

Sustainable water treatment

at Century Mine

Draft

Revised tasks for 2007

Completion of Feasibility study

By Boojum Research Ltd for Zinifex Century Mine

Lawn Hill, Northern Queensland

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Executive Summary

Ecological effluent treatment consists of promoting and supporting growth of indigenous biota which bio-mineralize contaminants, leading to containment and stabilization of contaminants within the waste management area. With two field investigations (2006 and 2007) of the Zinifex Mine site, indigenous microbial/algal material was found to contain an average of 11.6% Ca, 12.0% S and 2.5% Mg, the main salts of the effluents. Utilizing literature growth rates, it is estimated, that about 900 g of dry weight biomass grows per square meter per dry season. The growth rates translate into an extraction of about 1.0 t of Ca, 1.1 t of S and 0.22 t of Mg per ha surface area from the effluent. Selection of suitable growth substrates along with growth rates specific to the site are needed to define design parameters for the pilot scale tests, both in Dam # 3 and in Evaporation Pond.

The bio-mineralization capacity of the biota is lower in Evaporation Pond than in Dam #3. In Evaporation pond the accumulation of Ca is 0.51 t per ha per dry season and lower for S (0.14 t) and Mg (0.046 t). Improvement of growth and uptake of elements can be expected when growth limitations of the biota are known and ameliorated. Nutrient ratios of healthy algae biomass are well documented and are used to indicate growth limitations. For the algal mats in Evaporation Pond the ratio of carbon to nitrogen suggest that nitrogen is more limiting than carbon. On the other hand, nitrogen and phosphorus ratios for the mats and the sediment, suggest that nitrogen is not as limiting as phosphorus.

Growth promotion through the addition of phosphorus will increase growth. Geochemical modeling indicates that precipitation of calcium phosphate is likely to take place. This could delay a rapid growth response, as the precipitate is relegated to the sediment where it will be converted back to the water by microbes. Measurements of pH, Eh, electrical conductivity, oxygen at different depths were obtained in Evaporation Pond, which suggest the development of a chemical stratification, supported by reductions in sulphate concentrations in the water at 6 m depth. The extent, origin and effect of the chemical stratification need to be verified through an extensive sampling campaign. Test with phosphate additions in limno-corrals are suggested.

The monitoring data base (2004 -2006 V-notch and 2000 to 2006 Evaporation Pond) of the chemical composition of effluents associated with the mine waste management area was used to derive a framework for annual contaminant load to be treated. Material balances and water usage were estimated per annum. Several questions remain open and require resolution. Preliminary assessments of the seasonal contaminant loads suggest that promotion of the existing bio-mineralization process will facilitate salt management pre- and post closure, implemented through a series of well defined milestones.

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1.0 INTRODUCTION

1.1 Previous work (2006 Visit)

In 2006, Zinifex Limited invited Boojum Research Limited to study a pilot-scale wetland treatment system previously constructed by Century Mine in order to treat South West Waste Rock dump seepage collected at the V-Notch that was not performing satisfactorily. The Zinifex mine site was visited in July 2006. After the design of the water treatment system was examined and the chemistry of the seepage was studied, the reason for the difficulties were identified and recommendations were made for an alternate system to provide more favorable biogeochemical conditions. The Environmental department followed up on some of these suggestions. Subsequently, in the same year, an additional request was made to identify the origin of extreme pH in piezometer water located in a waste rock pile. The assessment of the piezometer was reported in late 2006.

The draft report on the 2006 site visit was submitted in February 2007 summarizing the information collected during the site visit and the literature was examined with respect to the observations made on the biological / ecological conditions. The scope of work was then expanded from the focus on SWRD seepage treatment to include identification and discussion of treatment options for the Evaporation Pond, Dam #8 Seepage and the Bulk Sample Pit (as its seepage is being diverted to Dam # 3 and might affect Dam #3 treatment).

A second site visit was made in February 2007 to address these expanded tasks and the ongoing field tests.

1.2 Expanded Project (2007 Visit)

The 2007 visit was scheduled to permit a first hand look at the effect of monsoon rains on the effluents and to characterize the limnology and ecology of the Evaporation dam. Since it did not rain by the end of February, Chara populations were located in the vicinity of the mine site and a field assessment was carried out on the placement of hay in Dam #3.

A detailed tasking of the major objectives was requested and submitted following the site visit in March 2007 along with the data summary of the field trip. The tasking report was reviewed by G. Lee and key tasks approved. This report presents the results of the feasibility study for the approved overall objectives and completes the related tasks and those which are implied, such as the summary and interpretation of the existing water monitoring data, with the objective of:

- A. Developing pilot test systems for the treatment of seepage from Dam #3 and Dam #8 to remove Ca, S and Mg.

- B. Suggesting water quality improvement options for Evaporation Pond which would reduce the salt concentrations.

Additionally, although not currently part of this scope of work, it is noted that Boojum is involved with AMIRA project P933 on Ecological Engineering approaches to reduce acid generation, which dovetails with the Zinifex support of the AMIRA project on waste rock focusing on inhibition of weathering with phosphate mining materials. A phosphate deposit is accessible close to the Century Mine site.

1.3 Objectives for SWRD Dam # 3, # 8 and Evaporation Dam

The algal material collected on the site and the V-notch water chemistry suggested that seepage treatment might be possible, utilizing biogeochemical approaches. It was suggested that four main treatment approaches are considered.

1.3.1 Promotion of Stromatolite Formation

Tufa or stromatolite-like formations were found at Dam #3 (Plate 1). These are conglomerations of algae, microbes and fungal material interspersed with crystalline minerals. The elemental composition was analyzed by ICP (Inductively Coupled Plasma Spectrometry), and minerals using XRD (X-ray Diffraction). The material was found to contain high concentrations of Ca, S and Mg. XRD identified some crystalline minerals, which suggests that permanent removal of elements from the water might be possible. By promoting the growth of the algae/microbes (the major constituent of tufa), these composite structures could remove a significant amount of the contaminants present in Dam #3 and Evaporation Pond. The tufa was further studied to determine if algal/microbial activity is involved metal precipitation process. REM/EDX provided a surface view of the structures and a detailed map of the elements on the material.



Plate 1 Tufa /stromatolite structures formed on brush submerged in Dam #3

Tufa-like mats were found associated with natural and artificial substrates (wire mesh, wood pieces and cut brush) in each of the three areas. We think that these substrates become colonized from microbes in the water, and start biofilms. Organic substrates may also be providing some nutritional benefit (e.g. the mimosa in Dam #3). By analyzing the growth of these biofilms on artificial substrates in the ponds, we can make a rough estimate of the primary productivity, and the tufa's ability to remove contaminants.

The collections of biofilms were made for quantification of biomass and growth rate on our limited field trips. Lacking actual field observations and data, we utilized published growth rates of similar algal /microbial formations. These estimates will provide us an estimate of the treatment potential and surface area of substrate needed. We also need to find a suitable substrate on which these tufa will grow. Based on Boojum's experience such surface areas have been found for many mining effluents.

1.3.2 Local *Chara* Populations

The macrophytic algae of the Charophyte family are known to accumulate large quantities of S, Ca and Mg on their outer cell wall and are abundant in many mine waste management areas. They generally tolerate high electrical conductivity and are the dominant macrophyte in tailings seepages. Local *Chara* populations were located close to Adele grove and healthy biomass was introduced to Dam # 3 and #8 and into Evaporation Pond. The plants were transplanted into wire cages set into the sediments, which should stimulate the growth of rhizomes (root-like structures).

Preliminary growth trials with salt-tolerant *Chara* failed for a variety of reasons (e.g. some cages were removed from the water and had dried out). Since most of these trial failures were not biological, a second introduction appeared warranted. More *Chara* was added to submerged cages, and allowed to grow. This time, limited growth was demonstrated in a photographic report. The second transplanted *Chara* were reproductive – e.g. they bore oospores (seeds). We hope that some of these oospores germinated. The *Chara* trials are being reformulated using suggestions of alternative introduction methods and acclimatization efforts. It has also been suggested that the former pilot wetland facility might serve as *Chara* nursery. No further comments are made on this option in this report.

1.3.3. Microbial Sulfate Reduction

Sulphate is one of the major contaminants of the Zinifex waste water. Sulphate is difficult to remove using algae, as it is not well concentrated by the plants. However, there are microbes which live in organic sediments under anaerobic conditions that are very efficient at removing sulphate. A third treatment option proposed for testing is the use of 'microbial sulphate reduction'. This treatment is dependent on the microbial reduction of sulphate to form gaseous hydrogen sulphide. Generally, this microbial process is housed in sediments where E_h conditions are suitable. It can be encouraged in the sediment by the addition of organic matter.

A very preliminary test was carried out through addition of hay to sections of Dam # 3(Plate 2a and 2b) and Dam # 8. The typical “rotten egg” smell of hydrogen sulphide in Dam # 3 confirmed the presence of microbial sulphate reduction, but the origin of the hydrogen sulphide (sediment or water) could not be identified. Specific sampling of the water in the hay-affected area is required. No H₂S smell was reported at Dam #8.



Plate 2a and 2b Hay in Dam #3 in 2007 dry season (left) and during placement in wet season 2006 (right)

Some theoretical considerations are presented in this report utilizing the known concentrations of hydrogen sulfide that can be detected due to their smell.

One method for promoting microbial sulphate reduction is to provide the physical and chemical conditions that are necessary for the microbes to flourish. Stagnant water, high organics, and low oxygen are the three major conditions required. Boojum Research has developed a system of adding “floating” cattails to ponds to promote all three conditions. These cattail rafts 1) cover the water surface reducing wind-driven circulation and enhancing stagnant water underneath; 2) provide a long-term source of carbon and nutrients for microbial sediments; and 3) the cattail root system removes oxygen from the water, decreasing the oxidation state of the water and sediments below.

1.3.4. Floating cattail islands

Floating cattail ‘islands’ were constructed by Glen Ware , following instructions provided by Boojum after the first field trip. The cattails grew in both dams, but the rafts beached in both locations. On the second field trip, Martin Smith made recommendations to improve the construction verbally as construction of new rafts was underway. With the purchase of the boat, by the environmental department, the location of the cattail rafts in the centre of the dams is now possible. It is the suspended root / rhizome zone underneath the rafts which will facilitate removal of elements through the microbial activity which is nurtured in this area, not the uptake of elements into the cattails. Hence if the roots are in contact with the sediments, their treatment capacity of the water is nil. Elements and nutrients are removed from the sediment and not from the water. The biofilms and their mass need to be sampled in the same fashion as described for the surfaces on which Tufa formation is tested. No further comments are made on this option in this report.

2.0 SWRD – V-notch and Dam 3#

M. Kalin

2.1 Monitoring data

Selecting a treatment process and designing a treatment plant requires foremost the knowledge of the water chemistry to be treated and the total contaminant loading per season / annum of contaminants to be treated. The most reliable understanding of the waste water is obtained through examination of the monitoring data, examine the trends over time and if at all possible project future trends in water quality to be expected. Further the chemistry determines the potentially applicable chemical or biogeochemical precipitation processes, i.e. removal processes which could be utilized.

The water quality monitoring data were provided by Century Mine and was assembled for all monitoring locations. The first requirement is that the assembled data are checked for their accuracy, consistency and obvious errors are detected. A simple approach was used to detect outliers. First a summary was made of the number of data point for each parameter, along with the min and max value. It became immediately clear, that for some parameters the reported value range was very large. All parameters were then plotted, reported concentrations against time, which showed clearly the outlying values. Those were removed from the data set as erroneous entries (details the Tasking report) and Table 1 was prepared for the V-notch data and in Table 6 for the Evaporation dam. No other manipulations were carried out.

A brief examination of Table 1 reveals that some parameters are measured which do not contain any information, as they would not be expected to be present, such as carbonate and hydroxide alkalinity, but others are present consistently at very low values and as such are of no consequence to the chemistry and or toxicity of the effluent. For some parameters the reported minimum and maximum values cover a wide range, such as the case for sulphate (assumed to be Total as filtered is reported) however for filtered only a few values exists (n=3 as opposed to n=28 for Total).

In general elemental concentrations are reported as filtered or total and the question arises how these values would relate to each other. The reasons for the determinations are not evident, as the parameter Total Suspended Solids (TSS) varies from 1 – 18 mg/L , which would suggest that at a given sampling date, a larger amount of suspended solids could contribute to the Total value reported and could be in part the reasons for the outlying values. This may also be the reason for the large range reported of the ionic balance which ranges from 0.49 to 4.83 %.

In some cases the data are reported with the designation Total and Filtered respectively, but in some cases the designation has to be deduced or assumed. We have considered if either total or filtered was not reported, that the values are total concentrations, i.e. acidified without filtration. This is for example the case for calcium, potassium and sulphate. In general, electrical conductivity, if the value is to be compared to other data sets, the value needs to be standardized

with temperature. It might well be that the instrument used reports a standard temperature, i.e. that it does this automatically, however temperature should be recorded in the field with any water sample taken. A total of 95 values are reported in the field but only 12 temperature values were found in the data base. The concentrations of sulphur and sulphate should reflect generally a 1 to 3 relationship unless hydrogen-sulphide is dissolved in the water. This relationship is not maintained, the reasons for which might be in the analytical methodology or due to the presence of hydrogen-sulphide.

While it is recognized that much of the data supplied was generated for operating or regulatory reasons rather than for the evaluation of the potential of aquatic systems for effluent remediation, good quality control protocols for all data generating activities (sampling, flow measurement, sample preparation and analysis) can minimize the risk of faulty conclusions in operating controls, research, development and compliance and thus are valuable. The forgoing discussion provides some flags where evaluation of procedures may be beneficial.

Table 1 Measured parameters for the V-Notch site (collected between 31/03/2004 and 02/10/2006)

Parameter and unit	Count (min, max)	Parameter and unit	Count (min, max)
Acidity as CaCO ₃ (mg/L)	30, (26, 439)	Manganese (Total) (mg/L)	26, (38, 280)
Alkalinity as CaCO ₃ (mg/L)	30, (38, 127)	Mercury (Total) (mg/L)	28, (0.0001, 0.00026)
Alkalinity Bicarbonate (mg/L)	31, (38, 127)	Molybdenum (Filtered) (mg/L)	1, (0.01)
Alkalinity Carbonate (mg/L)	31, (1, 1)	Molybdenum (Total) (mg/L)	28, (0.001, 0.05)
Alkalinity Hydroxide (mg/L)	15, (1, 1)	Nickel (Filtered) (mg/L)	1, (0.69)
Aluminium (Filtered) (mg/L)	1, (0.1)	Nickel (Total) (mg/L)	27, (0.52, 1.58)
Aluminium (Total) (mg/L)	5, (0.1, 0.3)	Nitrate as N (mg/L)	28, (9, 18)
Antimony (Filtered) (mg/L)	2, (0.002, 0.01)	Nitrite + Nitrate as N (mg/L)	29, (2, 18)
Antimony (Total) (mg/L)	29, (0.001, 0.08)	Nitrite as N (mg/L)	28, (0.01, 0.15)
Arsenic (Filtered) (mg/L)	24, (0.001, 0.01)	Oil & Grease (mg/L)	29, (5, 20)
Arsenic (mg/L)	29, (0.001, 0.05)	pH Field	96, (5.3, 7.3)
Barium (Total) (mg/L)	5, (0.1, 0.1)	pH Lab	5, (6, 7)
Beryllium (Total) (mg/L)	5, (0.01, 0.05)	Phosphorus (mg/L)	1, (1)
Boron (Filtered) (mg/L)	1, (0.6)	Potassium (mg/L)	28, (17, 39)
Boron (Total) (mg/L)	5, (0.4, 0.7)	Selenium (Filtered) (mg/L)	1, (0.01)
Cadmium (Filtered) (mg/L)	24, (0.008, 0.234)	Selenium (Total) (mg/L)	28, (0.01, 0.05)
Cadmium (mg/L)	28, (0.046, 0.258)	Silica (Total) (mg/L)	2, (18, 20)
Calcium (mg/L)	27, (434, 652)	Silicon (Total) (mg/L)	5, (8.5, 9.8)
Chloride (mg/L)	29, (91, 394)	Silver (Total) (mg/L)	29, (0.001, 0.05)
Chromium (Filtered) (mg/L)	1, (0.01)	Sodium (mg/L)	29, (16, 260)
Chromium (Total) (mg/L)	29, (0.001, 0.05)	Strontium (Total) (mg/L)	5, (0.3, 0.5)
Cobalt (Filtered) (mg/L)	1, (0.68)	Sulfate (mg/L)	28, (2830, 10700)
Cobalt (Total) (mg/L)	28, (0.21, 1.44)	Sulfate (Filtered) (mg/L)	3, (46, 7840)
Copper (Filtered) (mg/L)	2, (0.001, 0.01)	Sulphur as S (mg/L)	25, (1550, 3390)
Copper (Total) (mg/L)	28, (0.001, 0.05)	Temperature Water (oC)	12, (26, 37)
Cyanide WAD (mg/L)	23, (0.004, 0.045)	Tin (Total) (mg/L)	5, (0.01, 0.05)
EC Field (mS/cm)	95, (4.5, 11.0)	Titanium (Total) (mg/L)	5, (0.01, 0.05)
EC Lab (mS/cm)	6, (7.1, 10.6)	Total Anions (meq/L)	24, (104, 228)
Eh (mV)	14, (-4.4, 56)	Total Cations (meq/L)	24, (101, 217)
Flow Rate (L/s)	81, (0.43, 69.46)	Total Dissolved Solids (mg/L)	1, (11400)
Gauge Board (m)	81, (0.30, 0.56)	Total Kjeldahl Nitrogen as N (mg/L)	1, (1.5)
Ionic Balance (%)	20, (0.49, 4.83)	Total Nitrogen as N (mg/L)	1, (14.6)
Iron (Filtered) (mg/L)	1, (0.05)	Total Phosphorus as P (mg/L)	6, (0.01, 34)
Iron (Total) (mg/L)	25, (0.01, 0.05)	Total Suspended Solids (mg/L)	31, (1, 18)
Lead (Filtered) (mg/L)	23, (0.001, 0.01)	Vanadium (Total) (mg/L)	5, (0.01, 0.05)
Lead (mg/L)	27, (0.001, 0.05)	Zinc (Filtered) (mg/L)	25, (24, 265)
Magnesium (mg/L)	27, (260, 2180)	Zinc (mg/L)	26, (27, 281)
Manganese (Filtered) (mg/L)	1, (119)		

In Figures 1 to 3 the seasonal trends of the concentrations reported of V-notch are plotted with time along with the occurrence of the rain, the units of which are indicated on the right side of the graphs, the concentrations reported on the left side of the graphs. Given the intensity of the monsoon rains, changes in concentration can therefore be easily connected to the rainfall events.

During the dry season, weathering of the rocks in the waste rock pile will have liberated water soluble products to be carried out by the rain, hence leading to an increase in concentration of elements in the water at the beginning of the rain falls, showing a gradual decrease at the end of the monsoon rains. With a slight delay this trend is indeed evident for all elements with the exception of iron displayed in Figure 1. For cadmium and zinc a pronounced increase in values is noted for the rainy season in 04/05 from around 0.1 to 0.25 mg/L for cadmium and for zinc for the same period values increased by about 100 mg/L. The weathering of calcium and magnesium appear less sharply related to the rain events as do cobalt, zinc and cadmium, and increases over the observation period are not evident.

