0.00050 | <0.050 | 112 |
| | 7/7/2004 | 5 | VAN 5 | <0.050 | <0.0050 | <0.0050 | 0.0269 | <0.025 | <0.025 | <0.50 | 0.0914 | 240 | <0.025 | 0.716 | 0.241 | 11.8 | <0.0025 | <0.25 | 94.9 | 40.8 | | <0.0025 | 0.677 | <0.30 | 4.3 | <0.050 | 3.14 | <0.00050 | 5.7 | 1.42 | <0.0050 | <0.0050 | 0.011 | <0.00050 | <0.050 | 122 |
| | 7/7/2004 | 10 | VAN 10 | <0.050 | <0.0050 | <0.0050 | 0.0259 | <0.025 | <0.025 | <0.50 | 0.0997 | 240 | <0.025 | 0.754 | 0.257 | 15.4 | <0.0025 | <0.25 | 95.4 | 43.4 | | <0.0025 | 0.722 | <0.30 | 3.6 | <0.050 | 3.15 | <0.00050 | 5.7 | 1.43 | <0.0050 | <0.0050 | <0.010 | <0.00050 | <0.050 | 128 |
| | 7/7/2004 | 20 | VAN 20 | <0.050 | <0.0050 | <0.0050 | 0.0222 | <0.025 | <0.025 | <0.50 | 0.109 | 249 | <0.025 | 0.753 | 0.218 | 20.6 | <0.0025 | <0.25 | 99.7 | 43.5 | | <0.0025 | 0.714 | <0.30 | 3.1 | <0.050 | 3.34 | <0.00050 | 5.7 | 1.41 | <0.0050 | <0.0050 | <0.010 | <0.00050 | <0.050 | 130 |
| | 7/7/2004 | 30 | VAN 30 | <0.050 | <0.0050 | <0.0050 | 0.0217 | <0.025 | <0.025 | <0.50 | 0.11 | 249 | <0.025 | 0.744 | 0.211 | 23.4 | 0.0066 | <0.25 | 100 | 42.5 | | <0.0025 | 0.705 | <0.30 | 3.8 | <0.050 | 3.35 | <0.00050 | 5.8 | 1.4 | <0.0050 | <0.0050 | 0.012 | <0.00050 | <0.050 | 130 |
| | 7/7/2004 | 40 | VAN 40 | <0.050 | <0.0050 | <0.0050 | 0.0214 | <0.025 | <0.025 | <0.50 | 0.113 | 242 | <0.025 | 0.747 | 0.205 | 23.5 | 0.007 | <0.25 | 97.9 | 42.4 | | <0.0025 | 0.684 | <0.30 | 4.2 | <0.050 | 3.31 | <0.00050 | 5.6 | 1.41 | <0.0050 | <0.0050 | 0.011 | <0.00050 | <0.050 | 131 |

