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POGO Project

Documentation Series for Permitting Approval
February 2002

4 Water Management Plan

June 2002 Supplement

TECK-POGO INC.

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FROM:	Karl L. Hanneman		
RE:	Pogo June 2002 Supplement to February 2002 Water Management Plan	PAGES:	1

Enclosed please find a copy of a supplement to the Pogo February 2002 Water Management Plan.

This report augments the February document by describing a successful test at Pogo to remove manganese, additional information on sulfide precipitation and expected water treatment plant performance, and additional work on water quality modeling.

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June 2002 Supplement

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WATER MANAGEMENT PLAN SUPPLEMENT

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SECTION 1 | INTRODUCTION

1.1 Purpose of this Document

The purpose of this June 2002 Supplement to the Pogo Water Management Plan is to provide supplementary information and clarifications to the water management system proposed for the Pogo project as described in the February 2002 Pogo Water Management Plan.

This supplement was prepared to incorporate additional information and data developed from field investigations, testwork and engineering analyses, as well as investigations made in response to requests from the EIS team. This data has been used to reassess and where necessary make changes to the predicted water treatment levels.

The principle changes that have been made since February 2002 involve the upward adjustment of the projected treatment criteria for Cu and Se and the downward adjustment for Mn, as well as the use of greater precision in Monte Carlo modeling by representing water quality inputs with weekly probability distributions.

1.2 Organization of this Report

This document is organized into 5 sections: Section 1 consists of the introduction and summary of conclusions. Section 2 evaluates the Pogo water treatment plant field trial for Mn, provides a review of the relevant literature regarding water treatment plant performance, and reviews the performance of similar treatment plants. Section 3 follows with the revisions to the water quality inputs and use of weekly variations. Section 4 presents the predicted water quality during operations and a discussion of results. Section 5 updates the results of the Modflow modeling of the dispersion of the plume from the SAS.

All units of measure in this report are US standard except water chemistry data, which by convention is expressed in metric units.

1.3 Summary & Conclusions

Key conclusions demonstrated in this supplement to the Water Management Plan for the Pogo project are as follows.

Based on the Field Test of Manganese Removal at Pogo

- The operation of the Water Treatment Plant (WTP) with aeration, elevated pH and carbon dioxide addition achieved a 99% reduction in dissolved Mn from an average feed of 65 ppb to an average effluent of 0.65 ppb. The pH 8.0 condition alone resulted in a 95% reduction in dissolved Mn from a average feed value of 59 ppb to an average effluent value of approximately 3 ppb. In both cases, this clearly demonstrates the effectiveness of Mn removal. It also shows that elevated pH greatly increases Mn removal in the clarifier.

- Since the chemistry of the potential manganese sources during operation is likely to be similar to that observed during this test,, this test program indicated that a Mn target of 50 ppb is achievable with the proposed Pogo WTP design.

- This test work indicates that TDS removal is effective and confirmed that the predicted TDS removal for the proposed Pogo WTP design, (15%), is reasonable.

- From Published Literature on sulfide precipitation, Cd, Cu, Pb can reduced to low levels using sulfide addition to the lime precipitation system. This is supported by the results of the studies that demonstrated that the use of sulfide was able to reduce metals to levels equivalent to the proposed limits for Pogo even when treating acidic feeds containing metals at very high concentrations compared to Pogo.
- Sulfide addition will assist in targeting the removal of Cd, Hg, Ag and Cu over the more soluble sulfide species such as Fe or Zn.

- The treatment process design needs to accommodate experience gained with the chemistry after the start of operations. Optimal performance may require moving reagent addition points in the processing sequence. Achievement of the required flexibility is not considered a major design constraint.

Assessment of Performance of Other Mine WTPs

- Based on the review of the WTP performance of other mining operations the predicted Pogo WTP effluent upper limits for Cd, Cu, Fe, Pb should be readily achievable.

- Due to the assumed presence of small amounts of cyanide in the WTP feed, it is logical to expect a portion of this cyanide to complex copper. Based on this, and the experience at Red Dog, the target value for Pogo Cu has been revised to 10 ppb from 5 ppb.

- With respect to Se removal, the Red Dog WTP demonstrated an average 50% removal rate of Se levels at the 5 ppb level. The 95th percentile annual maximum feed concentration at Pogo is 7.8 ppb. Based on this predicted influent level, the Pogo WTP Se removal efficiency has been revised to 50% of influent level, with a minimum achievable Se concentration of 3 ppb.

- The use of sulfide precipitation at Red Dog does not demonstrate superior performance with respect to ferric co-precipitation for the major elements present at Pogo, i.e. As, Fe and Mn. For this reason, the use of sulfide precipitation at Pogo should be considered an installed back-up process capacity, which could be used to facilitate meeting projections, but does not allow for lowering the original effluent predictions.

- The treatment effluent predictions provided in the Water Management Plan, February 2002, Table 5.1, except those noted in Table 3.1, appear to be well supported by the available data, the performance of the existing WTP, and our knowledge of the proposed water collection and treatment system.

Revisions to the Water Balance and Predicted Water Quality Model

- The modeling changes have been relatively minor, with reductions in predicted TDS, and SO_4. CN, Mn, and Ag have decreased. Cu and Se increase somewhat as their treatment limits have been raised.

- Based on the proposed operating parameters and design criteria, the Pogo water management system will effectively maintain the water quality in the Goodpaster River under all reasonably foreseeable conditions.

Update of the Modflow Model

- The Modflow modeling of the plume from the SAS was updated to reflect the new WTP/SAS effluent water quality numbers. The values decreased for most species, but increased for Cu and Se due to the increase in target treatment limits.

SECTION 2 | WATER TREATMENT PLANT TESTWORK & OPERATIONAL DATA

2.1 Water Treatment Strategy

In order to gather additional information to assist with evaluation of the projected performance of the Pogo Water Treatment Plant, the following activities were carried out:

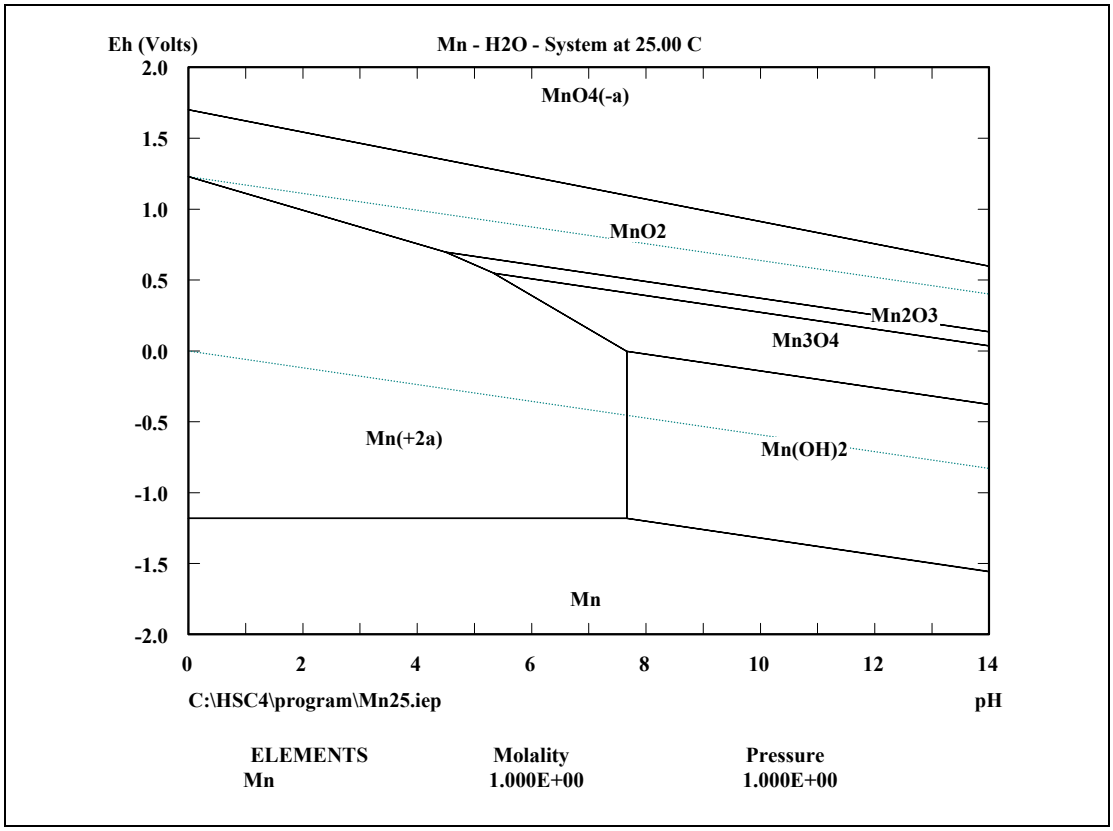
- A full-scale field trial was conducted at the existing Pogo WTP with lime softening and recarbonation operated at two pH levels to investigate Mn removal.
- A review of the published literature was conducted to clarify performance predictions.
- A review of the performance of other WTPs and an evaluation of their relevance to the performance of the Pogo WTP.

2.2 Water Treatment Plant Field Trial

Introduction and Objectives

Baseline data collection at Pogo has indicated that manganese naturally occurs in some surface and groundwater at levels up to an order of magnitude above the 50 mg/ℓ criteria. During the nearly 3 years that the existing water treatment plant at Pogo has operated, the process has not been optimized for manganese removal. However, recent consideration of the manganese chemistry postulated that effective removal of manganese would be possible by slight process modifications. The following Figure 2.1 shows the Manganese Eh pH diagram along with the stability fields for the various manganese oxides and hydroxide. This diagram shows that the formation of MnO_2 is favored at higher pH under mildly oxidizing conditions and prompted the selection of pH 10.8 as suitable for the filed trial.

Figure 2.1: Manganese Eh pH Diagram



In order to assess the effectiveness of these modifications on manganese removal, a full-scale field trial was conducted at the Pogo WTP by Teck Cominco personnel between April 5th and 13th, 2002. The objectives of this trial were as follows:

- Evaluate the use of high ph conditions (10.8) and aeration to reduce dissolved Mn concentrations.
- Evaluate the use of the partial lime softening process to remove hardness, alkalinity and thereby reduce total dissolved solids (TDS) levels in the treated effluent.
- Evaluate the impact of the high pH conditions (10.8) on the efficiency of arsenic removal using ferric co-precipitation.
- Estimate reagent requirements and sludge generation rates for the partial lime softening process.

Procedures

The overall procedures include two operating conditions:

- Base case condition with pH set-point at 8.0, without CO_2 addition
- Increase the reactor pH set-point to 10.8 to increase lime addition rate followed by neutralization of clarifier overflow by CO_2 addition to the filter feed tank prior to filtration.

The base case condition was operated for the first three days followed by an additional three days at the higher pH. Two-liter samples were taken four times daily (approximately 6 hours between samples) from each of five sample locations. The two-liter samples were then composited for the 24-hour period, preserved and filtered as required and shipped to ALS Environmental in Vancouver, B.C. for detailed analyses.

Samples were collected from the following points:

- Makeup Water (from the Pogo gravel pit)
- Mine Water
- Reactor Feed
- Clarifier Overflow
- WTP Effluent.

Note that reactor feed consisted of a mixture of make-up water from the gravel pit, added at Sump #2, and minewater. The minewater does not contain significant Mn so the make-up water was added to the reactor feed tank to provide a source of Mn to the system for the test. The WTP Effluent represents final effluent following filtration.

Results

The full set of analytical data that was collected during the trial, as well as the reagent consumption rates, feed flowrates and plots generated from the data are provided as Appendix A. The WTP was operated at flowrates from 85 to 91 gpm during the trial, slightly less than the rated design capacity of 100 gpm. The make-up water flowrate was approximately 4 gpm. Lime dosage was increased from approximately 0.04 g/ℓ to 0.46 g/ℓ when the pH setpoint was increased to 10.8 from 8.0. The CO_2 dosage to neutralize the effluent at the elevated pH condition was approximately 0.031 g/ℓ.

The trial was conducted at two different ferric chloride dosages for each test condition. The first day of operation at pH 8.0 used a ferric chloride dosage of 89 mg/ℓ. The dosage was reduced to 40 mg/ℓ for the last two days at pH 8.0 and the first two days at pH 10.8. The dosage was then increased to 74 mg/ℓ on the final day at pH 10.8.

Conclusions

Conclusions from the testwork are as follows:

- Lime softening was able to achieve reductions of 161 mg/ℓ and 108 mg/ℓ as $CaCo_3$ for TDS and hardness respectively (approximately 40% at the influent level).
- Aeration, CO_2 addition and elevated pH (to 10.8) were responsible for a 99% reduction in dissolved Mn from an average feed of 65 ppb to an average effluent of 0.65 ppb. A 95% reduction in dissolved Mn (from a average feed value of 59 ppb to an average effluent value of approximately 3 ppb), was achieved at a pH 8.0. This clearly demonstrates the effectiveness of this treatment on Mn removal and that elevated pH greatly increases Mn removal in the clarifier.
- Arsenic removal efficiency dropped slightly from pH 8.0 to 10.8 (98.6% versus 98.0). Average effluent dissolved As concentrations were 2.0 and 2.9 mg/ℓ at pH 8.0 and 10.8 respectively. Although the data is limited, the dissolved As removal efficiency was slightly better at the higher $FeCl_3$ dosage at pH 8.0 condition (1.5 ppb versus an average of 2.3). There was not significant difference in average As removal efficiency at pH 10.8 at the selected ferric dosages.
- Overall, this test program indicated that a Mn target of 50 ppb is achievable with the proposed Pogo WTP design.
- This test work further confirmed the effectiveness of TDS removal by lime softening as presented in the Feb 2002 Water Management Plan. The use of the lime softening process at high pH (above 8) will result in a significant increase in lime consumption and, by inference, sludge generation rates compared to the base case. The current estimate shows an increase in sludge production by a factor exceeding

2.3 Literature Review

A survey of the literature on water treatment was carried out to identify any relevant technical literature or studies that could provide guidance with respect to the performance of the proposed Pogo Water Treatment Plant.

This review of the literature focuses on providing supporting information on expected WTP performance of systems using sulfide treatment for enhanced metal precipitation.

As outlined and proposed in the February 2002 Water Management Plan, the conventional HDS ferric co-precipitation process for Pogo will be enhanced by incorporating a second stage reactor to provide process flexibility and allow for subsequent addition of a sulfide or other reagents. Sulfide addition could help remove metals such as Hg, Ag, Cd or Pb in order to achieve target concentrations.

There are two basic processes which can be used to provide removal of metals from effluents, precipitation as hydroxide or precipitation as sulfide. Sulfide precipitation uses the same basic principle as does hydroxide precipitation in that the process converts soluble metal compounds into relatively insoluble sulfide compounds through the addition of a precipitating agents, such as sodium sulfide (Na_2S), sodium hydrosulfide (NaHS), ferrous sulfide (FeS) or calcium sulfide (CaS). The process is generally carried out at neutral pH (7 to 9) to avoid the formation of highly toxic H_2S and to maximize the concentration of sulfide ion in solution. However, one of the advantages of sulfide over hydroxide is that it can operate over a considerably wider pH range.

Upstream addition of sulfide (Na_2S) is successfully carried out at Red Dog to assist with removal of Cd, while the literature also reports successful metal removal using sulfide reagent addition directly to neutralization reactors (Kim, 1983[1]; Talbot, 1984[2] and Bhattacharyya et al, 1979[3]).

The use of sulfide precipitation for metal removal is extensively supported and documented in the technical literature, with early work reported in the 1977. Authors, such as Bhattacharyya, have conducted a large number of bench and pilot plant studies on the use of sulfide for treating a wide variety of metal-bearing waste streams.

