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Detoxifying Pit Lakes by Controlled Algal Blooms: Laboratory Test and Pilot Phytoremediation Trail at Little Creek Pond at Vangorda Pit near Faro, Yukon Territory, Canada

By Microbial Technologies

March 2003

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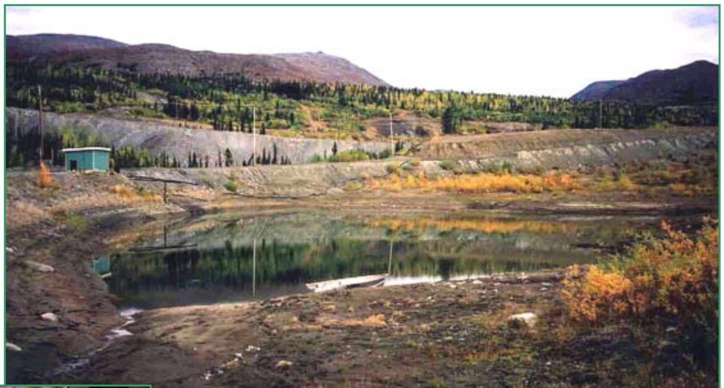
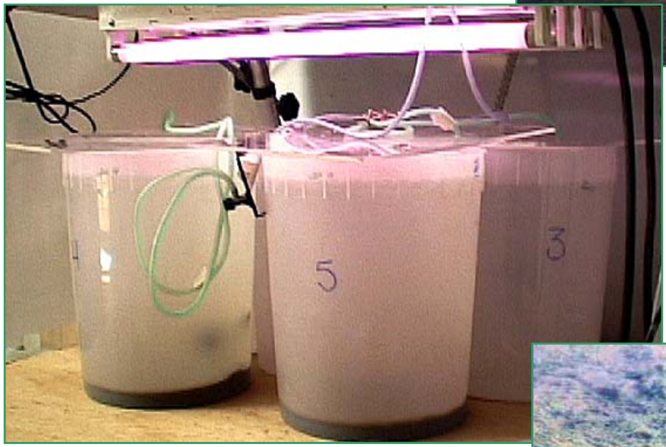
Prepared for:
MERG and
Environmental Biotechnology
Application Division,
Environmental Technology
Advancement Directorate,
Environment Canada





Final Report

FINAL REPORT - MARCH 2003

Detoxifying Pit Lakes by Controlled Algal Blooms (Aquatic Phytoremediation): Laboratory Study and Pilot Field Trial at the Little Creek Pond at Vangorda Pit near Faro, Yukon Territory, Canada

Final Report

A Report Prepared for:
Mining Environment Research Group (MERG)

and

Environmental Biotechnology Application Division
Environmental Technology Advancement Directorate
Environment Canada
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by

Microbial Technologies, Inc.
and
Laberge Environmental Services, Inc.

Executive Summary

When a mine closes, the open pit left behind often fills with water that washes metals from the pit walls. This water may be toxic and cannot be discharged without further treatment. This study evaluated the feasibility of using algal blooms to remove toxic metals from pit lakes. The study had two components: laboratory tests and pit lake fertilization trials. The site for the field trial was Little Creek Pond, a small collection pond located at Vangorda Pit, near Faro, Yukon Territory. The pond receives zinc-contaminated leachate form a waste rock dump and seepage from Vangorda Pit.

The laboratory study, using Little Creek Pond, demonstrated that zinc could be removed by promoting an algal bloom. Its concentrations were decreased dramatically during the 56-day study, from starting concentrations of 55 mg/L down to 3 mg/L. An interesting finding was that zinc was removed if pond sediments were present, but not if they were absent. The high initial zinc concentrations may have been too toxic to allow the development of a strong algal bloom in the absence of sediments. This idea is supported by other recent studies, which reported that zinc could be removed from the water column at lower initial concentrations.

During the short field season at Little Creek Pond, good algal growth was promoted on pond sediments by addition of fertilizer. This is remarkable, considering that pond water contained over 200 mg/L, a highly toxic level. Nevertheless, zinc removal was not shown in the field trial. This may be partially explained by the short time available to produce the algal blooms and the fact that metal laden waters were continuously seeping into Little Creek Pond during the study. Our attempt to determine if zinc removal still occurred was frustrated by our inability to calculate an accurate water balance. This was due to a lack of reliable data on seepage flows and zinc concentrations, on water volumes in the pond, and on other possible inputs into the pond from groundwater.

A single measurement of zinc content in harvested algae (over 12g per kg wet weight – Appendix G) indicates that zinc was successfully absorbed by algae growing on sediments. However, this provides insufficient information to conclude that significant zinc removal occurred.

Despite these qualified results, aquatic phytoremediation appears to be a promising, low cost alternative to conventional lime treatment. We recommend that further studies be undertaken in pit lakes that contain lower zinc concentrations, such as the Grum pit, near Faro, Yukon Territory.

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Introduction

There are over 100 active open-pit metal mines in North America, more than 80 in Australia and at least as many operating or developing mines in South America, Central Asia and West Africa. In many cases, those pits fill with water after mine closure and form pit lakes. Where sulphidic ores are present, mining accelerates rock weathering and formation of acidic leachates. Such leachates from pit lakes walls, waste rock piles, surface runoff and tailing ponds characteristically contain dissolved metals that are toxic to aquatic life in low concentrations and degrade the quality of waters in pit lakes and ponds.

Detoxification of pit lakes is difficult and expensive since large volumes of water with dilute metal concentration must be treated. Typically the treatment consists of lime addition, which makes water alkaline, and causes many commonly occurring dissolved metals (e.g. zinc, copper) to form insoluble compounds and precipitate out of the water column. although the resulting metallic sludge is relatively inert and stable, it requires careful management, i.e., disposal in a lined landfill, which adds to the cost and environmental liability of this treatment option.

Terrestrial phytoremediation (or managed use of plants to remove pollutants) have been investigated for some time, and is being increasingly applied to treat contaminated soils, its *aquatic* applications are much less firmly established. Potentially, such remedial technology could become a viable, low-cost, and low-maintenance alternative to the lime treatment. However, it has not as yet been conclusively demonstrated to effectively and permanently detoxify mined out pit lakes or ponds affected by mining effluents. Similarly, the design parameters for the algal phytoremediation of pit lakes are in their infancy.

Anecdotal evidence backed by fortuitous field observations suggested that algal blooms in the post-mining pit lakes coincide with the decrease of concentrations of some dissolved toxic metal compounds in the lake waters (e.g. copper and zinc concentration in the Island Copper Mine pit lake, Figure 1). It was speculated that such concurrence was *caused* by uptake and absorption of metals by algae and their consequent deposition to the lake bottom at the end of their lifecycle. Such mechanism is yet to be conclusively demonstrated.

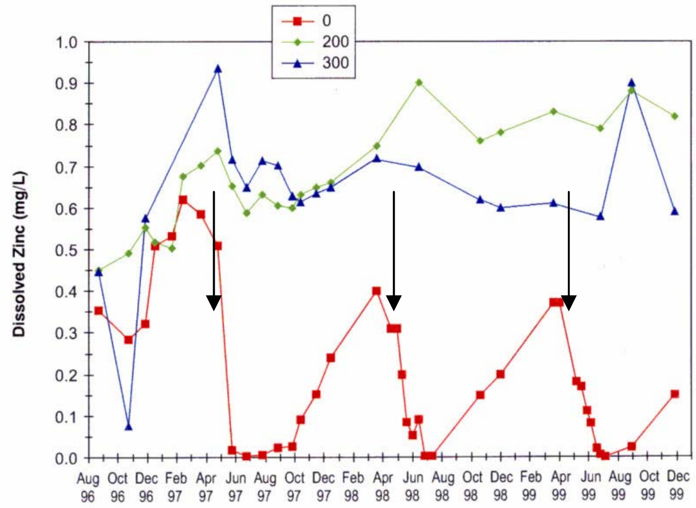

Figure 1. Seasonal changes in zinc concentrations at 0, 200, and 300 metres depth at the Island Copper Mine pit lake. Algal blooms developed at the lake surface (0 metres, black arrows).

This pilot project was designed to evaluate the effectiveness of detoxification of metal-contaminated pit ponds and lakes through the active uptake and passive adsorption of metals. Pit lake waters could be effectively detoxified if algal blooms could be reliably induced and managed in pit lakes, if the resulting metal scavenging rates were sufficient to offset the rates of incoming leachate, and if the resulting precipitates remained at the bottom permanently in the insoluble, no longer bioavailable forms. Demonstrating the method efficacy and describing the design criteria (i.e. critical factors that can be controlled and/or manipulated to optimize metal removal) required for algal phytoremediation of post-mining pit lakes could provide a novel, economically attractive and elegant alternative to the more invasive traditional lime precipitation. Moreover, pit lake *treatment* in this manner could be the first step to its eventual *reclamation*.

The study had two components: 1) a laboratory experiment in which water samples from Little Creek Pond at Vangorda Pit, near Faro, Yukon (Figure 1) were fertilized with two levels of fertilizer to induce algal blooms while zinc removal rates from the water column were assessed; and, 2) subsequent field fertilization trials of Little Creek Pond to test the encouraging laboratory results in the field.

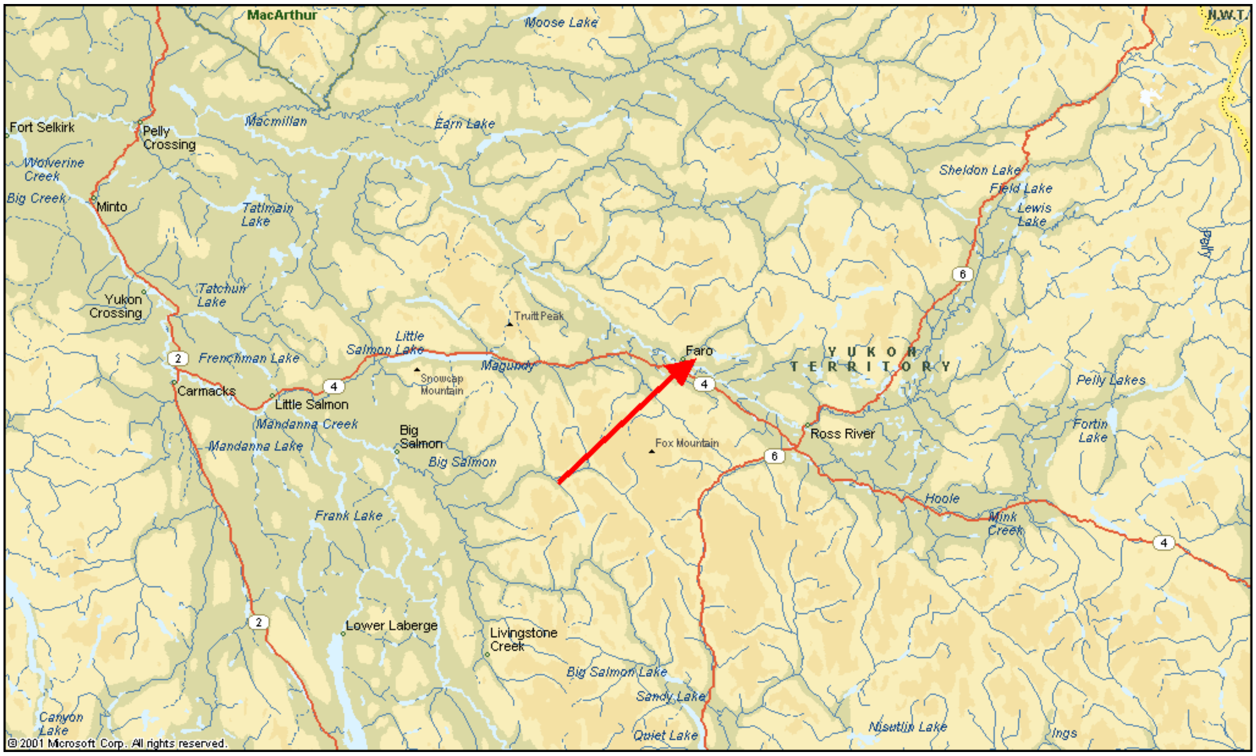

Figure 2. Location of Little Creek Pond at the Vangorda Pit near Faro, Yukon, Canada (background map © Microsoft Corp.).

This report describes the design and the factual results of both the laboratory simulation and field trial components of the study. Limited interpretation of the results is also provided. For clarity, only selected results are described in the main body of the report, while other relevant data generated by this study are included in the Appendices. Due to the nature of water quality in the Little Creek Pond, the focus of both the laboratory and the field component of the study was the removal of dissolved zinc, which is also reflected by the content of this report.

Laboratory Experiment

To evaluate the ability to induce algal blooms by controlled fertilization and to assess if such blooms correspond with the removal of dissolved zinc form the water column, a controlled bench-scale laboratory experiment was conducted. Five (5) experimental microcosms were created, subjected to various levels of fertilization and incubated in order to induce algal blooms.