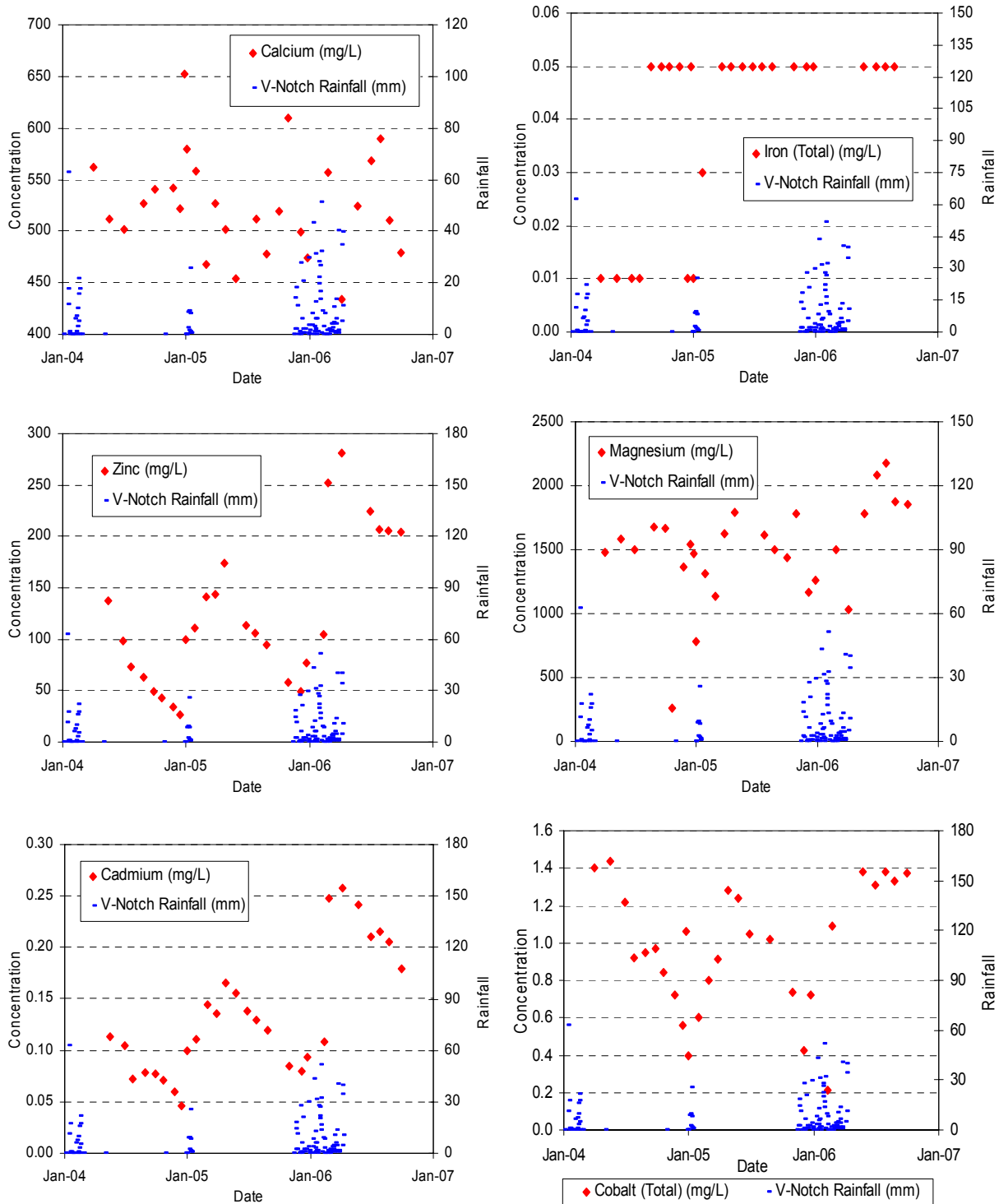


Figure 1 V-Notch Ca, Fe, Zn, Mg, Cd and Co concentrations

In Figure 2 the seasonal and annual trends of chloride, manganese and nickel are very sharp, pH and electrical conductivity respond less to the rain events and Nitrate as N does not respond at all. Chloride concentrations seem to decrease over the observation period between 04/05 and 06/07 but all other parameters appear to remain in the same range, as an increase from 14 to 18 mg/l for Nitrate is not relevant.

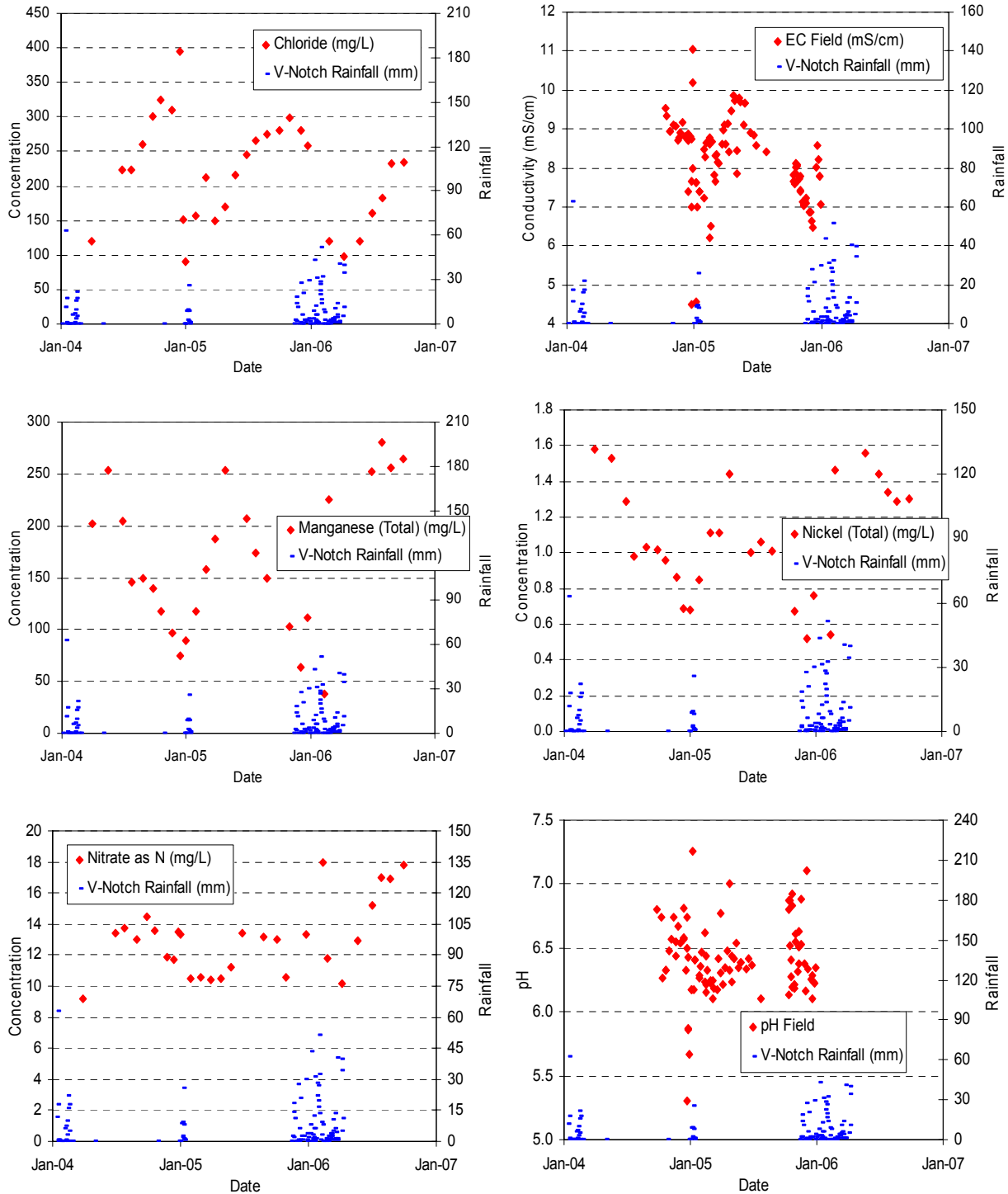


Figure 2 V-Notch Cl, Mg, Ni, Nitrate-N, pH and electrical conductivity

In Figure 3 the remaining elements for which a large enough data set exists to evaluate trends is plotted. Sodium (Figure 3) and chloride (Figure 2) reflect the identical leaching trend, suggesting that indeed NaCl is released from the waste rock pile with the rain. However potassium trends with the rain are less pronounced. Sulphate – sulphur response to rain may best be compared to the scatter noted for Ca, suggesting that some internal precipitation of gypsum is likely in the waste rock pile. The acidity/ alkalinity plot reflect the increase in zinc concentrations (Figure 1).

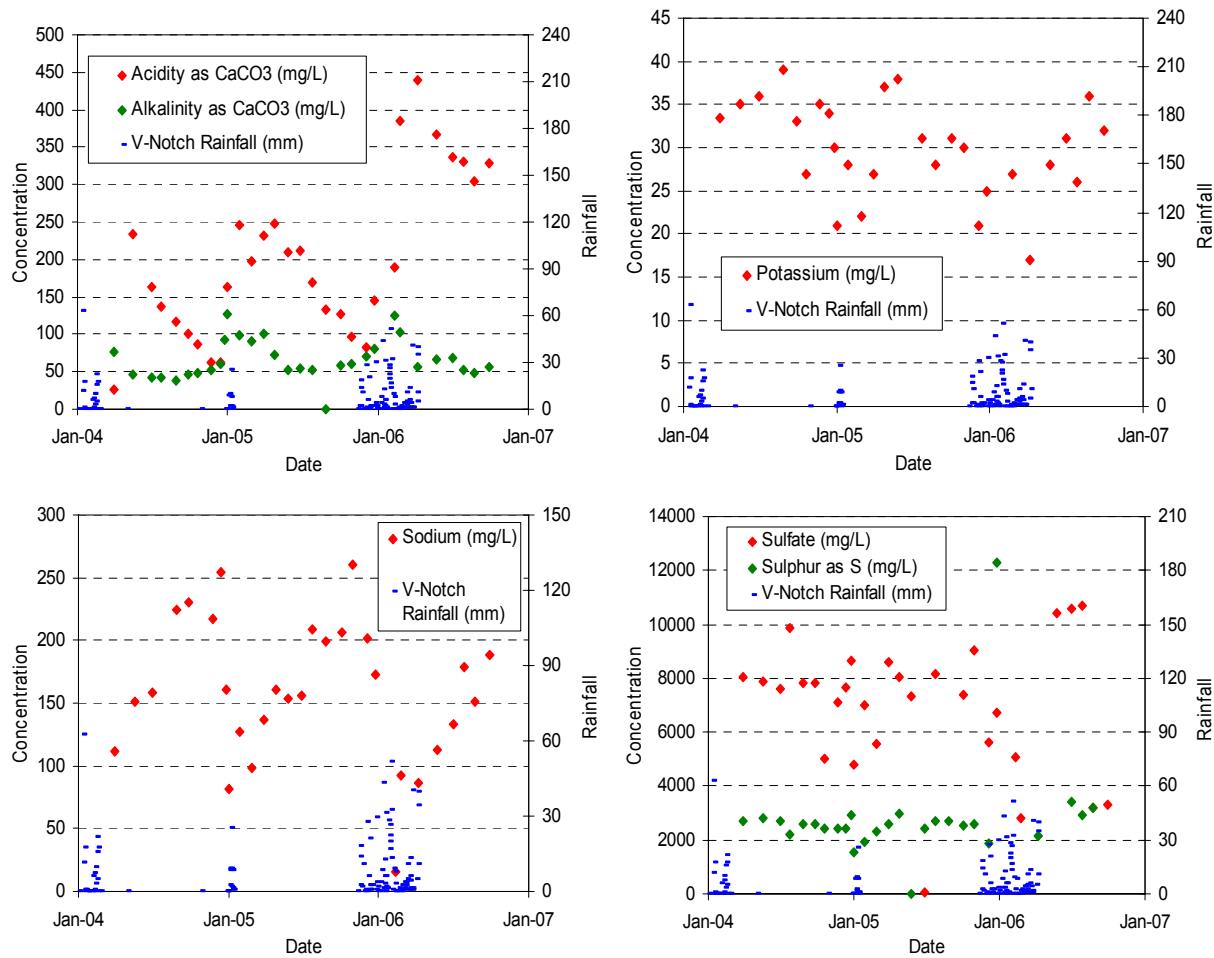


Figure 3 V-Notch acidity, K, Na and sulphate concentrations

The strong seasonal trend is evident from most parameters, with the exception of Fe, pH, alkalinity and S /sulphate. The time trends indicate that not all elements are released from the waste rock to the seepage in the same way, or they originate from different sources, i.e part of the natural ground water, as for example NaCl. The seasonality is likely a reflection of the hydrology. If indeed internal precipitates are forming in the waste rock pile, their long term stability may be of relevance. Some aspects of long term stability of secondary precipitates are under investigation under AMIRA project P933.

2.2 Contaminant Loading Using Data for 2004 to 2005

The need to examine a longer time span of water quality data becomes evident, when the concentrations discussed above are needed to derive contaminant loadings, derived from flow measurement of the effluent to be treated and the concentrations which result either during high or low flow season.

We have calculated monthly loadings of contaminants utilizing the data base (outlying values removed), utilizing average concentrations for each month and the average flow. Seasonal concentrations were calculated for both a dry and a rainy season. All values measured between May and October of a particular year were designated as ‘Dry Season’ and all values between November of the current year and April of the following year were designated ‘Rainy Season’.

Seasonal average concentrations were calculated by taking an average of all daily measurements that were available within each season. Monthly loadings were calculated by taking monthly average concentrations, multiplying them by the monthly average flow rate and calculating a total tonnage of contaminant for the month. Since there were some months with either no concentration data or no flow data, data was filled in by taking an average value of the months directly before and after the date for which the parameter was recorded. In the case of Dry Season 2004, only October flow rates were available and these were used for the other 5 months in this season.

We made this assumption about the dry season, as we could not understand the existence of a water sample of V-notch, where a submersible pump continuously delivers the seepage to the Evaporation Dam, which would not be the case unless some, albeit low flow would exist. This assumption is supported by the observation made during the 2006 field trip, where V-notch was twice visited within the 2 days. The pump had failed and V-notch overflowed. Also during inspection of the seepage bed, it suggested, that a flow exists within the gravel, but was not apparent on the surface, i.e producing a minimal flow. As such we may have overestimated the contaminant load.

In the case of Rainy Season 2005, no flow data was available after December 2005. This flow rate was used for the remaining months of this season. We have calculated non interpolated monthly loadings as well, but the interpolated data set was utilized for the assessment and hence our estimates are on the higher rather than the lower side of what would be needed to be removed by the treatment process.

The flow rate was found through conversion of the gauge board readings. Since relevant gauge board readings were only provided for the V-Notch site and not for Evaporation dam site, the estimates of contaminant loadings were restricted to V-Notch. Gauge board readings were converted to flow as follows:

$$\text{Flow (L/s)} = 1.342 \times \text{Height}^{(2.48)} \times 1000 \text{ where Height} = 0.599 - \text{Gauge Board in meters}$$

The results of the interpolated flows and average monthly loadings are summarized for the two available data sets 2004 and 2005, rainy season and dry season in Tables 2 and 3. For example in the rainy season 2004, 117 t of calcium were estimated to be released from the pile, whereas in 2005 it was only 17 t. For magnesium the loading in the 2004 Rainy season was 272 t and the sum of all the dry season was 24 t. However for 2005, Mg in the dry season loading sums to 83 t whereas the rainy season is 127 t. Given that only two years can be examined, due to the availability of matching flow with elemental concentrations for the same time span, large differences in contaminant load are evident between the two years assessed. This is even more evident when sulphate loading for the rainy season 2004 are considered, estimated at 1,460 t in comparison to the 2005 rainy season, with 69 t of sulphate. It may well be that erroneous assumptions are made, which lead to the strong influence of the flow on the loading. However in absence of discussions with a hydro-geologist familiar with the local site conditions, the data supplied have been used in good faith.

Table 2 Interpolated V-Notch monthly loadings in tonnes per month for 2004

	May-04	Jun-04	Jul-04	Aug-04	Sep-04	Oct-04	Dry Season 2004	Nov-04	Dec-04	Jan-05	Feb-05	Mar-05	Apr-05	Rainy Season 2004	2004 Total Load
Cd	0.0003	0.0003	0.0003	0.0002	0.0002	0.0002	0.0015	0.0001	0.0029	0.0077	0.0050	0.0032	0.0016	0.0205	0.022
Ca	1.5	1.5	1.4	1.5	1.6	1.6	9.0	0.8	37.5	41.4	21.7	11.2	4.8	117	126
Cl	0.5	0.6	0.6	0.8	0.9	0.9	4.3	0.5	17.4	9.0	6.2	4.1	1.6	39	43
Cr	0.00003	0.00003	0.00003	0.00003	0.00014	0.00014	0.0004	0.00008	0.00192	0.00073	0.00022	0.00002	0.00001	0.0030	0.0034
Co	0.00003	0.00003	0.00003	0.00003	0.00014	0.00014	0.0004	0.00008	0.00192	0.00109	0.00048	0.00019	0.00006	0.0038	0.0042
Pb	0.00003	0.00003	0.00003	0.00012	0.00014	0.00014	0.0005	0.00008	0.00192	0.00073	0.00023	0.00003	0.00001	0.0030	0.0035
Mg	4.6	4.4	4.3	4.9	4.8	0.8	24	2.1	96.2	76.2	49.4	31.0	17.1	272.1	295.8
Ni	0.004	0.004	0.003	0.003	0.003	0.003	0.02	0.001	0.044	0.056	0.038	0.025	0.014	0.178	0.198
K	0.10	0.10	0.10	0.11	0.10	0.08	0.59	0.05	2.04	1.78	1.00	0.55	0.35	5.78	6.38
SO4	23	24	25	23	23	15	132	11	521	427	264	159	77	1460	1592
S	8	8	7	8	7	7	45	4	170	127	85	55	28	470	514
Zn	0.4	0.3	0.2	0.2	0.1	0.1	1	0.1	1.7	7.6	5.0	3.2	1.7	19.3	20.7
Flow L/s	1	1	1	1	1	1	1	0.6	25	28	16	9	4	14	15
Water m3	2887	2887	2887	2887	2887	2887	17322	1548	63902	72742	40711	22491	9570	210964	213,851

Table 3 Interpolated V-Notch monthly loadings in tonnes per month for 2005

	May-05	Jun-05	Jul-05	Aug-05	Sep-05	Oct-05	Dry Season 2005	Nov-05	Dec-05	Jan-06	Feb-06	Mar-06	Apr-06	Rainy Season 2005	2005 annual Load
Cd	0.004	0.001	0.001	0.001	0.000	0.000	0.007	0.000	0.001	0.001	0.001	0.001	0.002	0.006	0.01
Ca	12	3	3	2	2	2	12	1	3	3	4	3	3	17	41
Cl	5	2	2	1	1	1	12	0.5	2	1	1	1	1	7	18
Cr	0.00010	0.00002	0.00002	0.00002	0.00003	0.00003	0.000	0.00002	0.00004	0.00002	0.00001	0.00001	0.00001	0.0001	0.0003
Co	0.00018	0.00008	0.00005	0.00002	0.00002	0.00002	0.000	0.00001	0.00005	0.00004	0.00003	0.00003	0.00004	0.0002	0.0006
Pb	0.00018	0.00002	0.00001	0.00000	0.00001	0.00001	0.000	0.00001	0.00009	0.00007	0.00004	0.00003	0.00003	0.0003	0.0005
Mg	44	11	10	8	6	5	83	3	8	9	10	8	7	44	127
Ni	0.03	0.01	0.01	0.01	0.00	0.00	0.06	0.00	0.00	0.01	0.01	0.01	0.01	0.03	0.09
K	0.97	0.24	0.18	0.14	0.12	0.10	1.74	0.05	0.15	0.16	0.17	0.14	0.11	0.78	2.52
SO4	186	53	48	39	31	23	381	16	40	32	25	39	53	204	585
S	69	17	16	14	11	8	134	5	12	12	13	13	14	69	202
Zn	4	1	1	1	0.3	0.2	6	0.1	0.4	1	1	2	2	6	12
Flow L/s	10	3	2	2	2	1	4	1	2	2	2	2	2	1	5.5
Water m3	25434	6824	5903	4982	4061	3139	50343	1775	6370	6370	6370	6370	6370	33627	83969

As the rainy season supplies the water to be treated for Dam # 3 these differences in loading are relevant for the treatment process to be considered. A more extensive data set should be utilized, and certainly an intensive sampling campaign, reflecting both the rainy and the dry season is desirable. An understanding of the ground water composition prior to receiving the waste rock weathering products along with the hydrological conditions would greatly improve the any long term projections on treatment requirements.