Regulations issued in the early 70's lead to interest in the use of sulfide. Much of the early treatment testwork with sulfide was aimed at generating treated effluents from metal finishing facilities that were acceptable for discharge to publicly-owned treatment works (POTW). The use of simple lime precipitation for treatment of metal finishing effluents was often unable to achieve the required specifications for release to POTW's, for a number of reasons. As discussed in Bhattacharyya et al., 1979[3], two key factors prevented effective precipitation of metals from metal finishing wastes using hydroxides:

[1] Kim, B. M., "Treatment of Metal Containing Wastewater with Calcium Sulfide", The American Institute of Chemical Engineers, 1983; and Kim, B. M., and Amodeo, P. A., "Calcium Sulfide Process for Treatment of Metal-Containing Wastes" 1983
[2] Talbot, Richard S., "Co-Precipitation of Heavy Metals with Soluble Sulfides Using Statistics for Process Control", 1984.
[3] Bhattacharyya, D., Jumawan, A. B. Jr., and Grieves, R. B., "Separation of Toxic Heavy Metals by Sulfide Precipitation", Separation Science and Technology, 14(5), pp. 441 – 452, 1979.

(1) the wide variation in optimum pH for the individual metals being precipitated, and (2) the presence of complexing agents. The use of sulfide can overcome these limitations, the process is not particularly pH sensitive and can overcome the presence of complexing agents. Both of these are critical factors in treating metal finishing effluents.

The theoretical advantage of metal precipitation using sulfide can be explained by reviewing the solubility limits for various metals as hydroxides and sulfides in distilled water, as presented in Table 2.1.

Table 2.1: Comparison of Hydroxide and Sulfide Metal Solubilities

Metal	Solubility of Metal Ion, mg/ℓ	
	As Hydroxide	As Sulfide
Cadmium (Cd ++)	2.3×10^{-5}	6.7×10^{-10}
Cobalt (Co ++)	2.2×10^{-1}	1.0×10^{-8}
Copper (Cu ++)	2.2×10^{-2}	5.8×10^{-18}
Iron (Fe ++)	8.9×10^{-1}	3.4×10^{-5}
Lead (Pb ++)	2.1	3.8×10^{-9}
Manganese (Mn ++)	1.2	2.1×10^{-3}
Mercury (Hg ++)	3.9×10^{-4}	9.0×10^{-20}
Nickel (Ni ++)	6.9×10^{-3}	6.9×10^{-8}
Silver (Ag +)	13.3	7.4×10^{-12}
Tin (Sn ++)	1.1×10^{-4}	3.8×10^{-8}
Zinc (Zn ++)	1.1	2.3×10^{-7}

As noted above, the solubility limits for Cd, Cu, Pb, Hg and Ag as sulfides are extremely low. This provides a large driving-force for sulfide precipitation. These metals will precipitate quickly and achieve lower dissolved metal concentrations than can be achieved with precipitation as hydroxides which typically are several orders of magnitude more soluble. As pointed out by Talbot, 1984[4] in his paper on the use of co-precipitation of metals using sulfides, metals will precipitate in a preferential order depending on their equilibrium sulfide ion concentration. Extremely insoluble metal sulfides such as Hg, Cu and Ag will precipitate in preference to more soluble sulfides such as Fe and Mn. Therefore these elements (or metals with low sulfide solubility limits) can be removed from solution at less than theoretical maximum sulfide dosages. Experiments, involving sulfide co-precipitation, conducted by Talbot demonstrated reductions in Hg from 2.9 mg/ℓ to less than 0.001 mg/ℓ and for Cd from 4.8 mg/ℓ to less than 0.05 mg/ℓ at pH 8.0. In the same experiment Cd removal with pH adjustment to 9.5 using hydroxide reduced Cd to only 0.24 mg/ℓ.

[4] Talbot, Richard S., "Co-Precipitation of Heavy Metals with Soluble Sulfides Using Statistics for Process Control", 1984.

An excellent summary review on treatment technologies was provided by Peters, Ku and Bhattacharyya, 1985[5]. This publication includes an extensive review of the literature on the use of sulfide for metals removal (as well as other treatment processes). This review provides a clear demonstration of the effectiveness of the various sulfide processes. The results presented in the document demonstrate the need to address metal removal on a specific element-by-element basis for the different steams being considered for sulfide treatment. As pointed out optimum conditions for pH, reaction time and presence of other co-precipitates will vary on a case-by-case basis. As mentioned above, this factor has been included in the process design for the proposed Pogo WTP, which will be sufficiently flexible and will allow for the use different reagents at multiple addition points. In the event that soluble metal concentrations are above acceptable levels for specific parameters after conventional ferric co-precipitation, the addition of small amounts of sulfide or other reagents can be introduction at different stages in the process. These reagents would be handled as solutions in totes and added to the process using metering pumps.

Bhattacharyya, 1979[6], who was one of the early researchers in the use of sulfide precipitation, reported the results of batch and continuous pilot testing on both synthetic and actual scrubber wash down water from a copper smelting plant, containing elevated levels of metals and low pH. The testwork involved a combination of neutralization using lime and sulfide addition with Na_2S. The results demonstrated at least an order of magnitude improvement for sulfide addition in combination with lime over lime by itself for Cd and Zn and about a 60% improvement for Cu. At sulfide dosage of 5.0 mM (60% of theoretical) and final pH of 8.0 to 8.5 Cd, Zn and Cu removals were greater than 99% at starting concentrations of 10.5, 85.5 and 297 mg/ℓ respectively. The work clearly demonstrated the process and the technical advantages of supplementing lime addition in a two-stage system with sulphide. However, the testwork also demonstrated that the optimum pH for As and Se removal was in the pH 5.0 to 5.5 range while the optimum pH for other metals was 7.0 to 8.5. This factor is considered in the design of the Pogo WTP process since ferric chloride solution is added upstream of the plant to create a low pH condition to enhance As removal.

Scott, 1979[7] presented the results for a pilot sulfide precipitation system used at Holley Carburetor in Paris, Tennessee. This was an EPA demonstration project conducted to evaluate the Sulfex process. The pilot treatment system treated rinse water from the carburetor casting line consisting of three streams: (1) zinc chromate, (2) deoxidize, and (3) aluminum chromate rinse solutions. The effluent from the carburetor facility

[5] Peters, Robert W., Ku, Young, and Bhattacharyya, Dibakar, "Evaluation of Recent Treatment Techniques for Removal of Heavy Metals from Industrial Wastewaters", AiChE Symposium Series – Separation of Heavy Metals, 1985.
[6] Bhattacharyya, D., Jumawan, A. B. Jr., and Grieves, R. B., "Separation of Toxic Heavy Metals by Sulfide Precipitation", Separation Science and Technology, 14(5), pp. 441 – 452, 1979.
[7] Scott, Murray C., "An EPA Demonstration Plan for Heavy Metals Removal by Sulfide Precipitation" 1979.

contained major amounts of Zn and Cr. The Sulfex process, developed by the Permutit Company, uses an insoluble sulfide salt instead of the soluble sulphide salts used by other researchers. As discussed in the paper, the selection of the specific salt is based on using a sulfide salt with a greater solubility than the metal being removed. The treatment process used freshly prepared ferrous sulfide generated on site. The Sulfex process was able to reduce metal concentrations to less than the analytical detectable limits that were in place at the time that test work was carried out in 1979. The effluent levels, achieved using the Sulfex process were as follows: Zn <0.05, Fe <0.5, Cu <0.01 and Cr <0.04 mg/ℓ. Stability testwork on the sludge demonstrated that the Sulfex process produced a very stable sludge compared to a hydroxide sludge generated from the same feed.

Feng, Aldrich and Tan, 2000[8] presented the results of testwork conducted on gold mine effluent using a combination of lime and sulfide precipitation. A key feature of the study was the parallel testwork conducted using both lime and lime plus sulfide. The results, summarized below in Table 2.2 along with the proposed limits for Pogo, demonstrated the benefit derived for Cd, Cu and Ni removal using lime and sulfide. Since this work is recent, the metal assays were conducted at lower detection limits than used in earlier studies and are comparable to those that would be required at Pogo. It is worth noting that the Feng et al. results also indirectly demonstrate the benefits derived from iron co-precipitation. The feed contained high concentrations of iron that would have precipitated during neutralization. Although the Pogo feed is a neutral pH stream, the results presented by Feng et al. demonstrated that sulfide addition would likely benefit both Cd and Cu removal if they became treatment issues at Pogo.

Conclusions

Review of the literature indicates that very low effluent metal levels for Cd, Cu, Pb can be achieved using sulfide addition supplemental to a lime precipitation system. This conclusion is supported by the results of the studies which demonstrated the effectiveness of sulfide even when treating acidic feeds containing metals at very high concentrations compared to those expected at Pogo.

Based on the relevant sulfide solubility products, sulfide addition will specifically target the removal of Cd, Hg, Ag and Cu over Fe or Zn.

[8] Feng, D., Aldrich, C., and Tan, H., "Treatment of Acid Mine Water by Use of Heavy Metal Precipitation and Ion Exchange", Minerals Engineering, Vol 13, No. 6, pp 623 – 642, 2000. Sulfide or Carbonate Precipitation for Enhanced Metal Removal.

Table 2.2: Summary of Results for Sulfide Co-precipitation Testwork (Feng et al, 2000) & Comparison to Pogo WTP Limits (mg/ℓ)

Parameter	Untreated Feed	Lime to 8.1 pH	Lime + 1x[1] Na2S to pH 8.0	Proposed Pogo Limits (Feb 2002)
pH	1.65	8.1	8.0	
Cd	0.26	0.121	0.0009	0.0003
Cu	1.80	0.0058	0.0015	0.005[2]
Fe	942	0.452	0.2141	0.3
Pb	0.349	0.0012	0.001	0.001
Mn	113	0.0898	0.0789	0.05
Ni	5.75	0.0899	0.0342	0.03
Zn	10.1	0.0001	0.0001	0.015

1. Theoretical sulfide dosage based on total metals in solution. **2**. Now revised to 10 ppb due to CN complexing.

The treatment process design needs to accommodate experience gained with the chemistry after the start of operations. For example, to obtain best performance, sulfide may need to be added either before ferric addition or after, or multiple addition points might be required, together with additional pH adjustment. Achievement of the required flexibility is not considered a major design constraint.

Uncited References

Whang, James S., Young, Daniel, Pressman, Maurice, “Design of Soluble Sulfide Precipitation System for Heavy Metals Removal” 1982.

2.4 Pogo Water Treatment Plant - Expected Performance Characteristics

Introduction and Objectives

The February 2002 Pogo Water Management Plan (WMP) presented the expected performance characteristics of the proposed Pogo Water Treatment Plant. During review of the WMP at the March 12, 2002 agency meeting in Anchorage, the EIS asked Teck-Pogo to review the expected performance of the plant, including the potential use of sulfide precipitation, as compared to similar facilities.

In response to that request, considerable time and effort was expended in an attempt to identify operations with comparable feed chemistry and process, that is, a basic (pH>7)

mine drainage with similar chemistry being treated by a ferric co-precipitation, HDS plant with the possible addition of sulfide precipitation followed by filtration. Mining operations were contacted in Canada and the USA to solicit data to allow the evaluation of performance. In most cases, mining operations were reluctant to release in-house information for public review. In addition, most of the mining operations focus on effluent compliance rather than contaminant removal efficiency, so little or no feed data was available. Data obtained from nine (9) operations of one worldwide mining company proved to be not applicable. Ultimately, it was not possible to identify and obtain data from WTPs that are directly comparable to the WTP proposed for Pogo. For this reason, it is not possible to address directly the efficacy of the Pogo process based on actual performance by similar plants.

Notwithstanding, we were able to obtain some data from mine sites operated by Teck Cominco. This data is also not directly comparable as the streams treated are quite dissimilar, the water treatment processes are different, and the effluent streams are typically not analyzed to the low detection limits that are being discussed for Pogo.

The data were reviewed in order to determine if there were any lessons that could be drawn from WTP practice at these mines sites and plants to assess the ferric co-precipitation HDS technology and assist with predicting effluent quality at Pogo, as outlined in Section 4.7 and Appendix L of the February 2002 Water Management Plan (WMP).

The approach taken to evaluating the technology was to evaluate the implications for effluent values at Pogo, assuming that the following conditions were valid.

- The influent would be at the WTP Feed 95th Percentile Annual Maximum Concentrations (presented in Appendix L of the February 2002 WMP).
- Performance of the other Teck-Cominco WTP's was representative of what could be expected at Pogo.

The predictions and rationale are presented in Table 2.3. The methods and approach taken to carry out the assessment are provided in the following sections.

Methods. Each WTP data set contained metal results from time-related sampling programs. Time intervals varied from weekly, bi-weekly, monthly or on a random basis.

Each WTP sample data set was sorted to include only metals listed in Table 5.1 of the WMP. Since in many cases the data set that was provided included a full set of site monitoring data, the next activity was to determine which data represented the influent (feed into plant) and the effluent (discharge from plant). The appropriate time interval to represent both influent and effluent concentrations was then selected.

Each metal was analyzed on an individual basis to provide correlations between the influent concentrations and effluent concentrations using calculated mean, standard deviation, and 95th percentile values.

The data sets for each site and specific metal were screened to determine the total number of real data points and the total number of less-than-detectable values.

If the total number of less-than detection limit readings (non-detects) was less than 50% of the total number of data points, then it was assumed that the numerical value for all the less-than-detectable readings was equal to one half of the reported detection limit value for each specific data point.

For some of the species of interest, high percentages of non-detects were common. In order to avoid overestimating low values in the presence of a large number of non detect values, it was considered necessary to "correct" the data. This is necessary because the proposed effluent limits are so close to the detection limits for many of the species of interest that common procedures such as using the detection limit or 50% of the detection limit value can seriously overestimate the actual values. The Maximum Likelihood Estimator (MLE) method, Murray and Verna, 2001[9], was adapted for this purpose.

If the total number of non-detect readings in a data set was greater than 50% of the total number of data points, the MLE method was used to correct the non-detect readings in each data set and complete the statistical calculations. The MLE method assumes that the observations follow a lognormal distribution. The MLE procedure has been utilized in the field of industrial hygiene to assess the impact of less-than-detectable levels of contaminant exposure when the percentage of readings that are non-detects is high. Details on the MLE procedure are presented in Murray and Verna, 2001.

The MLE procedure estimates the most likely mean and standard deviation for a lognormal distribution describing the data set. This distribution is the basis for calculating the 95th percentile value.

The results of the statistical calculations were then summarized for each site (see Appendix B).

[9] Murray, M.F. and D.K. Verna. 2001. Exposure Estimation in the Presence of Nondectable Values: Another Look. Am. Ind. Hyg. Assoc. J. 62:195-198 (2001).

Results and Discussion

A summary of the sites and relevant characteristics of the operations, evaluated are provided in Table 2.3.

The sites cover a wide range of different types of mines, feeds, water treatment system types, jurisdictions and permits limits. Therefore, in carrying out our assessment, a number of factors needed to be considered. These factors are as follows.

Differences in WTP Feeds and Type of System

Many of the cases in Table 2.3 involve treatment of acidic drainages with high dissolved metal, sulfate and total dissolved solids (TDS) concentrations, typical of WTP's at many mining operations. Due to the nature of the feeds, these plants are lime-based treatment plants using either low density or high density sludge processes. It is important to recognize that the solubility of metals in high TDS water can be enhanced due to the presence of anions such as sulfate and chloride. In contrast, the Pogo WTP will be a ferric co-precipitation high density system designed to treat a neutral to alkaline pH mine water and RTP water containing arsenic at up to 5 ppm as the primary contaminant and low TDS and metal concentrations compared to many feeds in the literature. The ferric co-precipitation process is typically capable of reducing metals in addition to As and Sb, to lower concentrations than conventional lime-based systems.

Different Cyanide Destruction System

The only gold mine site data reviewed was from the Teck Cominco Williams Mine. However, Williams handles and treats cyanide-bearing wastes significantly different than what is proposed for Pogo. The Williams Mine discharges untreated cyanidation tailings to a large tailings pond and relies on natural degradation for cyanide treatment. This results in some CN concentrations and complexed metals reporting to both untreated and treated effluent. In contrast, the treated cyanidation tailings at Pogo will be deposited and immobilized in cemented paste backfill. In the Pogo case, a small amount of cyanide is assumed to report to the minewater as leakage from the backfill. However, based on the modeling results presented in the WMP, the CN concentrations in the Pogo mine water and WTP feed will be an order of magnitude lower than the Williams case (95% values 32.7 and 435 ppb respectively). The presence of CN results in the formation of soluble metals complexes, namely Cu, Fe, Ni and Zn, at significantly higher concentration in the Williams mine case than would apply to Pogo. Therefore it was very difficult to use the Williams mine to assess the fate and behavior of cyanide at Pogo.