Materials and Methods

A set of five, 10-liter polyethylene buckets were acid-washed and rinsed (Figure 3). Each bucket was than filled with Little Creek Pond water (equal-part mixture of samples from LCD-1, LCD-2, and LCD-3 sampling stations shown in Figure 8, collected on June 11, 2002). Two of the buckets also received lake sediments to evaluate their effect on the algal growth and metal removal. All buckets were covered loosely with Plexiglas to minimize evaporation, aerated at moderate rates, and lit from 3 inches above with the full-spectrum ‘Aqua Glow’ lights.

Figure 3. Experimental Setup; note sediments at the bottom of buckets 4 and 5.

Each bucket received a different treatment:

1. B1- LCD water with no fertilizer (control).
2. B2- LCD water with low (10 µL/L) fertilizer.
3. B3- LCD water with high (25 µL/L) fertilizer.
4. B4- LCD water and 1200g sediments with low fertilizer.
5. B5- LCD water and 1200g sediments with high fertilizer.

The fertilizer used was a liquid fish fertilizer containing 5% total Nitrogen, 2% available Phosphate, and 2% soluble potassium. The low fertilizer addition resulted in a nominal concentration of 0.5 ppm N and 0.2 ppm P, whereas the high fertilizer addition resulted in nominal concentrations of 1.3 ppm N and 0.5 ppm P. On Day 32, additional fresh fish fertilizer was added to B2 and B4 (10 µL/L) and B3 and B5 (25 µL/L) buckets. All treatments were topped up to 10 liters with sterile, demineralized water on Day 30 to offset evaporation.

Data Collection

The following parameters were measured in each treatment during the experiment:

- pH: VWR Symphony Brand combination Meter and gel filled pH electrode;
- Dissolved Oxygen (DO) and temperature: Orion Model 810 dissolved oxygen meter & probe with built in thermistor;
- Specific Conductivity: Hanna Model 18A Conductivity meter and electrode was used;
- Nitrates (NO_3): Spectrophotometric method was used with HACH Nitraver pouches; and,
- Phosphates (PO_4): Spectrophotometric method was used with HACH Phosphaver pouches.

Each electrode was calibrated with standard solutions (pH and conductivity) or air-saturated water (DO), correcting for temperature.

In addition, filtered water samples collected during the experiment were tested for dissolved zinc and Chlorophyll 'a' by the commercial analytical laboratory (ALS, Vancouver). The latter parameter is used to measure algal growth.

Results

The results of the laboratory trials along with the lab notes are reported in Appendix A through D. Figure 3 to 6 summarize the parameters most relevant to controlling algal blooms and the removal of zinc measured in each of the experimental treatments (i.e. nutrient level, Chlorophyll 'a' as a measure of algal bloom, and the dissolved zinc remaining in water).

Phosphate

Phosphate concentrations measured approximately 0.05 mg/L in Little Creek Dam water (LCD water). Adding fertilizer on Day 0 increased dissolved phosphate concentrations in the water-only treatments to approximately 0.2 and 0.5 mg/L for low and high fertilizer doses, respectively (Figure 4). Dissolved phosphate concentrations increased slightly in the water + sediment/high fertilizer treatment, but not in the sample that received a low fertilizer dose. Dissolved phosphate concentrations returned to their original level within a week of applying fertilizer.

On Day 32, a second dose of fertilizer was applied. Once again, dissolved phosphate concentrations increased in both water-only treatments, and in the water + sediment/high fertilizer treatment. As before, dissolved phosphate concentrations decreased within a week of applying fertilizer.

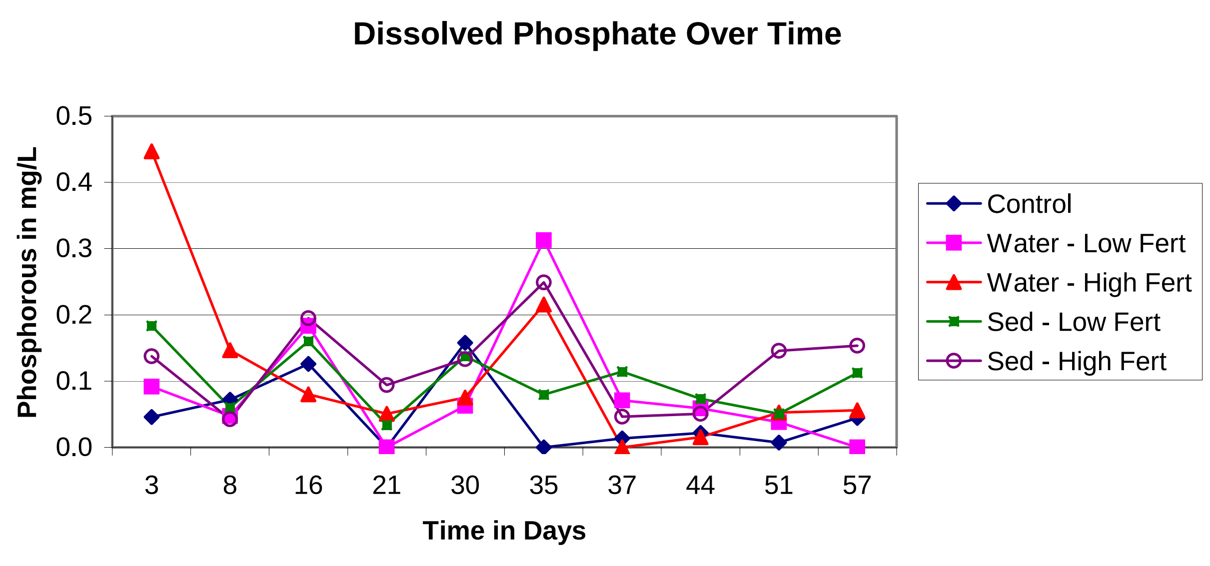

Figure 4. Laboratory Trials: Dissolved Orthophosphate as P.

The above results suggest that sediments adsorbed much of the phosphate that was added with the fertilizer. In addition, the rapid disappearance of dissolved phosphate after fertilizer application indicates that repeated lake fertilization will be required if algal blooms are to be sustained.

Dissolved nitrate were measured during the laboratory study, rather than Total Nitrogen levels (Figure 5). Nitrate concentrations in the control incubation varied between 1.0 and 1.5 mg/L.

Nitrate concentrations in the other treatments were lower, except for the water-only treatment receiving the high fertilizer dose, where it eventually reached 2.0 mg/L after 50 days. The water + sediment treatments had noticeably lower nitrate concentrations than the control or water only treatments.

The lower nitrate concentrations in the various treatments suggest that nitrate was consumed, except in the water-only/high fertilizer treatment. It is possible that much of the nitrogen in the fish fertilizer used during the laboratory study was present as ammonia or organic nitrogen, neither of which was measured during the study.

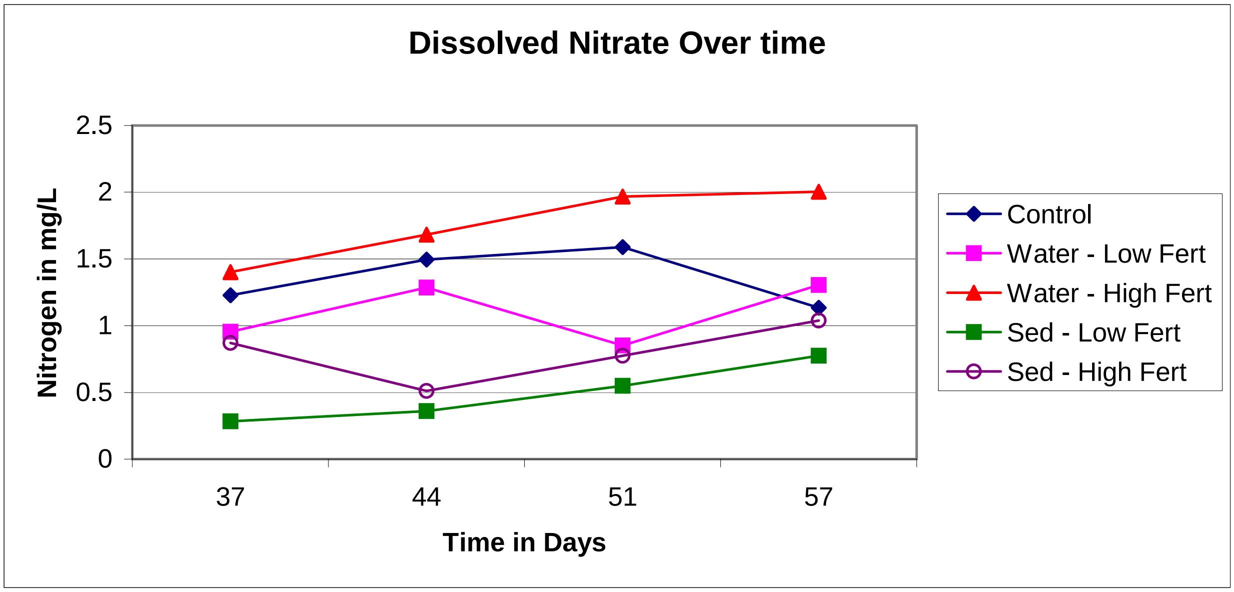

Figure 5. Laboratory Trials: Dissolved Nitrate as N.

Algal growth in the water column was estimating during the laboratory study by measuring Chlorophyll a levels. No growth occurred in the water column at the beginning of the study, but it did after the Day 32 fertilization. This was seen as a green coloration of the water in the fertilized tanks, and is reflected in the Chlorophyll a measurements (Figure 6). On Day 43, the water-only treatments had 3 and 6 mg/L Chlorophyll a for the low and high fertilizer dose, respectively.

The water + sediment treatments had only slightly elevated Chlorophyll a levels compared with the control (Water-only/no fertilizer), indicating negligible algal growth in the water column. However, there was a thick layer of algae covering the sediment surface in these treatments. This growth was already visible within one month of the test, but it was not quantified, and is not reflected in the above Chlorophyll a measurements.

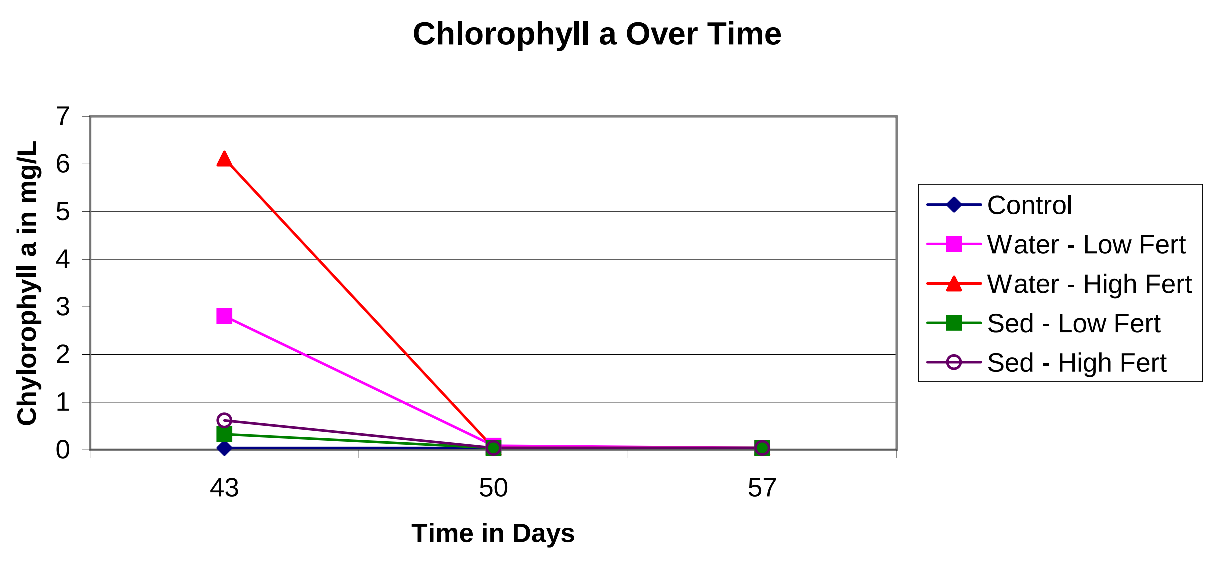

Figure 6. Laboratory Trials: Chlorophyll 'a'.

Dissolved zinc concentrations were measured in water samples collected periodically from each treatment during the laboratory study. Zinc concentrations in the control samples and the water-only treatments remained constant at approximately 55 mg/L throughout the study (Figure 7). In contrast, zinc concentrations decreased steadily down to 3 mg/L (Day 56) in both water + sediment treatments. This positive result indicates that sediments are key to the removal of zinc.