It is our understanding that V-notch water does get pumped to Evaporation Pond, other than during the monsoon rains, where Dam # 3 is used to contain the overflow. Thus Dam #3 is filled to capacity and remains full only to dry out during the dry season. If the pump fails or the rains are too intense, discharge to Page Creek occurs, which is undesirable. Treatment of Dam #3 water is proposed during the dry season for discharge prior to the next monsoon rains.

In essence therefore, the V-notch seepage is providing the loading to Dam #3 during the high flow months (December, January and February). Given the pronounced seasonal trends noted in the elemental concentrations and their noted relation to the rain events, an attempt is made to compare the flow values with those of the rain events, i.e. plotting for the available dates the recorded rain in mm and the available flows recorded at V-notch (Figure 4).

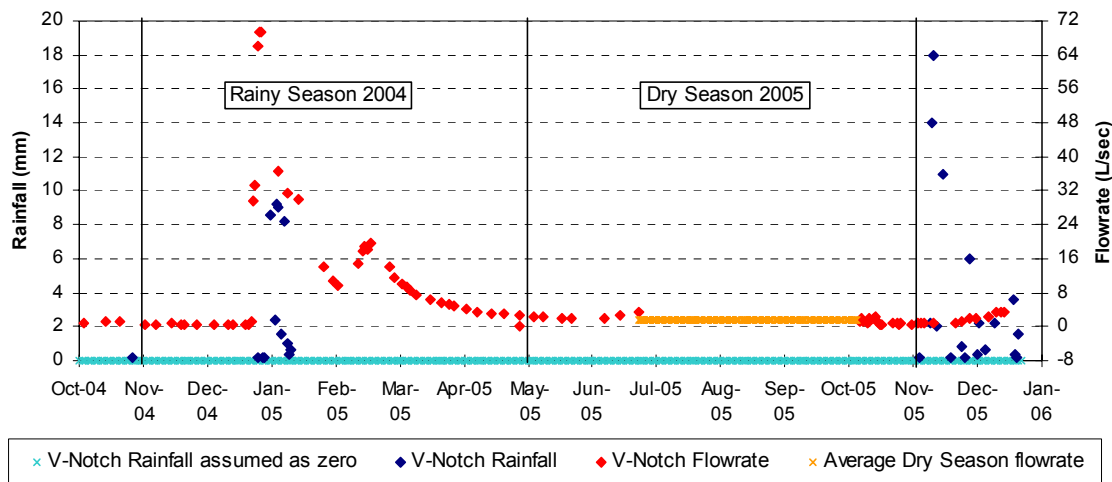


Figure 4 V-Notch flow rate and rainfall for the rainy and dry 2004 seasons

Note: No flow data is available before October 2004 and after December 2005. When no rain data was given, it was assumed that no rain fell on that day. It was also assumed that there was minimal flow during the period between July 2005 and October 2005.

It is noted, when the data are presented in this form, that a slight delay occurs, but again 2004 rains do not relate to the flows in the manner as the rains in 2005. In 2004 flows increase essentially about within 15 days of the rain, which is not the case in 2005.

The V-notch flows are generated by the seepage from the SWRD with a footprint of 465 ha (see Waste rock management report Doc. No. CP-058-00002). Estimates can be made of the volume of rain falling on the pile based on flow data supplied by G. Lee after a telephone discussion in the beginning of July with M. Kalin.

Utilizing these values for the years where we have estimated loadings (2004 and 2005), it becomes apparent that for the year 2004 we estimate a total flow of 213,851 m³ (Table 2) and calculated flows based on the footprint of the SWRD are 848,160 m³, nearly 4 times larger than the flow measured and interpolated reporting to V-notch. For the year 2005, we report based on the measured flow, only 83,969 m³, but the estimates from the rain records indicate a flow nearly 10 times larger with 977,430 m³. Even if we consider an evaporation rate of 10%, the discrepancy would suggest that the rain falling and the flows recorded have no direct relationship with each other. More water enters the ground than reports to V-notch seepage (Table 4). However, the season response of the concentrations in the seepage do not corroborate this conclusion, suggesting that the rains affect ground water flow, but not the concentrations of elements contained in the seepage.

Table 4 Estimates of rain water volume (SWRD 465 ha) assuming 10% evaporation.

Year	Volume of rain that falls on SWRD (m ³)	Rainfall Meters per square meter
2001	1,649,820	0.35
2002	658,440	0.14
2003	954,180	0.20
2004	848,160	0.18
2005	977,430	0.21
2006	2,508,210	0.54

In essence, many uncertainties remain in estimating the contaminant loading. The ground water database may provide insight together with the site hydro-geologist familiar with the site conditions, as suggested previously.

Treatment options are to be assessed by Boojum for Dam # 8, seepage which originates from the Northern Waste Rock Dump (NWRD), which is larger than the SWRD, but flow data are not available for Dam #8. Verbal communication with Glen Ware indicates that during the dry season no flow exists and flow is of relevance only during the rainy season. These flow conditions confound the lack of documentation needed to arrive at loading and an understanding of the interaction of rain events – surface water discharges and ground water conditions. Ground water data were not supplied to Boojum. Those, if available, should be integrated to understand and project present and future contaminant load. Thus contaminant loading for Dam # 8 cannot be generated.

A broader view on a water balance of the site, taking the construction of the waste rock pile into account, could suggest that the waste rock piles are large enough, and have sufficient void space to contain all the rains. Estimates derived utilizing the data provided in Report Waste Rock Management Doc. No CP-058-00002, Doc. Version: 00 indicates that even if there was no run-off or evaporation from the surface of the pile and all the rain entered the waste rock pile, it would be far from saturated. The calculations indicate 3% to 12% of the pores will be filled given the information in the report, and assuming that the piles represent the proposed conditions in final pile configuration (Table 5).

The bulk of the piles may still contain essentially all the water that fell on the pile since it was first established (assumed about 5 years ago). The seepage at V-notch may therefore represent drainage from the sides of SWRD, originating from the periphery transporting therefore only a fraction of the weathering products contained. Although channeling of water through the pile is likely, but given the appearance and friable rock and the variability of the permeability of the waste rock and the localized compaction with is generated through the transport of the waste rock with the dump trucks, channeling may not release all the rain water.

Table 5 Rock Pile Water Capacity Estimates

	Footprint m²	Design Volume Bulk Cubic meters (bcm)	Median height Meters	Void volume 40% bcm	Annual rain over footprint* m³	% Void space filled if all rain enters pile
South	4,500,000	48,000,000	10	19,200,000	2,325,000	12
North	5,000,000	101,000,000	20	40,000,000	2,500,000	6

** Total volume of rain falling on pile is assumed to be a maximum of 0.5 meters per year precipitation per square meter over the footprint area (from Table 4).*

Since the rock piles are designed through use of covers and compaction to inhibit entry of rainwater into the pile and promote run-off and surface evaporation, the amount of water entering the rock piles should be substantially less than the 100% assumed in Table 5.

2.3 Comparing V-Notch – Dam #3 and Dam #8 water chemistry

We have examined the database on water quality available for Dam # 8 along with that of Dam # 3 and V-notch. All of the available parameters have been used in a comparison between V-notch – Dam # 3 and Dam # 8. The data are grouped by season, as defined previously.

There are three reasons that differences in concentrations in Dam # 3 and # 8 should be expected, after the filling of the dams either with V-notch water or seepage emerging from the NWRD, were the seepage is generated for Dam # 8.

- Evaporation during the dry season would tend to concentrate the elements in the form of soluble evaporates. This is the most likely expectation since both dams dry out during the dry season and precipitates form as can be seen in Plates 3a and 3b for the Dam#8 and Dam #3, respectively.
- The accumulation of salt due to evaporation increases the elemental concentration in the freshly flooded dam year by year, if no mineralization processes take place, such as those suspected to occur with the Tufa formations in Dam # 3.
- The elemental concentrations might also be affected by upwelling or draining of seepage through the bottom of the dams either into or out of the water, as the bottom of the dams are not lined. However drainage out or into the dam’s through the centre of the dams has not been assessed. One observation might be offered that upwelling might take place is the fact that during the collection measurements on sediment pH and Eh values in Dam #3, in preparation for the hay placement into Dam #3, it was reported that the centre

could not be accessed, as it had not dried out and would not support walking being walk on. This may be an indication that indeed some upwelling exists.



Plate 3a and 3b Dam #8 precipitates formed at end of dry season 2007 (left) and Dam#3 white precipitate associated with algal jelly (right)

In Figures 5 and 6, histograms are presented that compare average concentrations of the major elements. On the left side of the figures are the rainy seasons and on the right side the dry season concentrations are presented.

The concentrations of Ca, Mg and S in V-notch and Dam # 3 are essentially the same, when the three years of rainy season are compared. For the dry season (only 2004 data available) a slight increase in might be evident in the concentration of sulphur in Dam #3. For Dam #8 however, the concentrations are lower for the rainy season compared to the other two seepages and for the dry season the data do not exist to facilitate a comparison (Figure 5).

In Figure 6 the concentrations of K and Zn are presented for the three seepages. The element K should be highly mobile and would show increases as it would form highly soluble evaporates at the edges of the dam. V-notch concentrations are essentially in both seasons at the same concentration, whereas for Dam #3 an increase is noted for the dry season both for 2004 and 2005. Although the data for Dam #8 are sparse, an increase is noted in K between the rainy season 2004 and 2005 with the highest concentrations found in the dry season 2005. Comparing the three seepages, Zn not K is lower in Dam #8.

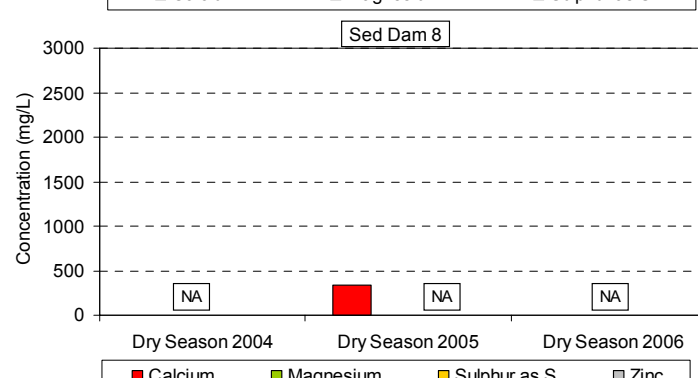
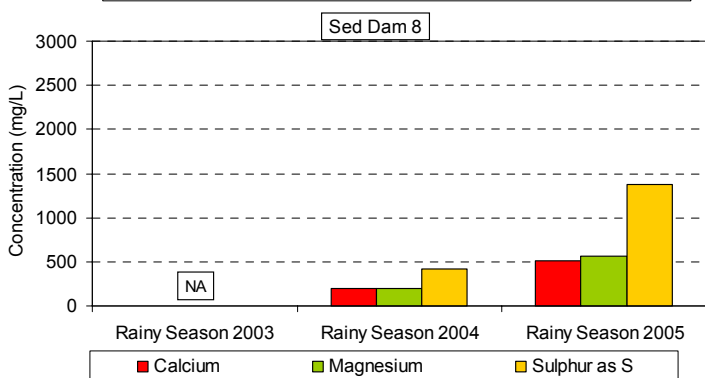
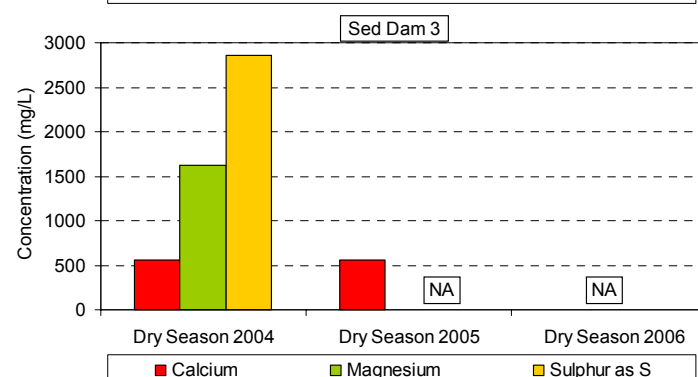
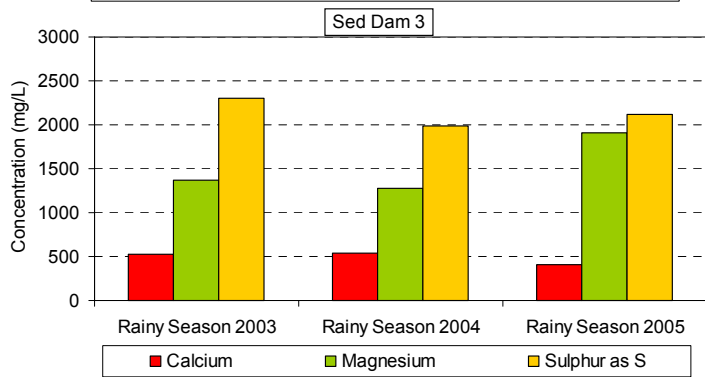
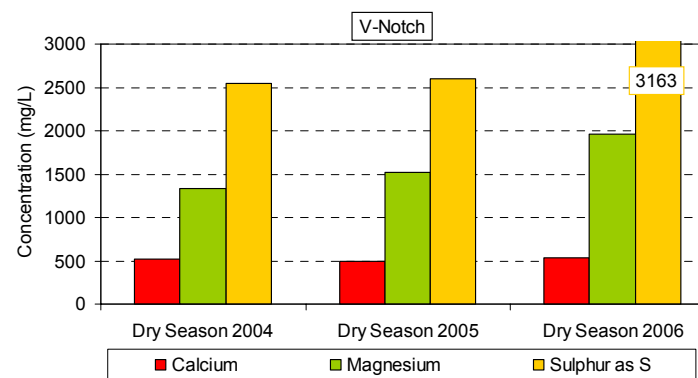
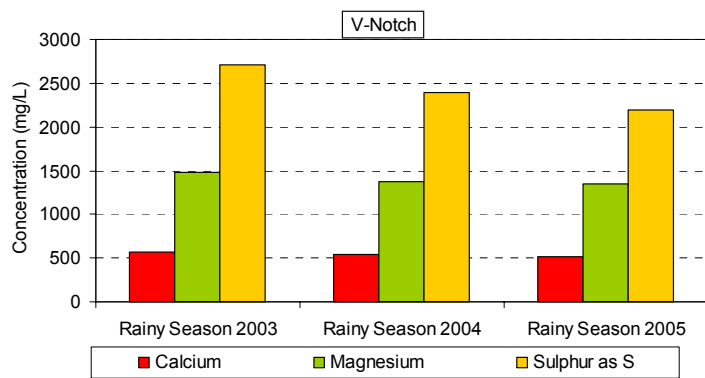


Figure 5 Rainy and dry season Ca, Mg and S concentrations V-Notch, Dam #3 and Dam #8

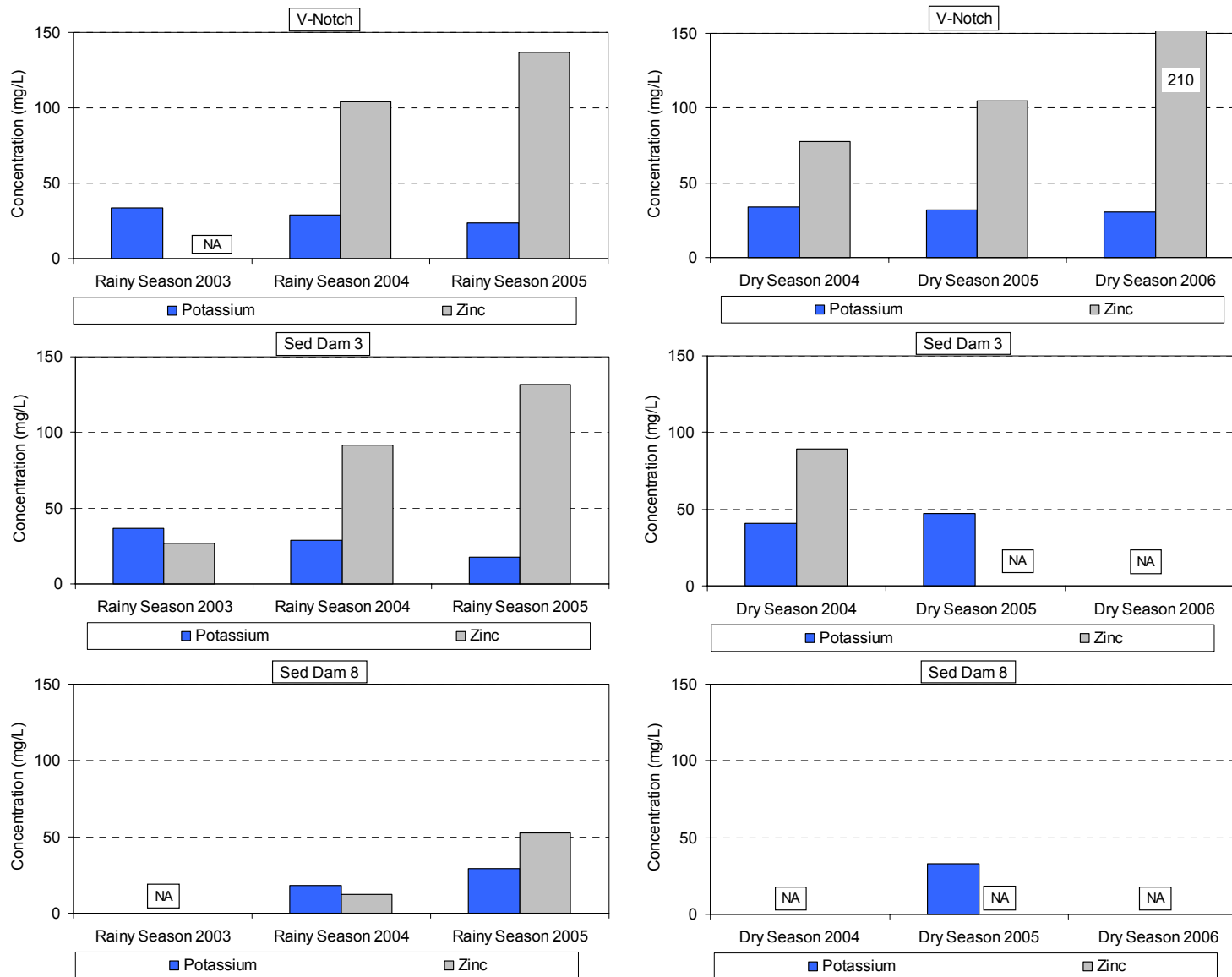


Figure 6 Rainy and dry season K and Zn concentrations V-Notch, Dam #3 and Dam #8

Based on the available data, segregated by season, there does not appear to be a prominent increase or decrease of the elemental concentrations. A larger data set needs to be examined to determine the seasonal behavior of the effects of the evaporates.

It was expected to find more prominent increases in elements, certainly between V-notch and Dam #3, given the extensive white evaporate formation on the edges of the dam. The formation of the Tufa-like structures may contribute to decreasing the solubility of the accumulating salts in addition to an extensive covering of the sides of the dam with a type of mineralized encrustment, which has the appearance of regular surface patterns and is thought to be of biological origin. This would prevent the seasonal re-dissolution of the accumulating evaporates.

In contrast to the coating and Tufa structures in Dam#3, re-dissolving salts were found surrounding Dam # 8, extruding from the previously flooded edges /shores of the pond during sampled during the 2006 field assessment. Sample #6 (assayer number 11219) revealed based on mol % element (not oxides) 47% Al, 3% Ca, 12% Fe, 19% Mg, 8% K and 5.8% S with about 10% LOI. These types of salts were not found in Dam #3, but this does not mean they had not been formed, hence contributing to the increases in concentration as the dam dries out and gets re-flooded with the next rainy season.