Impact of Permit Limits on WTP Design and Operation

Although information on permit limits was not sourced specifically during the assessment, it can be concluded from the effluent concentrations reported that the discharge targets for most of the operations in Table 2.3 are significantly higher than the limits proposed for Pogo. The design and operation of most of these treatment plants naturally reflects the need to meet specified targets. The data therefore does not answer the question of whether additional unit operations, like filtration or process optimization such as sulfide addition, would have resulted in compliance with lower discharge limits. The Red Dog WTP is the only HDS plant that uses both sulfide precipitation and final filtration to achieve lower limits than would have been possible with a conventional lime-based HDS treatment system. However Red Dog differs from Pogo in that it's a lime-based HDS system aimed at removing major amounts of Cd, Pb and Zn while Pogo is ferric co-precipitation system aimed at removing As as the primary contaminant.

Detection Limits

The detection limits vary by several orders of magnitude both between sites and, due to the time spans involved, at the individual sites as well. Historical data, older than about 5 years, was of limited value due to the detection limit issue. The detection limits used by an individual site also reflect the permit limits due to the costs associated with assaying. In many cases the detection limits used by the individual sites are an order of magnitude higher than the proposed targets for Pogo. In some cases, this made it impossible to assess whether an individual site might have actually been meeting a lower limit.

As outlined above, manipulation of the data sets with a high percentage of less-than-detectable readings at various detection limits required use of the MLE estimation procedure to yield unbiased means and standard deviations.

Speciation

Metals such as Se and Cr are typically present in solution in feeds as anions. The speciation of these metals is important in determining whether a lower effluent level could have been achieved through process modifications or additional unit processes. However, speciation data were not available. Also in many cases both total and dissolved metal data were unavailable, making it difficult to assess whether a simple process such as filtration may have been effective in reducing a particular metal to lower concentrations.

Evaluation of Data from Teck Cominco Sites

The summarized data for the individual Teck Cominco sites are provided in Appendix B. These summaries provide data on the detection limits and number of less-than-detectable values for each particular metal as well as the comparative Goodpaster receiving water criteria.

These data were then evaluated to provide a perspective on the proposed Pogo water treatment plant perform

Key assumptions in the evaluation were as follows:

- The overall performance of the other Teck Cominco operations can be used to assess expected performance at Pogo.
- The feed concentrations would be equivalent to the concentrations listed in Column 2 of Table 2.4.
- The feed would have a neutral to alkaline pH.

Discussion of Effluent Predictions

As discussed above, it is possible to do an assessment on a metal-by-metal basis to examine the potential upper limit of WTP effluent water quality and plant performance. This assessment is provided in Table 2.4. The actual WTP results for metals of interest to Pogo are presented in Table 2.3 for Red Dog, Pogo, Kimberly and Williams, along with the predicted values for Pogo. The data presented in Table 2.4 can be described as follows:

- Columns 1 and 2 are the predicted WTP Feed Annual Average and 95th Percentile Annual Maximum values extracted from Table 5.1 of the WMP.
- Column 3 provides and the original Predicted Effluent Quality values from Appendix L of the WMP.
- Column 4 provides revised predicted effluent quality values derived from assuming the WTP performance from the data sets can be used to assess the Pogo WTP case at the WTP Feed 95th Percentile Annual Max. Concentrations. The predictions are based on operation of a ferric co-precipitation HDS system at elevated pH with final filtration. Sulfide addition is retained a contingency to assist with achieving targets.
- Column 5 provides the Goodpaster receiving water criteria.
- Column 6 provides the rationale used to review and revise the original predictions.

Table 2.3: Summarized Metal Data for Teck Cominco Operations (µg/ℓ)

	Influent Mean	95th Percentile Annual Maximum	Effluent Mean	Predicted Pogo WTP Effluent Quality (Table 5.1, WMP)
As				
Predicted Value Pogo	1,680	5,360		30
Red Dog	878.4	163.4	0.75	0.975
Williams	107	299.2	0.77	15.1
Kimberly	No Data	No Data	1.53	4.77
Pogo Exploration Camp WTP	400	759	9.2	20.6
Cd				
Predicted Value Pogo	0.29	0.62		0.3
Red Dog	2709	4000	2.5	3.9
Williams	No Data	No Data	0.29	0.38
Kimberley	74.8	156.7	1.4	2.7
Pogo Exploration Camp WTP	0.044	0.14	0.034	0.08
Cr				
Predicted Value Pogo	5.87	13.1		30
Red Dog	7.51	23.5	0.468	1.05
Kimberley	74.8	156.7	1.4	2.7
Pogo Exploration Camp WTP	1.8	6.68	3.93	14.3
Cu				
Predicted Value Pogo	12.2	31.9		5
Red Dog	87.4	282	1.57	6.0
Kimberley	181	595	13	27
Williams	No Data	No Data	24	73.2
Pogo Exploration Camp WTP	1.4	3.4	1.2	3.0
Fe				
Predicted Value Pogo	1710	4,250		300
Red Dog	9145	44,545	214	1596
Kimberley	195,740	468,480	1117	2690
Williams	187	565	179	591
Pogo Exploration Camp WTP	1095	1243	180	446
Pb				
Predicted Value Pogo	20.7	69.5		1
Red Dog	2360.9.	3683.7	1.27	3.584
Kimberley	3320	6740	33	72
Williams	Non-Detects	Non-Detects	Non-Detects	Non-Detects
Pogo Exploration Camp WTP	0.514	1.780	0.103	0.300

Table 2.3: Summarized Metal Data – continued

	Influent Mean	95th Percentile Annual Maximum	Effluent Mean	Predicted Pogo WTP Effluent Quality (Table 5.1, WMP)
Hg				
Predicted Value Pogo	0.129	0.283		0.1
Red Dog	Non-Detects	Non-Detects	Non-Detects	Non-Detects
Kimberley	na	na	na	na
Williams	0.137	0.232	0.006	0.080
Pogo Exploration Camp WTP	Non-Detects	Non-Detects	Non-Detects	Non-Detects
Mn				
Predicted Value Pogo	492	1,250		200
Red Dog	13,652	17,586	17.7	159.5
Kimberley	18,100	28,400	181	440
Williams	No Data	No Data	629.8	693
Pogo Exploration Camp WTP	73.5	102.3	442	1146
Ni				
Predicted Value Pogo	13.3	34.1		30
Red Dog	656.8	877.7	10.4	33.8
Kimberley	No Data	No Data	No Data	No Data
Williams	192	307.4	122	233
Pogo Exploration Camp WTP	2.5	4.48	7.91	13.17
Se				
Predicted Value Pogo	3.54	7.79		2.0
Red Dog	5.13	18.17	2.56	6.1
Kimberley	No Data	No Data	No Data	No Data
Williams	No Data	No Data	2.6	3.0
Pogo Exploration Camp WTP	Non-Detects	Non-Detects	Non-Detects	Non-Detects
Ag				
Predicted Value Pogo	0.07	0.13		0.1
Red Dog	Non-Detects	Non-Detects	Non-Detects	Non-Detects
Kimberley	No Data	No Data	No Data	No Data
Pogo Exploration Camp WTP	Non-Detects	Non-Detects	Non-Detects	Non-Detects
Zn				
Predicted Value Pogo	28.6	66.9		15
Red Dog	264,717	341.217	55.4	93.5
Kimberley	45,490	81,490	276	634
Williams	14.3	26.9	8.49	22
Pogo Exploration Camp WTP	7.25	14.5	4.83	14.28

- Conclusions Predicted Pogo WTP effluent levels for Cd, Cu, Fe, Pb are lower than achieved at Red Dog, but should be readily achievable at Pogo due to the much lower influent levels, and other process differences such as ferric co-precipitation and filtration, implemented at Pogo.

- Due to the assumed presence of small amounts of cyanide in the Pogo WTP feed, it is logical to expect a portion of this cyanide to complex copper. Based on this assumption and the experience at Red Dog, it is recommended that the target value for Cu be revised to 10 ppb from 5 ppb.

With respect to Se, the Red Dog WTP demonstrated an average 50% removal rate of Se levels at the 5 ppb level. The 95th percentile annual maximum feed concentration at Pogo is 7.8 ppb. Se removal is subject to Se speciation, and without further information it is recommended that in the Pogo WTP case, Se removal efficiency be set 50%. However it is further recommended that minimum achievable Se concentration be set at 3 ppb, based on the expected chemistry of the minewater, i.e. elevated pH, oxidizing conditions.

It should also be noted that the use of sulfide precipitation at Red Dog does not demonstrate superior performance for the key elements at Pogo, i.e. As, Fe and Mn. For this reason, the use of sulfide precipitation at Pogo is considered to be installed back-up process capacity, which could be used to target certain metals but does not allow for overall lowering of the February 2002 effluent predictions.

In conclusion, the treatment effluent predictions provided in Table 5.1 of the February 2002 Water Management Plan, except those noted in Table 2.4, appear to be well supported by the available data, the performance of the existing WTP, and our knowledge of the proposed water collection and treatment system.

Table 2.4: Summary and Comparison of Feed and Predicted Effluent Concentrations (µg/ℓ)

	1	2	3	4	5	6
Metal (values in ppb)	**WTP Feed Annual Average Values**	**WTP Feed 95th Per Ann. Max.**	**Predicted Pogo WTP Effluent Quality (ppb) Table 5.1**	**Revised Pogo WTP Effluent Quality 95th Percentile Ann. Max. Feed Contingent Sulfide**	**Goodpaster Criteria**	**Comments and Recommendations**
As	1,680	5,360	30	30	50	Performance of the current Pogo WTP and the results from the Williams mine supports the 30 ppb limit for As.
Cd	0.29	0.62	0.3	0.3	0.4	Red Dog effluent quality is above the Predicted Effluent quality for Pogo. However the Red Dog Feed (mean 2,700 ppb) is over four orders of magnitude higher than the WTP Effluent 95th Annual Max value. The Kimberley WTP was able to reduce Cd from about 75 ppb in the feed to a 1.4 ppb (mean) but this was w/o filtration and less than optimum pH for Cd (9.5 vs. 10.5). At the 95th Percentile Annual Max. conc. of 0.69 ppb the Pogo WTP should be able to comply with the original predicted 0.3 ppb value for Cd. The use of sulfide should be capable of assisting in the control of Cd to this level if the elevated pH used in softening and ferric co-precipitation is not adequate.
Cr	5.87	13.1	30	30	71	Red Dog plant demonstrated effective removal of Cr at a feed concentration of 7.5 ppb. The behavior, removal and toxicity of Cr is governed by its species. Pilot plant experience using ferric co-precipitation HDS to treat minewater with elevated Cr has demonstrated reductions to less than 2 ppb from a feed containing 292 ppb. The 30 ppb limit for Cr is reasonable.
Cu	12.2	31.9	5	10	3.9	Red Dog effluent quality is above the original Predicted Effluent quality target for Pogo for Cu (95 percentile of 6 versus 5 ppb) with a feed 282 ppb. The Kimberley plant was able to reduce Cu from 595 ppb in the feed to a 27 ppb (95th percentile values) but this was w/o filtration or sulfide addition. Ferric co-precipitation pilot plant experience has generated effluent copper values of less than 2 ppb from a feed containing 95 ppb Cu. However, a portion of copper in the effluent will be complexed with cyanide. This copper complex may not be removed by the proposed process. Assuming that about 25% of the cyanide is present as a copper complexed and using a 95th percentile annual max. cyanide of 0.0327 mg/ℓ the amount copper complexed with cyanide becomes approximately 6 ppb. Assuming a solubility limit of about 4 ppb, the total copper in solution would be 10 ppb. Therefore it is recommended that the limit for copper be revised to 10 ppb.

Table 2.4: Summary and Comparison of Feed and Predicted Effluent Concentrations – continued

	1	2	3	4	5	6
Metal (values in ppb)	**WTP Feed Annual Average Values**	**WTP Feed 95th Per Ann. Max.**	**Predicted Pogo WTP Effluent Quality (ppb) Table 5.1**	**Revised Pogo WTP Effluent Quality 95th Percentile Ann. Max. Feed Contingent Sulfide**	**Goodpaster Criteria**	**Comments and Recommendations**
Fe	1,710	4,250	300	300	300	The current Pogo WTP effluent 95th percentile Fe value exceeded the 300 ppb target. However this was without the addition of aeration to the reactor, which has now been included. Recent pilot plant work for a proposed Cdn operation treating conventional mine water using ferric co-precipitation HDS system has demonstrated compliance with Fe levels of less than 15 ppb. The Kimberley WTP reported Fe effluent mean and 95th percentile values of 1,117 and 2,960 ppb respectively, this did not include filtration. Based on experience the presence of organics and cyanide in untreated feeds often results in elevated effluent Fe concentrations beyond conventional solubility limits. Therefore to remain conservative, the limit for Fe of 300 ppb should be retained.
Pb	20.7	69.5	1	1	0.6	Red Dog WTP was able to reduce feed Pb concentration of 2,360 ppb to achieve a mean of 1.27 and a 95th percentile of 3.58. The Kimberley WTP reported mean and 95th percentile values of 33 and 72 ppb, but without filtration. A major portion of the Pb in the feed (69 ppb) will be in the particulate form based on the expected alkaline chemistry of the feed. Therefore, the combination of ferric co-precipitation, elevated pH and filtration with the Pogo WTP should be capable of meeting 1 ppb Pb. The contingency of sulfide addition should assist with meeting the 1 ppb target, in line with the Red Dog WTP experience.
Hg	0.129	0.283	0.1	0.1	0.012	All feed and effluent data for both Red Dog and the current Pogo plant were less than detectable. Therefore it is difficult to make an assessment of the expected performance of the full scale plant using this information. The Williams WTP did however report an actual Hg feed of 0.137 and 0.232 ppb for mean and 95th percentile respectively which is in line with the estimated feed for Pogo. Since the Williams WTP, which used ferric co-precipitation, was able to reduce Hg in the effluent to mean and 95th percentile values of 0.006 and 0.08 ppb respectively it realistic to select the 0.1 ppb value for Hg based on a 95th percentile feed value of 0.28 ppb. Similar to the case with Cd and Pb the contingency of sulfide addition should assist in achieving the 0.1 ppb target should be become necessary.

Table 2.4: Summary and Comparison of Feed and Predicted Effluent Concentrations – continued

	1	2	3	4	5	6
Metal (values in ppb)	**WTP Feed Annual Average Values**	**WTP Feed 95th Per Ann. Max.**	**Predicted Pogo WTP Effluent Quality (ppb) Table 5.1**	**Revised Pogo WTP Effluent Quality 95th Percentile Ann. Max. Feed Contingent Sulfide**	**Goodpaster Criteria**	**Comments and Recommendations**
Mn	492	1,250	200	50	50	The existing WTP at Pogo has not originally optimized to achieve minimum levels for Mn. The combination of aeration and higher pH will reduce Mn below the original 200 ppb target. The Red Dog WTP was able to reduce Mn to approximately 160 ppb starting with a feed of 13,652 ppb. Based on this experience as well as the results from the recent full scale lime softening trail, it is recommended that the predicted effluent level for Mn be revised to 50 ppb. Sulfide addition would not be expected to benefit Mn removal.
Ni	13.3	34.1	30	30	52	The Red Dog WTP average and 95th percentile effluent values were 10.4 and 33.8 ppb respectively, which slightly exceed the original targets for Pogo of 30 ppb. However based on the alkaline pH of the feed, the Pogo WTP should be able to comply with the original target. The Ni limit on a worst case basis would be 50 ppb for conventional ferric co-precipitation HDS and 30 ppb with sulfide at the 500 ppb feed level.
Se	3.54	7.79	2	3	5	Se feed and effluent levels for the current Pogo plant are all less than detectable. The behavior of Se in a WTP sense is governed by its speciation. In line with the Red Dog experience and due to the uncertainty with respect to the selenium speciation, the original target for Se should be increased. An approximate 50 % reduction should be achievable with a minimum concentration in the order 3 ppb. Based on the chemistry of Se in solution, there's no basis to assume that sulfide addition will reduce Se effluent concentrations further.
Ag	0.07	0.13	0.1	0.1	0.12	None of the data reported Ag concentration above detection limit in either the feeds or treated effluent. Ag_2S is extremely insoluble, so the limit for Ag at 0.1 ppb is reasonable.
Zn	28.6	66.9	15	15	35	Both Red Dog and Kimberley demonstrated 99+ % removal of Zn at feed concentrations several orders of magnitude greater than the 95th Percentile value of 66.9 ppb. Pilot plant studies using ferric co-precipitation and filtration to treat mine water have proven successful in reducing Zn to 9 ppb. Therefore given the expected alkaline pH of the Pogo WTP feed and the fact that the full-scale plant will be operated at higher pHs than is currently carried out, the plant should be capable of meeting the original 15 ppb target. Sulfide addition could assist in meeting this target if required .