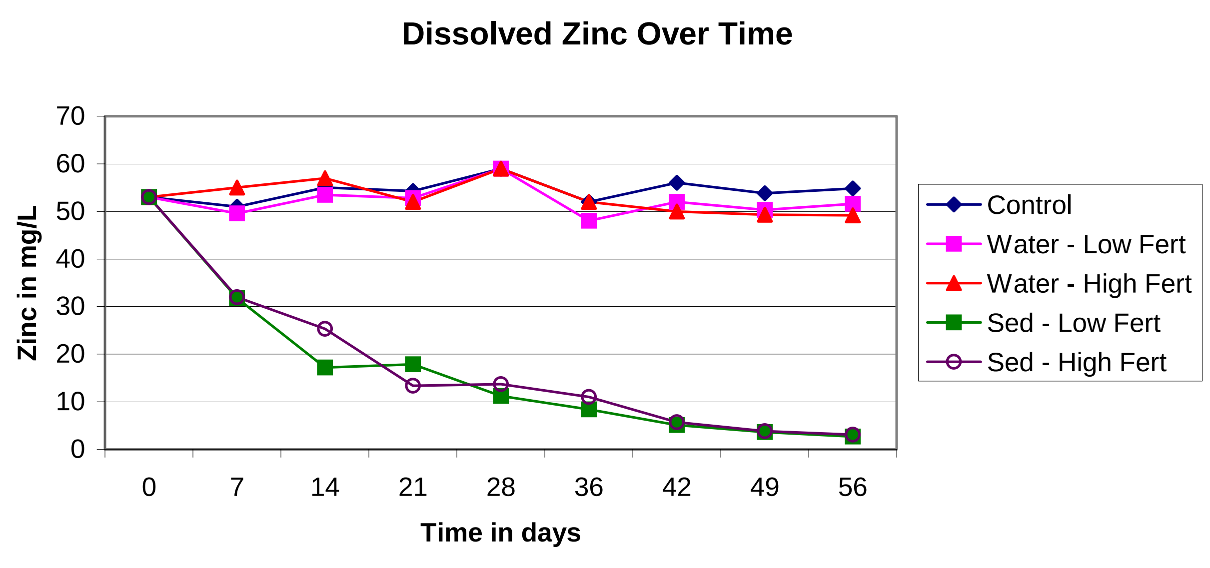

Figure 7. Laboratory Trials: Dissolved Zinc

Field Trials

The Little Creek Collection Facility is located immediately northwest of the Vangorda Rock Dump. It was constructed in 1990 to collect water pumped from the Vangorda Pit and seepage from the Vangorda Rock Dump. The collection facility consists of Little Creek Dam, an earth embankment built from compacted local clay till and a storage pond (Little Creek Pond). Other infrastructures include a wet well, pump house, and a pipeline system allowing to pump the water from Little Creek Pond to the Water Treatment Plant near Grum Pit.

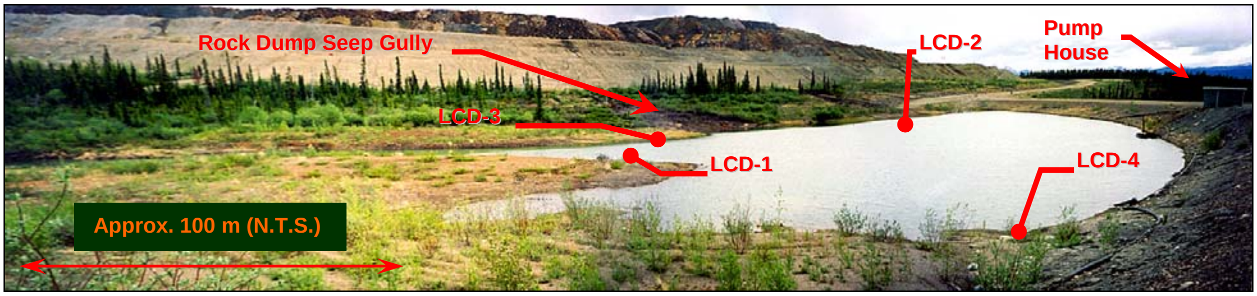

Figure 8. Little Creek Pond: sampling stations and selected features shown (panoramic composite; original photos © Bonnie Burns).

The crest elevation of Little Creek Dam varies from 1114.5 to 1120.0 m above mean sea level (MSL) and is approximately 10 m above grade. Little Creek Pond has a holding capacity of approximately 120,000 m^3. Since the mine shutdown in 1998, the water elevation in Little Creek Pond has been controlled by periodic pumping of some of the lake waters back into Vangorda Pit. This is usually done annually in response to the snowmelt run-off in the spring.

Six transverse drains, constructed in 1994, pass seepage from the toe of the Vangorda rock dump through the till containment berm around the dump. A seepage collection ditch captures any drainage from Drains 1 to 4, conveying the combined discharge into Little Creek Pond. Seepage from Drains 5 and 6 flows directly into Little Creek Pond.

Historically, there has been little or no flow in the first four drains. Drain 5 tends to have consistent flow through the spring, summer and fall, and Drain 6 has erratic flow during open water season. Little Creek Pond is also the collection point for local area runoff and precipitation, including surface run off from the Vangorda Rock Dump.

Pond Sampling

On June 11, 2002, approximately 100 litres of Little Creek Pond water was collected from four different locations within the pond and sent to Microbial's laboratory for the bench tests. During this initial collection, additional water samples were collected and shipped to ALS Laboratories in Vancouver, BC to be analyzed for Chlorophyll a (1 L amber glass), nutrients (1 L plastic bottle) and dissolved metals (100 mL plastic bottle, filtered on site and preserved with nitric acid). In-situ temperature and pH readings were also taken at each of the four locations and are listed in Appendix.

Water samples were also collected from three sites prior to the addition of the fertilizer on July

24, August 5, August 22 and September 5. A final set of samples was collected on September 18, 2002. In-situ limnological measurements were collected at the sites more frequently.

Fertilization rates were determined during the bench tests and applied by hand throughout the pond from a 16-foot aluminum Lund boat. Table 1 provides the fertilization schedule.

Table 1. Nutrient Application Schedule During the Field Trials

Nutrient Application Schedule at Little Creek Pond		
Date, 2002	Ammonium Phosphate (kg)	Ammonium Nitrate (kg)
July 24	100	250
August 5	75	250
August 22	75	250
September 5	75	225
TOTAL	**325**	**975**

Water characteristics

Water quality samples and in-situ analyses were collected from Little Creek Pond on June 11, July 24, September 5 and September 18, 2002 (Table 2). Water levels were drawn down by five metres between the June 11 and July 24 sampling periods.

Table 2. In-situ limnological parameters measured in the Little Creek Pond.

***In-Situ* Limnological Measurements at Little Creek Pond, 2002**				
	Site #1	**Site #2**	**Site #3**	**Site #4**
June 11:				
Temp ^{o}C	14.1	13.5	13.6	13.8
pH	6.5	7.4	7.4	7.6
July 24:				
Temp ^{o}C	16.6	16.6	16.7	
pH	7.46	7.37	7.28	
Conductivity µS/cm	1650	1654	1652	
Dissolved Solids (mg/L)	805	808	809	
Dissolved Oxygen (%)	81	81	78	
September 5:				
Temp ^{o}C	10.6	10.4	10.4	
pH	7.28	7.44	7.43	
Conductivity µS/cm	2780	2790	2790	
Dissolved Oxygen (%)	77.4	79.6	79.3	
September 18:				
Temp ^{o}C	9.0			
pH	7.25			
Conductivity µS/cm	3030	3040	3030	1616
Dissolved Solids (mg/L)	1480	1490	1470	775
Dissolved Oxygen (%)	72		65	

Water temperatures reflected the time of sampling, i.e., warmer summer than fall temperatures. Water pH was consistently neutral throughout the study period, averaging 7.31. This indicates that there was no significant inflow of acidic water into the pond. In contrast, conductivity increased continually during the study, reflecting the inputs of nutrients from the biweekly applications, and dissolved chemical components from the seepages. Dissolved oxygen decreased in percent saturation throughout the sampling program.

Sites #1-3 exhibited similar water chemistry throughout the study, except for an initial low pH value at Site #1. Water from site #4 was initially comparable to that of the other sites, but it had a substantially lower conductivity and Dissolved Solids concentration on the September 18 sampling. This is because Site 4 became an isolated part of the pond, when water levels were drawn down prior to the July 24 sampling, and because it was not fertilized during the study. However zinc concentrations here were similar to the rest of the pond (See below).

The fertilized pond experienced algal blooms as shown in Figure 9. Algae grew abundantly on the surface of sediments throughout the study, even as zinc concentrations increased to very high levels near the end of the study (See Figure 10, below).

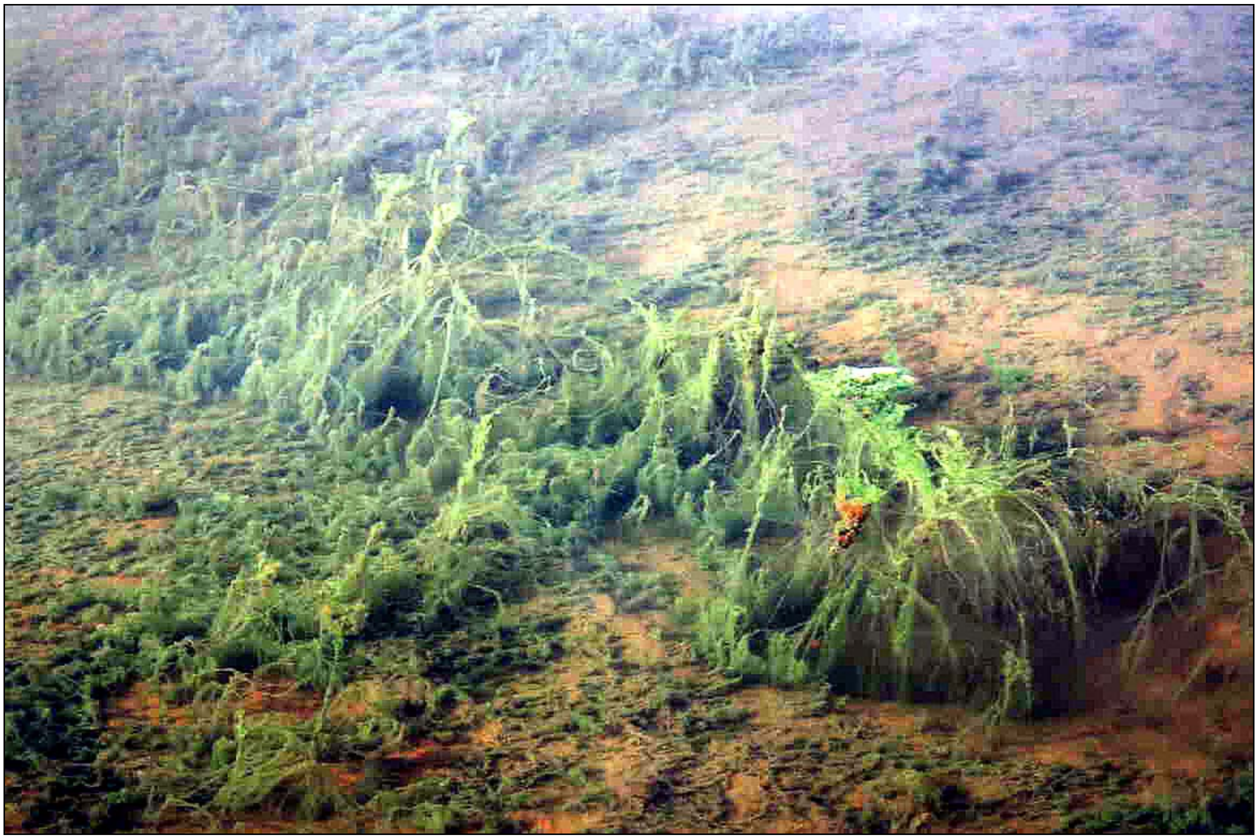

Figure 9. Algal blooms in the Little Creek Pond: September 18, 2002.

Water Chemistry Changes during the Field Trials

The chemistry of Little Creek Pond appears to have changed over time. When planning this study, zinc levels within the pond were less than 10 mg/L. Little Creek Pond had been sampled annually from 1997 to 2000, with average pH and zinc concentrations of 7.44 and 7.70 mg/L, respectively, making it ideal for the present study. No samples were collected in 2001. However, water samples collected during the summer of 2002 had slightly decreased pH values (average 7.31), and zinc levels increased to much greater concentrations throughout the course of the study (Figure 10; average 208 mg/L, well above levels recognized to be phytotoxic). Considering that the pond was fertilized throughout this period and that algal growth was recorded (See Figure 9 above, and Figure 13 below), this increase in zinc is contrary to the expected result, based on the preceding laboratory study.