The suggestion that indeed the covering and the Tufa-like structures in Dam # 3 are a factor in the mineralizing salts is a hypothesis or a suggestion. Although striking, these structures and coatings over the sediment are not present in Dam #8. Glen Ware submitted photographs from the dried out Dam #8, being covered with a type of precipitate as the water receded in the 2007 dry season. On first sight the photographs suggest the crystals are some type of calcium carbonate or gypsum. A drop of acid resulting in dissolution with the evolution of carbon dioxide would provide some direction in identification.

The sparse data set of comparable water quality needs to be expanded and a quantitative sampling and analysis of the evaporates, sediment coverings and the Tufa structures needs to be performed. Based on the limited data, a seasonal pattern may be present, and does lead to a select accumulation of elements over time.

To ascertain if the visual biological observations on the water of Dam #8 are reflected in the water chemistry, during the February 2007 field trip, water samples were collected of both Dam #3 in the vicinity of the hay placement and in Dam #8 (Samples #19 and 18 respectively, Appendix 4). In Dam # 8 Ca, F, Zn concentrations are lower than in Dam #3 and the TKN value, the organic nitrogen compounds, is at or below the detection limit, but TKN values above the detection limit are reported for Dam #3 and the same differences exists for the essential element phosphate. The concentrations of Mg and SO₄ are higher in Dam #8 (nearly 2 times) and higher K, COD as well as very high concentrations of Nitrate – N and Nitrite –N have been analyzed in the 2007 samples for Dam #8. This suggests that the monitoring data reflect real differences in the water chemistry between the dams, hence the ecology and likely the treatment approach needed for Dam #8.

The two waste rock pile seepages differ with respect to the elements they release to the surface seepage. Not only does the chemistry of the seepage in Dam #8 appear to differ from the SWRD, but the physical differences between the two piles are striking. The NWRD is larger, contains more waste rock but produces less surface seepage. This suggests that the rain falling on the pile reports elsewhere but not to Dam #3 and likely reaches the ground water. Monitoring of the flow leaving Dam #8 would be advisable, to reconcile the water balance of this pile and to generate a contaminant load to consider a treatment option for this seepage.

Field observations also confirmed that the water characteristics in Dam #8 are different. No Tufa structures were found and the biota are sparse and of poor growth, although the floating cattail raft did not do as well as that on Dam #3 (?). The treatment option for this pond should be based on the ongoing tests using the submerged substrates and possibly the cattail rafts. It is suspected that the high concentrations of N compounds could exert some toxicity, particularly in the absence of any phosphate.

The differences in water chemistry, ecology, precipitate occurrences and the reported flow between the SWRD and the NWRD could be connected to the preparation of the basement for the NWRD (discussion with Cookie who is familiar with the operation of the site since Pasminto times) in addition to the type of waste rock placed in the pile, the geomorphology of the drainage basin below the pile, potential changes in the usage of explosive and other factors.

In summary with the available information, the differences in seepage characteristics emerging from the two waste rock piles are not understood. In light of the construction of the Western dump which will extend over the acidic seepage originating from the old Bulk waste rock dump, directed toward Dam #3, the differences in chemistry of the seepages should be addressed, as they may have implications of unknown dimensions for the waste management overall. The diversion of the acidic seepage to Dam #3 will likely alter the chemistry, most pronounced during the dry season. It is suggested that this aspect be clarified as previously proposed in Tasking document: Study waste rock weathering product generation to understand differences in chemistry of seepage Dam #8 and Dam #3 and the Bulk Waste Dump.

3.0 EVAPORATION POND

3.1 Monitoring Data

In Table 6 an overview is given of the parameters which are in the database for this location, summarized in the same way as in Table 1 for V-Notch. A comparison of Table 1 and Table 6 indicates that different parameters appear to be important to be monitored for the two stations. The most frequent parameters are sampled from January 2000 to October 2006, 70 to 40 times when V-notch samples have been collected between March 04 and October 06 generally 20 to 28 times.

These imbalances in the available data of relevant parameters such sulphate, magnesium, calcium and zinc do not facilitate tracing key important elements throughout the operation i.e. from the mine water intake - from the ground through the mill and finally into the tailings. Such a tracing of the elements from source to sink within the waste management area would be extremely useful in developing control measures. Sampling protocols should be developed which would facilitate the fate of an element throughout the entire system at the same time (plus minus 12 to 24 h), reflecting dry and rainy season conditions. Similar observations can be made on the data as discussed for V-notch but are not repeated.

Table 6 All measured Evaporation Pond Parameters

Parameter and unit	Count (min, max)	Parameter and unit	Count (min, max)
Acidity as CaCO ₃ (mg/L)	1, (8)	Mercury (Total) (mg/L)	3, (0.0001, 0.91)
Alkalinity as CaCO ₃ (mg/L)	1, (56)	Molybdenum (Total) (mg/L)	2, (0.03, 0.033)
Alkalinity Bicarbonate (mg/L)	1, (56)	Nickel (Total) (mg/L)	2, (0.003, 0.01)
Alkalinity Carbonate (mg/L)	1, (1)	Nitrate as N (mg/L)	1, (0.18)
Aluminum (Total) (mg/L)	1, (0.1)	Nitrite+Nitrate as N (mg/L)	1, (0.24)
Antimony (Total) (mg/L)	2, (0.001, 0.01)	Nitrite as N (mg/L)	1, (0.07)
Arsenic (mg/L)	7, (0.001, 0.01)	pH Field	45, (6.4, 8.6)
Barium (Total) (mg/L)	1, (0.1)	pH Lab	69, (6.9, 8.4)
Beryllium (Total) (mg/L)	1, (0.01)	Potassium (mg/L)	20, (115, 166)
Boron (Total) (mg/L)	1, (0.3)	Selenium (Total) (mg/L)	2, (0.01, 0.01)
C10 - C14 Fraction (ug/l)	45, (42, 125)	Silica (Total) (mg/L)	1, (16.6)
C29 - C36 Fraction (ug/l)	44, (50, 145)	Silver (Total) (mg/L)	2, (0.001, 0.01)
C6 - C9 Fraction (ug/l)	46, (20, 27)	Sodium (mg/L)	21, (182, 381)
Cadmium (Filtered) (mg/L)	43, (0.0001, 0.012)	Strontium (Total) (mg/L)	1, (0.4)
Cadmium (mg/L)	71, (0.0001, 0.0122)	Sulfate (mg/L)	62, (269, 2440)
Calcium (mg/L)	22, (0.0005, 400)	Sulfate (Filtered) (mg/L)	40, (269, 1950)
COD (mg/L)	1, (32)	Sulphur as S (mg/L)	3, (433, 538)
Chloride (mg/L)	19, (59, 162)	Temperature Water (oC)	46, (20, 37)
Chromium (Total) (mg/L)	2, (0.001, 0.01)	Thallium (Total) (mg/L)	1, (0.01)
Cobalt (Total) (mg/L)	2, (0.004, 0.01)	Thiocyanate (mg/L)	19, (0.1, 16)
Copper (Total) (mg/L)	2, (0.002, 0.01)	Tin (Total) (mg/L)	1, (0.01)
Cyanide Total (mg/L)	43, (0.001, 13)	Titanium (Total) (mg/L)	1, (0.01)
Cyanide WAD (mg/L)	43, (0.001, 0.04)	Toluene (ug/L)	3, (93, 99)
EC Field (mS/cm)	49, (0.7, 4.3)	Total Anions (meq/L)	1, (37)
EC Lab (mS/cm)	63, (0.7, 4.2)	Total Cations (meq/L)	1, (36)
Gauge Board (m)	68, (0.05, 169)	TDS (mg/L)	70, (404, 4110)
Ionic Balance (%)	1, (2.1)	Tot Organic Carbon (mg/L)	59, (0.5, 17)
Iron (Filtered) (mg/L)	42, (0.01, 0.5)	Total Pet. Hydrocarbons	40, (0.11, 10)
Iron (Total) (mg/L)	42, (0.005, 0.22)	Tot. Phosphorus as P(mg/L)	1, (1)
Lead (Filtered) (mg/L)	45, (0.001, 0.022)	TSS (mg/L)	71, (0.5, 43)
Lead (mg/L)	70, (0.001, 0.062)	Turbidity (NTU)	71, (0.1, 50)
Magnesium (mg/L)	64, (0.2, 221)	Vanadium (Total) (mg/L)	1, (0.01)
Manganese (Filtered) (mg/L)	43, (0.001, 1.7)	Zinc (Filtered) (mg/L)	44, (0.008, 0.3)
Manganese (Total) (mg/L)	46, (0.021, 2.9)	Zinc (mg/L)	70, (0.009, 24)

In Figure 7, the time trends are presented for the electrical conductivity, Mg, Sulphate TDS, Calcium and Iron. Again, we have plotted on the time axis the rain events, as given the large drainage basin in which Evaporation Pond is located along with its size, one would expect some seasonal trend, i.e. dilution to take place. For the year 2000 and 2001 some seasonality appeared to be evident reflected in the TDS values. Sulphate and magnesium seem to be steadily increasing since 2002 reflecting since 2005 a steeper increase than in the previous years.

Zinc and lead concentrations are suddenly increasing although presently still at low concentrations (Figure 8). The irregular patterns of TDS, calcium and pH occur roughly since 2005, the time when the V-notch seepage was discharged to Evaporation Pond, although calcium was not measured previously. It is not clear why iron is monitored so frequently, as at this high pH it will all report to the TSS solids as a hydroxide. In general however, the absence of iron streaking coloration, as well as the accumulations of iron-hydroxide precipitates, normally typical for any mine waste management area where acid generation occurs, is noteworthy. One would expect that at least the tailings would release some iron, or it all precipitates in the Decant pond on the tailings dam. Similarly not even the seepages of the Bulk Waste Dump show significant precipitate areas in the stream bed and seepage origins, albeit a low pH.

The process of acid generation process in the tailings is unclear from these data, albeit a rather high release of sulphate both from the waste rock piles reporting to the seepages and in Evaporation Pond, which receives the milling effluents and the water from the pit. Some insight was hoped to be gained from a water sample collected on an isolated surface water section on the tailings, sample #6. This water is standing on the tailings, isolated from the fresh tailings discharge. However also here no iron was found and the pH with 7.2 was not depressed, as might be expected.

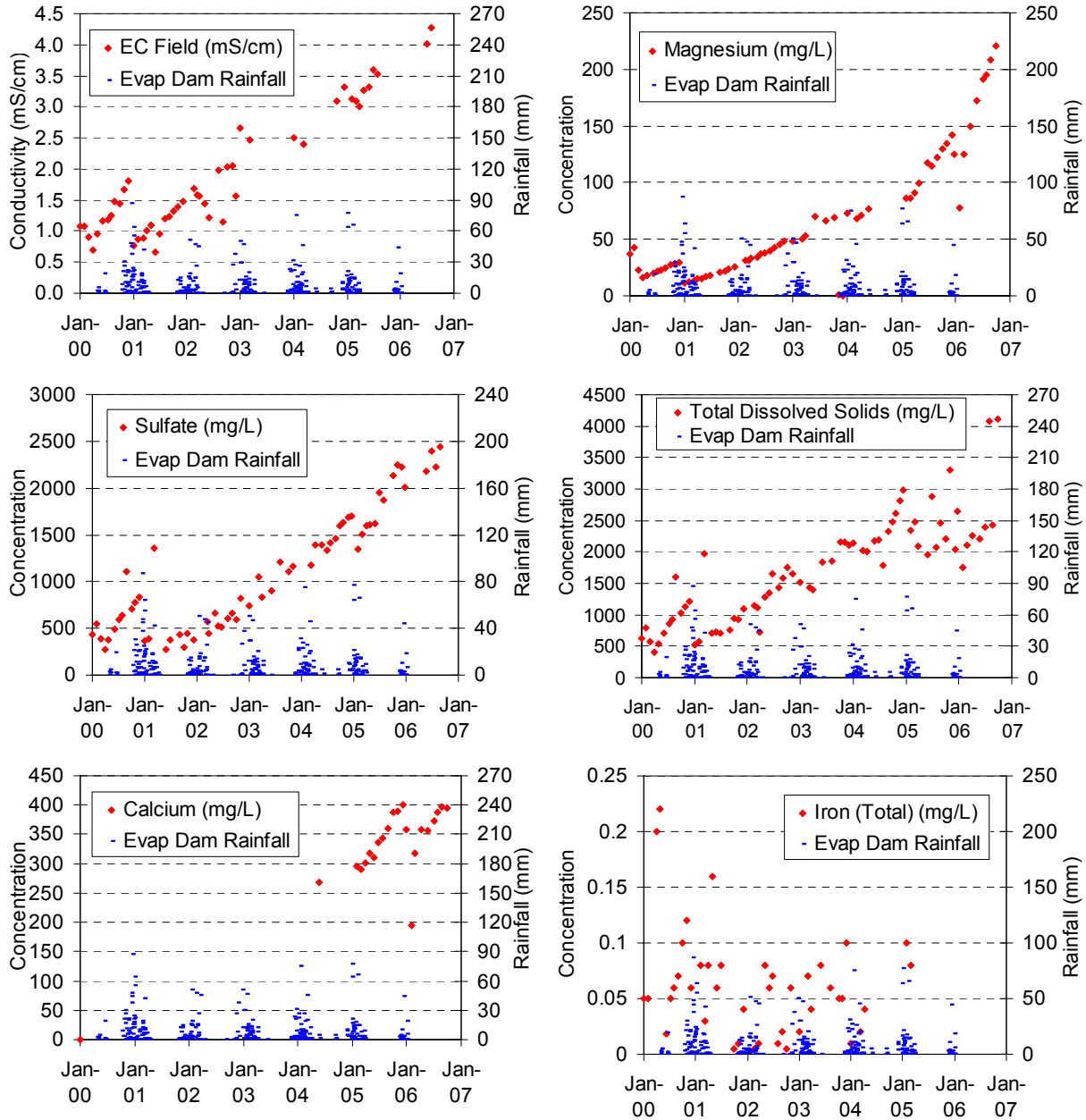


Figure 7 Evaporation Pond conductivity, Mg, SO₄, TDS, Ca and Fe concentrations

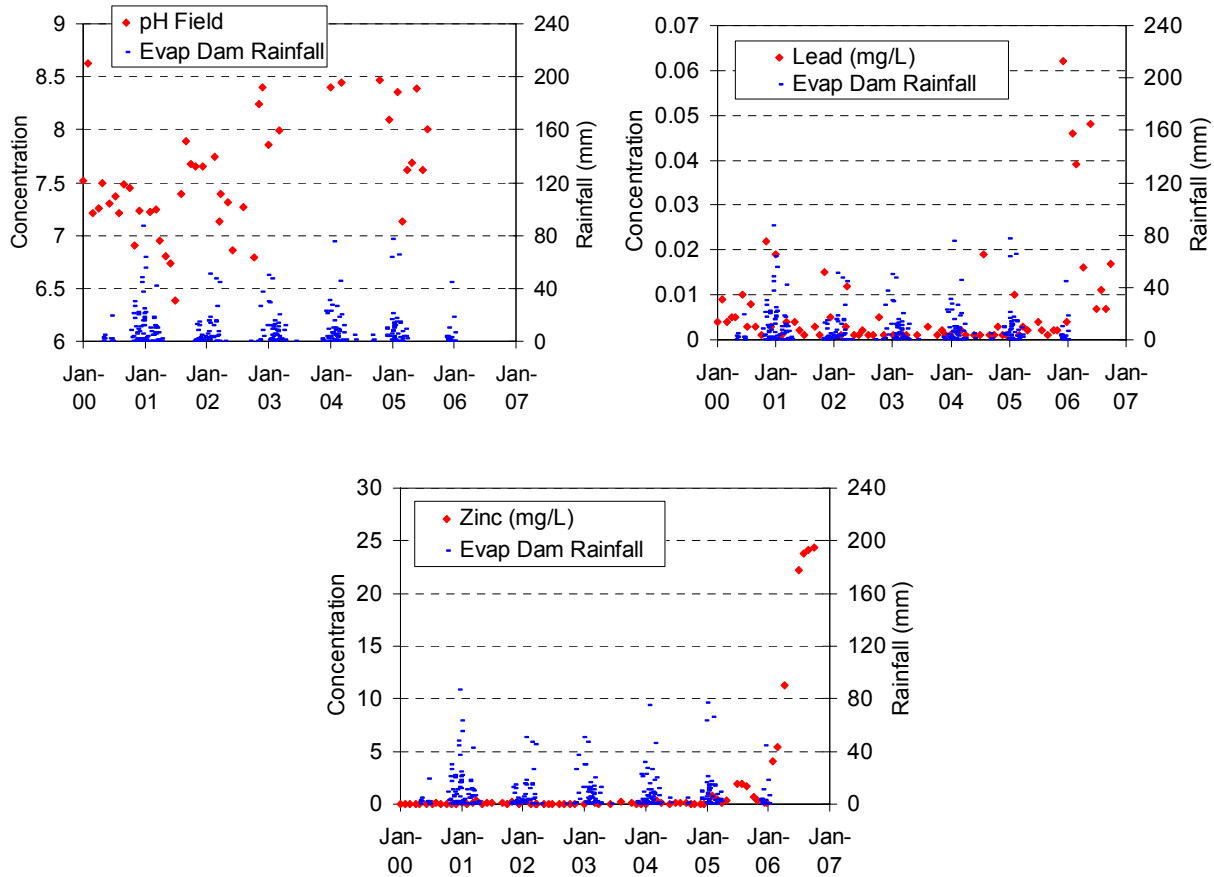


Figure 8 Evaporation Pond pH, Pb and Zn concentrations

A different approach to examine seasonal trends of the chemical parameters in Evaporation Pond has been attempted by sorting the parameters which are frequently measured by month for each year. Tables 7 to 12 represent the months in which generally one water sample has been collected throughout the years 2000 to 2006. Unfortunately not a single year exists, where each month would be represented throughout all the years though this would facilitate a representative summary for the rainy season and the dry season. Using an average for these seasons as was done for V-notch, the potential effects of the rains on Evaporation Pond would disappear.