SECTION 3 | WATER BALANCE & MANAGEMENT

3.1 Introduction

This June Supplement incorporates the latest information and data developed from field investigations, recent field test work at Pogo and engineering analysis as well as design decisions made in response to requests from the EIS team.

The principle changes that have been made in the design and modeling assumptions since February 2002 are as follows:

- The modeling has been revised to reflect weekly variation in the input chemistry for the various water inflows in Tables 4.4, 4.5, and 4.6 of February 2002 Water Management Plan.
- The CN_T input parameters for Tables 3.1 D. Tailings Seepage and G. Mine Drainage were revised to use a probability distribution rather than being fixed at RWC (Reasonable Worst Case) values.
- Water treatment plant characteristics were revised to reflect the investigations and testwork carried out in the intervening period (as indicated in Section 2 above).

The following sections describe the updated water qualities, balances, treatment and water management concepts for the Pogo project.

3.2 Monte Carlo Model

The Pogo modeling has been revised in this June 2002 Supplement to the February 2002 Water Management Plan to reflect weekly variation in the input chemistry for the various water inflows in Tables 4.4, 4.5, and 4.6. The inputs were previously modeled on the basis of one value for each iteration (model year), as this was conservative and allowed for a shorter run time for the model. In response to suggestions from the EIS team, weekly variation of these inputs has been incorporated as this may more accurately reflect expected conditions.

Some of the input parameters for Tables 3.1 were revised to use probability distributions rather than being fixed at RWC (Reasonable Worst Case) values. This was undertaken to improve the quality of the simulations and to assess the sensitivity of the predictions to these changes.

To do this, distributions having the following properties were fitted to the available data:

- lognormal distribution
- mean equals standard deviation
- mean and standard deviation adjusted to set the RWC estimate equal to the 95th percentile of the distribution.

The parameters treated in this way for this revision were:

- Plant Site and Road Drainage CN(t)
- Development and Temporary Rock Seepage CN(t)
- Tailings Seepage CN(t)
- Fault Water TDS, SO_4, NO_3, CN(t), Fe, Hg, Mn, Ag
- Mine Water TDS, SO_4, NO_3, CN(t), Fe, Hg, Mn, Ag
- Backfill Drainage TDS, SO_4, NO_3, CN(t), Fe, Hg, Mn, Ag.

Table 3.1 shows the revised data and revisions are shown in bold.

Table 3.1: Water Quality Input Sheet (Sections A through I)

A. Plant Site, Road Drainage, Ditch Leakage

Parameter	Distribution	Selected Mean	Selected Std. Deviation	Reasonable Worst Case	Units
TSS	LogNormal	109	315	417	mg/ℓ
TDS	LogNormal	204	41.7	279	mg/ℓ
Cl	LogNormal	8.49	6.53	20.6	mg/ℓ
SO_4	LogNormal	27.0	10.7	47.0	mg/ℓ
TKN	LogNormal	1.73	0.160	2.01	mg/ℓ N
NO_3	LogNormal	4.70	7.83	16.1	mg/ℓ
CN_T	**LogNormal**	**0.0018**	**0.0018**	**0.005**	**mg/ℓ**
As	LogNormal	0.0172	0.00832	0.0329	mg/ℓ
Cd	LogNormal	0.000059	0.000028	0.000113	mg/ℓ
Cr	LogNormal	0.00163	0.00054	0.00263	mg/ℓ
Cu	LogNormal	0.00647	0.00214	0.0104	mg/ℓ
Fe	LogNormal	1.03	0.320	1.62	mg/ℓ
Pb	LogNormal	0.00036	0.00026	0.000838	mg/ℓ
Hg	LogNormal	0.00809	0.00381	0.0153	µg/ℓ
Mn	LogNormal	0.516	0.520	1.44	mg/ℓ
Ni	LogNormal	0.00433	0.00062	0.00542	mg/ℓ
Se	LogNormal	0.00067	0.00022	0.00108	mg/ℓ
Ag	LogNormal	0.000011	0.0000016	0.0000137	mg/ℓ
Zn	LogNormal	0.0299	0.0170	0.0620	mg/ℓ

B. Development & Temporary Rock Seepage

Parameter	Distribution	Selected Mean	Selected Std. Deviation	Reasonable Worst Case	Units
TSS	LogNormal	33.3	45.7	107	mg/ℓ
TDS	LogNormal	435	117	772	mg/ℓ
Cl	LogNormal	37.3	27.7	89	mg/ℓ
SO_4	LogNormal	634	295	386	mg/ℓ
TKN	LogNormal	10	1.8	15	mg/ℓ N
NO_3	Constant at RWC			9	mg/ℓ
CN_T	**LogNormal**	**0.0075**	**0.0075**	**0.02**	**mg/ℓ**
As	LogNormal	0.18	0.18	0.5	mg/ℓ
Cd	LogNormal	0.0005	0.0014	0.005	mg/ℓ
Cr	LogNormal	0.00258	0.00352	0.014	mg/ℓ
Cu	LogNormal	0.004	0.002	0.03	mg/ℓ
Fe	LogNormal	0.521	0.522	1.45	mg/ℓ
Pb	LogNormal	0.0009	0.0025	0.005	mg/ℓ
Hg	LogNormal	0.144	0.413	2	µg/ℓ
Mn	LogNormal	0.235	0.666	0.98	mg/ℓ
Ni	LogNormal	0.02	0.073	0.236	mg/ℓ
Se	LogNormal	0.004	0.0165	0.03	mg/ℓ
Ag	LogNormal	0.000029	0.000024	0.002	mg/ℓ
Zn	LogNormal	0.05	0.335	0.699	mg/ℓ

C. Tailings Runoff

Parameter	Distribution	Selected Mean	Selected Std. Deviation	Reasonable Worst Case	Units
TSS	Constant at USLE Value			400	mg/ℓ
TDS	Constant Mass			523	mg/ℓ
Cl	Constant Mass			164	mg/ℓ
SO_4	Constant Mass			302	mg/ℓ
TKN	Constant at RWC			0.5	mg/ℓ
NO_3	Constant Mass			19.8	mg/ℓ
CN_T	**Constant at RWC**			**0.02**	**mg/ℓ**
As	Constant Mass			0.4	mg/ℓ
Cd	Constant Mass			0.0004	mg/ℓ
Cr	Constant Mass			0.0011	mg/ℓ
Cu	Constant Mass			0.003	mg/ℓ
Fe	Constant Mass			0.0003	mg/ℓ
Pb	Constant Mass			0.0004	mg/ℓ
Hg	Constant Mass			0.2	µg/ℓ
Mn	Constant Mass			0.38	mg/ℓ
Ni	Constant Mass			0.02	mg/ℓ
Se	Constant Mass			0.006	mg/ℓ
Ag	Constant Mass			0.0002	mg/ℓ
Zn	Constant Mass			0.06	mg/ℓ

D. Tailings Seepage

Parameter	Distribution	Selected Mean	Selected Std. Deviation	Reasonable Worst Case	Units
TSS	Constant at RWC			5	mg/ℓ
TDS	LogNormal	600	610	3000	mg/ℓ
Cl	LogNormal	12.2	12.3	34	mg/ℓ
SO_4	LogNormal	57.4	125	2002	mg/ℓ
TKN	LogNormal	1	1	17.8	mg/ℓ N
NO_3	Constant at RWC			4	mg/ℓ
CN_T	LogNormal	0.018	0.018	0.05	mg/ℓ
As	LogNormal	1.6	2	5.1	mg/ℓ
Cd	LogNormal	0.00035	0.002	0.005	mg/ℓ
Cr	LogNormal	0.00251	0.0034	0.014	mg/ℓ
Cu	LogNormal	0.004	0.007	0.034	mg/ℓ
Fe	LogNormal	2	22	29.6	mg/ℓ
Pb	LogNormal	0.0009	0.0025	0.005	mg/ℓ
Hg	LogNormal	0.189	0.376	2	µg/ℓ
Mn	LogNormal	0.108	0.182	4.75	mg/ℓ
Ni	LogNormal	0.025	0.12	0.24	mg/ℓ
Se	LogNormal	0.013	0.05	0.13	mg/ℓ
Ag	LogNormal	0.000069	0.000064	0.002	mg/ℓ
Zn	LogNormal	0.05	0.335	0.699	mg/ℓ

E. Precipitation on RTP

Parameter	Distribution	Selected Mean	Selected Std. Deviation	Reasonable Worst Case	Units
TSS	Constant at RWC			0	mg/ℓ
TDS	Constant at RWC			10	mg/ℓ
Cl	Constant at RWC			0.056	mg/ℓ
SO_4	Constant at RWC			0.185	mg/ℓ
TKN	Constant at RWC			0.03	mg/ℓ N
NO_3	Constant at RWC			0.1525	mg/ℓ
CN_T	Constant at RWC			0	mg/ℓ
As	Constant at RWC			0	mg/ℓ
Cd	Constant at RWC			0	mg/ℓ
Cr	Constant at RWC			0	mg/ℓ
Cu	Constant at RWC			0	mg/ℓ
Fe	Constant at RWC			0	mg/ℓ
Pb	Constant at RWC			0	mg/ℓ
Hg	Constant at RWC			0	µg/ℓ
Mn	Constant at RWC			0	mg/ℓ
Ni	Constant at RWC			0	mg/ℓ
Se	Constant at RWC			0	mg/ℓ
Ag	Constant at RWC			0	mg/ℓ
Zn	Constant at RWC			0	mg/ℓ

F. RTP Evaporation

Parameter	Distribution	Selected Mean	Selected Std. Deviation	Reasonable Worst Case	Units
TSS	Constant at RWC			0	mg/ℓ
TDS	Constant at RWC			0	mg/ℓ
Cl	Constant at RWC			0	mg/ℓ
SO_4	Constant at RWC			0	mg/ℓ
TKN	Constant at RWC			0	mg/ℓ N
NO_3	Constant at RWC			0	mg/ℓ
CN_T	Constant at RWC			0	mg/ℓ
As	Constant at RWC			0	mg/ℓ
Cd	Constant at RWC			0	mg/ℓ
Cr	Constant at RWC			0	mg/ℓ
Cu	Constant at RWC			0	mg/ℓ
Fe	Constant at RWC			0	mg/ℓ
Pb	Constant at RWC			0	mg/ℓ
Hg	Constant at RWC			0	µg/ℓ
Mn	Constant at RWC			0	mg/ℓ
Ni	Constant at RWC			0	mg/ℓ
Se	Constant at RWC			0	mg/ℓ
Ag	Constant at RWC			0	mg/ℓ
Zn	Constant at RWC			0	mg/ℓ

G. Mine Drainage

Parameter	Distribution	Selected Mean	Selected Std. Deviation	Reasonable Worst Case Untreated	Units
TSS	Constant at RWC			1500	mg/ℓ
TDS (Fault Water)	**LogNormal**	**105**	**105**		**mg/ℓ**
TDS (Mine Water)	**LogNormal**	**235**	**235**		**mg/ℓ**
Cl	Constant at RWC			5	mg/ℓ
SO_4 (Fault water)	**LogNormal**	**31**	**31**		**mg/ℓ**
SO_4 (Mine water)	**LogNormal**	**102**	**102**		**mg/ℓ**
TKN	**Constant at RWC**			**10**	**mg/ℓ N**
NO_3	**LogNormal**	**3.6**	**3.6**		**mg/ℓ**
CN_T	**LogNormal**	**0.0075**	**0.0075**		**mg/ℓ**
As	Constant at RWC			5.36	mg/ℓ
Cd	Constant at RWC			0.0005	mg/ℓ
Cr	Constant at RWC			0.013	mg/ℓ
Cu	Constant at RWC			0.02	mg/ℓ
Fe	**LogNormal**	**1.55**	**1.55**		**mg/ℓ**
Pb	Constant at RWC			0.07	mg/ℓ
Hg	**LogNormal**	**0.09**	**0.09**		**µg/ℓ**
Mn	**LogNormal**	**0.26**	**0.26**		**mg/ℓ**
Ni	Constant at RWC			0.03	mg/ℓ
Se	Constant at RWC			0.002	mg/ℓ
Ag	**LogNormal**	**0.000036**	**0.000036**		**mg/ℓ**
Zn	Constant at RWC			0.021	mg/ℓ

H. Backfill Drainage

Parameter	Distribution	Selected Mean	Selected Std. Deviation	Reasonable Worst Case Untreated	Units
TSS	Constant at RWC			250	mg/ℓ
TDS	**LogNormal**	**4950**	**4950**		**mg/ℓ**
Cl	Constant at RWC			27	mg/ℓ
SO_4	**LogNormal**	**2450**	**2450**		**mg/ℓ**
TKN	LogNormal	15	13	64	mg/ℓ N
NO_3	**LogNormal**	**0.87**	**0.87**		**mg/ℓ**
CN_T	**LogNormal**	**0.37**	**0.37**		**mg/ℓ**
As	Constant at RWC			5.59	mg/ℓ
Cd	Constant at RWC			0.01	mg/ℓ
Cr	Constant at RWC			0.02	mg/ℓ
Cu	Constant at RWC			1	mg/ℓ
Fe	**LogNormal**	**1.1**	**1.1**		**mg/ℓ**
Pb	Constant at RWC			0.03	mg/ℓ
Hg	**LogNormal**	**1.1**	**1.1**		**µg/ℓ**
Mn	**LogNormal**	**3.7**	**3.7**		**mg/ℓ**
Ni	Constant at RWC			0.37	mg/ℓ
Se	Constant at RWC			0.43	mg/ℓ
Ag	**LogNormal**	**0.00085**	**0.00085**		**mg/ℓ**
Zn	Constant at RWC			0.43	mg/ℓ

I. Makeup Fresh Water

Parameter	Distribution	Selected Mean	Selected Std. Deviation	Reasonable Worst Case	Units
TSS	Constant at RWC			12.9	mg/ℓ
TDS	Constant at RWC			106	mg/ℓ
Cl	Constant at RWC			0.96	mg/ℓ
SO_4	Constant at RWC			20.2	mg/ℓ
TKN	Constant at RWC			0.33	mg/ℓ N
NO_3	Constant at RWC			0.45	mg/ℓ
CN_T	Constant at RWC			0	mg/ℓ
As	Constant at RWC			0.00040	mg/ℓ
Cd	Constant at RWC			0.000053	mg/ℓ
Cr	Constant at RWC			0.00367	mg/ℓ
Cu	Constant at RWC			0.0017	mg/ℓ
Fe	Constant at RWC			0.026	mg/ℓ
Pb	Constant at RWC			0.00023	mg/ℓ
Hg	Constant at RWC			0.058	µg/ℓ
Mn	Constant at RWC			0.0403	mg/ℓ
Ni	Constant at RWC			0.00144	mg/ℓ
Se	Constant at RWC			0.00070	mg/ℓ
Ag	Constant at RWC			0.000016	mg/ℓ
Zn	Constant at RWC			0.0047	mg/ℓ

Note: Species shown in bold type have been changed from February 2002 WMP

3.3 Water Model Catchment Areas

The Pogo water model catchment area inputs were reviewed in detail to verify that they corresponded to the latest designs for Pogo. The following Figure 3.1 shows the areas used in the model for the various catchments. Table 3.2 following shows the changes in areas between the February 2002 Water Management Plan and this June 2002 Supplement.