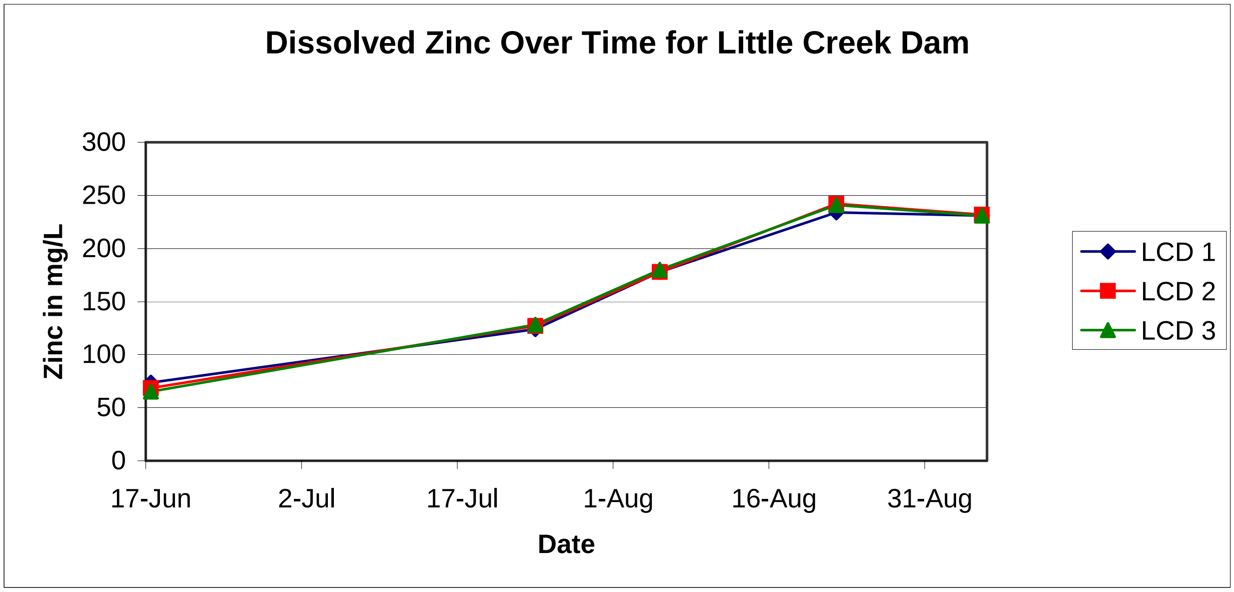

Figure 10. Little Creek Pond: Dissolved Zinc

It appears that the Little Creek Pond received metal-laden drainage from the Vangorda Rock Dump during the summer of 2002. Of all the drains associated with the dump, no flow was observed from the collection ditch (representing Drains 1 to 4) until September, Drain 5 flowed consistently into Little Creek Pond, and Drain 6 flowed sporadically. A seep survey of the total property was conducted in June 2002, with Drains 5 and 6 being sampled on June 10, 2002. These drains have been sampled annually since 1995. Zinc concentrations have been increasing over time (Annual Report for Vangorda, 2001). Zinc concentrations documented in June 2002 were 6,370 mg/L in Drain 5 and 1,650 mg/L in Drain 6. Although the flow at Drain 5 is low (usually less than 1 L/sec), this flow was continuous for the sampling period. In addition, the water elevation in Little Creek Pond was decreased between the June 11 and July 24 sampling dates, possibly further concentrating the existing zinc levels in the pond. Finally, it appears that the contaminated seepages entering the Pond from the Vangorda Rock Dump significantly increased in zinc concentrations over the summer.

Mass loading calculations (based on a flow rate of 0.6 L/sec for Drain 5 and 0.1 L/s in Drain 6) indicate that approximately 344 kilograms of zinc enter Little Creek Pond per day, based on the June survey data. Substantially more could have entered the pond if zinc concentrations increased during the summer. Thus, Little Creek Pond received an unknown, and possibly increasing amount of zinc during the time of the study, confounding any possible decrease due to algal removal. Unfortunately, this was only appreciated well after the field trial had begun.

Sampling at three to four locations within Little Creek Pond over the 6 sampling dates, indicate that the water is well mixed. This could suggest that groundwater inputs may have been received as well. Zinc levels were similar in the isolated part of the pond (occurring after early summer pumping) as they were in the main body of the pond (Appendix E and F).

Figure 11 to Figure 13 illustrate nutrient levels and water column Chlorophyll ‘a’ concentrations in the lake waters. Dissolved phosphorus concentrations were quite low throughout the study, remaining mostly between 0.005 and 0.01 mg/L (Figure 11). This is 100X less than the 0.1-0.2 mg/L concentrations observed during the laboratory study. It is unclear what could account for these differences.

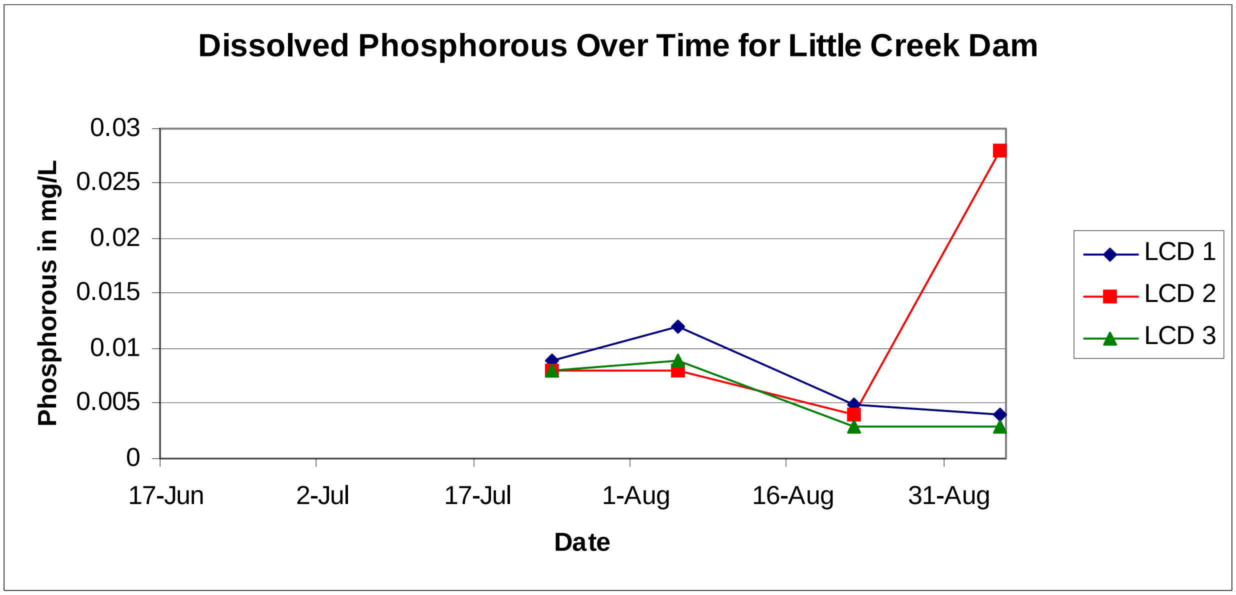

Figure 11. Little Creek Pond: Dissolved phosphorus

In contrast, Dissolved nitrogen concentrations increased steadily during the course of the field trial, rising from less than 1 mg/L in July to 10 mg/L in September (Figure 12). This steady increase is undoubtedly the outcome of repeated fertilizer application in the pond. Given that Dissolved Phosphorus concentrations did not exhibit the same steady increase during that time, it follows that phosphorus was continually removed from the water column. This removal may have been due to biological uptake, chemical precipitation, or a combination of these two factors.

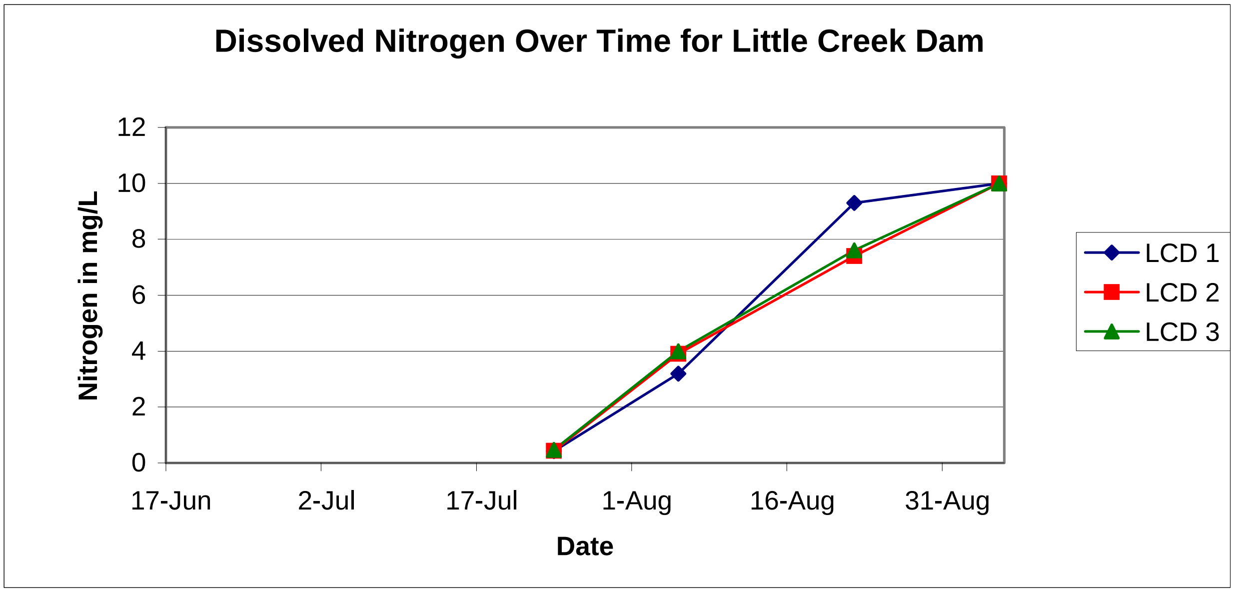

Figure 12. Little Creek Pond: Dissolved Nitrogen

Chlorophyll a levels increased progressively during the course of the field trial, beginning at less than 0.05 mg/L in June and increasing to over 0.5 mg/L in September (Figure 13). These levels are much lower than the high Chlorophyll a levels measured in the laboratory (Figure 6). Nevertheless, they indicate that there was some algal growth in the water column during the field trial, even at the very high zinc concentrations of Little Creek Pond (Figure 10). However, as already noted above in Figure 9, there was extensive algal growth on the bottom of Little Creek Pond, though this dense growth was not quantified by the Chlorophyll a measurements.

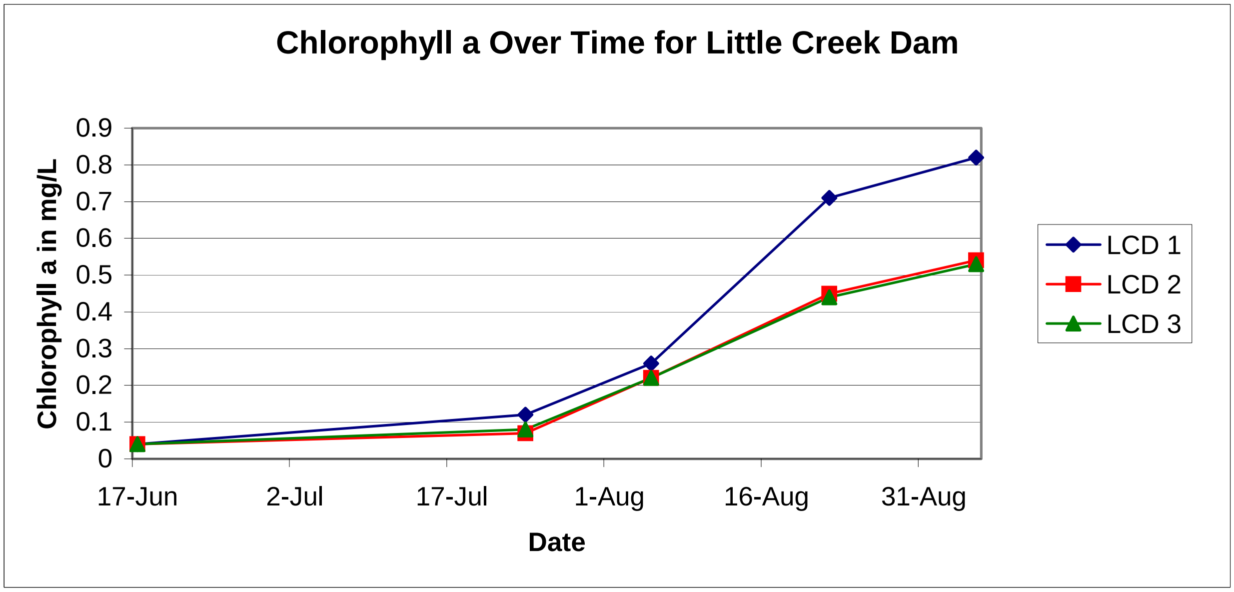

Figure 13. Little Creek Pond: Chlorophyll 'a'

While the above observations and measurements indicate that algae were growing in the water column and on the sediments of Little Creek Pond, despite its high zinc concentrations. However, it is not immediately clear that they were responsible for any zinc removal, as was seen in the laboratory study. A single measurement of zinc content in harvested algae found that they contained over 12g per kg wet weight (Appendix G), indicative of successful absorption and bioconcentration of this metal by algae. In the absence of overall biomass measurements, or even estimates, there is insufficient information to conclusively demonstrate that algae removed significant amounts of zinc during this field trial.

Discussion

The laboratory study showed that algae remove zinc from Little Creek Pond water, but the field trial failed to show this conclusively.