Table 7 Average Evaporation Pond Monthly Concentrations for 2000 in mg/L

	Jan-00	Feb-00	Mar-00	Apr-00	Jun-00	Jul-00	Aug-00	Oct-00	Nov-00	Dec-00
Ca	0 (1)	-	-	-	-	-	-	-	-	-
Cl	-	-	-	-	-	-	-	-	-	-
EC Field (mS/cm)	1.08 (1)	0.99 (2)	0.70 (1)	0.95 (1)	1.16 (1)	1.22 (2)	1.48 (1)	1.56 (2)	1.81 (1)	0.76 (1)
EC Lab (mS/cm)	1.08 (1)	0.99 (2)	0.70 (1)	0.95 (1)	1.16 (1)	1.22 (2)	1.48 (1)	1.56 (2)	1.81 (1)	0.76 (1)
Fe	0.05 (1)	0.05 (1)	0.2 (1)	0.22 (1)	0.02 (1)	0.06 (2)	0.07 (1)	0.11 (2)	0.06 (1)	-
Pb	0 (1)	0.01 (2)	0.01 (1)	0.01 (1)	0.01 (1)	0.01 (2)	0 (1)	0.01 (2)	0 (1)	0.02 (1)
Mg	37 (1)	33 (2)	16 (1)	18 (1)	20 (1)	23 (2)	25 (1)	28 (2)	29 (1)	11 (1)
Mn	0.79 (1)	0.52 (2)	0.9 (1)	0.52 (1)	0.26 (1)	0.27 (2)	0.48 (1)	0.47 (2)	0.77 (1)	0.36 (1)
pH Field	7.52 (1)	7.92 (2)	7.26 (1)	7.5 (1)	7.3 (1)	7.29 (2)	7.48 (1)	7.18 (2)	7.23 (1)	-
pH Lab	7.99 (1)	7.81 (2)	7.3 (1)	7.3 (1)	7.43 (1)	7.5 (2)	7.63 (1)	7.52 (2)	7.49 (1)	7.45 (1)
K	-	-	-	-	-	-	-	-	-	-
Na	-	-	-	-	-	-	-	-	-	-
SO4	436 (1)	468 (2)	279 (1)	374 (1)	491 (1)	614 (2)	1103 (1)	741 (2)	834 (1)	364 (1)
TDS	632 (1)	678 (2)	404 (1)	543 (1)	712 (1)	890 (2)	1600 (1)	1075 (2)	1210 (1)	528 (1)
Zn	0.01 (1)	0.01 (2)	0.04 (1)	0.04 (1)	0.04 (1)	0.05 (2)	0.05 (1)	0.04 (2)	0.03 (1)	0.09 (1)

Table 8 Average Evaporation Pond Monthly Concentrations for 2001 in mg/L

	Feb-01	Mar-01	Apr-01	May-01	Jun-01	Aug-01	Sep-01	Oct-01	Dec-01
Ca and Cl	-	-	-	-	-	-	-	-	-
EC Field (mS/cm)	0.87 (1)	0.94 (2)	1.09 (1)	0.66 (1)	0.95 (1)	1.21 (1)	1.24 (1)	1.35 (2)	1.48 (1)
EC Lab (mS/cm)	0.87 (1)	0.94 (2)	1.09 (1)	0.66 (1)	0.95 (1)	1.21 (1)	1.24 (1)	1.36 (2)	1.48 (1)
Fe	0.08 (1)	0.06 (2)	0.16 (1)	0.06 (1)	0.08 (1)	-	-	0.01 (2)	0.04 (1)
Pb	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)	-	0 (1)	0.01 (2)	0.01 (1)
Mg	12 (1)	14 (2)	15 (1)	17 (1)	18 (1)	-	21 (1)	23 (2)	26 (1)
Mn	0.26 (1)	0.61 (1)	0.4 (1)	0.15 (1)	0.21 (1)	-	0.07 (1)	0.03 (2)	0.16 (1)
pH Field	7.22 (1)	7.1 (2)	6.8 (1)	6.74 (1)	6.38 (1)	7.39 (1)	7.89 (1)	7.66 (2)	7.65 (1)
pH Lab	7.24 (1)	7.1 (2)	7.3 (1)	7.4 (1)	7.37 (1)	-	7.45 (1)	7.58 (2)	7.54 (1)
K	-	-	-	-	-	-	-	-	-
Na	-	-	-	-	-	-	-	-	-
SO4	392 (1)	1359 (1)	-	269 (1)	374 (1)	-	435 (1)	373.5 (2)	380 (1)
TDS	568 (1)	1970 (1)	712 (1)	720 (1)	716 (1)	-	764 (1)	930 (2)	1090 (1)
Zn	0.04 (1)	0.23 (2)	0.03 (1)	0.07 (1)	0.1 (1)	-	0.07 (1)	0.13 (2)	0.03 (1)

Note: Parentheses indicates the number of samples

Table 9 Average Evaporation Pond Monthly Concentrations for 2002 and 2003 in mg/L

	Feb-02	Mar-02	May-02	Jun-02	Aug-02	Sep-02	Oct-02	Nov-02	Jan-03	Mar-03	Jun-03	Aug-03	Oct-03	Nov-03	Dec-03
Ca and Cl are NA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
EC Field (mS/cm)	1.68 (1)	1.58 (2)	1.45 (1)	1.22 (1)	1.98 (1)	1.14 (1)	2.04 (1)	1.8 (2)	2.65 (1)	2.46 (1)	-	-	-	-	2.51 (1)
EC Lab	1.68 (1)	1.58 (2)	1.45 (1)	1.22 (1)	1.98 (1)	1.14 (1)	2.04 (1)	1.81 (2)	2.65 (1)	2.46 (1)	-	-	-	-	2.51 (1)
Fe	0.01 (1)	0.01 (1)	0.08 (1)	0.07 (2)	0.01 (1)	0.02 (1)	0.01 (1)	0.06 (1)	0.02 (1)	0.06 (2)	0.08 (1)	0.06 (1)	0.05 (1)	0.05 (1)	0.06 (2)
Pb	0 (1)	0.01 (2)	0 (1)	0 (2)	0 (1)	0 (1)	0.01 (1)	0 (1)	0 (1)	0 (2)	0 (1)	0 (1)	0 (1)	0 (1)	0 (2)
Mg	31 (1)	32 (2)	34 (1)	38 (2)	40 (1)	43 (1)	45 (1)	48 (1)	48 (1)	52 (2)	70 (1)	66 (1)	69 (1)	1 (1)	37 (2)
Mn	0.19 (1)	0.25 (2)	0.4 (1)	0.4 (2)	0.05 (1)	0.09 (1)	0.09 (1)	0.1 (1)	0.31 (1)	0.52 (2)	0.66 (1)	0.34 (1)	0.21 (1)	0.16 (1)	0.21 (2)
pH Field	7.74 (1)	7.26 (2)	7.31 (1)	6.86 (1)	7.27 (1)	-	6.79 (1)	8.32 (2)	7.86 (1)	7.99 (1)	-	-	-	-	8.4 (1)
pH Lab	7.58 (1)	7.1 (2)	7.82 (1)	7.54 (2)	7.7 (1)	7.81 (1)	7.9 (1)	7.77 (1)	7.82 (1)	7.97 (2)	7.78 (1)	7.39 (1)	7.88 (1)	8.38 (1)	8.08 (2)
K and Na are NA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SO4	-	510 (2)	664 (1)	523 (2)	602 (1)	658 (1)	598 (1)	817 (1)	744 (1)	942 (2)	904 (1)	1210 (1)	1110 (1)	1160 (1)	-
TDS	1140 (1)	915 (2)	1280 (1)	1505 (2)	1440 (1)	1590 (1)	1760 (1)	1650 (1)	1520 (1)	1415 (2)	1830 (1)	1850 (1)	2150 (1)	2160 (1)	2120 (2)
Zn	0.02 (1)	0.02 (2)	0.02 (1)	0.03 (2)	0.05 (1)	0.04 (1)	0.03 (1)	0.02 (1)	0.03 (1)	0.06 (2)	0.03 (1)	0.22 (1)	0.1 (1)	0.04 (1)	0.03 (2)

Table 10 Average Evaporation Pond Monthly Concentrations for 2004 in mg/L

	Mar-04	Apr-04	May-04	Jun-04	Jul-04	Aug-04	Sep-04	Oct-04	Nov-04	Dec-04
Ca	-	-	268 (1)	-	-	-	-	-	-	-
Cl	-	-	-	-	-	-	-	-	-	-
EC Field (mS/cm)	2.39 (1)	-	-	-	-	-	-	3.1 (1)	-	3.31 (1)
EC Lab (mS/cm)	2.39 (1)	-	2.69 (1)	2.8 (1)	2.89 (1)	2.93 (1)	3.01 (1)	3.37 (1)	3.21 (1)	3.21 (1)
Fe	0.02 (1)	0.04 (1)	-	-	-	-	-	-	-	-
Pb	0 (1)	0 (1)	0 (1)	0 (1)	0.02 (1)	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)
Mg	68 (1)	71 (1)	77 (1)	-	-	-	-	-	-	-
Mn	0.84 (1)	1.64 (1)	-	-	-	-	-	-	-	-
pH Field	8.44 (1)	-	-	-	-	-	-	8.47 (1)	-	8.1 (1)
pH Lab	7.98 (1)	8.18 (1)	7.75 (1)	7.52 (1)	7.84 (1)	7.84 (1)	8.12 (1)	7.93 (1)	7.88 (1)	7.87 (1)
K	-	-	121 (1)	-	-	-	-	-	-	-
Na	-	-	231 (1)	-	-	-	-	-	-	-
SO4	1180 (1)	1390 (1)	1390 (1)	1340 (1)	1410 (1)	1460 (1)	1600 (1)	1630 (1)	1690 (1)	1700 (1)
TDS	2020 (1)	2000 (1)	2170 (1)	2190 (1)	1790 (1)	2320 (1)	2470 (1)	2620 (1)	2820 (1)	2980 (1)
Zn	0.34 (1)	0.06 (1)	0.05 (1)	0.11 (1)	0.14 (1)	0.07 (1)	0.05 (1)	0.05 (1)	0.03 (1)	0.02 (1)

Note: Parentheses indicates the number of samples

Table 11 Average Evaporation Pond Monthly Concentrations for 2005 in mg/L

	Jan-05	Mar-05	Apr-05	May-05	Jun-05	Jul-05	Aug-05	Oct-05	Nov-05	Dec-05
Ca	296 (1)	296 (2)	317 (1)	310 (1)	337 (1)	343 (1)	360 (1)	387 (1)	389 (1)	379 (2)
Cl	-	123 (2)	84 (1)	76 (1)	98 (1)	135 (1)	110 (1)	95 (1)	104 (1)	92 (2)
EC Field (mS/cm)	3.12 (1)	3.05 (2)	3.26 (1)	3.31 (1)	3.59 (1)	3.53 (1)	-	-	-	-
EC Lab (mS/cm)	2.8 (1)	2.96 (2)	3.41 (1)	3.11 (1)	3.08 (1)	3.47 (1)	4.11 (1)	3.71 (1)	3.74 (1)	3.76 (2)
Fe	0.1 (1)	0.08 (1)	-	-	-	-	-	-	-	-
Pb	0.01 (1)	0 (2)	0 (1)	-	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)	0.03 (2)
Mg	86 (1)	89 (2)	99 (1)	-	117 (1)	115 (1)	122 (1)	130 (1)	134 (1)	134 (2)
Mn	2.15 (1)	2.9 (1)	-	0.02 (1)	-	-	-	-	-	-
pH Field	8.36 (1)	7.38 (2)	7.69 (1)	8.39 (1)	7.62 (1)	8 (1)	-	-	-	-
pH Lab	7.84 (1)	7.88 (2)	7.98 (1)	7.85 (1)	7.76 (1)	7.65 (1)	8.04 (1)	8.23 (1)	8.37 (1)	8.04 (2)
K	116 (1)	128(2)	155 (1)	166 (1)	134 (1)	153 (1)	140 (1)	142 (1)	154 (1)	137 (2)
Na	278 (1)	258 (2)	269 (1)	285 (1)	286 (1)	314 (1)	332 (1)	332 (1)	347 (1)	351 (2)
SO4	1350 (1)	1555 (2)	1610 (1)	1620 (1)	1950 (1)	1870 (1)	-	2130 (1)	2250 (1)	2115 (2)
TDS	2340 (1)	2280 (2)	-	1960 (1)	2890 (1)	2080 (1)	2460 (1)	2200 (1)	3300 (1)	2340 (2)
Zn	0.84 (1)	0.25 (2)	0.33 (1)	-	1.97 (1)	1.9 (1)	1.66 (1)	0.68 (1)	0.31 (1)	0.1 (2)

Note: Parentheses indicates the number of samples

Table 12 Average Evaporation Pond Monthly Concentrations for 2006 in mg/L

	Feb-06	Apr-06	May-06	Jul-06	Aug-06	Oct-06
Ca	256 (2)	358 (1)	356 (1)	381 (2)	396 (1)	394 (1)
Cl	78 (2)	101 (1)	79 (1)	97 (2)	117 (1)	113 (1)
EC Field (mS/cm)	-	-	-	4.15 (2)	-	-
EC Lab (mS/cm)	3.01 (2)	-	3.99 (1)	-	4.02 (1)	4.2 (1)
Fe	-	-	-	-	-	-
Pb	0.04 (2)	0.02 (1)	0.05 (1)	0.01 (2)	0.01 (1)	0.02 (1)
Mg	102 (2)	150 (1)	172 (1)	193 (2)	208 (1)	221 (1)
Mn	-	-	-	-	-	-
pH Field	-	-	-	-	-	-
pH Lab	7.64 (2)	-	7.11 (1)	-	7.67 (1)	7.51 (1)
K	125 (1)	146 (1)	130 (1)	135 (2)	150 (1)	148 (1)
Na	232 (2)	353 (1)	298 (1)	332 (2)	320 (1)	352 (1)
SO4	-	-	2180 (1)	2310 (2)	2440 (1)	-
TDS	1930 (2)	2260 (1)	2200 (1)	3240 (2)	2420 (1)	4110 (1)
Zn	4.7 (2)	11.3 (1)	-	23 (2)	24.1 (1)	24.4 (1)

Note: Parentheses indicates the number of samples

The monthly samples examined in detail suggest rather rapid changes in concentration in some months, albeit the generally increasing trend as evident from Figures 7 and 8. For example in August to November of 2000, the concentrations of Mg range between 25 and 29 mg/l, but in December only 11 mg/l are reported. A similar reduction is noted for sulphate, TDS and Zn. On the other hand for the year 2001, reductions are not evident but a continual increase occurs starting from the December 2000 concentration and the highest value is reported in December 2001 with 26 mg /l of Mg. However

sulphate increased rapidly in this year from 392 mg/l in February 2001 similar to the December 2000 value, to 1394 mg/L in March 2001. Then the concentration dropped again to the same concentration range as reported previously by December 2001.

For 2002 and 2003, Mg increases gradually from the December 2001 value of 26 mg/l to 69 mg/l in October 2003, only to drop to 0.5 mg/l in November 2003 and 36.6 mg/L in December 2003. It increases to 77 mg/l in May 2004 after which time no further Mg concentrations are reported. By January 2005 the concentrations of Mg have increased to 86 mg /l and climb by the end of the year to 133 mg/l in December 2005 only to drop back to 101 mg/l in February 2006, thereafter steadily increasing until the end of the available data record until the month October 2006 with 221 mg/l. Generally the Mg concentration changes are associated with those of sulphate. In February 2007 the concentrations of Mg had further increased from the October 2006 value to 250 mg/l.

The cause of these differences could be multifold and speculations are not warranted at this time. Given that this large water body is represented by one single station on the shores ('Chara Trials' location on Figure 10) inside the dam close to Coglán creek (Location 3, Figure 10), but the tailings decant discharge tower is located at the far eastern side, fluctuations in concentrations could be related to run off but it is unlikely that they are connected to the input from the tailings area.

It would be suspected that during the rainy season, the tailings release evaporates formed during the dry season, but with the present data set, differences between the seasons are not realistically definable. The ideal point of control of salt releases to Evaporation Pond would clearly be the tailings area and the Decant pond, rather than in Evaporation Pond.

A brief examination of the pattern of the TSS concentration might reveal some trends as it could be expected that the monsoon rains carry particulates into Evaporation Pond and those may lead to the changes in elements, if they do not settle out in the centre of the water body.

In Figure 9, the available TSS concentrations are plotted from the year 2000 to October 2006 along with the concentrations of Zn filtered and total. No obvious relationship exists between Zinc potentially associated with tailings particulates. A slight seasonality of TSS is evident in increases with a January- February high of about 10 mg/l followed by values close to zero in the dry season, mid year.

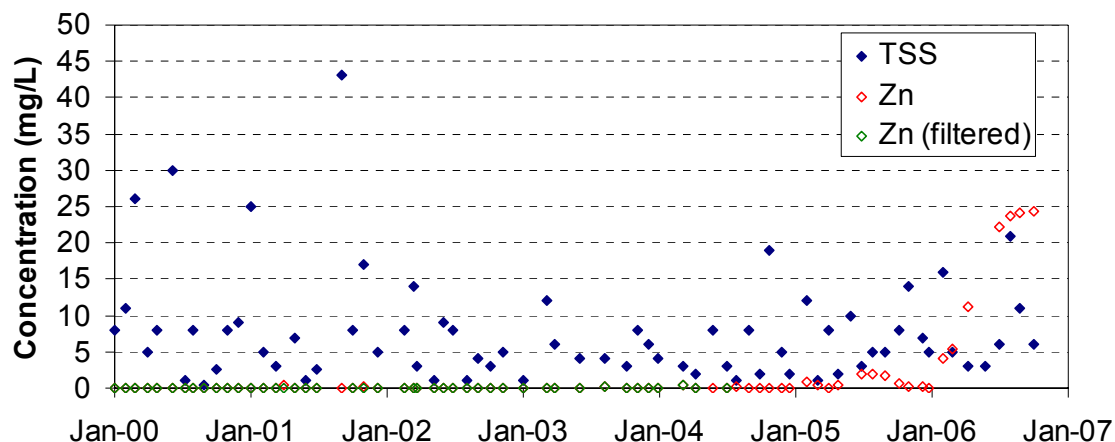


Figure 9 TSS and zinc filtered and total concentrations with time

3.2 Field investigation February 2007

3.2.1 General observations

Three relevant sets of observations emerging from this truly brief snap shot assessment (1.5 days on the lake) of the large water body are:

- Indications of chemical stratification at depth of 6m appear to occur
- Most inlets or bays which surround the pond which are narrow and shallow are ecologically very productive. This is likely due to nutrient input and/or decaying, flooded vegetation.
- A large thriving *Potamogeton spp* was recovered from the bottom of Loc 13 at a depth of 4m (Plate 4). Based on our experience, the presence of macrophytes at single locations within a water body, occurs at upwelling water (“pop ups”) often found adjacent to tailings dams and their ponds. In this case it might be Coglán Creek feeding the pop ups, presumably associated with a change in the water quality, supporting growth of rooted macrophytes. Preliminary assessments of the old flow path of Coglán (see the 1972 overlay map in Tasking document Appendix 3) seems to correspond with areas colonized by these macrophytes. Rooted macrophytes are a mixed blessing as the roots mobilize contaminants from the sediment. During the investigations of the sediments, no living macrophytic growth was noted in the deeper portions of the pond, with this one striking exception, close to the main tailings dam.



Plate 4 Striving *Potamogeton spp* from Evaporation Pond

3.2.2 Sampling site description and locations

In Table 13 the sampling locations and a brief description are given. In Figure 10 the approximate locations have been placed onto an aerial photograph of the Evaporation Pond including the Tailings area and the Decant pond. Green numbers show the surface distribution of Ca determined in the samples collected during the field investigation, displaying the differences of the fresh water to those in Evaporation Pond. It does highlight that indeed run-off water or seepage water entering the pond would contribute for some dilution. The southern drainage area (outlined in the map with a red line) may indeed be supportive of the extensive ecology in the inlet bays on this shore. The GPS coordinates were recorded (Appendix 4) with a hand held instrument.