Table 3.2: Catchment Areas for Model in Year 6

	February 2002(Ac)	June 2002 (Ac)
Drystack area	19.2	19.2
RTP catchment	40.7	39.8
Plantrite & road	49.0	49.0
RTP area (for evap)	1.1	1.0
Pumpback area	15.6	5.0
	125.6 Ac	114.0 Ac
Diversion catchment	970.0	970.0

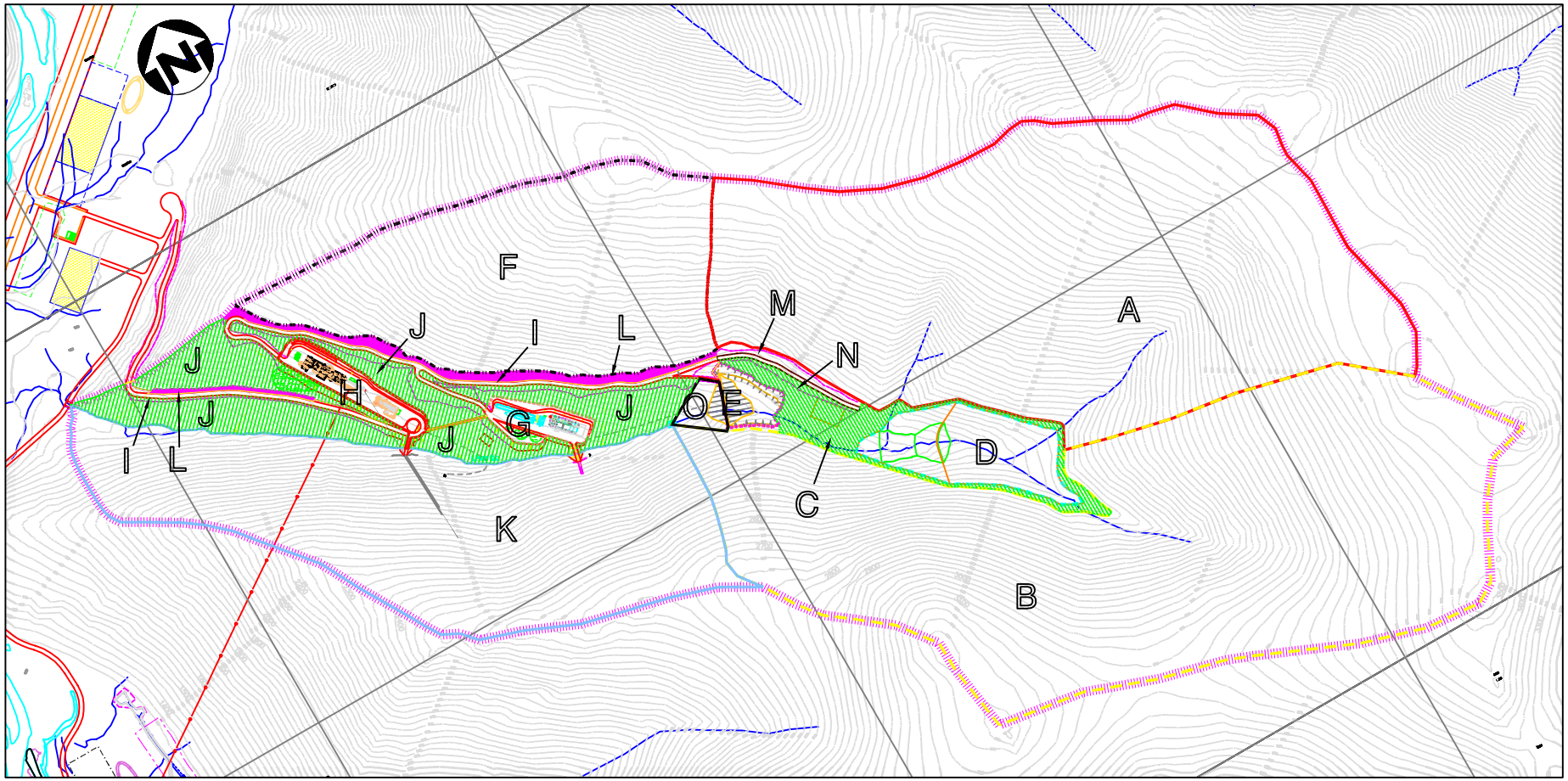
3.4 Water Balance & Quality Modeling

The Pogo water balance and quality model was rerun based on the revised Table 4.4 of the February 2002 Water Management Plan, now Table 3.1 of this June 2002 Supplement, to better evaluate the water quantity and quality.

The Monte Carlo model was rerun varying the inputs according to the appropriate probability density functions, that is weekly variation of all water quality inputs and revision of the inputs as described above.

The model was updated to incorporate the input changes described in Table 3.1 and using weekly variation of the water quality predictions.

Differences in simulation results between R19a, the February 2002 Water Management Plan and R21, this June 2002 Supplement, other than the concentration outputs in Table 5.1, are shown in Table 3.3.



AREA	CATCHMENT AREA (ACRES)	AREA	CATCHMENT AREA (ACRES)	AREA	CATCHMENT AREA (ACRES)
A	390	F	166	K	217
B	414	G	9	L	11
C	21	H	11	M	4
D	32	I	12	N	2
E	7	J	81	O	5

TOTAL (AREA A TO O) 1,382 ACRES

SCALE 1" = 1,000'

0 1,000 2,000 3,000 4,000 FT.

teckcominco
Teck–Pogo Inc.

Figure 3.1
Pogo Mine
Catchment Areas

CAD FILE NAME: WMP supp figure 3.1.dwg
LAST UPDATED: 02/06/13 9:24am

Table 3.3: Comparison of Result for February 2002 Model Simulation vs. June 2002

Category	Feb 2002 WMP	June WMP Supplement
Mean annual precipitation	19"	19"
Mean RTP to Treatment	155 gpm	120 gpm
Mean Recycle off-spec to RTP	31 gpm	2.4 gpm
No. of spills in 1000 simulations (years)	22	10
PumpBack Water	13 gpm	8 gpm
Mean RTP Water Treated	155 gpm	120 gpm

The differences in the treatment flows and recycles can be attributed to the use of weekly distributions for TDS and SO4, upon which the recycle flows depend. The use of weekly distributions rather than annual reduces the modeling impact of high influent values as the values in the next period are likely to be lower. This is definitely a more realistic result than using fixed annual inputs.

The lower recycle flows in the June 2002 Supplement model results in a reduction in modeled spillway usage in 1,000 iterations. The difference in pumpback water flow is attributed to a reduction in the estimated catchment area from 16 acres to 5 acres. The difference is not proportional to area because it also includes estimated seepage under the dam.

3.5 Chemical Treatment Process System (Water Treatment Plant)

The February 2002 Water Management Plan described the Water Treatment Plant (WTP) for Pogo. The WTP will utilize two basic processes to remove contaminants from the water before discharge. These processes are:

- High-Density Sludge (HDS) process to achieve enhanced co-precipitation of metals, including arsenic.
- Partial Lime Softening and Recarbonation to remove calcium, magnesium and other metals, thereby reducing metals and TDS.

Sulfide precipitation, will be an installed contingency treatment measure to be used as necessary to achieve the projected metals concentration limits. The use of sulfide precipitation has been shown to be effective for heavy metals, and while probably not capable of achieving the very low theoretical levels demonstrated in Table 2.1, may be required to achieve the projected metal limits for certain elements. The process will utilize sodium hydrosulfide (NaHS), sodium sulfide (Na_2 S) or other reagents, to

precipitate and remove heavy metals from the WTP effluent. As shown below, sulfide precipitation takes advantage of the extremely low solubility of these metal sulfides to achieve low levels in the discharge stream.

$M^{+2} + HS^{-} \Leftrightarrow MS + H^{+}$

$H^{+} + OH^{-} \Leftrightarrow H_2O$

$M^{+2} + S^{-2} \Leftrightarrow MS$

The much lower metal solubilities associated with the metal sulfides, as shown in Table 2.1, and demonstrated by various papers in Section 2 provides confidence that the Pogo WTP can meet the projected effluent targets.

System Performance

Subject to proper design, process optimization and operation, the proposed treatment scheme can typically treat feeds containing metals at concentrations several orders of magnitude greater than the RTP water characteristics predicted by modeling. Therefore, the water treatment plant performance with respect to metals will not be sensitive to the accuracy of the influent water quality estimates for the RTP. The following Table 3.4 shows the revised predicted WTP performance for the highest expected values of the Pogo WTP influent. The values for Cu and Se have been increased from 0.005 to 0.010 mg/ℓ and 0.002 to 0.003 mg/ℓ respectively based on the investigations described in Section 2. The value for Mn has been reduced from 0.200 mg/ℓ to 50 mg/ℓ based on the demonstrated performance of the existing Pogo WTP also as described in Section 2. Table 3.4 values are used to predict effluent values in Section 4 following.

Table 3.4: Expected WTP Treatment Performance

Parameter	WTP Feed Maximum	Estimate for Treated Effluent
TSS (mg/ℓ)	1,483	20
TDS (mg/ℓ)	640	85%
As (mg/ℓ)	5.36	0.03
Cd (mg/ℓ)	0.00062	0.0003
Cr (mg/ℓ)	0.0131	0.03
Cu (mg/ℓ)	**0.0319**	**0.010**
Fe (mg/ℓ)	4.25	0.30
Pb (mg/ℓ)	0.0695	0.001
Hg (µg/ℓ)	0.283	0.10
Mn (mg/ℓ)	**1.25**	**0.050**
Ni (mg/ℓ)	0.0341	0.03
Se (mg/ℓ)	**0.00779**	**50% to 0.003**
Ag (mg/ℓ)	0.00013	0.0001
Zn (mg/ℓ)	0.0669	0.015

SECTION 4 | WATER TREATMENT & DISCHARGE

4.1 Treatment Predictions

This section presents the results of the modeling described in Section 3, and develops appropriate conclusions based on this work. The Monte Carlo water balance and quality model was described in Section 4 of the Water Management Plan. The model has been used to generate predicted water quality for the various streams of interest for the Pogo project.

The results are presented in Table 4.1 for the base case Monte Carlo modeling of both inflows and water quality chemistry.

These tables show that under the given scenarios, the combined treatment provided by the water treatment plant and the soil absorption system will ensure that the release of treated effluent has no significant adverse effect on the Goodpaster River.

4.2 Summary of Changes in Water Quality Predictions

This June 2002 Supplement to the February 2002 Water Management Plan presents an updated analysis in response to agency comments on the Water Management Plan.

Weekly inputs have been used for several model parameters as described in Sections 3.1 and 3.2. The changes to input chemistry for Monte Carlo modeling are presented in Table 3.1. As shown in Table 3.3, these changes reduce the need to recycle treated effluent due to high TDS or SO_4, and hence buildup of contaminants in the RTP resulting from this practice is reduced. The results also reflect the changes in treatment predictions summarized in Table 3.4.

Table 4.2 compares the results of the February 2002 Water Management Plan to this June 2002 Supplement. With respect to the WTP discharge water quality most parameters are reduced somewhat except for Cu and Se, where the predicted treatment levels have been decreased. TDS and SO_4 levels have decreased substantially, while CN_T, Mn, and Ag have decreased to a lesser extent.

Table 4.1: Water Treatment & Water Quality Predictions for Variable Weekly Inputs (Revised from February 2002 WMP Table 5.1)

	RTP Quality			WTP Feed Quality			WTP Treatment	SAS Feed Quality		
Parameter	RTP Mean Annual Average Dissolved	RTP 95% Annual Average Dissolved	RTP 95% Annual Maximum Dissolved	WTP Feed Mean Annual Average Dissolved	WTP Feed 95% Annual Average Dissolved	WTP Feed 95% Annual Maximum Dissolved	Estimate for Treated Effluent	SAS Feed Mean Annual Average Dissolved	SAS Feed 95% Annual Average Dissolved	Upset Dissolved
TSS (mg/ℓ)	31.7	92.3	281	602	1,097	1,485	20	19.1	20.0	40
TDS (mg/ℓ)	299	364	465	246	364	448	85%	220	309	728
Chloride (mg/ℓ)	38.3	54	78	24.4	43	73	Note1	85.2	108	86
Sulfate (mg/ℓ)	88	123	175	81	143	179	Note1	92	143	285
TKN - mg/ℓ N	1.56	2.11	2.37	4.78	7.74	10.04	Note1	4.91	7.74	15.5
Nitrate - mg/ℓ N	6.97	10.7	26.5	5.39	8.7	24.6	Note1	6.2	9.8	17.5
Cyanide Total (mg/ℓ)	0.0066	0.0090	0.0131	0.0080	0.0159	0.0205	Note1	0.0085	0.0159	0.200
As (mg/ℓ)	0.235	0.388	0.862	2.19	3.92	5.36	0.03	0.0300	0.0300	0.0600
Cd (mg/ℓ)	0.00015	0.00026	0.00041	0.00032	0.00048	0.00062	0.0003	0.00022	0.00030	0.00060
Cr (mg/ℓ)	0.00213	0.00319	0.0049	0.00641	0.00999	0.0131	0.03	0.00620	0.00999	0.06000
Cu (mg/ℓ)	0.00538	0.00877	0.01020	0.0147	0.0233	0.0319	0.01	0.00802	0.01000	0.0200
Fe (mg/ℓ)	0.859	1.27	2.66	1.06	2.32	3.30	0.30	0.300	0.300	0.600
Pb (mg/ℓ)	0.00042	0.00083	0.00116	0.0272	0.0504	0.0695	0.001	0.00075	0.00100	0.00200
Hg (µg/ℓ)	0.0680	0.087	0.146	0.078	0.153	0.210	0.10	0.0683	0.096	0.200
Mn (mg/ℓ)	0.405	0.632	1.48	0.345	0.568	1.41	0.05	0.050	0.050	0.100
Ni (mg/ℓ)	0.00328	0.0079	0.0181	0.0149	0.0249	0.0341	0.03	0.0140	0.0234	0.0600
Se (mg/ℓ)	0.00298	0.00654	0.01252	0.00419	0.00575	0.00873	50%>.003	0.00315	0.00335	0.005
Ag (mg/ℓ)	0.00005	0.00006	0.00009	0.00005	0.00007	0.00009	0.0001	0.00005	0.00007	0.00020
Zn (mg/ℓ)	0.0354	0.0649	0.0842	0.0302	0.0454	0.0677	0.015	0.0150	0.0150	0.0300

Note1: no freeze protection water to SAS.