The present study only partially succeeded in achieving its objective: to demonstrate the feasibility of using phytoremediation to treat metal-contaminated pit lakes. The laboratory study showed that algae could remove dissolved zinc from mine water, reducing its levels from 55 to 3 mg/L in 56 days (Figure 7). This result is remarkable because zinc concentrations were high enough to be toxic: the most sensitive algae are killed at concentrations below 1 mg/L, while many others are killed at concentrations between 1-10 mg/L[1]. Evidently, algae that are not as sensitive to zinc were able to grow on sediments and remove it from solution.

Unfortunately, the field trial did not show that algae can remove dissolved zinc from the water column. There was evidence of abundant algae growth on the sediments of Little Creek Pond, indicating that they can grow even at zinc concentrations exceeding 200 mg/L. Moreover, the finding of high concentrations of zinc in one algal sample suggests that zinc was being removed from the water column. Unfortunately, it appears that unquantified inputs of zinc from seepage, and possibly from groundwater, caused its concentrations to increase in Little Creek Pond throughout the field trial (Figure 10). Thus, flows from two seeps (Drains 5 and 6) were unquantified, though they were known to flow into Little Creek Pond, and their zinc concentrations was measured once in 2002, reporting at 6,370 mg/L in Drain 5 and 1,650 mg/L in Drain 6.

The zinc loading from the above drains was estimated at 344 kg/day. Assuming that no zinc was removed from the pond, and assuming a constant pond volume of 100,000 m^3, zinc concentration in Little Creek Pond are predicted to increase by 3.44 mg/L each day during the field trial. The observed zinc concentrations during the study rose from 65 mg/L on June 17 to 241 mg/L on August 22, an average daily increase of 2.67 mg/L. It would be tempting to suggest that this lower than predicted increase is due to zinc removal, but there is too much uncertainty in the data[2] to justify this suggestion.

Other recent field studies support the concept of using algal blooms to remove metals from pit lakes.

There are indications from other studies that algae can effectively remove metals from pit lakes. A study at the Island Copper Mine flooded pit showed that copper and zinc removal from the water column coincided with the appearance of algal blooms in surface waters (Figure 1, for zinc only).

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[1] E.g., lethal zinc concentrations (96 hr-LC_{50}) for *Skeletonema costatum* (diatom) and *Ditylum brightwellii* (diatom) are reported to be 200-400 µg/L and 580 µg/L, respectively. Other algae, e.g., the green algae *Chlorella vulgaris*, *Enteromorpha flexuosa*, and *Ulva lactuca*, have 96 hr-LC_{50} of 1-5 mg/L (US Environmental Protection Agency ECOTOX Database, accessible via Internet at http://www.epa.gov/ecotox).

[2] The uncertainty extends to flow rates from both drains, their zinc concentrations, possible groundwater inputs, and water volumes in Little Creek Pond.

Another recent study at Highland Valley Copper designed to stimulate algal blooms in a flooded pit showed that both copper and molybdenum are adsorbed by algae and deposited in sediments, where they are retained[3]. Finally, a recent study at the Equity Silver Mine showed that algal blooms induced in limnocorrals removed zinc and cadmium from surface waters[4]. Altogether, these recent studies support the concept of using phytoremediation for metal removal.

The laboratory study demonstrated the importance of sediments in promoting zinc removal from mine water.

The laboratory study was simple in its design, but very informative. Zinc was only removed in treatments that received sediments (Figure 7), indicating that they play a key role. Their function appears to be a source of algae and a medium for attachment. A layer of algae was visible within two weeks, and their appearance coincided with the removal of zinc from the water column, suggesting that they were responsible for its removal. In contrast, the water-only treatments had better algal growth in the water column – as reflected in their higher Chlorophyll a levels (Figure 6) – but this did not result in significant removal of zinc.

The sediments also removed phosphorus from the water column, reflected in lower dissolved phosphorus concentrations in the water column (Figure 4). Perhaps phosphorus became concentrated at the sediment surface, thereby facilitating algal growth. However, this led to lower growth of algae in the water column, as reflected in lower Chlorophyll a levels in the water column of the water + sediment treatments (Figure 6).

Fertilization rates developed in the laboratory study stimulated algal growth.

Both the low and high fertilizer doses tested in the laboratory study gave the same zinc removal rate (Figure 7). This information was used to determine how much fertilizer to add in the field trial. It is obviously naïve to extrapolate results from one directly to the other when considering fertilizer dosage, given the large differences between the 10 Litre bench-scale treatments and the 120,000 m^3 Little Creek Pond.

The laboratory test supported the (nominal) targets of 5 mg/L Total Nitrogen and 0.5 mg/L Dissolved Phosphorus that were aimed for Little Creek Pond from fertilizer addition. In fact, Total Nitrogen concentrations in Little Creek Pond reached 10 mg/L by the end of the study, but Dissolved Phosphorus concentrations were substantially less than the target of 0.5 mg/L. Nevertheless, the laboratory test also predicted that phosphorus will be removed from the water column by sediments, and that this sediment-bound phosphorus will support algal growth on the sediment surface, as was observed in the field trial (Figure 9).

Algae also grew in the water column in Little Creek Pond following its fertilization, as evident by the steady increase in Chlorophyll a levels during the field trial (Figure 13). This result is unexpected, since Dissolved Phosphorus concentrations were low in the water column (Figure

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[3] Heather Larratt, H.M. Larratt Aquatic Consulting, Kelowna, B.C. Personal communication.

[4] J. Crosius *et al.* 2002. Testing metal removal strategies in the Equity Silver pit lake using limnocorrals. Presentation in the 9th Annual British Columbia Ministry of Energy and Mines-MEND Metal Leaching and Acid Rock Drainage Workshop. December 4-5, 2002, Vancouver, B.C.

11) and zinc concentrations were well-above toxic levels (Figure 10). This result suggests that algae should be able to grow in pit lakes that have lower zinc concentrations and may well detoxify them.

Phytoremediation may offer cost-effective treatment of pit lakes, but its effectiveness remains to be demonstrated. Further tests should be conducted on ponds or pit lakes with less than 10 mg/L zinc.

A few pit lakes in the Yukon Territory and other Northern sites have elevated zinc concentrations that may be may be good candidate for testing further this approach, i.e., Grum Pit, with 10 mg/L. Presently, treatment is provided periodically by lime addition, which is relatively expensive for such dilute solutions. Moreover, lime treatment produces a metal-laden sludge that must be managed. In contrast, pit lake phytoremediation could remove metals less expensively, and the organic carbon provided by algal growth can begin the process of reclaiming pit lakes into biologically viable water bodies.

The results of this study suggest that phytoremediation will be most effective in shallow pit lakes or pond, where the sediments receive enough light to support algal growth. However, other studies (e.g., Island Copper Mine, Highland Valley Copper Mine) successfully removed metals by promoting algal blooms in the water column. It is possible that their success was due to lower starting zinc concentrations, while our study failed to produce significant algal blooms due to toxic zinc concentrations in the water column. If this is true, future trials or applications should be tested in ponds or pit lakes containing less than 10 mg/L dissolved zinc in the water column.

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APPENDICES

Appendix A – Laboratory Trials: Protocol

Appendix A. Lake Phytoremediation – Zinc removal using algae Laboratory Protocol and Observations

Microbial Technologies
Zoey Ennenberg
Date: June 18

June 14th, 2002
Received Samples: 4 20Litre samples labeled LCD-1, LCD-2, LCD-3, LCD-4.
4 Sediment samples varying amounts labeled LCD-1, LCD-2, LCD-3, and LCD-4.
4 1Litre brown glass bottle sample for Chlorophyll.
4 100mL samples for dissolved metals (ICP scan) Filtered and Preserved in the field.

June 17th, 2002
Initial Tests:
LCD-1 20L- pH: 7.45 Conductivity: 1.21 mS DO: 5.7 (still probe)
Phosphate: 0.281 mg/L as PO4 Nitrate:
LCD-2 20L- pH: 7.45 Conductivity: 1.21 mS DO: 5.7 (still probe)
Phosphate: 0.281 mg/L as PO4 Nitrate:
LCD-3 20L- pH: 7.45 Conductivity: 1.21 mS DO: 5.7 (still probe)
Phosphate: 0.281 mg/L as PO4 Nitrate: 2 mg/L
LCD-4 20L- pH: 7.45 Conductivity: 1.21 mS DO: 5.7 (still probe)
Phosphate: 0.281 mg/L as PO4 Nitrate: 1 mg/L

Sent Tests to ALS:
LCD-1, LCD-2, and LCD-3 1L glass bottles Chlorophyll - Chlorophyll as an algae indicator.
LCD-1, LCD-2, and LCD-4 100mL dissolved metals – ICP scan.

June 18th, 2002
Test Setup:
5 - 10 Litre ice cream buckets washed and rinsed.
Filled each bucket with 10 Litres of LCD water a mixture of LCD-1, LCD-2, and LCD-3.

Bucket contents:

1. 10 L. LCD water, aerated.
2. 10 L. LCD water, aerated, with Low 10mg/L Fertilizer (0.1mL)
3. 10 L. LCD water, aerated, with High 25mg/L Fertilizer (0.250mL)
4. 10 L. LCD water, aerated, with Low 10mg/L Fertilizer (0.1mL), 1200g comp. sediments.
5. 10 L. LCD water, aerated, with High 25mg/L Fertilizer (0.250mL), 1200g comp. sediments.

All buckets are covered loosely with Plexiglas to minimize evaporation, aerated lightly, and lit from 3 inches above with full spectrum aqua glow lights.

Appendix A. Lake Phytoremediation – Zinc removal using algae Laboratory Protocol and Observations

June 19th, 2002
Samples taken from Bucket #4 and #5 for zinc to see if adding sediments added any zinc. Filtered with 0.45 micron syringe filter and preserved with nitric acid.

Initial Tests
LCD-1,2,3,&4 were identicle
PH: 7.45 D.O.: 5.7 Conductivity: 1.21 mS NO3: 2 mg/L as N PO4: 0.28 mg/L as PO4

June 26th, 2002
Samples Taken from Tanks #1 - 5, filtered with a 0.45 um filter, preserved with nitric acid, and sent for Zinc analysis.

June 28th, 2002
Cell counts:
There were no algal cells detected in the liquid portion of the tanks or in the residue stuck to the sides. In Tanks 4 & 5 algal growth was obsevred as a green skin on top of the sediment this was sampled and confirmed as dense algal cell growth. Thick, long, green with visible divisions and vacuoles.There were also a few small white eruptions on the surface of the sediment, this is presumably denitrification.

July 3rd ,2002
Samples Taken from Tanks #1 - 5, filtered with a 0.45 um filter, preserved with nitric acid, and sent for Zinc analysis.

July 5th, 2002
Cell counts:
Algal cells were found in the residue scrapings from the sides of Tank #4. The algal cells were much thinner and shorter and a less vibrant green. Still no algal cell in the liquid portion. Lots of Bacterial cell in liquid, residue and sediment samples in Tank # 4, Some in Tank # 5.

July 8th, 2002
Samples Taken from Tanks #1 - 5, filtered with a 0.45 um filter, preserved with nitric acid, and sent all collected samples for Zinc analysis.

July 15th, 2002
Samples Taken from Tanks #1 - 5, filtered with a 0.45 um filter, preserved with nitric acid, and sent all collected samples for Zinc analysis.

July 17th, 2002
Topped up Tanks # 1-5 with MT's Reverse osmosis H_2O to initial 10 Litre volume, conductivity measurements and volumes added is as follows:

Tank ID	**Conductivity Before H_2O**	**Conductivity After H_2O**	**Conductivity After 1 hour**	**Volume RO H_2O Added in Litres**

B1-control	1.23	1.14	1.15	1Litres
B2-Low F	1.27	1.14	1.15	1.25 Litres
B3-High F	1.25	1.16	1.15	1 Litres
B4-Low F sed.	1.25	1.11	1.11	1.35 Litres
B5-High F sed.	1.26	1.14	1.14	1.15 Litres

July 22nd, 2002
Added fresh fish fertilizer to Tanks 2-4 @ 100ul/ 10L to B2 and B4 & 250ul/ 10L to B3 and B5
NO3 and PO4 values recorded before and after adding fertilizer is as follows:

Tank ID	**PO4 Before**	**NO3 Before**	**PO4 after**	**PO4 after**
B2-Low F	0.123 mg/L	2 mg/L	0.959 mg/L	2 mg/L
B3-High F	0.566 mg/L	3 mg/L	0.661 mg/L	2 mg/L
B4-Low F sed.	0.117 mg/L	1 mg/L	0.244 mg/L	2 mg/L
B5-High F sed.	0.0 mg/L	2 mg/L	0.763 mg/L	1 mg/L

July 29th, 2002
Samples Taken from Tanks #1 - 5, filtered with a 0.45 um filter, preserved with nitric acid, and sent all collected samples for Zinc analysis.