Table 13 Samples taken and site description (numbers correspond to Map)

Sample Location	Description	Water	Sediment	Algae
1 -2	Seiche Bay "Fresh" shallow	X		
4- 5	Fresh water outside tailings	X		
6	Pond water on tailings.	X		
7 -8	Lead conc. ponds	X		
9	Inlet north shore shallow	X		X
10	In open water outside island, 3m deep	X	X	
11 - 12	Outside/inside north inlet shallow (foam collected) shallow	X		X
	Location G 6m deep, profile only			
13	Outside tailings dam 4.4m deep	X	X	X
14	Off Tailings Dam A 9m deep	X	X	
15	Between Island and tailings dam , deep 6.5m	X		
16	North Bay A Inlet	X		
17	Wetland south shore (also location H) shallow	X	X	X

Note: The water analysis at Sample Location 14 includes measurements at depths of 0, 6 and 9 meters; shallow is 0.5 m depth

Boojum Sampling Locations – Feb 2007

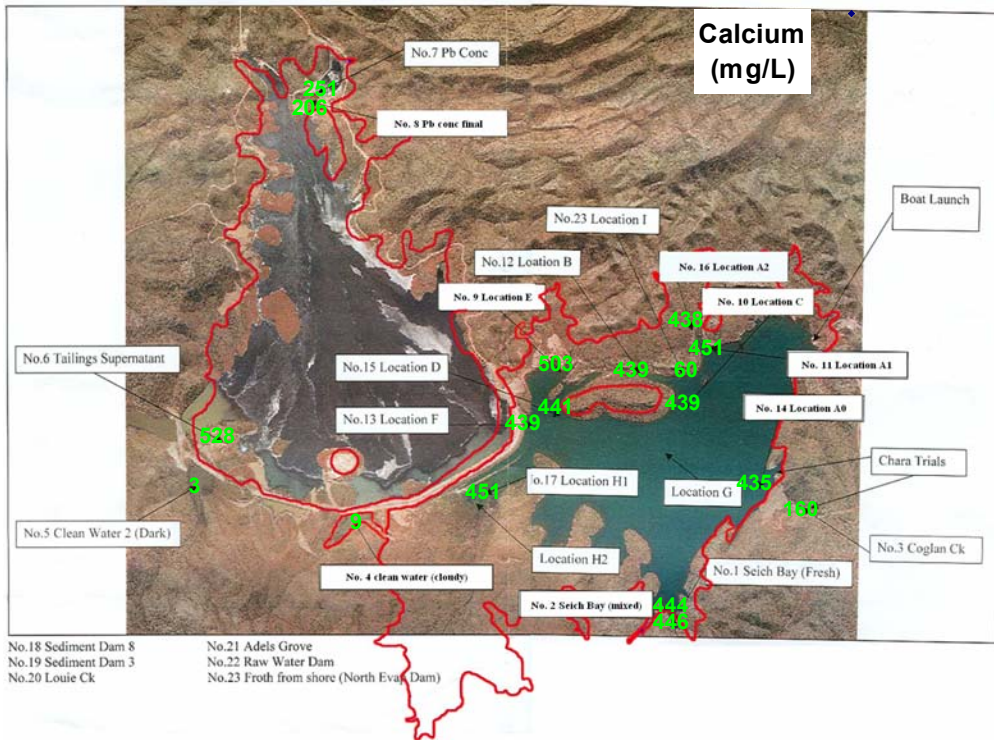


Figure 10 Aerial photograph of the Evaporation Pond, Tailings Area and Decant Pond

The locations were chosen to seek out differences between the open water and the shallow beaches and inlets with extensive growth and decay. Water samples were taken not taken in all locations, since values of pH, Eh, oxygen, conductivity and temperature did not differ from location to location. The instrumentation was rented from Hoskin YSI 650 display with the YSI 6600 sonde.

When depth profiles were carried out in open water and the inlets, the last measurement was with the probe lying on or in the sediment. An Eckman grab sampler was used to recover sediment from the deep locations. The depth measurements are approximate as anchorage was not always the best. Wherever possible, we marked the sampling locations with flagging tape, or otherwise described the location according to some topographical feature and floats were installed where possible to mark the location (Table 13).

All water samples represent grab samples, collected about 20 cm below the surface , except for location 14 where water was collected with an onboard pump to which a poly- ethylene tube was fastened and lowered to a desired depth. Light penetration was measured with a Secchi disk. Generally it was limited to about 1 m in the open water and in the shallow bays the turbidity was higher but often the bottom was visible. Grab samples were taken of some floating mat algae.

The time on Evaporation Pond was limited, impaired by the late arrival of the safety gear. The data collected are but a snapshot.

3.2.3 Depth Profiles

Between the Tailings dam (Location 13) and the dam closing off Coglean Creek (Location 3) the depth profiles are located (location 13, location G in the center of the pond to location 14 just in front of the dam (measurements repeated on the second day).

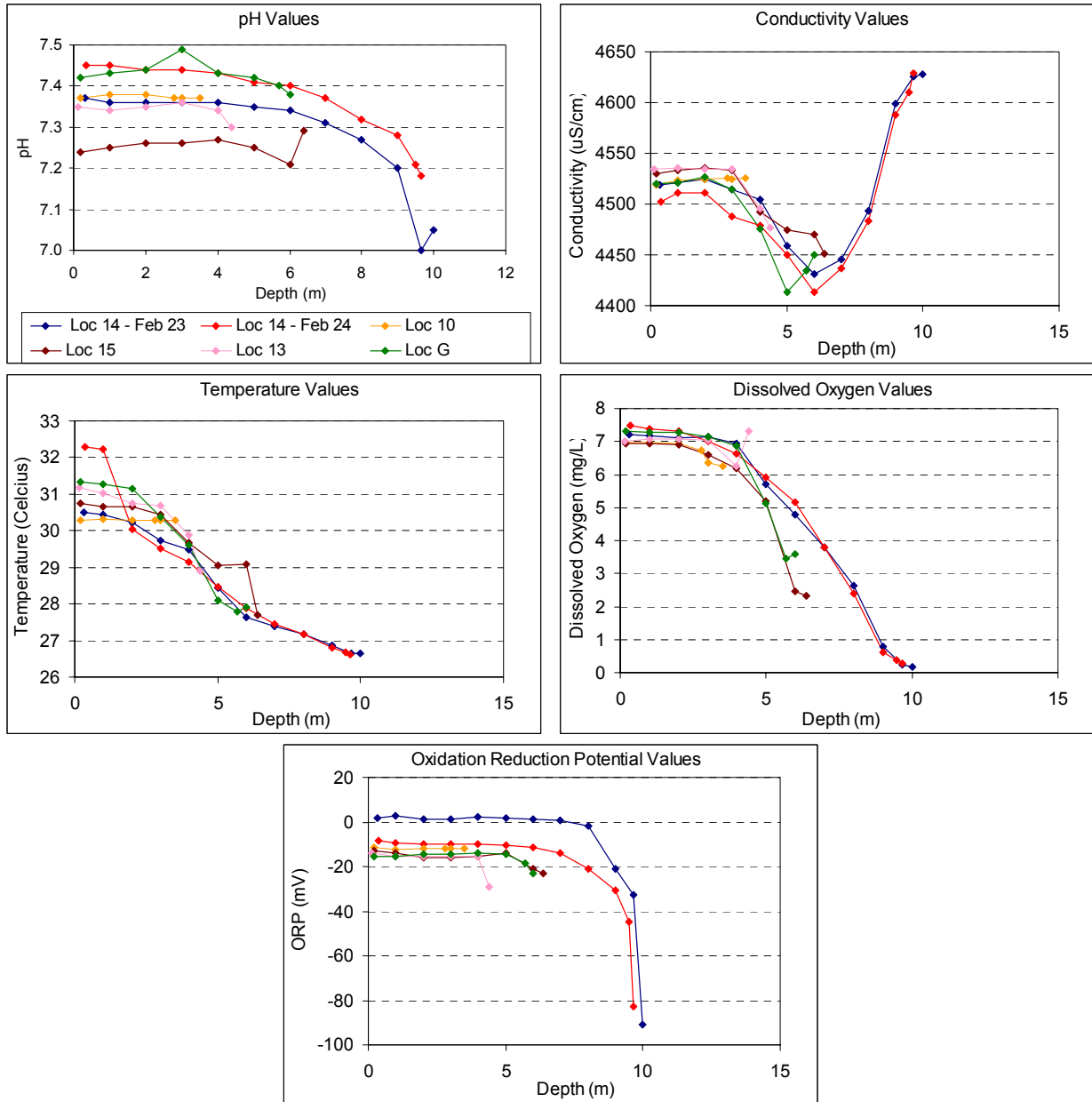


Figure 11 Measurements taken February 2007 from the Evaporation Pond

The depth profiles of the measured parameters are remarkably similar, in that conductivity shows a decrease at around 6m, along with decreasing dissolved oxygen content which occurs more smoothly in the deeper locations than in the less deep locations. The redox values however remain essentially slightly positive up to 6m and then start to decline for the deeper locations at 8m. For location 14 the

profile was taken twice, on the 23rd and the 24th of February. Both profiles show a decrease in pH of about 0.5 units associated with changes in all other parameters. Location 14 is the deepest location measured and signals the beginning of a chemo-cline, i.e. changes in water chemistry.

Water samples have been collected at this station at 3 depths, the surface, and depths of 6m and 9m (Figures 12 and 13).

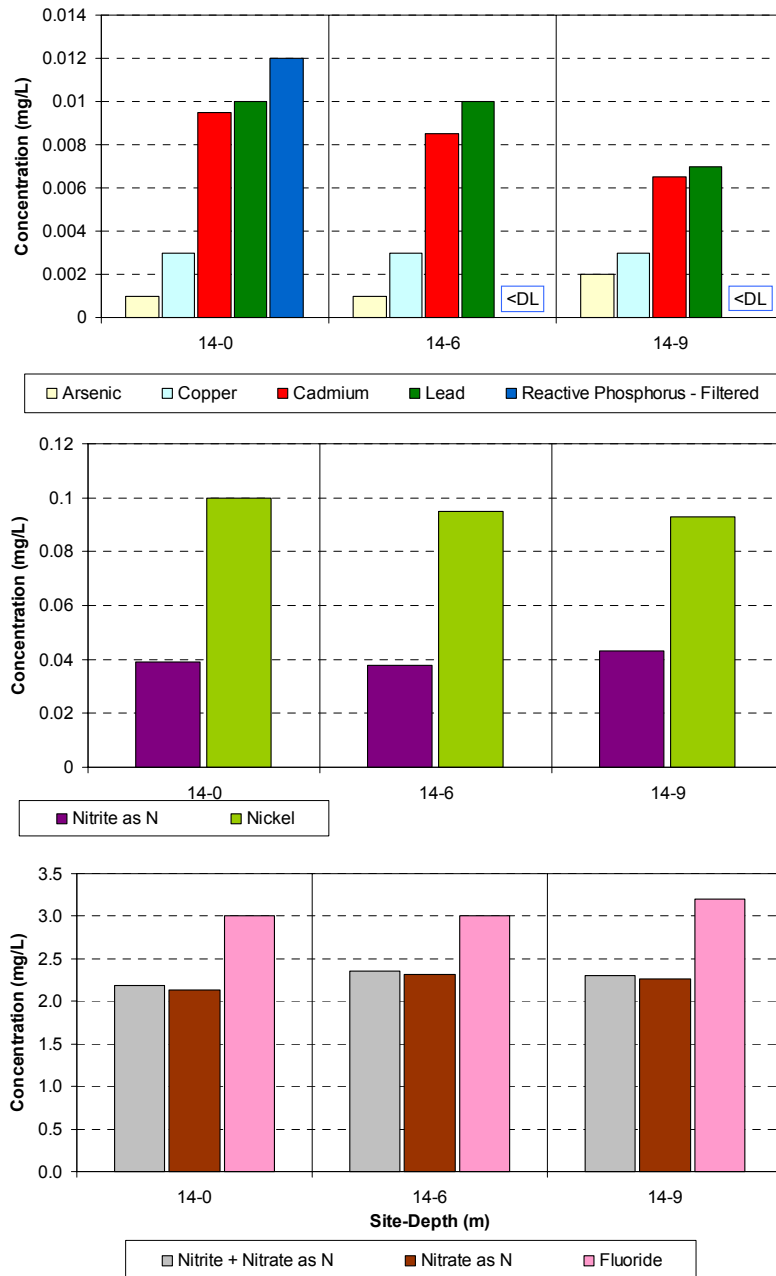


Figure 12 The major elemental concentrations for site 14 surface (0) , 6 and 9 m depths

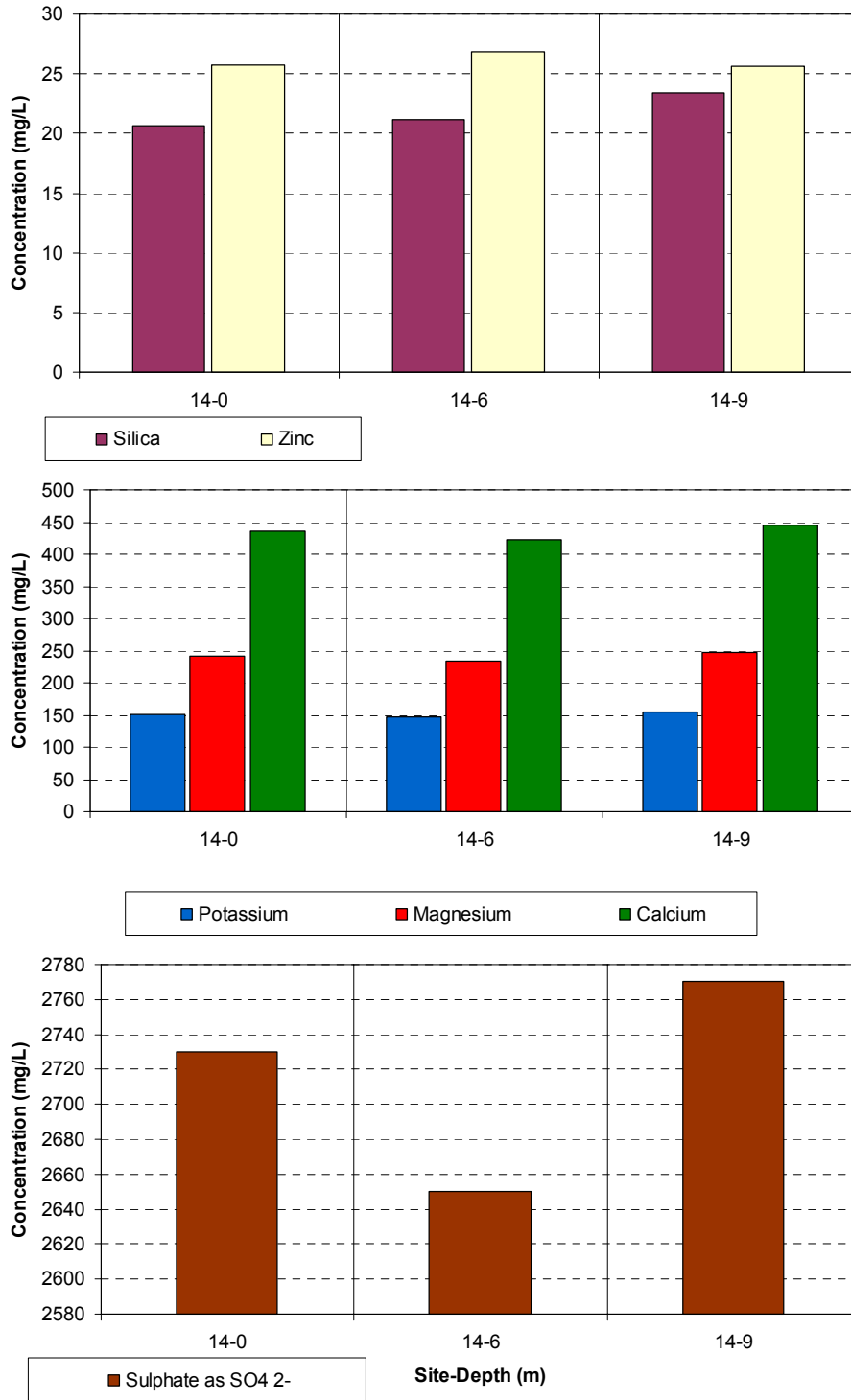


Figure 13 The concentrations of Si, Zn, K, Mg, Ca and SO4 for site 14 surface (0) , 6 and 9 m depths

The concentrations of most elements do not vary with depth, with the dramatic exception of sulphate, which shows a reduction at 6m (the location of the beginning chemo-cline) of about 100 mg/l only to increase to the highest value at 9m.

The speciation of the major elements in Evaporation Pond is given in Figure 14a. In Figure 14b the boomerang shape area is demarking the redox region in which the most common bacteria/ algae are occurring and the different groups of bacteria are designating with color. It is evident that at least some samples lie in the region where sulphate reducers could be active, and these are the measurements which were taken with the probe lying on the sediment. However, it is most likely that denitrifying and blue green algae are dominant (Figure 14b). They indeed form the majority of the floating mats in Evaporation Pond (Plate 5). Sulphate reduction could lead to the noted changes in sulphate with depth at location 14, if water currents facilitate such a difference. Clearly, more depth profile sampling is required, to address the stratification noted at around 6m.



Plate 5 Blue and green algae floating mats

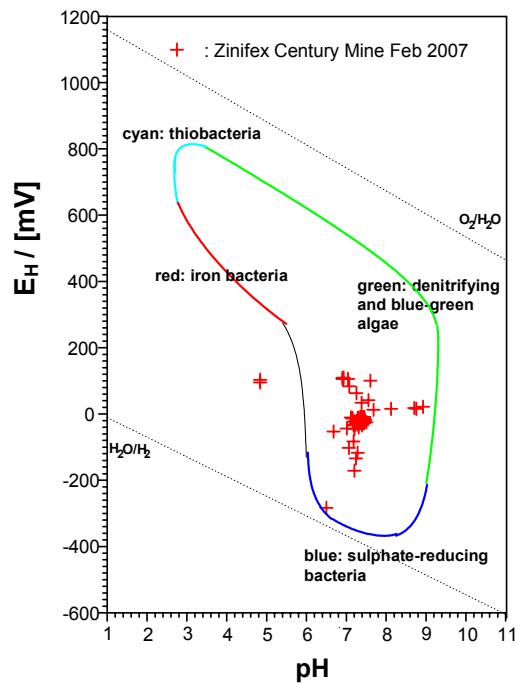
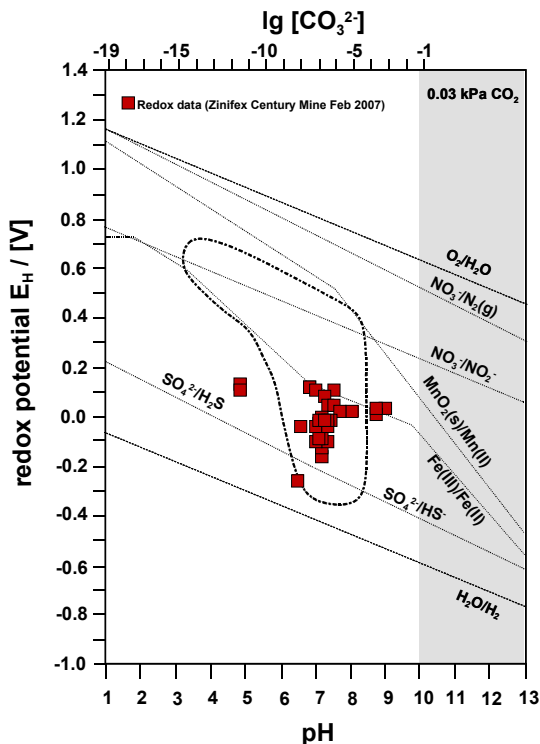


Figure 14a and b Eh-pH plots

In Figure 15 the shallow water profiles up to 1m depth are presented and essentially they show slight differences to the open water, in that the pH is slightly lower, but electrical conductivity, dissolved oxygen as well as the redox values are higher. Chemical differences between the open water and the shallow inlets are slight if the shallow water with the ecology (green font) is compared (Table 14) to that of the open water (red font). This would have been very surprising, since the exchange of water between inlets and the open water is likely intense, with any wind action.