Table 4.1: Water Treatment & Water Quality Predictions – Continued

Parameter	SAS Treatment			After SAS Treatment			Groundwater Mixing, Attenuation & Dispersivity				Potential Water Quality in Goodpaster River[2]					Goodpaster Criteria
	Treatment for Mean %	Treatment for 95th Percentile	Treatment for Upset	Mean Annual Average Dissolved	95th Percentile Annual Average Dissolved	Upset Dissolved	Ground-water Quality	Mean Annual Average Dissolved	95th Percentile Annual Average Dissolved	Upset Dissolved	Goodpaster Quality Total	Dissolved to Total Xlator	Annual Average Goodpaster	95th Percentile Goodpaster	Upset Goodpaster	
TSS (mg/ℓ)	0%	0%	0%	19.1	20.0	40.0	7.65	13.40	13.8	23.8	5.70	1.00	5.96	5.98	6.32	30
TDS (mg/ℓ)	0%	0%	0%	220	309	728	88.8	155	199	408	75.0	1.00	77.7	79.3	86.5	100[3]
Chloride (mg/ℓ)	0%	0%	0%	85.2	107.6	86	0.388	42.8	54.0	43.0	0.340	1.00	1.80	2.2	1.81	230
Sulfate (mg/ℓ)	0%	0%	0%	92	143	285	27.5	59.8	85	156	16.7	1.00	18.2	19.1	21.5	250
TKN - mg/ℓ N	30%	30%	60%	3.43	5.42	6.19	0.117	1.78	2.77	3.16	0.200	1.00	0.254	0.288	0.302	10
Nitrate - mg/ℓ N	0%	0%	0%	7.7	12.1	26.7	0.148	3.93	6.15	13.4	0.232	1.00	0.359	0.436	0.687	10
Cyanide Total (mg/ℓ)	30%	30%	60%	0.00596	0.0112	0.0800	0.00250	0.00423	0.00683	0.0413	0.00430	1.00	0.00430	0.00439	0.00557	0.0052
As (mg/ℓ)	40%	40%	80%	0.0180	0.0180	0.0120	0.00073	0.00936	0.00936	0.00636	0.00029	0.87	0.00065	0.00065	0.00053	0.05
Cd (mg/ℓ)	0%	0%	0%	0.00022	0.00030	0.00060	0.00003	0.00013	0.00016	0.00032	0.00002	0.92	0.00003	0.00003	0.00003	0.0004
Cr (mg/ℓ)	40%	40%	80%	0.00372	0.00599	0.01200	0.00036	0.00204	0.00318	0.00618	0.00089	0.68	0.00096	0.00102	0.00117	0.071
Cu (mg/ℓ)	5%	5%	10%	0.00762	0.00950	0.01800	0.00063	0.00413	0.00506	0.00931	0.00088	0.92	0.00100	0.00104	0.00120	0.0039
Fe (mg/ℓ)	25%	25%	50%	0.225	0.225	0.300	0.102	0.163	0.163	0.201	0.147	0.32	0.160	0.160	0.164	0.30
Pb (mg/ℓ)	0%	0%	0%	0.00075	0.00100	0.00200	0.00015	0.00045	0.00057	0.0011	0.00048	0.75	0.00048	0.00049	0.00051	0.0006
Hg (µg/ℓ)	0%	0%	0%	0.0683	0.096	0.200	0.00519	0.0367	0.0506	0.103	0.00660	0.87	0.0078	0.0084	0.01043	0.012
Mn (mg/ℓ)	0%	0%	0%	0.050	0.050	0.100	0.0323	0.0411	0.041	0.066	0.0101	0.89	0.0114	0.0114	0.0123	0.050
Ni (mg/ℓ)	40%	40%	80%	0.00838	0.0140	0.01200	0.00024	0.00431	0.00714	0.00612	0.00062	0.94	0.00076	0.00086	0.00082	0.052
Se (mg/ℓ)	40%	40%	80%	0.00189	0.00201	0.00100	0.00050	0.00119	0.00125	0.00075	0.00060	0.76	0.00063	0.00064	0.00061	0.005
Ag (mg/ℓ)	0%	0%	0%	0.00005	0.00007	0.00020	0.00001	0.00003	0.00004	0.00010	0.00001	0.39	0.00001	0.00001	0.00002	0.00012
Zn (mg/ℓ)	30%	30%	60%	0.01050	0.01050	0.0120	0.00117	0.00583	0.00583	0.00658	0.00107	0.95	0.00124	0.00124	0.00127	0.035

1. WTP not effective at treatment for these parameters. **2**. Goodpaster flow taken as 50 cfs. **3**. Standard is 1.33 times background.

Table 4.2: Comparison of Water Quality Predictions

Parameter	RTP Quality				WTP Feed Quality				SAS Feed Quality					
	Feb 2002 RTP Mean Annual Average Dissolved	Jun 2002 RTP Mean Annual Average Dissolved	Feb 2002 RTP 95% Annual Average Dissolved	Jun 2002 RTP 95% Annual Average Dissolved	Feb 2002 WTP Feed Mean Annual Average Dissolved	Jun 2002 WTP Feed Mean Annual Average Dissolved	Feb 2002 WTP Feed 95% Annual Average Dissolved	Jun 2002 WTP Feed 95% Annual Average Dissolved	Feb 2002 SAS Feed Mean Annual Average Dissolved	Jun 2002 SAS Feed Mean Annual Average Dissolved	Feb 2002 SAS Feed 95% Annual Average Dissolved	Jun 2002 SAS Feed 95% Annual Average Dissolved	Feb 2002 Upset Dissolved	Jun 2002 Upset Dissolved
TSS (mg/ℓ)	32.4	31.7	89.4	92.3	462	602	1,064	1,097	19.2	19.1	20.0	20.0	40	40
TDS (mg/ℓ)	281	299	396	364	352	246	465	364	317	220	402	309	929.9	728.1
Chloride (mg/ℓ)	85.1	38.3	228.4	54.4	52.6	24.4	139.3	42.8	99.0	85.2	139.3	107.6	279	86
Sulfate (mg/ℓ)	102.0	87.7	168	123	132	81	200	143	139	92	201	143	400.9	285.0
TKN - mg/ℓ N	2.31	1.56	4.86	2.11	4.39	4.78	7.55	7.74	4.49	4.91	7.55	7.74	15	15
Nitrate - mg/ℓ N	7.04	6.97	13.8	10.7	7.60	5.39	12.3	8.7	8.4	6.2	13.1	9.8	24.63	17.45
Cyanide Total (mg/ℓ)	0.0125	0.0066	0.0172	0.0090	0.0164	0.0080	0.0227	0.0159	0.0163	0.0085	0.0227	0.0159	0.20	0.20
As (mg/ℓ)	0.184	0.235	0.488	0.388	1.68	2.19	3.79	3.92	0.0300	0.0300	0.0300	0.0300	0.06	0.06
Cd (mg/ℓ)	0.00017	0.00015	0.00027	0.00026	0.00029	0.00032	0.00046	0.00048	0.00022	0.00022	0.00029	0.00030	0.00	0.00
Cr (mg/ℓ)	0.00314	0.00213	0.00600	0.00319	0.00587	0.00641	0.00967	0.00999	0.00561	0.00620	0.00967	0.00999	0.06000	0.06000
Cu (mg/ℓ)	0.00513	0.00538	0.00767	0.00877	0.0122	0.0147	0.0219	0.0233	0.00483	0.00802	0.00500	0.01000	0.01000	0.02000
Fe (mg/ℓ)	0.678	0.859	1.23	1.27	1.71	1.06	3.26	2.32	0.300	0.300	0.300	0.300	0.60000	0.60000
Pb (mg/ℓ)	0.00052	0.00042	0.00090	0.00083	0.0207	0.0272	0.0488	0.0504	0.00075	0.00075	0.00100	0.00100	0.002	0.002
Hg (µg/ℓ)	0.0731	0.0680	0.104	0.087	0.129	0.078	0.212	0.153	0.0797	0.0683	0.100	0.096	0.20000	0.20000
Mn (mg/ℓ)	0.364	0.405	0.885	0.632	0.492	0.345	0.884	0.568	0.197	0.050	0.200	0.050	0.400	0.100
Ni (mg/ℓ)	0.00588	0.00328	0.0144	0.0079	0.0133	0.0149	0.0239	0.0249	0.0125	0.0140	0.0226	0.0234	0.060	0.060
Se (mg/ℓ)	0.00252	0.00298	0.00504	0.00654	0.00354	0.00419	0.00494	0.00575	0.00193	0.00315	0.00200	0.00335	0.0040	0.0050
Ag (mg/ℓ)	0.00006	0.00005	0.00008	0.00006	0.00007	0.00005	0.00010	0.00007	0.00007	0.00005	0.00009	0.00007	0.00020	0.00020
Zn (mg/ℓ)	0.0304	0.0354	0.0541	0.0649	0.0286	0.0302	0.0438	0.0454	0.0150	0.0150	0.0150	0.0150	0.03000	0.03000

Table 4.2: Comparison of Water Quality Predictions – continued

Parameter	After SAS Treatment						Groundwater Mixing, Attenuation, and Dispersivity						Potential Water Quality in Goodpaster River					
	Mean Annual Average Dissolved	Mean Annual Average Dissolved	95th Percentile Annual Average Dissolved	95th Percentile Annual Average Dissolved	Upset Dissolved	Upset Dissolved	Feb 2002 Mean Annual Average Dissolved	Jun 2002 Mean Annual Average Dissolved	Feb 2002 95th Percentile Annual Avg. Diss.	Jun 2002 95th Percentile Annual Avg. Diss.	Feb 2002 Upset Dissolved	Jun 2002 Upset Dissolved	Feb 2002 Annual Average Goodpaster	Jun 2002 Annual Average Goodpaster	Feb 2002 95th Percentile Goodpaster	Jun 2002 95th Percentile Goodpaster	Feb 2002 Upset Goodpaster	Jun 2002 Upset Goodpaster
TSS (mg/ℓ)	19.2	19.1	20.0	20.0	40.0	40.0	13.4	13.40	13.8	13.8	23.8	23.8	5.97	5.96	5.98	5.98	6.32	6.32
TDS (mg/ℓ)	317	220	402	309	930	728	203	155	246	199	509	408	79.4	77.7	80.9	79.3	90.0	86.5
Chloride (mg/ℓ)	99.0	85.2	139.3	107.6	278.5	85.6	49.7	42.8	69.8	54.0	139.5	43.0	2.039	1.801	2.732	2.187	5.129	1.808
Sulfate (mg/ℓ)	139	92	201	143	401	285	83.5	59.8	114	85	214	156	19.0	18.2	20.1	19.1	23.5	21.5
TKN - mg/ℓ N	3.14	3.43	5.28	5.42	6.04	6.19	1.63	1.78	2.70	2.77	3.08	3.16	0.249	0.254	0.286	0.288	0.299	0.302
Nitrate - mg/ℓ N	9.76	7.70	15.41	12.15	33.68	26.74	4.96	3.93	7.78	6.15	16.92	13.4	0.395	0.359	0.492	0.436	0.806	0.687
Cyanide Total (mg/ℓ)	0.01143	0.00596	0.01589	0.01116	0.08000	0.08000	0.00697	0.00423	0.00920	0.00683	0.04125	0.0413	0.00439	0.00430	0.00447	0.00439	0.00557	0.00557
As (mg/ℓ)	0.01800	0.01800	0.01800	0.01800	0.01200	0.01200	0.00936	0.00936	0.00936	0.00936	0.00636	0.00636	0.00065	0.00065	0.00065	0.00065	0.00053	0.00053
Cd (mg/ℓ)	0.00022	0.00022	0.00029	0.00030	0.00060	0.00060	0.00012	0.00013	0.00016	0.00016	0.00032	0.00032	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003
Cr (mg/ℓ)	0.00337	0.00372	0.00580	0.00599	0.01200	0.01200	0.00187	0.00204	0.00308	0.00318	0.00618	0.00618	0.00095	0.00096	0.00102	0.00102	0.00117	0.00117
Cu (mg/ℓ)	0.00459	0.00762	0.00475	0.00950	0.00900	0.01800	0.00261	0.00413	0.00269	0.00506	0.00481	0.00931	0.00095	0.00100	0.00095	0.00104	0.00103	0.00120
Fe (mg/ℓ)	0.225	0.225	0.225	0.225	0.300	0.300	0.163	0.163	0.163	0.163	0.201	0.201	0.160	0.160	0.160	0.160	0.164	0.164
Pb (mg/ℓ)	0.00075	0.00075	0.00100	0.00100	0.00200	0.00200	0.00045	0.00045	0.00057	0.00057	0.00107	0.0011	0.00048	0.00048	0.00049	0.00049	0.00051	0.00051
Hg (µg/ℓ)	0.0797	0.0683	0.1000	0.0960	0.2000	0.2000	0.0424	0.0367	0.0526	0.0506	0.1026	0.103	0.00805	0.00783	0.00845	0.00837	0.01043	0.01043
Mn (mg/ℓ)	0.197	0.050	0.200	0.050	0.400	0.100	0.1145	0.0411	0.116	0.041	0.216	0.066	0.0142	0.0114	0.0143	0.0114	0.0181	0.0123
Ni (mg/ℓ)	0.00751	0.00838	0.01355	0.01404	0.01200	0.01200	0.00387	0.00431	0.00689	0.00714	0.00612	0.00612	0.00074	0.00076	0.00085	0.00086	0.00082	0.00082
Se (mg/ℓ)	0.00116	0.00189	0.00120	0.00201	0.00080	0.00100	0.00083	0.00119	0.00085	0.00125	0.00065	0.00075	0.00062	0.00063	0.00062	0.00064	0.00061	0.00061
Ag (mg/ℓ)	0.00007	0.00005	0.00009	0.00007	0.00020	0.00020	0.00004	0.00003	0.00005	0.00004	0.00010	0.00010	0.00001	0.00001	0.00001	0.00001	0.00002	0.00002
Zn (mg/ℓ)	0.01050	0.01050	0.01050	0.01050	0.01200	0.01200	0.00583	0.00583	0.00583	0.00583	0.00658	0.00658	0.00124	0.00124	0.00124	0.00124	0.00127	0.00127

SECTION 5 | MODFLOW MODELING

5.1 Modeling Objective

The Modflow modeling was carried out as described in the May 13, 2002 memo from Davies and Emerson (Appendix C).

As discussed the purpose of this analysis is to evaluate the post SAS water quality along the flow path from the Soil Adsorption System to the Goodpaster River. The following Tables 5.1 and 5.2 show the maximum predicted groundwater concentrations in the aquifer immediately adjacent to the Goodpaster River for SAS application rates of 144 and 365 gpm based on the revised predictions for SAS water quality presented in Section 4.

Figure 5.1 provides the observation locations used to track the predicted groundwater chemistry adjacent to the Goodpaster River. Figures 5.2 through 5.6 show the geochemical profile between stations OB-1 and OB-14 along the Goodpaster River for various parameters. Along this profile, the modeling indicates two peaks in predicted concentrations near stations OB-3 and OB-10. Figure 5.7 shows the transient simulation for iron.

Table 5.1: Maximum Predicted Groundwater Concentrations under Average SAS Application Rate of 144 gpm

Parameter	Groundwater Quality (Dissolved)	Mean Annual Average Discharge (Dissolved)	95th Percentile Annual Average Discharge (Dissolved)	Maximum Groundwater Concentration at River Assuming 95th Percentile Loading (Total)	Goodpaster Criteria (Total)
TSS	7.65	19.1	20	N/A	30
TDS	88.8	220	309	128.4	100
Cl	0.388	85.2	107.6	N/A	230
SO4	27.5	92	143	N/A	250
TKN	0.117	3.43	5.42	N/A	10
NO3	0.148	7.7	12.1	4.93	10
CNT	0.0025	0.00596	0.0112	0.0046	0.0052
As	0.00073	0.018	0.018	N/A	0.05
Cod	0.0003	0.00022	0.0003	N/A	0.0004
Cr	0.00036	0.00372	0.00599	N/A	0.071
Cu	0.00063	0.00762	0.0095	0.0006	0.0039
Fe	0.102	0.225	0.225	0.3	0.3
Pb	0.00015	0.00075	0.001	0.00015	0.0006
Hg	0.00519	0.0683	0.96	0.00519	0.012
Mn	0.0323	0.05	0.05	0.0235	0.05
Ni	0.00024	0.00838	0.014	N/A	0.052
Se	0.0005	0.00189	0.00201	N/A	0.005
Ag	0.0001	0.00005	0.0007	0.0001	0.00012
Zn	0.00117	0.0105	0.0105	N/A	0.035

Note: All Concentration in mg/ℓ except Mercury which is µm/ℓ.

Table 5.2: Maximum Predicted Groundwater Concentrations under 95th Percentile Application Rate of 365 gpm

Parameter	Groundwater Quality (Dissolved)	Mean Annual Average Discharge (Dissolved)	95th Percentile Annual Average Discharge (Dissolved)	Maximum Groundwater Concentration at River Assuming 95th Percentile Loading (Total)	Goodpaster Criteria (Total)
TSS	7.65	19.1	20	N/A	30
TDS	88.8	220	309	222	100
Cl	0.388	85.2	107.6	N/A	230
SO4	27.5	92	143	N/A	250
TKN	0.117	3.43	5.42	N/A	10
NO3	0.148	7.7	12.1	8.62	10
CNT	0.0025	0.00596	0.0112	0.0077	0.0052
As	0.00073	0.018	0.018	N/A	0.05
Cod	0.0003	0.00022	0.0003	N/A	0.0004
Cr	0.00036	0.00372	0.00599	N/A	0.071
Cu	0.00063	0.00762	0.0095	0.00084	0.0039
Fe	0.102	0.225	0.225	0.506	0.3
Pb	0.00015	0.00075	0.001	0.00015	0.0006
Hg	0.00519	0.0683	0.096	0.00519	0.012
Mn	0.0323	0.05	0.05	0.04	0.05
Ni	0.00024	0.00838	0.014	N/A	0.052
Se	0.0005	0.00189	0.00201	N/A	0.005
Ag	0.0001	0.00005	0.0007	0.0001	0.00012
Zn	0.00117	0.0105	0.0105	N/A	0.035

Notes: All concentration in mg/ℓ except mercury, which is µm/ℓ.
N/A: Input concentrations less than criteria.