July 29th, 2002
Cell counts:
Tank B2 liquid: Alagal cells found in liquid portion, short rodlike algae cells scattered.
Tank B3 liquid: Algal cells found in liquid portion, same cells as Tank B2 but less in numbers.
Tank B4 liquid: none found.   Tank B5liquid: none found.
Tank B2 side scrapings: Lots of short rodlike algal cell in dense group on solids single cells and small <5 cell chains.
Tank B3 side scrapings: Some short rodlike algal cell in small group on solids and many single foating cells and small <5 cell chains.
Tank B4 side srapings: Dense mass of long thin algae cells no visible segments on and around solids, some shorter segmented cells outside around mass.
Tank B5 side scrapings: Dense mass of long thin algae cells no visible segments on and around solids, some shorter and smaller segmented algal cells or different type outside around mass, also short thick rodlike cells in singles or pairs floating sporadically (similar to but different from rodlike cells in liquid portion of Tank B2 & B3).
*Noted new growth in Tank B2 and B3 may be attributed to addition of new fertilizer, H_2O addition, and replacement light bulbs for rear lamp.

July 30th, 2002
Samples taken for Chlorophyll :

Filtered a 50 mL. portion from tanks #B1-B5 with a gridded 0.45um filter wrapped filter carefully in tinfoil and kept cold. Sent all collected sample for Zinc analysis along with filters for chorophyll analysis to ALS Environmental.

August 7th , 2002
Samples Taken from Tanks #1 - 5, filtered with a 0.45 um filter. The filtrate was preserved with nitric acid, and sent for Zinc analysis. The filters were wrapped in foil and sent for chlorophyll analysis. Both to ALS Environmental.

pg. 2

August 9th , 2002
Cell counts:
Tank B2 liquid: some Algal cells found in liquid portion, short rodlike algae cells scattered 2 per view.
Tank B3 liquid: none
Tank B4 liquid: none found. Tank B5liquid: none found.
Tank B2 side scrapings: some algal cells on solids single cells and small <5 cell chains it was hard to obtain side scrapings.
Tank B3 side scrapings: lots short rodlike algal cell in small groups on solids and many single floating cells and small <5 cell chains 2 per square 64 per view.
Tank B4 side scrapings: Dense mass of long thin algae cells no visible segments on and around solids, some shorter segmented cells outside around mass.
Tank B5 side scrapings: Dense mass of long thin algae cells no visible segments on and around solids, some shorter and smaller segmented algal cells or different type outside around mass, also some short thick rodlike cells in singles or pairs floating sporadically.

August 12th, 2002
Tank B2 liquid: some Algal cells found in liquid portion, short rodlike algae cells scattered 2 per view.
Tank B3 liquid: none Tank B4 liquid: none found. Tank B5liquid: none found.
Tank B2 side scrapings: some algal cells on solids single cells and small chains, it was hard to obtain side scrapings.
Tank B3 side scrapings: lots short rodlike algal cell in small groups on solids and many single foating cells and small <5 cell chains 2 per square 64 per view.
Tank B4 side scrapings: Dense mass of long thin algae cells no visible segments on and around solids, some shorter segmented cells outside around mass.
Tank B5 side scrapings: Dense mass of long thin algae cells no visible segments on and around solids, some shorter and smaller segmented algal cells or different

August 13th ,2002
Samples Taken from Tanks #1 - 5, filtered with a 0.45 um filter. The filtrate was preserved with nitric acid, and sent for Zinc analysis. The filters were wrapped in foil and sent for chlorophyll analysis. Both to ALS Environmental.

Methods of Analysis and equipment used:
? pH: VWR Symphony Brand combination Meter and gel filled pH electrode.

Appendix A. Lake Phytoremediation – Zinc removal using algae Laboratory Protocol and Observations

? DO: Orion Model 810 dissolved oxygen meter & probe w/ built in thermometer (used for temperature readings).
? Conductivity: Hanna Model 18A Conductivity meter and electrode.
? NO3: Used reflectoquant system with nitrate strips/ spec method with HACH Nitraver pouches.
? PO4: Used spectrophotometric method with HACH Phosphaver pouches.

Tank No. ID	**pH**	**DO mg O2/L**	**Conductivity (milliSiemens)**	**Temperature (°C)**	**NO3 (mg/L N)**	**PO4 (mg/L PO4)**
Day 1 June 19th, 2002 24hr. light cycle						
B1-control	7.25	6.07	1.20		3	
B2-Low F	7.30	6.07	1.22		2	
B3-High F	7.33	6.05	1.23		3	
B4-Low F sed.	7.37	4.78-5.35	1.25		4	
B5-High F sed.	7.40	5.35-5.78	1.25		3	
Day 3 June 21st, 2002 12hr. light cycle						
B1-control	7.01+	5.2-5.55	1.16	24.3		0.141
B2-Low F	7.15+	5.4-5.5	1.21	24.3		0.281
B3-High F	7.22+	4.3-4.5	1.22	24.3 oC		1.37
B4-Low F sed.	7.34	4.8-5.05	1.23	24.3 oC		0.562
B5-High F sed.	7.44	4.25-4.5	1.25	24.3 oC		0.422
Day 6 June 24th, 2002 16hr. light cycle						
B1-control	7.46	4.9-5.1	1.16	25 oC		
B2-Low F	7.46	5.1-5.3	1.20	25 oC		
B3-High F	7.44	4.4-4.6	1.19	25 oC		
B4-Low F sed.	7.59	5.05-5.25	1.21	25 oC		
B5-High F sed.	7.56	4.95-5.15	1.23	25oC		

Day 8 June 26th, 2002 16hr. light cycle						
B1-control	7.28	5.85-6.05	1.17		3	1.16
B2-Low F	7.34	6.00-6.1	1.20		3	0.63
B3-High F	7.36	5.25-5.8	1.20		2	2.78
B4-Low F sed.	7.53	5.85-6.05	1.22		3	0.91
B5-High F sed.	7.60	4.9-5.1	1.23		3	0.53
Day 10 June 28th, 2002 16 hr. Light cycle						
B1-control	7.32	5.35-5.6	1.			
B2-Low F	7.33	6.0-6.1				
B3-High F	7.34	5.95-6.2				
B4-Low F sed.	7.64					
B5-High F sed.	7.63					
Day 16 July 3rd , 2002 16 hr Light cycle						
B1-control	7.32	5.35-5.6	1.20	21.3		0.386
B2-Low F	7.33	6.0-6.1	1.24	21.3		0.562
B3-High F	7.34	5.95-6.2	1.24	21.3		0.246
B4-Low F sed.	7.64	5.7-5.9	1.25	21.3		0.491
B5-High F sed.	7.63	5.5-5.8	1.26	21.3		0.597
Day 18 July 5th , 2002 16 hr. Light cycle (only one lamp, front over #4 & #5 mostly)						
B1-control	7.32	6.05	1.20	21.6		
B2-Low F	7.33	6.2-6.8	1.24	21.6		
B3-High F	7.34	5.65-5.85	1.25	21.6		
B4-Low F sed.	7.64	5.65-5.85	1.26	21.7		

B5-High F sed.	7.68	5.6-5.8	1.265	21.7		
Day 21 July 8th , 2002 16hr. light cycle (only one lamp, front over #4 & #5 mostly)						
B1-control	7.29	4.8-4.9	1.21	23.5		0
B2-Low F	7.29	5.5-5.6	1.24	23.5		0.01
B3-High F	7.30	4.1-4.3	1.24	23.5		0.155
B4-Low F sed.	7.62	5.3-5.55	1.25	23.5		0.104
B5-High F sed.	7.63	5.0-5.3	1.26	23.5		0.288
Day 23 July 10th ,2002 16hr. light cycle (only one lamp, front over #4 & #5 mostly)						
B1-control	7.29	4.75-5.0	1.21	23.0		
B2-Low F	7.29	5.1-5.3	1.25	22.7		
B3-High F	7.30	4.95-5.05	1.24	22.7		
B4-Low F sed.	7.67	4.9-5.3	1.25	23.1		
B5-High F sed.	7.67	4.8-5.15	1.26	22.9		
Day 25 July 12th, 2002 16 hr. light cycle (no light for ½ - 1 day)						
B1-control	7.28	4.5	1.21	23.6		
B2-Low F	7.28	4.9-5.3	1.25	23.5		
B3-High F	7.30	5.1	1.24	23.6		
B4-Low F sed.	7.65	5.2-5.6	1.25	23.9		
B5-High F sed.	7.65	4.4-4.7	1.26	23.9		
Day 28 July 15th, 2002 No lamp						
B1-control	7.27	6.7-7.3	1.22	22.4		NH4: 0.019
B2-Low F	7.28	7.4-7.8	1.265	22.0		NH4: 0.005
B3-High F	7.28	7.3-7.8	1.25	22.0		NH4: 0.018
B4-Low F sed.	7.67	7.1-7.7	1.25	22.7		NH4: 0.010

B5-High F sed.	7.65	7.4	1.26	22.7		NH4: 0.006
Day 30 July 17th, 2002 New Bulbs 12 pm. start 16 hr light cycle						PO4 mg/L
B1-control	7.29	5.5-5.7	1.22	23.1		0.484 mg/L
B2-Low F	7.29	5.4-5.9	1.26	22.9		0.193 mg/L
B3-High F	7.29	4.6-5.0	1.25	23.1		0.231 mg/L
B4-Low F sed.	7.63	5.2-5.4	1.25	23.1		0.421 mg/L
B5-High F sed.	7.60	5.4	1.26	23.3		0.408 mg/L
Day 32 July 19th, 2002 16 hr. light cycl.e 2 lamps (Kim took readings) Topped up each tank to intial volume with RO water (1Litre +).						
B1-control	7.06	6.96-7.24	1.08	23.7		
B2-Low F	7.07	7.23-7.37	1.14	23.4		
B3-High F	7.07	6.6-6.78	1.15	23.7		
B4-Low F sed.	7.33	6.5-6.6	1.12	23.9		
B5-High F sed.	7.35	6.35-6.65	1.14	23.9		
Day 35 July 22nd, 2002 16 hr. light cycle 2 lamps (Kim took readings) Added new Fertilizer on July 22nd, 2002 – 100ul to B2 and B4 & 250ul to B3 and B5 / 10 Litres.						
B1-control	7.0	5.1-5.6	1.06	23.8		
B2-Low F	7.02	5.6-5.95	1.14	23.5		
B3-High F	7.01	5.35	1.15	23.6		
B4-Low F sed.	7.27	5.25-5.65	1.12	23.8		
B5-High F sed.	7.32	5.2-5.7	1.14	24.0		
Day 37 July 24th, 2002 16 hr. light cycle (Kim took readings)					NO3 RQ / Spec mg/L	
B1-control	6.92	4.3-4.5	1.09	23.9	3 / 1.229	0.041 mg/L
B2-Low F	6.98	4.9-5.1	1.16	23.5	2 / 0.956	0.218 mg/L
B3-High F	6.96	5.1-5.3	1.18	23.3	3 / 1.4	0.0 mg/L

B4-Low F sed.	7.27	4.75-5.3	1.13	24.1	2 / 0.284	0.351 mg/L
B5-High F sed.	7.28	5.05-5.15	1.15	24.3	2 / 0.87	0.142 mg/L
Day 39 July 26th, 2002 16 hr. light cycle (Kim took readings)						
B1-control	7.06	7.3-7.8	1.09	23.7		
B2-Low F	7.08	7.7-8.0	1.16	23.6		
B3-High F	7.07	7.0-7.3	1.18	23.4		
B4-Low F sed.	7.44	7.2-7.5	1.12	23.8		
B5-High F sed.	7.45	7.4-7.6	1.14	23.7		
Day 42 July 29th, 2002 16 hr. light cycle (Zoey's back)						
B1-control	7.18	4.5-5.0	1.16	22.7		
B2-Low F	7.19	5.1-5.3	1.18	22.5		
B3-High F	7.22	3.8-4.1	1.19	22.5		
B4-Low F sed.	7.62	4.9-5.5	1.11	22.8		
B5-High F sed.	7.67	4.4-4.8	1.13	22.9		
Day 44 July 31st, 2002 16 hr. light cycle						
B1-control	7.17	6.8-7.1	1.13	20.3	1.494	0.067 mg/L
B2-Low F	7.19	7.6-7.8	1.18	20.4	1.286	0.180 mg/L
B3-High F	7.22	5.00	1.19	20.0	1.683	0.048 mg/L
B4-Low F sed.	7.66	5.9-6.7	1.12	20.2	0.360	0.225 mg/L
B5-High F sed.	7.67	6.6-6.8	1.13	20.7	0.511	0.155 mg/L
Day 51 August 7th, 2002 16 hr. light cycle						
B1-control	7.06	4.7	1.14	21.6	1.589	0.022 mg/L
B2-Low F	7.05	5.4	1.22	21.6	0.851	0.117 mg/L
B3-High F	7.07	4.2	1.21	21.6	1.967	0.161 mg/L

B4-Low F sed.	7.69	5.4-5.6	1.11	22.1	0.549	0.155 mg/L
B5-High F sed.	7.68	5.67	1.12	22.1	0.776	0.446 mg/L
Day 57 August 13th , 2002 16 hr light cycle						
B1-control	7.13	5.05	1.15	23.8	1.135	0.136 mg/L
B2-Low F	7.12	5.4	1.23	23.7	1.305	-0.035 mg/L
B3-High F	7.07	4.03	1.22	23.7	2.004	0.172 mg/L
B4-Low F sed.	7.72	5.35	1.12	23.7	0.776	0.345 mg/L
B5-High F sed.	7.81	4.75-5.3	1.12	24.2	1.040	0.471 mg/L

Appendix B – Laboratory Trials: Observations on Algae Growth

Appendix B. Observation of algae growth at different times.