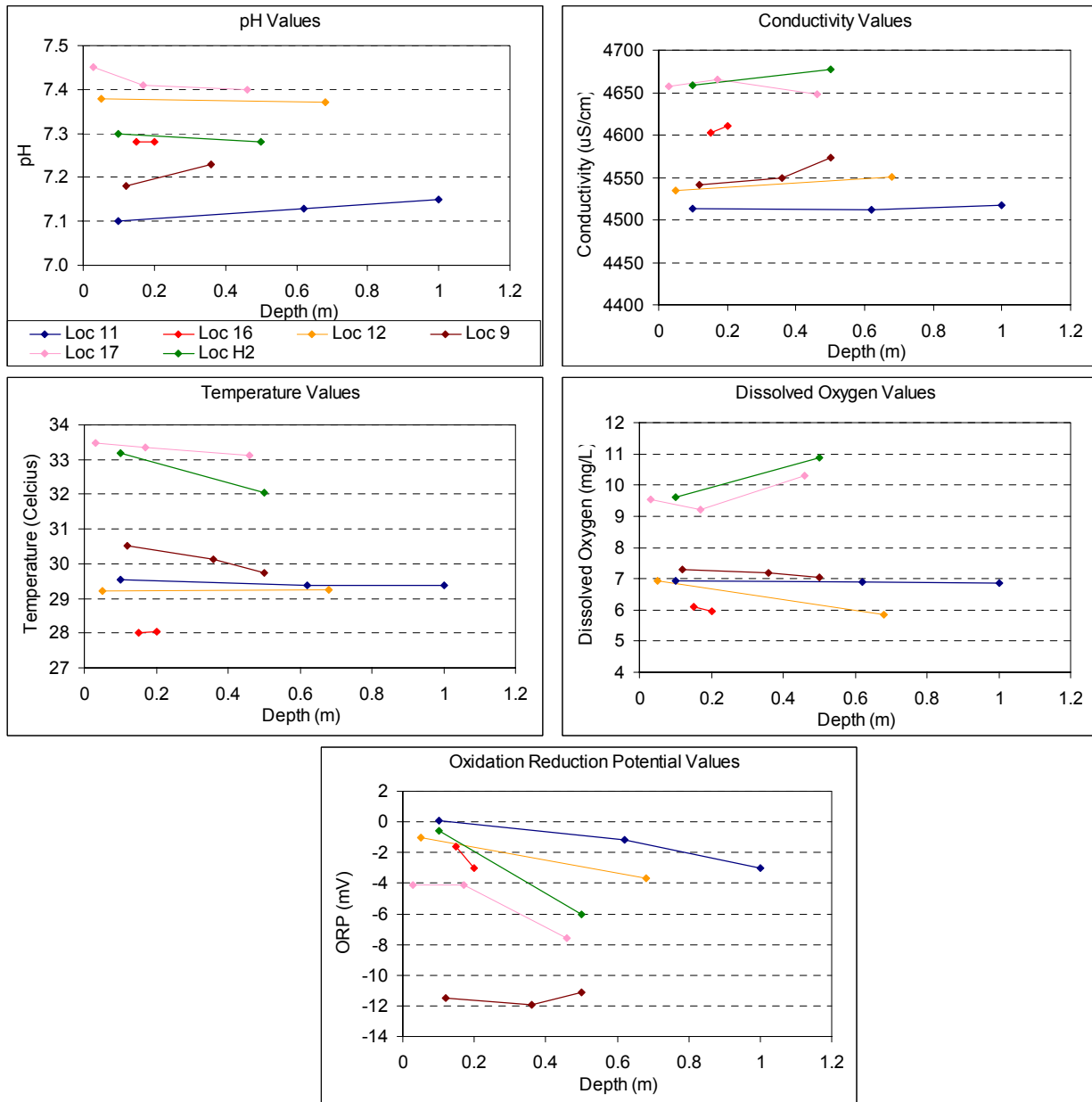


Figure 15 Depth profiles from stations in Evaporation Pond in February 2007

Table 14 Evaporation Pond Site Specific Water Sample Analysis in mgL⁻¹

Location	Cu	Ni	Pb	Zn	K	SO ₄ ⁻²	Mg	Ca	Cd
1	0.006	0.102	0.041	45.6	151	2780	246	446	0.0095
4 clean	0.004	0.002	0.003	0.03	7	46	8	9	<0.0001
5 clean	0.002	0.002	<0.001	0.02	5	4	2	3	0.0001
6 tailings	0.014	0.036	0.245	49.5	179	2770	135	528	0.0371
7 Pb conc	0.005	0.307	4.53	456	46	1870	114	251	0.453
8 Pb conc.	0.017	0.293	3.42	355	48	1720	117	206	0.383
9	0.003	0.1	0.011	26.4	167	3130	274	503	0.0093
10	0.004	0.1	0.011	26	151	2740	243	439	0.0092
11	0.003	0.096	0.009	24	154	2820	249	451	0.0082
12	0.003	0.098	0.01	25.9	153	2740	244	439	0.0093
13	0.03	0.13	0.011	26.6	152	2730	243	439	0.0094
14	0.003	0.1	0.01	25.7	151	2730	241	435	0.0095
15	0.004	0.1	0.011	25.9	153	2760	244	441	0.0093
16	0.003	0.098	0.01	25.8	152	2730	242	438	0.0089
17	0.003	0.093	0.008	21.7	154	2810	250	451	0.0074
Detection Limit	0.001	0.001	0.001	0.005	1	1	1	1	0.0001

3.3 Estimating contaminant loading to Evaporation Pond Water

Mike Sudbury, P. Eng.

3.3.1 Establishing Physical & Chemical Conditions

Recent sampling of the Evaporation Pond has established the current composition of the water but to assess the annual inputs which would need to be counteracted, a prediction of the changes that will occur over time is required. Prediction requires that a dynamic balance be established between all the inputs and outputs to the Evaporation Pond system.

The dominant source of salt (TDS) into the pond is the tailings decant pond overflow. The decant pond overflow volume and composition is in turn determined by the inputs to and the conditions within the tailings storage facility (TSF). The salt (TDS) inputs to the tailings storage facility are the mine run-off water pumped to the TSF, the south west waste rock dump seepage as monitored at V-notch and diverted to the TSF and the concentrator thickened tailings and recycle water bleed. The quantity of thickened tailings and recycle water bleed are in turn influenced by the concentrator operating conditions.

Material balances have been prepared around the concentrator, the tailings storage facility and the Evaporation Pond. The balances provide a basis for first order estimates of current pond inputs and outputs and hence a basis for predicting future conditions. The balances are only as reliable as the data used and provide an opportunity to identify errors and omissions in the data used (critical data gaps) and a ready means of updating predictions to take account of changes in operating conditions.

3.4 Material Balances

A material balance for solids and water around the concentrator was prepared and is summarized in Table 15.

Table 15 Concentrator Solids and Water Balance

Material	Solids t/y	Water t/y Before thickening	Water t/y After thickening	Recycle Water t/y
Ore	5,500,000	10,214,285		
Zinc Concentrate	806,897	3,227,588	379,716	2,847,872
Lead Concentrate	110,606	205,411	43,013	162,398
Tailings	4,582,497	13,747,490	2,490,277	11,279,992
Combined	5,500,000	17,180,489	2,913,006	14,290,262

The fresh water make up is reported to be 8 t/t day metal in concentrate or 4,328,000 t/y. The loss of water with thickener products is 2913,006 t/y. The difference in water quantity of 1,437,723 t/y is assumed to be distributed 1,000,000 t/y bleed-off of recycle water to the tailings storage facility and 437,723 t/y water used to separate concentrates in the pipeline or lost to evaporation in process. The tailings will be further compacted in settling freeing additional water. The volume of water estimated to be retained in the tailings is summarized in Table 16 allowing an estimate of the water leaving to the Evaporation Pond.

Table 16 Water Retained in Tailings

Dry Tailings t	Solid Volume m ³ @ S.G. 3	Volume Water in Tailings Discharged m ³	Water Retained in 40% Void Volume m ³ (x40/60)	Water Released from Tailings m ³ /y
4,582,500	1,527,500	2,913,006	1,018,000	1,894,006

The water and salt inputs to the tailings storage facility are summarized in Table 17.

Table 17 Water and Salt (TDS) Input to the Tailings Storage Facility

Input/Output	Water t/y	TDS mg/L	TDS t/y
Tailings Water Total	2,913,006	1500	4370
Retained in Voids	1,018,000	1500	1527
Tailings Water Released	1,894,006	1500	2843
Recycle Water Released	1,000,000	1500	1500
Pit Seepage	630,720	3,000	1892
Pit Run Off	539,280	1500	601
Rock Pile (V Notch)	161,000	3382	1413
Precipitation 3,300,000 m ² @ 491.2 mm/m ² /y	1,621,000	0	0
Net Input	4,386,006	1881	8249
Evaporation – dry beach 2,670,000 m ² @ 217 mm/y	579,000	0	0
Evaporation - wet beach 315,000m ² @ 2171 mm/y	684,000	0	0
Evaporation – decant pond 315,000 m ² @ 2171 mm/y	684,000	0	0
Total Evaporation	1,947,000	0	0
Decant by Difference	2,439,006	3382	8249

The Evaporation Pond receives input from the decant pond, run-off from the land surrounding the pond and precipitation over the total area of the pond taken as 4,400,000 m². The pond surface loses of water by evaporation and possibly by seepage loss (no estimate located). The balance is shown in Table 18.

Table 18 Evaporation Pond Input-Output Balance

Input/Output	Water t/y	TDS mg/l	TDS t/y
Input from Decant Pond	2,439,006	3382	8249
Area Run Off	475,000	160	76
Precipitation on Pond	1,960,000	0	0
Total Input	2,678,006		8325
Evaporation 1,233,536 m ² @ 2171 mm/y	2,678,006		
Seepage Loss	0	0	0
Total Output	2,678,006	0	0
Balance	0		8325

The relationship between Evaporation Pond volume and surface area was developed from records of gauge levels and pond area as summarized in Table 19.

Table 19 Relationship between Evaporation Pond Level, Volume and Surface Area

Gauge Level m	Pond Maximum Depth m	Pond Volume m ³	Pond Surface Area m ²
149	0	0	0
155	6	10,154,000	1,015,400
158	9	12,000,000	1,200,000
162	13	20,000,000	2,000,000
166	17	28,760,000	2,876,000
168	19	32,000,000	3,200,000
175	26	44,000,000	4,400,000

The Evaporation Pond area of 1,233,536 m² from Table 18 equates to an Evaporation Pond volume of 12,335,360 m³ and a gauge level of 158.1m. Recent data relating gauge level and TDS concentration is lacking. Assuming that the projection in appended Figure 16 is valid for typical conditions and that current conditions are typical then a TDS around 4000 mg/l would be expected. Accepting this figure then a prediction for July 1st 2008 is developed in Table 20.

Table 20 Predicted Loadings for July 1st, 2008

	Pond Volume m ³	TDS mg/L	TDS t
July 1, 2007	12,335,360	4000	49340
Add net addition	0		8235
July 1, 2008	12,335,360	4668	57575

A loading of 57,575 tonnes TDS in seven and a half years implies an average input of 6,773 t/y TDS into the Evaporation Pond. A current pond gauge level and corresponding TDS analysis would be a valuable check on these estimates.

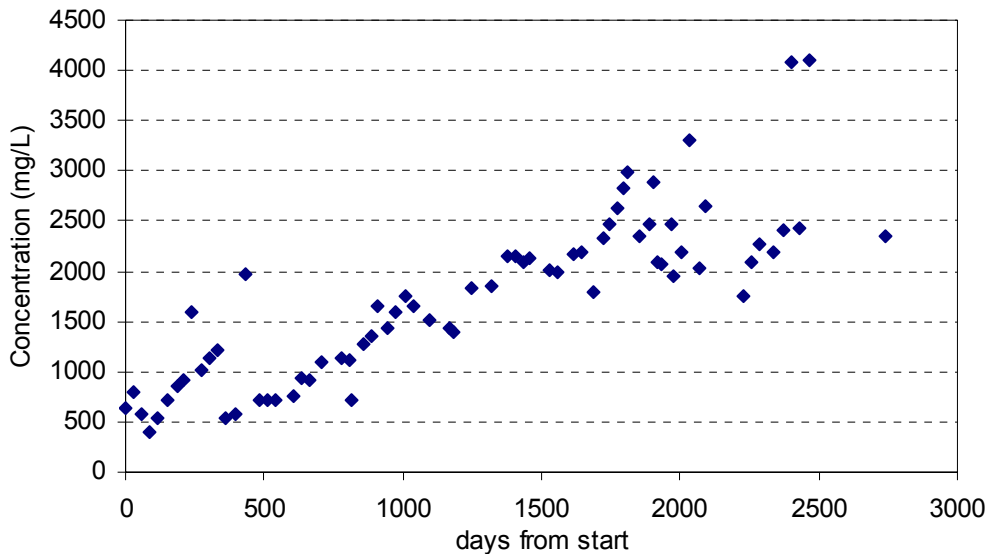


Figure 16 Build up of Salt Concentration in Evaporation Pond over Time (July 1, 2007 = 2735 days)

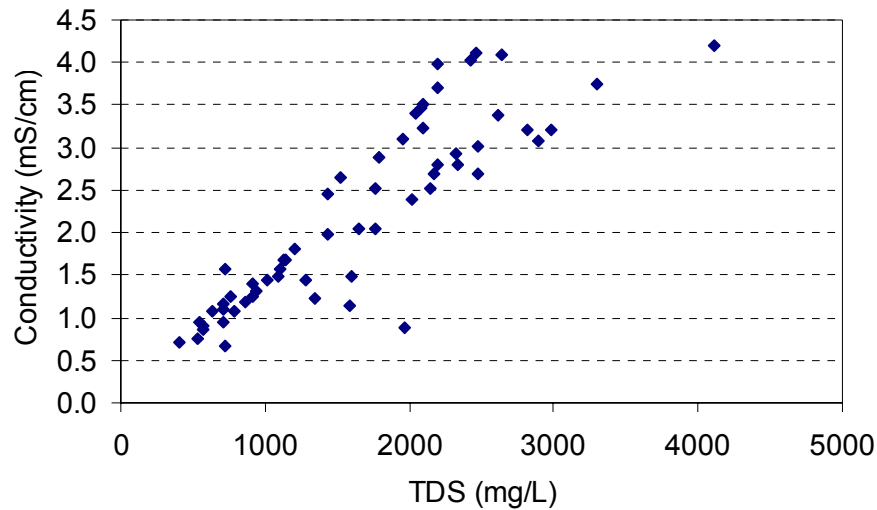


Figure 17 Relationship between TDS and electrical conductivity in the Evaporation Pond

The plot of TDS against electrical conductivity (EC) in Figure 17 indicates a relatively good relationship. It is suggested, that EC is used throughout the operation to survey the entire water pathway throughout the operation. This would assist in a cost effective manner to develop sampling locations for water, which would allow to obtaining relevant water chemistry. This in turn can leading to the identification of sources and sinks of contaminants and hence provide guidance for most effective control locations to contain the contaminants within the waste management area.

3.5 Assumptions and Needed Additions

The balances can serve a number of functions:

1. Provide an approximate quantitative framework for the ecological planning and a preliminary insight into the dynamics of the system
2. Offer a structure that can be readily updated for process changes or revised to take account of new or more precise information.
3. Identify potentially critical knowledge gaps.
4. Encourage the collection or development of information to fill knowledge important gaps.

Additionally information that would permit and improvement of the balance includes:

1. A freshwater balance for the concentrator.
2. The chemical/mineralogical size distribution of tailings elements/minerals.
3. The chemical analysis of the recycle and tailings water.
4. The hydro-geochemical examination of the top meter of the 'dry' tailings (vadose layer) to determine the rate of oxidation of sulphides within that layer and the movement of those sulphides e.g. capillary migration of sulphates to surface.
5. The rate of moisture loss from the 'dry' tailings by capillary migration/diffusion and surface evaporation.

6. The level measurement of the Evaporation Pond surface with simultaneous water sampling to permit the rate of salt build up to be monitored.
7. A check on the accuracy of the relationship between gauge level in the Evaporation Pond and the volume/surface area of the pond.
8. A hydrological (limnological) examination of the Evaporation Pond to establish if the incoming decant pond water remains on surface, sinks to the bottom or mixes readily and freely with the bulk volume.

Other items that would be helpful in improving the balance include:

1. Confirmation of the area of peripheral run-off and the volume and composition of water input from that source.
2. Clarification of the extent of groundwater inflow or seepage outflow from the Evaporation Pond (Golder estimates?)
3. Checking the validity of the pit Wound water and run off flow estimates used for the balances.
4. A review of the water balances around the rock storage areas to evaluate the probably volume and composition of seepage from that source. Ideally this would involve trenching to expose an internal face for examination and sampling.

Footnote: It is suspected that conclusions on the basis of present samples are confounded by lack of homogeneity within and around the pond and the lack of level measurement to permit confident estimates of pond loading.

More frequent Evaporation Pond level measurements would permit pond volume to rainfall changes due to rainfall events and evaporation rates to be estimated.

Routine monitoring of the rates of controlled inputs (tailings, surplus recycle water, V-notch transfer and pit pump operation) and decant pond discharge would also improve estimates.

The determination of rate of sulphate loading increase in the Evaporation Pond may be the simplest way of assess the effectiveness of actions to inhibit sulphide oxidation or of alerting to new, substantial or otherwise unsuspected sources of sulphate

4.0 CONTAMINANT REMOVAL BY MICROBIAL MATS

W.N. Wheeler

Algae, microbes and fungi grow together as “microbial mats”. If conditions are right, these mats grow extensively, altering the geochemistry of the water around them. Within and around the mats, altered chemical conditions lead to precipitation of carbonates of various elements, such as CaCO_3 or CaSO_4 . This process, in simple terms, is called bio-mineralization, which results in the formation of stone-like structures. These structures are not water soluble, unless the chemical conditions around them change from alkaline to acidic. As this bio-mineralization process continues, larger structures called stromatolites or tufa are formed. These structures have been found world-wide and, in some cases are hundreds of millions of years old.

Structures similar to those described in the literature have been found in Dam #3 and in the spray zone of the Mine Water Pond (Plate 6), and are a cyanobacterial-microbial association. In Evaporation Pond the mats grow extensively on the shallow sediments in inlets of the pond, and float due to excessive photosynthetic activity. Those display less bio-mineralization as the Tufa and the coating which is forming on the slopes of Dam #3 (Plate 7). One aspect that the mats all have in common is that they grow attached to surfaces, be it submerged branches (Mimosa bushes?), on the rough concrete culverts in the spray zone of the discharge to the Mine Water Pond, or on the sediment, branches of trees and on decaying vegetation in Evaporation Pond (Plate 8).



Plate 6-8 Tufa like structure in spray zone of mine water pond (6), Coating on edges of Dam #3 (7), Evaporation Pond floating mats, Location 17 (8)

In this section, we utilize the elemental composition of the sampled mats and the organic carbon content to forecast contaminant removal rates. The organic carbon content is converted to biomass and with growth rate information, we can derive estimates of biomass production and the associated removal of the contaminants.

4.1 V-Notch Water – Dam # 3 Treatment

The elemental composition of two samples from V-Notch and Dam #3 are given in Table 21. Sample #2 (*Ulothrix* jelly with white entrustment), which did not dissolve when V-Notch flooded and Sample #3 (tufa-like structure from Dam #3) were considered representative.

The air dried microbial mats (gDW⁻¹) have high concentrations of calcium (10.2 and 12.9%), magnesium (3.3 and 1.6%) and sulphur (11.7 and 12.3%; Table 21). The concentration of zinc is also high in both samples with 2.2% and 1.9%. All other metals are present in lower concentrations.

Table 21 Elemental concentrations in Samples #2 and #3 from V-Notch

Element	Al	Ca	Pb	Mg	Ni	P	K	S	Zn
Sample #2 µg gDW ⁻¹	7420	102000	31	32500	57	250	2700	117000	22100
Sample #3 µg gDW ⁻¹	5910	129000	53	16400	53	67	2100	123000	19000

The treatment capacity of these structures depends on the amount of biomass the microbial mats can generate and in what time frame. Primary production estimates of microbial mats from the Mediterranean (Urmeneta et al. 1998), which were derived from photosynthesis measurements performed throughout the year, were used to estimate biomass production. The values determined were 234 and 208 g carbon m⁻² a⁻¹. These values of carbon have to be converted to dry weight.

In 2007, we analyzed the microbial mats to determine their TIC, TOC and LOI. TIC is the total inorganic carbon concentration, TOC is the total organic carbon concentration, and LOI is loss of mass after ashing the samples at 400 °C. The LOI is equivalent to the “ash free dry weight” that is used as the basis of productivity estimates in much of the scientific literature. Both TIC and TOC are usually vaporized upon ashing. The remaining ash is composed primarily of solid elemental mass.