Figure 5.1: Example of Plume; TDS at 365 gpm and Observation Stations OB1-OB14

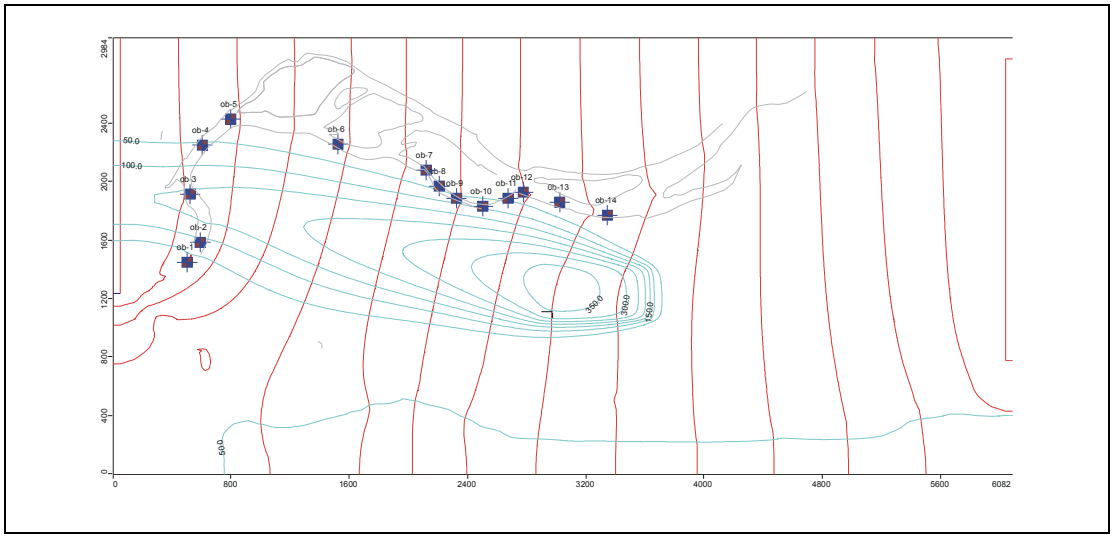


Figure 5.2: TDS in Groundwater at OB1-OB14 at 144 and 365 gpm

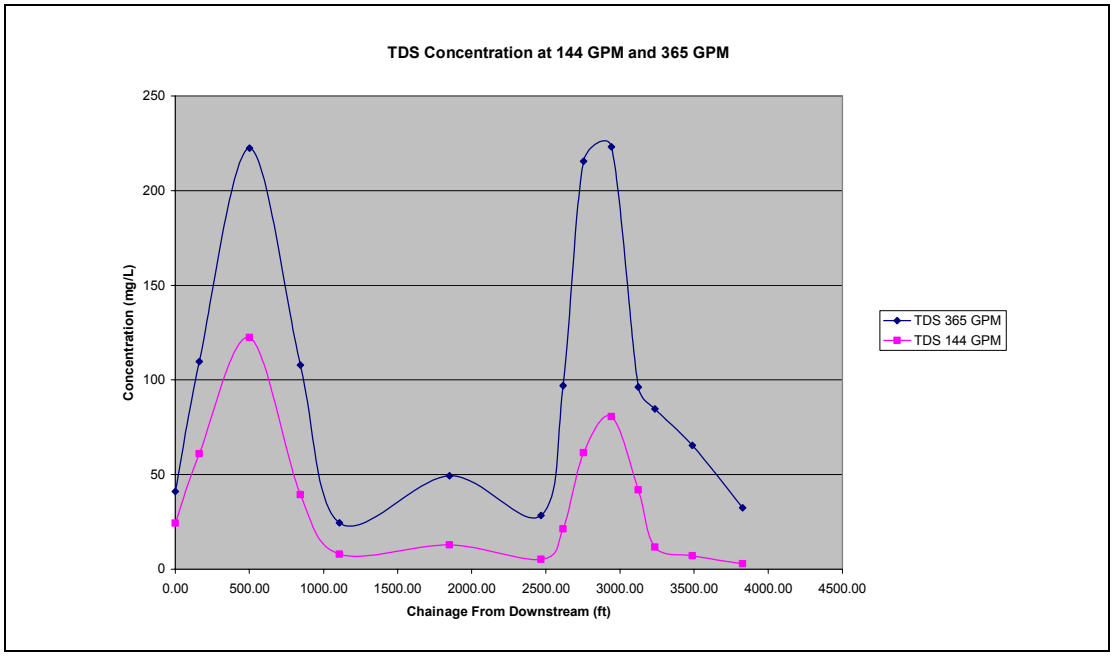


Figure 5.3: Nitrate along River at OB1-OB14 at 144 and 365 gpm

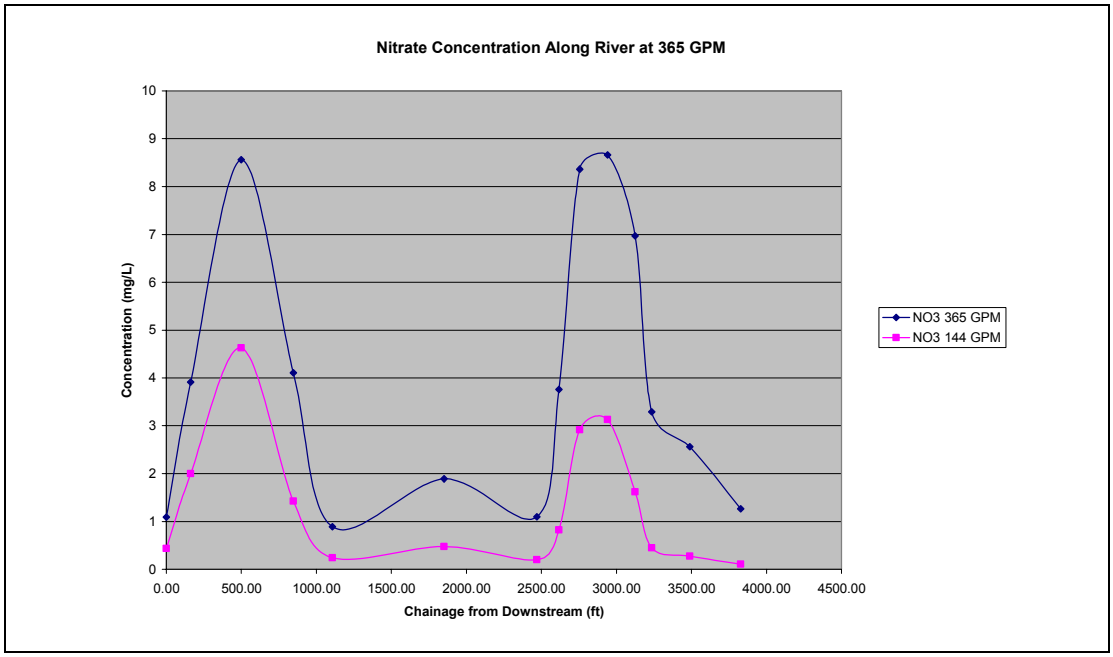


Figure 5.4: Cyanide along River at OB1-OB14 at 144 and 365 gpm

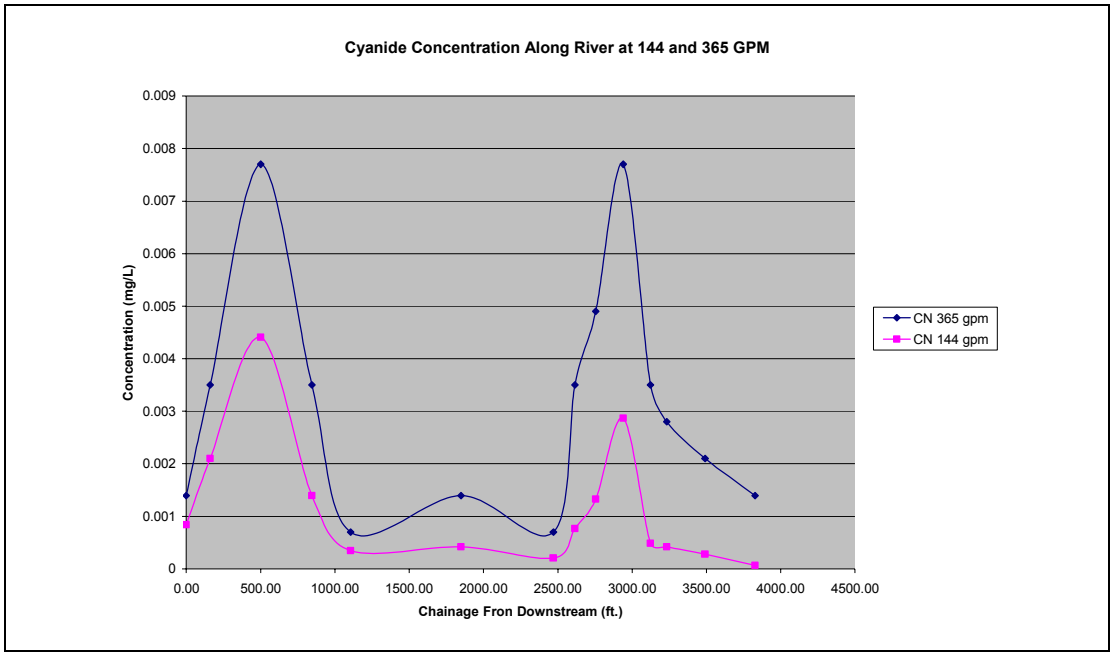


Figure 5.5: Iron along River at OB1-OB14 at 144 and 365 gpm

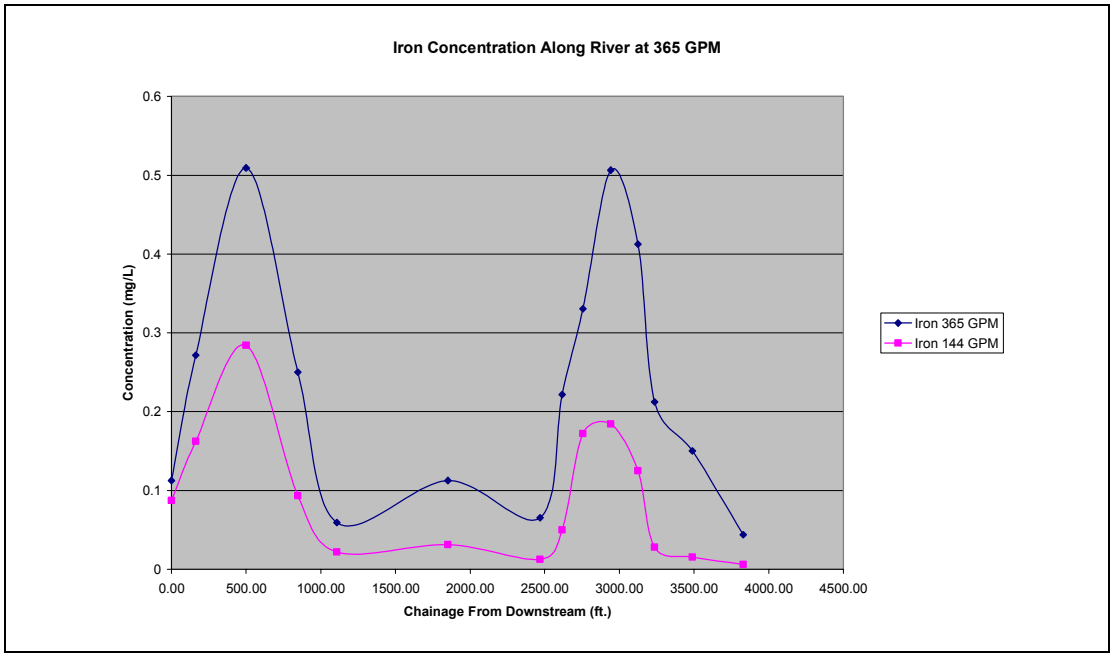


Figure 5.6: Manganese along River at OB1-OB14 at 144 and 365 gpm

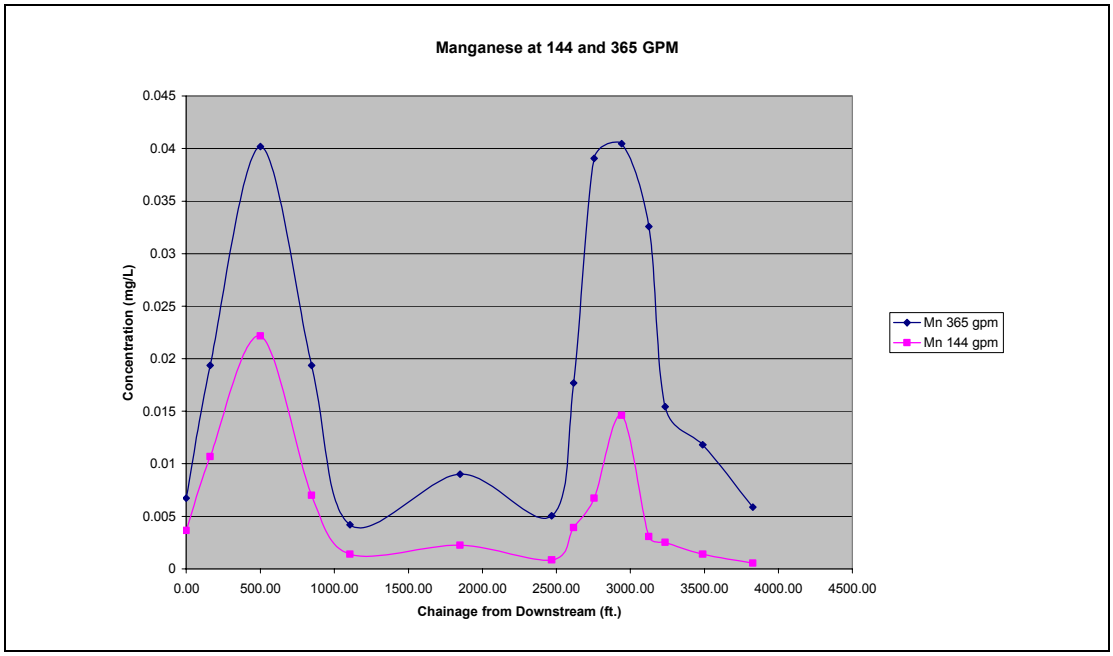
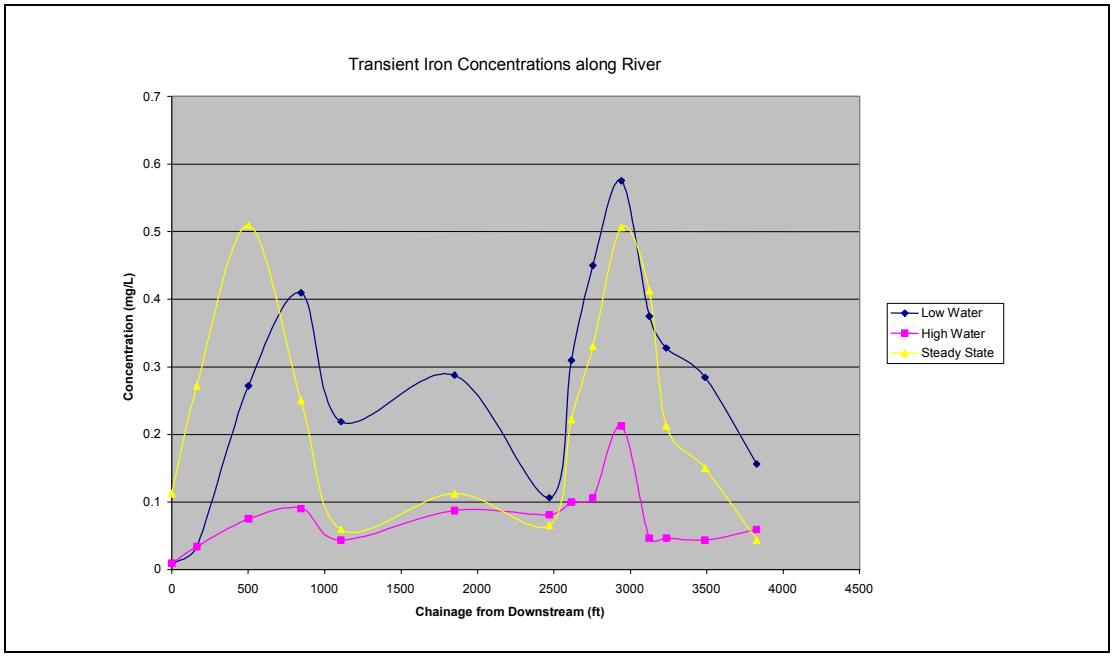