Date	B-1 Control	B-2 Low Fert.	B-3 High Fert.	B-4 Low Fert.	B-5 High Fert.
Day 10					
Water	No algae present	No algae present	No algae present	No algae present	No algae present
Residues on side of tank	No algae present	No algae present	No algae present	No algae present	No algae present
Sediments	N/A	N/A	N/A	Green skin on top of the sediment. Confirmed by microscope to be algal cell growth. Cells thick, long, and green with visible divisions and vacuoles. Two dime sized, white eruptions on the surface of the sediment.	
Day 28					
Water	No algae present	No algae present	No algae present	No algae present.	No algae present.
Residues on side of tank	No algae present	No algae present	No algae present	Algae cells were thin and short with a dull green color.	No algae present
Sediments	N/A	N/A	N/A	Observations same as day 10.	
Day 42					
Water	No algae present	Scattered short rod-like algae cells.	Fewer scattered short rod-like algae cells.	No algae present.	No algae present.
Residues on side of tank	No algae present	Lots of short rod-like algal cells in dense group on solids. Single cells and small <5 cell chains.	Some short rod-like algal cell in small group on solids. Many single floating cells and small <5 cell chains.	Dense mass of long thin algae cells. No visible segments on and around solids. Some shorter segmented cells outside around mass. .	
					Also short thick rod-like cells in singles or pairs floating sporadically.
Sediments	N/A	N/A	N/A	Observations same as day 10.	

Observation of algae growth at different times.

Appendix B. Observation of algae growth at different times.

Date	B- 1 Control	B-2 Low Fert.	B-3 High Fert.	B-4 Low Fert.	B-5 High Fert.
Day 53					
Water	No algae present	Short rod-like algae cells scattered 2 per view.	No algae present	No algae present	No algae present
Residues on side of tank	No algae present	Some algal cells on solids. Single cells. Small <5 cell chains. It was hard to obtain side scrapings.	Lots of short rod-like algal cell in small groups on solids and many single floating cells. Small <5 cell chains 2 per square 64 per view.	Dense mass of long thin algae cells. No visible segments on and around solids. Some shorter segmented cells outside around mass.	
					Some short thick rod-like cells in singles or pairs floating sporadically.
Sediments	N/A	N/A	N/A	Same observations as day 10.	
Day 56	Observations were identical to those taken on day 53.				

Appendix C – Laboratory Trials: Environmental Conditions

Appendix C. Environmental lab conditions for experiments investigating zinc removal using algae.

Treatment	**pH**	**DO (mg O_2/L)**	**SpC (mS/cm)**	**Temperature (°C)**	**Light Cycle (hr)**	**Comments**
Day 0						
B1-Control	7.45	5.70	1.21		24	
B2-Low F	7.45	5.70	1.21		24	
B3-High F	7.45	5.70	1.21		24	
B4-Low F	7.45	5.70	1.21		24	
B5-High F	7.45	5.70	1.21		24	
Day 1						
B1-Control	7.25	6.05	1.20		24	
B2-Low F	7.30	6.05	1.22		24	
B3-High F	7.33	6.05	1.23		24	
B4-Low F	7.37	5.05	1.25		24	
B5-High F	7.40	5.55	1.25		24	
Day 3						
B1-Control	7.01	5.40	1.16	24.3	24	
B2-Low F	7.15	5.45	1.21	24.3	24	
B3-High F	7.22	4.40	1.22	24.3	24	
B4-Low F	7.34	4.95	1.23	24.3	24	
B5-High F	7.44	4.40	1.25	24.3	24	
Day 6						
B1-Control	7.46	5.05	1.16		12	
B2-Low F	7.46	5.20	1.20		12	
B3-High F	7.44	4.50	1.19		12	
B4-Low F	7.59	5.15	1.21		12	
B5-High F	7.56	5.05	1.23		12	
Day 8						
B1-Control	7.28	5.95	1.17		16	
B2-Low F	7.34	6.05	1.20		16	
B3-High F	7.36	5.50	1.20		16	
B4-Low F	7.53	5.95	1.22		16	
B5-High F	7.60	5.00	1.23		16	
Day 10						
B1-Control	7.07	5.80	1.20	22.7	16	
B2-Low F	7.38	6.00	1.22	22.7	16	
B3-High F	7.40	5.50	1.23	22.7	16	
B4-Low F	7.62	5.80	1.25	22.7	16	
B5-High F	7.64	6.30	1.25	22.7	16	

Appendix C. Environmental lab conditions for experiments investigating zinc removal using algae.

Treatment	**PH**	**DO (mg O_2/L)**	**SpC (mS/cm)**	**Temperature (°C)**	**Light Cycle (hr)**	**Comments**
Day 16						
B1-Control	7.32	5.50	1.20	21.3	16	
B2-Low F	7.32	6.05	1.24	21.3	16	
B3-High F	7.34	6.10	1.24	21.3	16	
B4-Low F	7.64	5.80	1.25	21.3	16	
B5-High F	7.62	5.65	1.26	21.3	16	
Day 18						
B1-Control	7.21	6.05	1.20	21.6	16	Only one lamp, front of B-4 and B-5
B2-Low F	7.23	6.40	1.24	21.6	16	
B3-High F	7.26	5.75	1.25	21.6	16	
B4-Low F	7.64	5.75	1.26	21.6	16	
B5-High F	7.68	5.70	1.26	21.6	16	
Day 21						
B1-Control	7.29	4.85	1.21	23.5	16	Only one lamp, front of B-4 and B-5
B2-Low F	7.29	5.55	1.24	23.5	16	
B3-High F	7.30	4.20	1.24	23.5	16	
B4-Low F	7.62	5.45	1.25	23.5	16	
B5-High F	7.63	5.15	1.26	23.5	16	
Day 23						
B1-Control	7.29	4.90	1.21	23.0	16	Only one lamp, front of B-4 and B-5
B2-Low F	7.29	5.20	1.25	22.7	16	
B3-High F	7.30	5.00	1.24	22.7	16	
B4-Low F	7.67	5.10	1.25	23.1	16	
B5-High F	7.67	5.00	1.26	22.9	16	
Day 25						
B1-Control	7.28	4 .50	1.21	23.6	16	No light for 12 to 24 hours
B2-Low F	7.28	5.1 0	1.25	23.5	16	
B3-High F	7.30	5.10	1.24	23.6	16	
B4-Low F	7.65	5.40	1.25	23.9	16	
B5-High F	7.65	4.55	1.26	23.9	16	
Day 28						
B1-Control	7.27	7.00	1.22	22.4	0	
B2-Low F	7.28	7.60	1.27	22.0	0	
B3-High F	7.28	7.55	1.25	22.0	0	
B4-Low F	7.67	7.40	1.25	22.7	0	
B5-High F	7.65	7.40	1.26	22.7	0	

Appendix C. Environmental lab conditions for experiments investigating zinc removal using algae.

Treatment	**pH**	**DO (mg O_2/L)**	**SpC (mS/cm)**	**Temperature (°C)**	**Light Cycle (hr)**	**Comments**
Day 30						
B1-Control	7.29	5.60	1.22	23.1	16	New bulbs. At 12 Noon start 16 hour light cycle. Top up tank with water.
B2-Low F	7.29	5.65	1.26	22.9	16	
B3-High F	7.29	4.80	1.25	23.1	16	
B4-Low F	7.63	5.30	1.25	23.1	16	
B5-High F	7.60	5.40	1.26	23.3	16	
Day 32						
B1-Control	7.06	7.10	1.08	23.7	16	Two lamps.
B2-Low F	7.07	7.30	1.14	23.4	16	
B3-High F	7.07	6.70	1.15	23.7	16	
B4-Low F	7.33	6.60	1.12	23.9	16	
B5-High F	7.35	6.50	1.14	23.9	16	
Day 35						
B1-Control	7.00	5.40	1.06	23.8	16	Two lamps. Fertilizer added.
B2-Low F	7.02	5.75	1.14	23.5	16	
B3-High F	7.01	5.35	1.15	23.6	16	
B4-Low F	7.27	5.45	1.12	23.8	16	
B5-High F	7.32	5.45	1.14	24.0	16	
Day 37						
B1-Control	6.92	4.45	1.09	23.9	16	
B2-Low F	6.98	5.05	1.16	23.5	16	
B3-High F	6.96	5.20	1.18	23.3	16	
B4-Low F	7.27	5.05	1.13	24.1	16	
B5-High F	7.28	5.10	1.15	24.3	16	
Day 39						
B1-Control	7.06	7.55	1.09	23.7	16	
B2-Low F	7.08	7.85	1.16	23.6	16	
B3-High F	7.07	7.15	1.18	23.4	16	
B4-Low F	7.44	7.35	1.12	23.8	16	
B5-High F	7.45	7.55	1.14	23.7	16	
Day 42						
B1-Control	7.18	4.75	1.16	22.7	16	
B2-Low F	7.19	5.20	1.18	22.5	16	
B3-High F	7.22	3.95	1.19	22.5	16	
B4-Low F	7.62	5.20	1.11	22.8	16	
B5-High F	7.67	4.60	1.13	22.9	16	

Appendix C. Environmental lab conditions for experiments investigating zinc removal using algae.

Treatment	**pH**	**DO (mg O_2/L)**	**SpC (mS/cm)**	**Temperature (°C)**	**Light Cycle (hr)**	**Comments**
Day 44						
B1-Control	7.00	6.95	1.13	20.3	16	
B2-Low F	7.00	7.70	1.18	20.4	16	
B3-High F	7.15	5.00	1.19	20.0	16	
B4-Low F	7.66	6.30	1.12	20.2	16	
B5-High F	7.67	6.70	1.13	20.7	16	
Day 51						
B1-control	7.06	4.70	1.14	22.0	16	
B2-Low F	7.05	5.40	1.22	21.6	16	
B3-High F	7.07	4.20	1.21	21.6	16	
B4-Low F	7.69	5.50	1.11	22.1	16	
B5-High F	7.68	5.65	1.12	22.1	16	
Day 57						
B1-Control	7.13	5.05	1.15	23.8	16	
B2-Low F	7.08	5.40	1.23	23.7	16	
B3-High F	7.07	4.05	1.22	23.7	16	
B4-Low F	7.72	5.35	1.12	23.7	16	
B5-High F	7.81	5.05	1.12	24.2	16	

Appendix D – Laboratory Trials: Nitrogen and Phosphate Data

Appendix D. Nitrogen and Phosphate Data

Treatment	**NO_3 (mg/L N)**	**PO_4 (mg/L PO_4)**
Day 1		
B1-Control	3	
B2-Low F	2	
B3-High F	3	
B4-Low F	4	
B5-High F	3	
Day 3		
B1-Control		0.141
B2-Low F		0.281
B3-High F		1.37
B4-Low F		0.562
B5-High F		0.422
Day 6		
B1-Control		
B2-Low F		
B3-High F		
B4-Low F		
B5-High F		
Day 8		
B1-Control	3	1.16
B2-Low F	3	0.63
B3-High F	2	2.78
B4-Low F	3	0.91
B5-High F	3	0.53
Day 10		
B1-Control		
B2-Low F		
B3-High F		
B4-Low F		
B5-High F		
Day 16		
B1-Control		0.386
B2-Low F		0.562
B3-High F		0.246
B4-Low F		0.491
B5-High F		0.597

Day 18		
B1-Control		
B2-Low F		
B3-High F		
B4-Low F		
B5-High F		
Day 21		
B1-Control		0
B2-Low F		0.01
B3-High F		0.155
B4-Low F		0.104
B5-High F		0.288
Day 23		
B1-Control		
B2-Low F		
B3-High F		
B4-Low F		
B5-High F		
Day 25		
B1-Control		
B2-Low F		
B3-High F		
B4-Low F		
B5-High F		
Day 28		
B1-control	NH4: 0.019	
B2-Low F	NH4: 0.005	
B3-High F	NH4: 0.018	
B4-Low F sed.	NH4: 0.010	
B5-High F sed.	NH4: 0.006	
Day 30		
B1-control		0.484 mg/L
B2-Low F		0.193 mg/L
B3-High F		0.231 mg/L
B4-Low F sed.		0.421 mg/L
B5-High F sed.		0.408 mg/L

Appendix D. Nitrogen and Phosphate Data

Day 32		
B1-Control		
B2-Low F		
B3-High F		
B4-Low F		
B5-High F		
Day 35		
B1-Control		
B2-Low F		
B3-High F		
B4-Low F		
B5-High F		
Day 37		
B1-Control	3 / 1.229	0.041 mg/L
B2-Low F	2 / 0.956	0.218 mg/L
B3-High F	3 / 1.4	0.0 mg/L
B4-Low F	2 / 0.284	0.351 mg/L
B5-High F	2 / 0.87	0.142 mg/L
Day 39)		
B1-Control		
B2-Low F		
B3-High F		
B4-Low F		
B5-High F		
Day 42		
B1-Control		
B2-Low F		
B3-High F		
B4-Low F		
B5-High F		
Day 44		
B1-Control	1.494	0.067 mg/L
B2-Low F	1.286	0.180 mg/L
B3-High F	1.683	0.048 mg/L
B4-Low F	0.360	0.225 mg/L
B5-High F	0.511	0.155 mg/L
Day 51		
B1-control	1.589	0.022 mg/L
B2-Low F	0.851	0.117 mg/L