# Appendix E

## Characteristics of Water Types
## Used In Predicting Wall Rock Loadings

# Appendix E.1

## Faro Pit

| Type | ID | Statistic | pH | Acidity | Alk | Cl | SO4 | Ca | Mg | K | Na | Al | Cd | Co | Cu | Fe | Pb | Mn | Ni | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Faro Type 1 | FT1 | Average | 7.3 | 14 | 185 | 1.6 | 722 | 154 | 114 | 6.5 | 29 | 0.2 | 0.01 | 0.01 | 0.01 | 0.03 | 0.06 | 0.11 | 0.06 | 2.5 |
| | | Median | 7.2 | 15 | 190.5 | 1.6 | 493 | 145 | 86 | 4.0 | 7.5 | 0.2 | 0.01 | 0.01 | 0.01 | 0.03 | 0.05 | 0.05 | 0.05 | 2.0 |
| | | Min | 6.6 | 3 | 112 | 0.5 | 266 | 82.2 | 27 | 3.0 | 4.0 | 0.2 | 0.01 | 0.01 | 0.01 | 0.03 | 0.05 | 0.005 | 0.05 | 0.17 |
| | | Max | 8.1 | 29 | 242 | 2.7 | 2470 | 263 | 378 | 24 | 122 | 0.2 | 0.01 | 0.01 | 0.01 | 0.03 | 0.15 | 0.422 | 0.09 | 5.3 |
| | | N | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 |
| Faro Type 2 Waste | FT2 | Average | 6.7 | 51 | 137 | 1.6 | 1701 | 288 | 231 | 7.9 | 16 | 0.3 | 0.03 | 0.052 | 0.04 | 1.9 | 0.06 | 4.9 | 0.17 | 26 |
| | | Median | 6.8 | 46 | 71.5 | 1.3 | 1425 | 227 | 177 | 8.0 | 11 | 0.2 | 0.02 | 0.045 | 0.01 | 0.12 | 0.05 | 2.8 | 0.12 | 26 |
| | | Min | 5.8 | 15 | 4 | 0.5 | 334 | 49.1 | 37 | 2.0 | 3.0 | 0.2 | 0.01 | 0.01 | 0.01 | 0.03 | 0.05 | 0.037 | 0.05 | 3.9 |
| | | Max | 7.3 | 115 | 407 | 4.6 | 3860 | 628 | 584 | 15 | 122 | 1.6 | 0.09 | 0.15 | 0.5 | 20.2 | 0.23 | 19 | 0.6 | 51 |
| | | N | 26 | 26 | 26 | 26 | 26 | 26 | 26 | 26 | 26 | 26 | 26 | 26 | 26 | 26 | 26 | 26 | 26 | 26 |
| Faro Type 2 Ore | FT3 | Average | 6.5 | 601 | 242 | 12 | 3783 | 491 | 505 | 13 | 49 | 0.4 | 0.16 | 0.41 | 0.08 | 33 | 0.10 | 44 | 0.61 | 261 |
| | | Median | 6.4 | 477 | 319.5 | 15 | 4285 | 529 | 635 | 14 | 54 | 0.4 | 0.07 | 0.45 | 0.05 | 31.95 | 0.075 | 49.5 | 0.63 | 221 |
| | | Min | 6.2 | 37 | 13 | 0.7 | 962 | 272 | 51 | 7.0 | 11 | 0.2 | 0.01 | 0.03 | 0.01 | 0.09 | 0.05 | 3.84 | 0.05 | 13.7 |
| | | Max | 7.0 | 2160 | 350 | 17.5 | 4600 | 576 | 694 | 17 | 69 | 0.6 | 0.62 | 0.53 | 0.3 | 89.9 | 0.2 | 54 | 0.9 | 595 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| Faro Type 3 Waste | FT4 | Average | 3.9 | 968 | 16 | 3.1 | 1614 | 173 | 161 | 6.4 | 7.5 | 15 | 0.16 | 0.30 | 2 | 76 | 0.36 | 10 | 0.56 | 109 |
| | | Median | 3.4 | 177 | 1 | 0.60 | 1170 | 239 | 104 | 5.0 | 4.0 | 4.1 | 0.08 | 0.20 | 0.58 | 3.91 | 0.08 | 3.79 | 0.24 | 46.7 |
| | | Min | 2.6 | 27 | 1 | 0.50 | 69 | 6.45 | 3.8 | 2.0 | 2.0 | 0.2 | 0.01 | 0.01 | 0.03 | 0.03 | 0.05 | 0.161 | 0.05 | 2.2 |
| | | Max | 5.9 | 8750 | 92 | 23.8 | 4780 | 410 | 504 | 14 | 36 | 73 | 0.85 | 1.5 | 8.06 | 416 | 1.6 | 64.3 | 3.2 | 751 |
| | | N | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 17 |
| Faro Type 3 Ore | FT5 | Average | 3.4 | 14470 | 6 | 126 | 17107 | 305 | 727 | 39 | 44 | 207 | 6.5 | 5.0 | 92 | 2773 | 1.5 | 388 | 3.9 | 4260 |
| | | Median | 2.5 | 6550 | 1 | 2.9 | 7490 | 268 | 235 | 20 | 46 | 71 | 6.9 | 1.7 | 7.8 | 1040 | 1.78 | 125 | 1.5 | 2260 |
| | | Min | 2.2 | 227 | 1 | 0.50 | 700 | 107 | 38.8 | 2.0 | 2.0 | 0.2 | 0.12 | 0.080 | 0.14 | 1.3 | 0.3 | 5.7 | 0.08 | 128 |
| | | Max | 6.0 | 49500 | 31 | 1050 | 59000 | 504 | 3210 | 100 | 100 | 986 | 15.5 | 20 | 559 | 15100 | 3.0 | 2360 | 15 | 10900 |
| | | N | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 |
| Others (average only) | FT6 | FD04 | 2.4 | 30970 | 1.00 | 342 | 35523 | 378 | 1655 | 73 | 73 | 502 | 10 | 11 | 187 | 6748 | 2 | 936 | 7.7 | 6930 |
| | FT7 | FD05/06 | 7.2 | 12 | 204 | 1.9 | 462 | 133 | 95 | 3.9 | 6.9 | 0.20 | 0.010 | 0.010 | 0.010 | 0.030 | 0.05 | 0.044 | 0.05 | 2.2 |
| | FT8 | FD14 | 7.6 | 16 | 111 | 0.77 | 2050 | 211 | 283 | 18 | 121 | 0.20 | 0.013 | 0.013 | 0.027 | 0.317 | 0.05 | 0.14 | 0.07 | 6.0 |
| | FT9 | FD19 | 7.1 | 85 | 398 | 2.1 | 3680 | 601 | 558 | 10 | 20 | 0.25 | 0.013 | 0.055 | 0.038 | 0.785 | 0.063 | 18 | 0.31 | 45 |
| | FT10 | FD37 | 2.4 | 11700 | 1.0 | 0.50 | 14850 | 242 | 273 | 31 | 31 | 94 | 11.3 | 4.0 | 127 | 1410 | 1.3 | 149 | 4.1 | 6985 |
| | FT11 | FD40 | 4.3 | 98 | 10 | 0.57 | 386 | 42 | 46 | 2.0 | 2.7 | 2.8 | 0.05 | 0.09 | 0.37 | 2.2 | 0.08 | 2.3 | 0.093 | 35 |
| | FT12 | 04FP02 | 7.5 | 2 | 139 | 0.64 | 428 | 44 | 10 | 2.0 | 150.0 | 0.2 | 0.01 | 0.01 | 0.01 | 0.0 | 0.05 | 0.0 | 0.050 | 0 |
| Faro Unit 10E Seeps | FT13 | Average | 7.49 | 4.1 | 242 | 0.5 | 137 | 68 | 34 | 3.7 | 18 | 0.2 | 0.01 | 0.01 | 0.01 | 0.03 | 0.05 | 0.034 | 0.05 | 0.28 |
| | | Median | 7.32 | 4.1 | 239 | 0.5 | 99 | 59 | 28 | 3.1 | 15 | 0.2 | 0.01 | 0.01 | 0.01 | 0.03 | 0.05 | 0.005 | 0.05 | 0.005 |
| | | Min | 7.03 | 3.9 | 193 | 0.5 | 26 | 50 | 13 | 2 | 2.6 | 0.2 | 0.01 | 0.01 | 0.01 | 0.03 | 0.05 | 0.005 | 0.05 | 0.005 |
| | | Max | 8.12 | 4.2 | 293 | 0.5 | 287 | 94 | 59 | 6.1 | 36 | 0.2 | 0.01 | 0.01 | 0.01 | 0.03 | 0.05 | 0.093 | 0.05 | 0.83 |
| | | N | 3 | 3 | 3 | 3.0 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |

# Appendix E.2

## Grum Pit

## Appendix E.2 Definition of Grum Pit Wall Rock Water Types

| Type | ID | Statistic | pH | Acidity | Alk | Cl | SO4 | Ca | Mg | K | Na | Al | Cd | Co | Cu | Fe | Pb | Mn | Ni | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Grum Phyllite Avg | VG7 | Average | 8.0 | 8 | 238 | 0.9 | 633 | 134 | 122 | 3.6 | 3.8 | 0 | 0.00 | 0.01 | 0 | 0 | 0.02 | 0 | 0.08 | 0 |
| | | Median | 8.0 | 3 | 254.5 | 0.81 | 570 | 110 | 97.65 | 3.7 | 4.1 | 0.2 | 0.01 | 0.01 | 0.01 | 0.03 | 0.05 | 0.00665 | 0.075 | 0.01605 |
| | | Min | 7.4 | 1 | 139 | 0.50 | 225 | 64.8 | 59.6 | 2.5 | 2.0 | 0.2 | 0.01 | 0.01 | 0.01 | 0.03 | 0.05 | 0.005 | 0.05 | 0.005 |
| | | Max | 8.4 | 36 | 297 | 2.7 | 1050 | 268 | 235 | 5 | 6 | 0.2 | 0.01 | 0.0 | 0.01 | 0.03 | 0.05 | 0.0168 | 0.17 | 0.073 |
| | | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| Grum Sulphide Avg | VG8 | Average | 7.6 | 56 | 216 | 0.2 | 830 | 180 | 111 | 2.7 | 7.7 | 0 | 0.02 | 0.15 | 0.35 | 14 | 0.01 | 4 | 0.73 | 28 |
| | | Median | 7.5 | 37 | 217 | 0.50 | 782 | 176 | 109 | 3.0 | 6.0 | 0.2 | 0.01 | 0.10 | 0.01 | 0.03 | 0.05 | 0.158 | 0.65 | 12 |
| | | Min | 6.8 | 5.8 | 28.5 | 0.50 | 716 | 113 | 66.9 | 2.0 | 2.7 | 0.2 | 0.01 | 0.01 | 0.01 | 0.03 | 0.05 | 0.015 | 0.418 | 6.69 |
| | | Max | 8.5 | 173 | 373 | 1.18 | 989 | 239 | 167 | 3 | 16 | 0.2 | 0.098 | 0.5 | 1.73 | 72 | 0.074 | 17.4 | 1.03 | 97.5 |
| | | N | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Grum Till Avg | VG9 | Average | 8.0 | 2 | 112 | 0.7 | 325 | 111 | 26 | 3.4 | 10.0 | 0 | 0.01 | 0.01 | 0 | 0 | 0.05 | 0 | 0.05 | 0 |
| | | Median | 8.0 | 1 | 99.2 | 0.74 | 350 | 103 | 34.3 | 2.9 | 8.3 | 0.2 | 0.01 | 0.01 | 0.01 | 0.03 | 0.05 | 0.0252 | 0.05 | 0.005 |
| | | Min | 7.9 | 1 | 91.8 | 0.50 | 34.7 | 46 | 9.78 | 2.0 | 6.9 | 0.2 | 0.01 | 0.01 | 0.01 | 0.03 | 0.05 | 0.005 | 0.05 | 0.005 |
| | | Max | 8.3 | 3.3 | 145 | 0.76 | 590 | 185 | 34.8 | 5.2 | 14.7 | 0.2 | 0.01 | 0.0 | 0.01 | 0.03 | 0.05 | 0.558 | 0.05 | 0.0307 |
| | | N | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |

# Appendix E.3

## Vangorda Pit

## Appendix E.3 Definition of Vangorda Pit Wall Rock Water Types

| Type | ID | Statistic | pH | Acidity | Alk | Cl | SO4 | Ca | Mg | K | Na | Al | Cd | Co | Cu | Fe | Pb | Mn | Ni | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Vang Phyllite Avg | VG10 | Average | 6.2 | 94 | 88 | 0.7 | 615 | 157 | 51 | 2.3 | 2.3 | 1 | 0.07 | 0.11 | 0 | 2 | 0.18 | 10 | 0.30 | 46 |
| | | Median | 6.8 | 17.4 | 59.5 | 0.50 | 600 | 129 | 55.6 | 2.0 | 2.3 | 0.2 | 0.01 | 0.05 | 0.01 | 0.03 | 0.05 | 0.698 | 0.125 | 5.19 |
| | | Min | 3.4 | 1.3 | 1 | 0.50 | 23.3 | 27 | 2.33 | 2.0 | 2.0 | 0.2 | 0.01 | 0.01 | 0.01 | 0.03 | 0.05 | 0.005 | 0.05 | 0.0074 |
| | | Max | 7.3 | 356 | 216 | 1.37 | 1370 | 324 | 91.8 | 3.1 | 3 | 4 | 0.322 | 0.4 | 1.54 | 6.14 | 0.685 | 31.7 | 0.646 | 180 |
| | | N | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Vang Sulphide Avg | VG11 | Average | 5.0 | 1212 | 17 | 0.7 | 2514 | 180 | 152 | 6.8 | 7.3 | 15 | 0.64 | 1.43 | 6 | 307 | 0.77 | 105 | 1.21 | 452 |
| | | Median | 4.8 | 382 | 1 | 0.50 | 740.5 | 135.5 | 50.05 | 2.1 | 3.6 | 5.69 | 0.1645 | 0.35 | 1.655 | 28.07 | 0.468 | 18.75 | 0.674 | 114.05 |
| | | Min | 2.8 | 35 | 1 | 0.50 | 212 | 28.1 | 13.3 | 2.0 | 2.0 | 0.2 | 0.025 | 0.072 | 0.01 | 0.03 | 0.05 | 4.13 | 0.075 | 12.1 |
| | | Max | 7.2 | 4370 | 90 | 1.19 | 8080 | 455 | 675 | 20 | 20 | 49.3 | 3.21 | 4.7 | 41.3 | 1410 | 2.49 | 559 | 3.34 | 1550 |
| | | N | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| Vg Bleached Phyll. Avg | VG12 | Average | 3.8 | 1994 | 4 | 0.8 | 6060 | 333 | 458 | 12.5 | 10.4 | 25 | 0.65 | 4.44 | 7 | 360 | 0.50 | 442 | 2.04 | 779 |
| | | Median | 3.2 | 2070 | 1 | 0.75 | 5110 | 363 | 326 | 9.5 | 6.0 | 19.1 | 0.823 | 3.34 | 8.64 | 421 | 0.5 | 312 | 1.69 | 558 |
| | | Min | 2.7 | 643 | 1 | 0.50 | 1930 | 232 | 131 | 7.9 | 5.1 | 0.4 | 0.059 | 0.844 | 0.025 | 166 | 0.1 | 90 | 0.65 | 229 |
| | | Max | 5.6 | 3270 | 10.6 | 1.02 | 11139 | 404 | 918 | 20 | 20 | 54.6 | 1.08 | 9.1 | 11.9 | 492 | 0.91 | 924 | 3.77 | 1550 |
| | | N | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Vang Till | VG13 | 04VP03 | 7.6 | 1 | 201 | 0.6 | 25 | 53 | 15 | 2.0 | 6.0 | 0.20 | 0.010 | 0.010 | 0.010 | 0.030 | 0.050 | 0.0084 | 0.050 | 0.0050 |