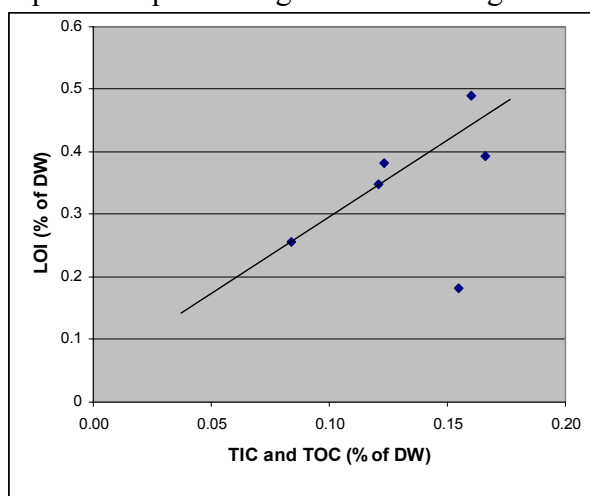


Figure 18 Relationship between LOI and TIC + TOC for microbial mat samples from Evaporation Pond

In Figure 18 the values of LOI are plotted against TIC and TOC. There is a high degree of correlation between them which allows us to extrapolate TIC and TOC to ash free dry weights. The only outlier is the sample from the Raw Water Dam (#22), which is less mineralized than the other mats. Next, we need to convert the dry mass to a production rate. Since we don't have any information from the Zinifex mine site, we have to look elsewhere. Primary production estimates were taken from studies produced from similar locations. Detailed calculations are given in the Appendix 2. These are used to estimate the elemental removal rates presented in Table 23.

Table 22 The amount of carbon in the AFDW of microbial mats from Evaporation Pond

Sample #	TOC+TIC g gDW ⁻¹	AFWD g gDW ⁻¹	gC gAFWD ⁻¹
9 Shore	0.17	0.393	2.4
9 Floating mat	0.16	0.491	3.1
11 Near shore	0.12	0.348	2.9
11 Shore	0.12	0.381	3.1
17 Floating mat	0.08	0.257	3.1
22	0.16	0.182	1.2

Note: TIC and TOC were not determined for V-notch so Evaporation Pond values were substituted

Table 23 Removal estimates for Samples #2 and #3 V-notch – Dam # 3

	Avg Conc. of Samples 2 and 3 mg kg ⁻¹	Removal t ha ⁻¹ ds ⁻¹	Loadings 2004- 2005 t ws ⁻¹	Area Needed (ha)
Cadmium	6.2	0.000055	0.01	183
Calcium	115500	1.02	79	77
Lead	42	0.000374	0	8
Magnesium	24450	0.226	172	791
Nickel	55	0.000489	0	204
Potassium	2400	0.0213	4	178
Sulfur	120000	1.06	297	278
Zinc	20550	0.183	9	51

Note: ds = dry season; ws = wet season

Substrate area is different from the pond area, in that artificial substrates placed in the pond will have a higher surface area than just the pond surface. For example we might be able to place a substrate that would have 5 square meters of surface area in one square meter of pond.

Our estimates, detailed in Table 22, suggest that just over 1 tonne of calcium for each hectare of substrate surface area would be removed. For magnesium, we could remove 0.23 tonnes per hectare, and we might also be able to remove 1.1 tonnes of sulphur.

We can also estimate the substrate area needed to completely remove the contaminants. For this, we divide the tonnes per hectare per season that the microbial mats could remove by the contaminant loading contained in Dam #3. For contaminant loadings, we have taken the interpolated monthly loadings from December and January (04/5 and 05/6) presented in Tables 2 and 3. These estimates suggest that 77 ha of microbial mats would be needed to remove all of the calcium (Table 23), while half of the annual load would be removed during the dry season with half of the surface area. Site specific removal rates will be determined with the pilot tests.

Magnesium removal appears to be a challenge, as it is not as well bio-mineralized as calcium. Not only is it not removed well by the microbial mats, but the loading is large. To remove all of the loading during the dry season we estimate it would take nearly 800 ha of microbial mat structures. Partial removals would be expected to be proportional. Since we do not need to remove all the magnesium, a much smaller surface area would be required. A pilot-scale test system would provide better estimates of growth rates and allow us to test different baffle systems to optimize the removal of magnesium (and other contaminants).

4.2 Evaporation Pond

In February 2007, mats were collected from Evaporation Pond which contained lower elemental concentrations than those samples obtained from V-Notch (Table 24). Two samples were collected from station #9, one on the surface and one from a floating microbial mat. Two samples were taken from station #11, one near shore and one on shore. Samples were also taken from stations 13 and 17 (see Table 13 and Figure 10 for descriptions)

Table 24 Evaporation Pond microbial mat and sediment Analyses

Site	Substrate	Cu	Cd	Ni	Pb	Mg	Ca	K	S	Zn
9 surface	Microb. mat	20	41	96	297	3300	7890	9200	10400	73500
9 Float mat	Microb. mat	20	37	92	331	3590	8760	10300	11600	70100
11 Shore	Microb. mat	23	67	116	551	2420	3830	4300	6310	176000
11 NearShore	Microb. mat	18	44	111	362	8580	18000	8200	31400	140000
13	Microb. mat	45	149	36	282	3720	10200	43500	18200	20200
17	Microb. mat	11	24	76	158	4330	33100	10300	34900	78800
10	Sediment	30	47	72	510	5100	35900	12200	32000	43200
13	Sediment	40	31	34	740	4300	3950	16600	20800	15800
14	Sediment	35	42	76	630	5500	4600	17700	27200	35600
17	Sediment	20	4	19	170	3000	3610	10600	9200	6420
Det Lim (mgL ⁻¹)		0.2	0.05	0.1	0.1	1	0.5	20	1	0.2

The same extrapolations that were made for Dam #3 were also made for Evaporation Pond. The concentration of contaminants found in Evaporation Pond are also multiplied by the primary production of microbial mats (again from the Mediterranean), to provide estimates of contaminant removal per hectare of substrate (Table 25).

In Evaporation Pond, the concentrations of contaminants are increasing annually as discussed in Section 3. As can be calculated from Table 25, we would need many times the area of Evaporation Pond to remove all of the contaminants over the dry season. However, combining the promotion of microbial mat growth in Evaporation Pond with some contaminant control at the source, and enhancements to the organic sediments, may allow us to significantly improve the water quality. Pilot-scale testing is required to provide more accurate scale-up figures.

Because the microbial mats at V-Notch and Dam #3 contain higher levels of contaminants in and around the biomass, Evaporation Pond mats are not as efficient at contaminant removal. For example, microbial mats in V-Notch were able to sequester 1.1 tonnes per hectare per season, while those mats in the Evaporation Pond were only able to sequester 0.5 tonnes per hectare per season (compare Tables 23 and 25).

Table 25 Evaporation Pond average concentration and removal rates

	mg kg ⁻¹	Removal t ha ⁻¹ ds ⁻¹
Cd	45.0	0.000318
Ca	18310	0.511
Cu	17.3	0.000149
Pb	357	0.00255
Mg	5083	0.0461
Ni	101	0.000741
K	7600	0.0639
S	120000	142716
Zinc	131600	804144

In the discussion below, the nutrient status is evaluated of the algal mats in both locations, to assess if growth could be promoted with effective addition of limiting nutrients.

4.3 Assessment of limiting growth factors

Nitrogen and phosphorus are, respectively, the fourth and sixteenth most abundant elements on earth. They are present in rocks and soils with a mass ratio (N:P) estimated to be between 0.01 and 0.8 (Vinogradov 1962), therefore generally there is more P in soils than N. For aquatic biota, the ratio of these elements has been determined to be between 3 and 20, suggesting nitrogen is required in higher concentrations than phosphorus.

Nitrogen can be present in several forms. The most oxidized form is nitrate (NO₃⁻), followed by nitrite (NO₂⁻), ammonium (NH₄⁺) and then amino acids. In most natural water bodies, NO₂⁻ is not common, as plant and microbial enzymes break this down quickly to ammonium.

Organic nitrogen and ammonium can be measured by Kjeldahl digestion (Total Kjeldahl Nitrogen: TKN), which breaks down the organics to ammonium. The total amount of ammonium is then measured. TKN plus nitrate plus nitrite give us the total concentration of nitrogen available to the microbial mats.

Algae and microbes can actively take up nitrate and store it for later reduction to ammonium and amino acids (Wheeler 1984). Although in many species, nitrate is immediately reduced to ammonium and not stored. In the case of the microbial mats from the Evaporation Pond, nitrate + nitrate was not measured, but we did determine TKN.

Phytoplankton have an average N:P ratio of 7.2 (Harris 1986), a value known as the Redfield ratio, representing healthy, growing populations. Algae that are P deficient have higher mass N:P ratios (Healey 1975). Those that are more N deficient have N:P ratios of 7 or lower (Vallentyne 1974). These rules have been well established to assess the nutrient status of aquatic biota general and, at the same time, give an indication of which of the two essential nutrients might be the most limiting to growth. Microbial mats and phytoplankton are not dissimilar with respect to their nitrogen and phosphorus metabolisms, so we expect that our mats will behave in a similar fashion.

While the N:P ratios do not give us the entire picture of a mat's health status, we have found that these ratios can be useful indicators. We can use the ratios to assist us choosing the proper fertilizer to optimize growth, which sequesters contaminants and improves water quality. Nutrients do not need to be added continuously, as much of the N and P are recycled in the sediments. We need only to “jump start” the system. Our objective here is to give the ecosystem an initial shot at the beginning of the growth season, where a growth spike would be a potentially great benefit.

4.3.1 Redfield ratio estimates of aquatic biomass collected

TKN and P in microbial mats in Evaporation Pond were measured by two independent laboratories, Levay and SRC on sub-samples of microbial mats. Table 26 shows a comparison between results from the sub-samples. The data from the SRC lab are consistent and within the range expected for biological materials and those ratios based on the Levay analyses are outside the normal biological range, suggesting that they may be inaccurate, likely due to methodological differences which would need to be discussed for clarification. We have used the values of SRC, since these values proved reliable in other Boojum systems constructed in the past.

Table 26 Comparison between SRC and Levay nitrogen and phosphorus data

Sample #	SRC N:P			Levay N:P		
	SRC TKN	SRC P	N:P	Levay TKN	Levay P	N:P
#9 Surface	9560	540	17.7	x	x	
#9 Floating Mat	14300	660	21.7	x	x	
#11 Shore	6630	320	20.7	1350	260	5.2
#11 Near Shore	9780	370	26.4	12200	200	61.0
#17	6180	340	18.2	1250	325	3.8
#22	3020	160	18.9	6120	180	47.8

x = sample not supplied to Levay laboratories

Table 27 shows the algal concentrations of TKN, P and their mass ratio for algae growing in the Evaporation Pond. The N:P ratio between 17 and 26 suggests that the algae from the Evaporation Pond are phosphorus limited. Adding the concentrations of NO₃+NO₂ would only make the ratios higher.

Table 27 N:P Mass ratios for mats and sediments in the Evaporation Pond

Sample #	TKN	P	TKN/P
Microbial Mats			
9 Surface	9560	540	17.7
9 Floating Mat	14300	660	21.7
11Near Shore	9780	370	26.4
11Shore	6630	320	20.7
17	6180	340	18.2
22	3020	180	16.8
Sediment Samples			
10	4140	800	5.2
13	3130	340	9.2
14	3480	350	9.9
17	8490	270	31.4

We currently do not have many nutrient data points for Dam #3 algae. However, V-Notch algae were analyzed for P. Mat samples #1, 2, and 3 contained 1800, 250 and 67 $\mu\text{g g}^{-1}$ of P. While these values are not as consistent as the P values for Evaporation Pond mats, Sample #1 (*Ulothrix*) contained a significant amount of P, which reflects the absence of mineralization which takes place as the *Ulothrix* turns into the jelly mass collected with the white encrustment and the tufa structure. The leather-like sample, likely also an early form of tufa, collected at the mine water pond had a Redfield ratio of 19 containing 3020 $\mu\text{g g}^{-1}$ of N and 160 $\mu\text{g g}^{-1}$ of TKN.

Table 28 C:N Mass Ratios in algae and sediments

Sample #	TOC	TIC	TOC/TKN
Microbial Mats			
9 Surface	10.50	6.1	11.0
9 Free mat	9.86	6.14	6.9
11Near shore	4.53	7.57	4.6
11Shore	5.05	7.25	7.6
17	3.97	4.42	6.4
22	9.97	5.53	33.0
Sediments			
10	2.46	4.41	5.9
13	2.12	1.87	6.8
14	1.78	1.51	5.1
17	1.86	1.65	2.2

The carbon content of organic matter is, for the most part, an order of magnitude greater than that of organic nitrogen. The proteolytic metabolism of fungi and microbes removes proportionately more nitrogen than carbon, as organic matter decomposes in the sediments. Thus, sediments with decomposing plant material usually have higher C:N ratios than living organic matter. In the case of the microbial mat samples shown above (Table 27), C:N ratios are all 11 or less, with the exception of the Sample #22 (Raw Water algae). The high C:N ratio for this sample suggests that it is nitrogen limited.

Sample 22 has the highest lowest N:P ratio (Table 26) and the lowest C:N ratio (Table 28). The TIC and TOC numbers for this sample are not different from the others, so the answer must lie with the P or N. High C:N ratios in plants suggest that they are nitrogen limited, as the common ratio for well-fed algae is below 10, and nitrogen becomes a critical nutrient at C:N ratios between 10 and 15 (Hanisak 1979). Sample 22 also has very low concentration of phosphorus. This microbial mat sample is more indicative of natural populations which are both N and P stressed.

4.3.2 The Water – Sediment Interface and nutrients

The sediments at some of the Evaporation Pond stations were also sampled, dried and analyzed for chemical make up. The low TKN:P ratios for the sediments (with the exception of sample #17) suggest either that they have a high phosphorus content, or a low nitrogen content (Table 27). Organic material in sediments is decomposed by microbes that preferentially remove nitrogen and phosphorus, leaving more organic carbon than nitrogen in the sediments. This is borne out by the Evaporation Pond sediment samples analyzed in Table 27. The C:TKN ratios in Table 28 are also low for biological samples, again confirming that the nitrogen is probably limiting in the sediments as well.

The N:P mass ratios of the water in Evaporation Pond show a different story (Table 29). Here the ratio is very high – too high for natural waters, which have a ratio around 10. As we have frequently noted, nitrate and ammonium are elevated, often due to the usage of ammonium nitrate as explosives in the mining operation. This is especially true for the sample taken from stations 17 and 18 (Table 28). Sample #18 is not from the Evaporation Pond, but rather from Dam #8. But, both 17 and 18 show similar trends with regard to nitrogen. The P concentrations are at or below detection limit, so the ratios are probably higher.

Table 29 Evaporation Pond and Dam #8 (Sample #18) nitrogen and phosphorus concentrations and their mass ratios in mg L⁻¹

	Sample #	NO ₃ +NO ₂	TKN	Total N	P	N:P
24-Feb-07	14	2.18	2.6	4.31	0.01	431
24-Feb-07	15	2.13	2.4	4	0.01	400
24-Feb-07	17	1.87	2.8	107	0.01	10687
24-Feb-07	18	105	0.1	105	0.02	5250

At Dam #3, the water was sampled for nitrate + nitrite, but only one water sample was analyzed for TKN and P (2/24/2006; Boojum Field Sample #30). The nitrate + nitrite concentrations at Dam #3 are significantly higher than those from stations in Evaporation Pond, with the exception of Station 18. Since the P concentration was near the detection limit, we can assume that the water N:P ratio was greater than 14.5. This also confirms that P is limiting in the Dam #3 and Evaporation Ponds.

4.4 Fertilizer applications

From the preliminary data presented above, it is obvious that we need to add phosphorus to Dam #3 and the Evaporation Pond. The addition of just phosphorus to the ponds at the Century Mine is difficult, as most of the phosphate fertilizers also contain other elements. There are two types of phosphate fertilizer that are commonly found in agricultural supply stores, Superphosphate and ammonium phosphate.

Superphosphate contains only about 8% P, but has 20% calcium and 11% sulfur. The mixture, in an alkaline environment, will form insoluble calcium phosphate. But, the extent of the precipitation will depend on other geochemical factors (see Appendix 3). In Appendix 3 we discuss the solubilities of various fertilizers in Evaporation Pond water. This might help with the excess calcium in the water, but would make the fertilizer less available for use by plants. The sulfur and calcium would also add to our problem, rather than detract from it.

Ammonium phosphate fertilizer has very little sulfur and no calcium. It comes as a liquid, which from what can be extracted from the limited literature, is better than granular or powdered products, as more P might be available to the algae in the water than to microbes in the sediment. We still run the risk of having the P and Ca precipitate. Ammonium phosphate comes as mono-ammonium phosphate and di-ammonium phosphate. MAP (mono-ammonium phosphate= $[\text{NH}_4\text{H}_2\text{PO}_4]$) is 27%P. DAP (Di-ammonium phosphate $[(\text{NH}_4)_2\text{HPO}_4]$) has more ammonium for the same amount of phosphate.

Geochemical modelling results indicate that at any small additions of ammonium phosphate, in both waters to be fertilized becomes super-saturated with hydroxyapatite, hence may precipitate out of the water and settle to the sediments (Appendix). Additions of fertilizer have been modeled for both dry and wet season concentrations, but precipitation probability of the added phosphate did not change appreciably. If we use super-phosphate, the addition of Ca and sulfate would slightly shift the system towards gypsum super-saturation. The estimates obtained by geochemical modeling indicate, however, that the overall amount of Ca and sulfate added is marginal compared to the amount of these elements already present in V-Notch. Thus, the decision on the P-containing material can be based upon the total costs.

Given the complexity of losing the P as a precipitate to the sediment, we require some pilot-scale testing. Limno-corrals (a column of water that is isolated from the lake water but connected to the sediment using strong plastic) are an ideal way to test these fertilizers on relatively large bodies of water. If the limno-corral tests are positive we would enclose or section off some of the bays in the Evaporation Pond and Dam #3. These scale-up procedures will give us the engineering and biological data necessary to optimize the biomineralization of calcium, magnesium, sulphate and zinc in the Zinifex waste water systems.

5.0 CONCLUSIONS

The monitoring data examined reveal a complex weathering system, not typical of classical acid generation. The waste waters are free of iron, high in pH, rich in sulphate, Mg and Ca and contain moderate concentrations of Zn. The seasonal release of weathering products from the SWRD is pronounced but could not be related to the waste rock dump, as the hydro-geological conditions are unclear.

Estimates of a material balance for Evaporation Pond have been derived, but need refinement which would assist in locate control points for contaminants prior to reaching Evaporation Pond, for example in Decant pond on the tailings. The summary of the monitoring data in general reveal data gaps, which require a concerted effort to identify sources and sinks of salts within the mine waste management area and the milling operation.

The main objectives of this feasibility study were to develop a pilot test system for the treatment of seepage from Dam #3 and Dam #8 to remove Ca, S and Mg and to suggest water quality improvements which would reduce the salt concentrations. Bio-mineralization estimates derived based on the few site specific samples and literature growth rates support the conclusion that this avenue of treatment of effluents shows promise.

Smaller scale pilot tests should precede large scale pilot tests. Suitable growth substrates have to be found, site specific growth of the microbial mats have to be defined. Water treatment in Dam # 3 can only be envisaged, if the dam receives water throughout the dry season, to prevent complete drying out of the dam. For Dam #8 the water chemistry and the flow regime should be determined. The installation of floating cattail rafts, the accumulations of biomass on the suspended roots need to be quantified through sampling and analysis for their elemental content.

Our first cut estimates of contaminant loading for V-notch and Evaporation Pond are insufficient to provide details for the site specific pilot tests. The cost and commitment required to implement the pilot testing (one year) and to carry out the observations, measurement sampling and analytical work for at least two to three years are not warranted given the number of questions regarding the monitoring data, the ecosystem and the operational decisions of water management of the site (such as the addition of the Bulk waste rock seepage addition to Dam # 3, which might alter the chemical conditions).

The ultimate objective of the work has not been discussed in any detail. It is assumed to be the inhibition salt dissolution from waste rock and tailings and to undertake sufficient treatment of Zinifex mine and mill effluents so that standards for water discharge, agricultural use, or recycling to the concentrator would be met. This preliminary insight into the chemical and ecological system of the Zinifex mine waste management area allows us to conclude that the conditions hold a unique potential to utilize bio-mineralization as part of the overall needed salt management.

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