B3-High F	1.967	0.161 mg/L
B4-Low F	0.549	0.155 mg/L
B5-High F	0.776	0.446 mg/L
Day 57		
B1-Control	1.135	0.136 mg/L
B2-Low F	1.305	-0.035 mg/L
B3-High F	2.004	0.172 mg/L
B4-Low F	0.776	0.345 mg/L
B5-High F	1.040	0.471 mg/L

Appendix E – Field Trials: Water Chemistry (dissolved metals, chlorophyll. N and P: 3 sites: June 17th – September 5th, 2002)

Appendix E: Little Dam Water Chemistry - June 17 to September 5th, 2002

RESULTS OF ANALYSIS - Water form Little Creek Dam

Sample ID		LCD-1	LCD-2	LCD-3	LCD-1	LCD-2	LCD-3	LCD-1	LCD-2	LCD-3	LCD-1	LCD-2	LCD-3	LCD-1	LCD-2	LCD-3
Date Sampled		17-Jun	17-Jun	17-Jun	24-Jul	24-Jul	24-Jul	5-Aug	5-Aug	5-Aug	22-Aug	22-Aug	22-Aug	5-Sep	5-Sep	5-Sep
Nutrients																
Nitrate Nitrogen	N				0.418	0.435	0.47	3.2	<0.01	<0.01	9.3	7.4	7.6	10	10	10
Total Phosphate	P				0.009	0.008	0.008	0.012	0.008	0.009	0.005	0.004	0.003	0.004	0.028	0.003
Dissolved Metals																
Aluminum	D-Al	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.05	<0.05	<0.05	<0.1	<0.1	<0.1	<0.05	<0.05	<0.05
Antimony	D-Sb	<0.2	<0.2	<0.2	<0.02	<0.02	<0.02	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Arsenic	D-As	<0.2	<0.2	<0.2	<0.02	<0.02	<0.02	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.015	0.015	0.014
Barium	D-Ba	0.04	0.03	0.04	0.03	0.04	0.03	0.029	0.031	0.029	0.024	0.025	0.024	0.023	0.023	0.023
Beryllium	D-Be	<0.005	<0.005	<0.005	<0.1	<0.1	<0.1	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Bismuth	D-Bi	<0.2	<0.2	<0.2	<0.1	<0.1	<0.1	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Cadmium	D-Cd	0.06	0.05	0.06	0.1	0.1	0.1	0.148	0.158	0.153	0.199	0.202	0.201	0.219	0.226	0.22
Calcium	D-Ca	104	97.3	92.2	141	145	147	184	188	190	211	219	218	211	211	211
Chromium	D-Cr	<0.01	<0.01	<0.01	<0.1	<0.1	<0.1	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Cobalt	D-Co	0.31	0.28	0.27	0.55	0.56	0.55	0.921	0.998	0.958	1.23	1.25	1.24	1.38	1.37	1.32
Copper	D-Cu	<0.01	<0.01	<0.01	<0.02	<0.02	<0.02	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.013	<0.005
Iron	D-Fe	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Lead	D-Pb	<0.05	<0.05	<0.05	<0.02	<0.02	<0.02	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Magnesium	D-Mg	77	71.6	67.9	127	129	127	178	194	183	186	188	189	252	255	248
Manganese	D-Mn	30.3	27.9	26.6	57.6	58.5	58.1	91	97.1	93.3	115	117	116	124	127	122
Mercury	D-Hg	-	-	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Molybdenum	D-Mo	<0.03	<0.03	<0.03	<0.02	<0.02	<0.02	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Nickel	D-Ni	0.28	0.27	0.26	0.5	0.5	0.5	0.77	0.84	0.81	1.01	1.03	1.03	1.11	1.14	1.09
Phosphorus	D-P	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
Potassium	D-K	2	<2	2	<10	<10	<10	4	4	4	<3	<3	<3	5	5	4
Selenium	D-Se	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Silver	D-Ag	<0.01	<0.01	<0.01	<0.002	<0.002	<0.002	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Sodium	D-Na	<2	<2	<2	3	3	3	4.7	5.3	4.8	4.9	4.9	4.9	6.2	6.1	5.9
Strontium	D-Sr	0.365	0.34	0.32	0.62	0.63	0.63	0.83	0.906	0.869	0.973	0.985	0.99	1.04	1.05	1.02
Thallium	D-Tl	<0.2	<0.2	<0.2	<0.02	<0.02	<0.02	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Tin	D-Sn	<0.03	<0.03	<0.03	<0.02	<0.02	<0.02	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Titanium	D-Ti	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Uranium	D-U	-	-	-	<0.002	<0.002	<0.002	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Vanadium	D-V	<0.03	<0.03	<0.03	<0.2	<0.2	<0.2	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Zinc	D-Zn	73.6	68.4	65.2	124	127	128	178	178	180	234	242	241	231	232	231
Organic Parameters																
Chlorophyll a (a)		<0.04	<0.04	<0.04	0.12	0.07	0.08	0.26	0.22	0.22	0.71	0.45	0.44	0.52	0.64	0.35

Appendix F – Field Trials: Water Chemistry (total and dissolved metals 7 sites – September 18, 2002)

Appendix F: Little Creak Dam Water Chemistry - September 18

Little Creek Dam Project Water Analysis

RESULTS OF ANALYSIS

Sample ID		S. Side Seep	N.W. Side	Pump- house	N.E.Isolated Pond	E. Kill Zone Seep	E. Side	S. Corner
Date Sampled		09/18/2002	09/18/2002	09/18/2002	09/18/2002	09/18/2002	09/18/2002	09/18/2002
ALS Sample ID		1	2	3	4	5	6	7
Nature		Water	Water	Water	Water	Water	Water	Water
Nutrients								
Nitrate Nitrogen	N	-	14.3	-	-	-	-	-
Total Phosphate	P	-	0.221	-	-	-	-	-
Total Metals								
Aluminum	T-Al	8	-	-	0.17	0.8	-	0.13
Antimony	T-Sb	<0.1	-	-	<0.005	<0.02	-	<0.005
Arsenic	T-As	<0.1	-	-	<0.005	<0.02	-	<0.005
Barium	T-Ba	<0.1	-	-	0.024	<0.02	-	0.023
Beryllium	T-Be	<0.5	-	-	<0.03	<0.1	-	<0.03
Bismuth	T-Bi	<0.5	-	-	<0.03	<0.1	-	<0.03
Cadmium	T-Cd	3.11	-	-	0.209	0.55	-	0.21
Calcium	T-Ca	305	-	-	249	367	-	244
Chromium	T-Cr	<0.5	-	-	<0.03	<0.1	-	<0.03
Cobalt	T-Co	9.2	-	-	1.23	5.26	-	1.3
Copper	T-Cu	<0.2	-	-	<0.005	0.06	-	<0.005
Iron	T-Fe	1.1	-	-	0.35	12	-	0.12
Lead	T-Pb	<0.1	-	-	<0.02	0.16	-	<0.007
Magnesium	T-Mg	1240	-	-	249	795	-	239
Manganese	T-Mn	921	-	-	122	497	-	124
Mercury	T-Hg	<0.001	-	-	<0.001	<0.001	-	<0.001
Molybdenum	T-Mo	<0.1	-	-	<0.005	<0.02	-	<0.005
Nickel	T-Ni	7	-	-	1.06	2.9	-	1.05
Phosphorus	T-P	<6	-	-	<0.6	<2	-	<0.6
Potassium	T-K	<50	-	-	4	<10	-	4
Selenium	T-Se	<1	-	-	<0.05	<0.2	-	<0.05
Silver	T-Ag	<0.01	-	-	<0.0005	<0.002	-	<0.0005
Sodium	T-Na	<10	-	-	6.3	10	-	6
Strontium	T-Sr	1	-	-	1.11	1.57	-	1.03
Thallium	T-Tl	<0.1	-	-	<0.005	<0.02	-	<0.005
Tin	T-Sn	<0.1	-	-	<0.005	<0.02	-	<0.005
Titanium	T-Ti	<0.2	-	-	<0.02	<0.04	-	<0.02
Uranium	T-U	<0.01	-	-	<0.0005	<0.002	-	<0.001
Vanadium	T-V	<1	-	-	<0.05	<0.2	-	<0.05
Zinc	T-Zn	2660	-	-	270	842	-	275

Little Creek Dam Project Water Analysis

Sample ID	S. Side Seep	N.W. Side	Pump- house	N.E.Isolated Pond	E. Kill Zone Seep	E. Side	S. Corner
Date Sampled	09/18/2002	09/18/2002	09/18/2002	09/18/2002	09/18/2002	09/18/2002	09/18/2002

Appendix F: Little Creak Dam Water Chemistry - September 18

ALS Sample ID	1	2	3	4	5	6	7
Nature	Water	Water	Water	Water	Water	Water	Water
Dissolved Metals							
Aluminum D-Al	-	0.1	-	-	0.9	0.13	0.1
Antimony D-Sb	-	<0.005	-	-	<0.02	<0.005	<0.005
Arsenic D-As	-	<0.005	-	-	<0.02	<0.005	<0.005
Barium D-Ba	-	0.021	-	-	<0.02	0.021	0.022
Beryllium D-Be	-	<0.03	-	-	<0.1	<0.03	<0.03
Bismuth D-Bi	-	<0.03	-	-	<0.1	<0.03	<0.03
Cadmium D-Cd	-	0.218	-	-	0.57	0.209	0.216
Calcium D-Ca	-	228	-	-	378	228	238
Chromium D-Cr	-	<0.03	-	-	<0.1	<0.03	<0.03
Cobalt D-Co	-	1.34	-	-	5.29	1.32	1.36
Copper D-Cu	-	<0.005	-	-	0.06	<0.005	<0.005
Iron D-Fe	-	<0.06	-	-	5.5	<0.06	<0.06
Lead D-Pb	-	<0.005	-	-	0.13	<0.005	<0.005
Magnesium D-Mg	-	245	-	-	807	238	253
Manganese D-Mn	-	133	-	-	502	128	128
Mercury D-Hg	-	<0.001	-	-	<0.001	<0.001	<0.001
Molybdenum D-Mo	-	<0.005	-	-	<0.02	<0.005	<0.005
Nickel D-Ni	-	1.09	-	-	2.9	1.05	1.08
Phosphorus D-P	-	<0.6	-	-	<2	<0.6	<0.6
Potassium D-K	-	5	-	-	<10	4	4
Selenium D-Se	-	<0.05	-	-	<0.2	<0.05	<0.05
Silver D-Ag	-	<0.0005	-	-	<0.002	<0.0005	<0.0005
Sodium D-Na	-	6	-	-	10	5.7	6.3
Strontium D-Sr	-	1.03	-	-	1.59	1.02	1.07
Thallium D-Tl	-	<0.005	-	-	<0.02	<0.005	<0.005
Tin D-Sn	-	<0.005	-	-	<0.02	<0.005	<0.005
Titanium D-Ti	-	<0.02	-	-	<0.04	<0.02	<0.02
Uranium D-U	-	<0.0005	-	-	<0.002	<0.0005	<0.0007
Vanadium D-V	-	<0.05	-	-	<0.2	<0.05	<0.05
Zinc D-Zn	-	263	-	-	860	265	269
Organic Parameters							
Chlorophyll a	-	IP	-	-	-	-	-

Footnotes: Results are expressed as milligrams per litre except where noted.

< = Less than the detection limit indicated.

Appendix G – Field Trials: Algal Tissue Analysis (total metals)

Appendix G. Little Creek Dam: Metals in algae.

Project	Little Creek Dam Algae Analysis
Report to	Microbial Technologies Inc.

RESULTS OF ANALYSIS

Sample ID	LittleCkDam Algae
ALS Sample ID	1
Nature	Tissue
Total Metals	
Aluminum T-Al	2470
Antimony T-Sb	4.2
Arsenic T-As	14.8
Barium T-Ba	141
Beryllium T-Be	<2
Bismuth T-Bi	<2
Cadmium T-Cd	13.7
Calcium T-Ca	813
Chromium T-Cr	8
Cobalt T-Co	151
Copper T-Cu	40.1
Lead T-Pb	78.6
Lithium T-Li	3
Magnesium T-Mg	1200
Manganese T-Mn	3870
Molybdenum T-Mo	2.1
Nickel T-Ni	37
Selenium T-Se	<4
Strontium T-Sr	11.3
Thallium T-Tl	0.6
Tin T-Sn	<1
Uranium T-U	2.54
Vanadium T-V	7
Zinc T-Zn	12100

Footnotes: Metals results expressed as milligrams per wet kilogram except where noted.
< = Less than the detection limit indicated.