Figure 5.7: Iron along River during Transient Simulation



Reference

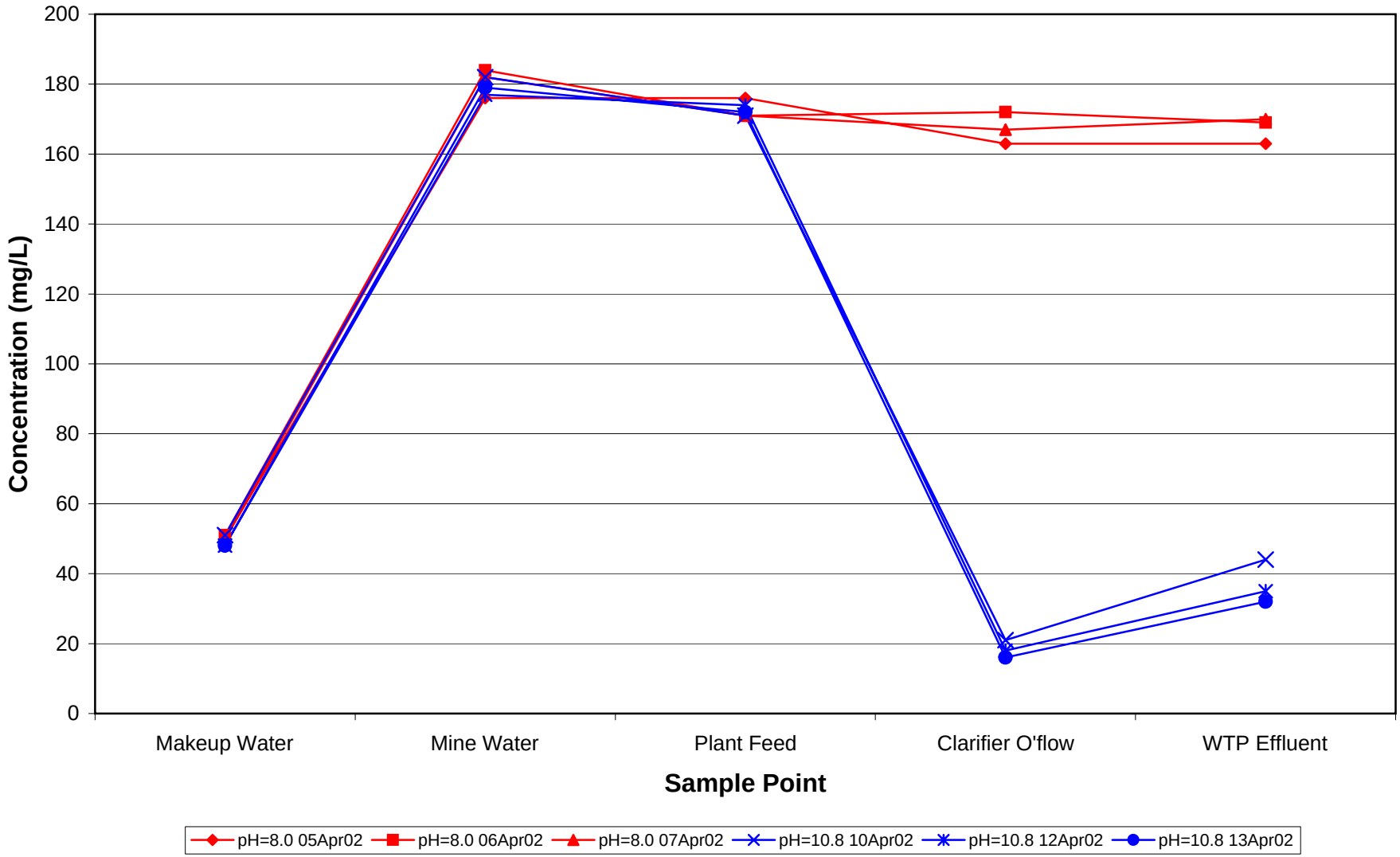
US Environmental Protection Agency (1999). Partition Coefficients for Metals in Surface Water, Soil, and Waste. US EPA, Office of Solid Waste, June 22.

Appendix A

Water Treatment Field Trial

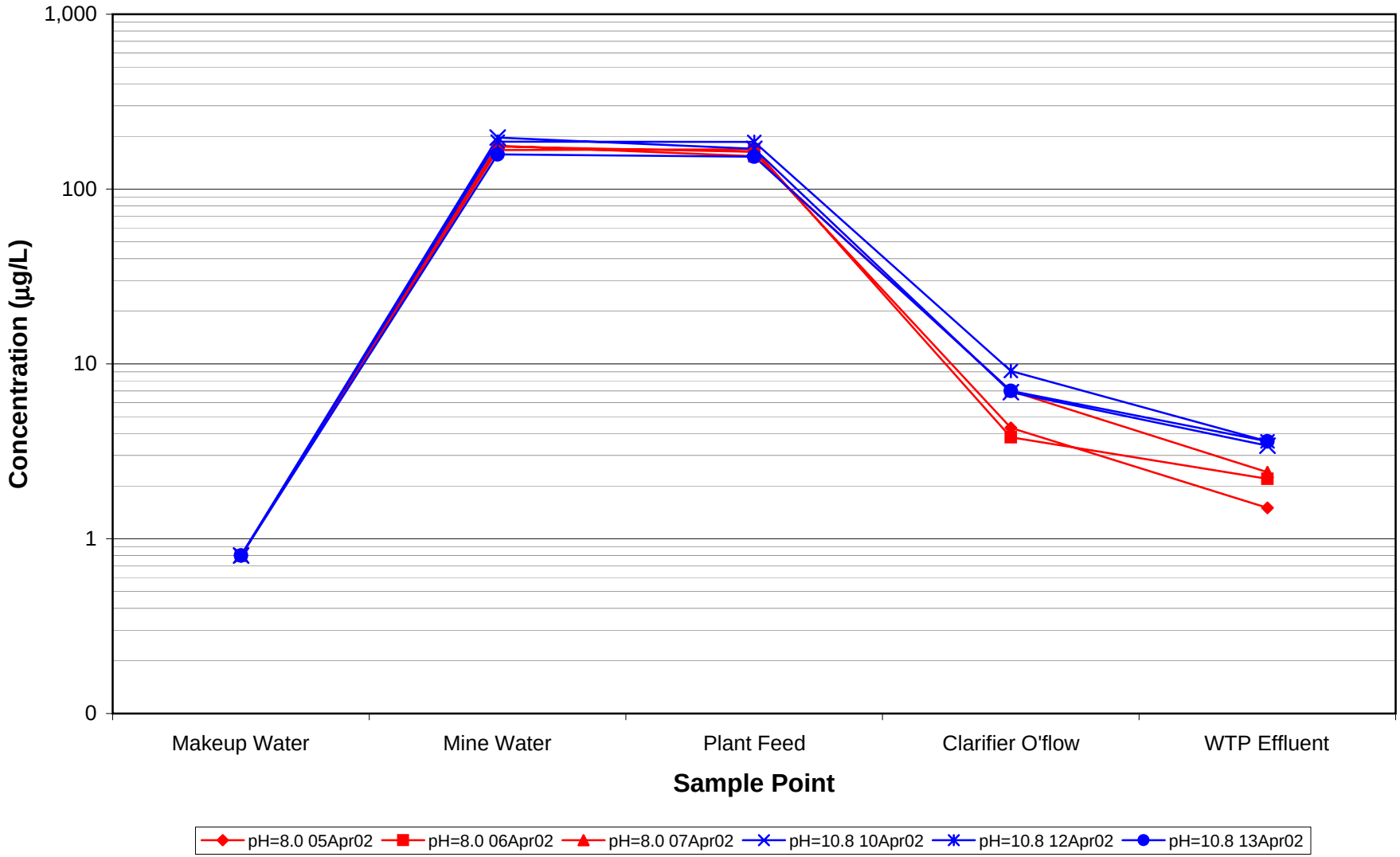
Teck-Pogo Inc.
Lime Softening Investigation

Alkalinity, Total as CaCO3



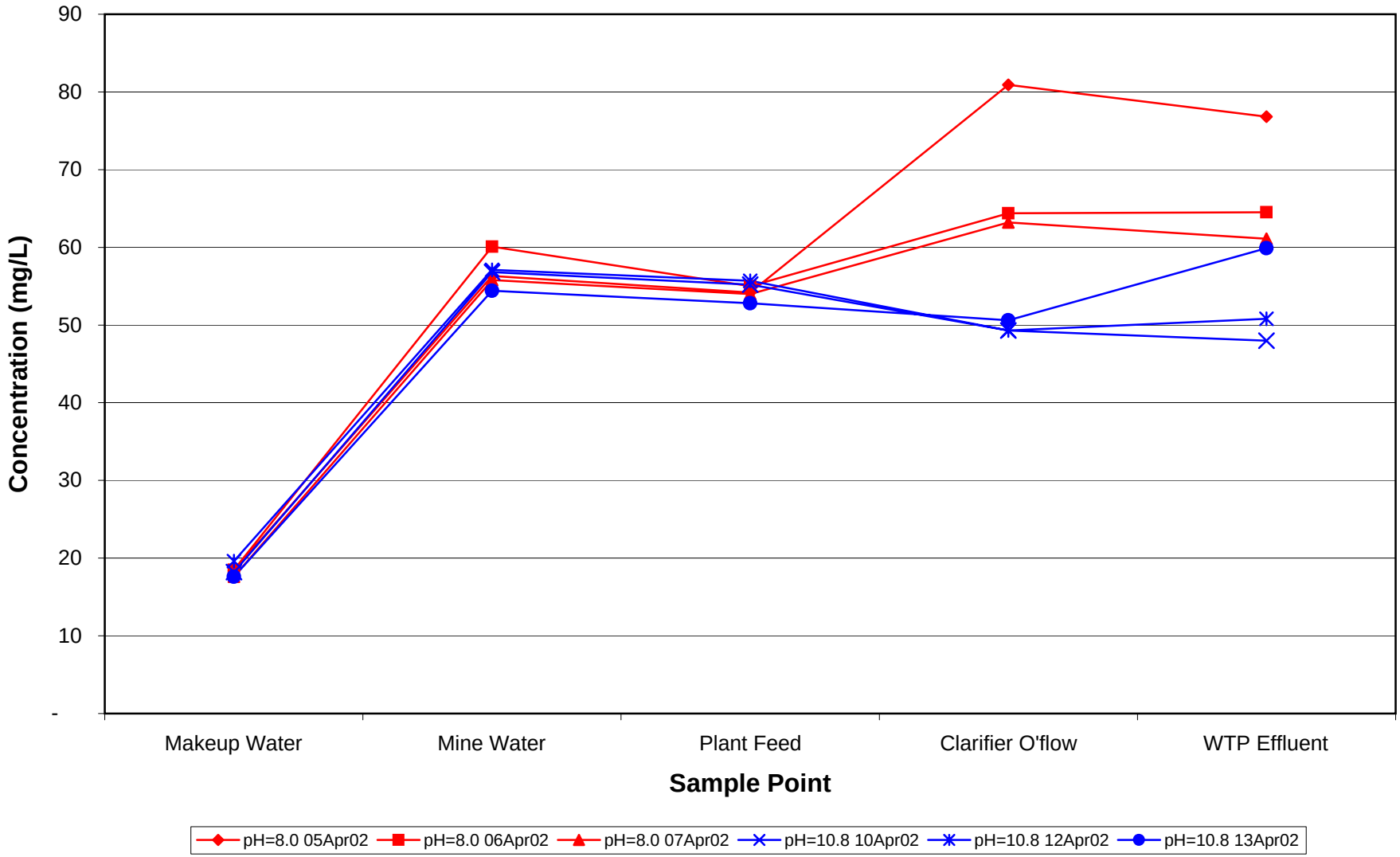
Teck-Pogo Inc.
Lime Softening Investigation

Arsenic, Total



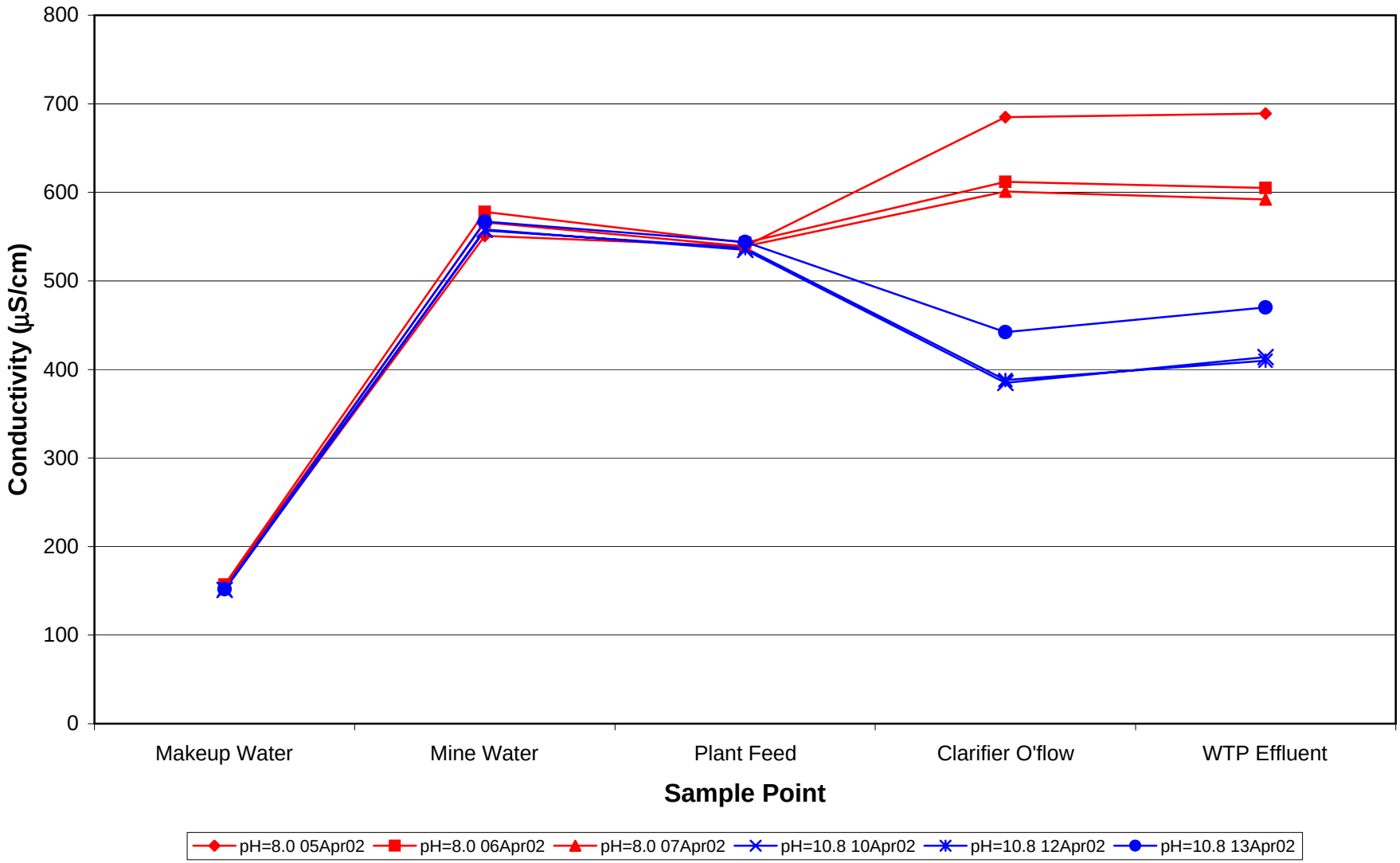
Teck-Pogo Inc.
Lime Softening Investigation

Calcium, Total



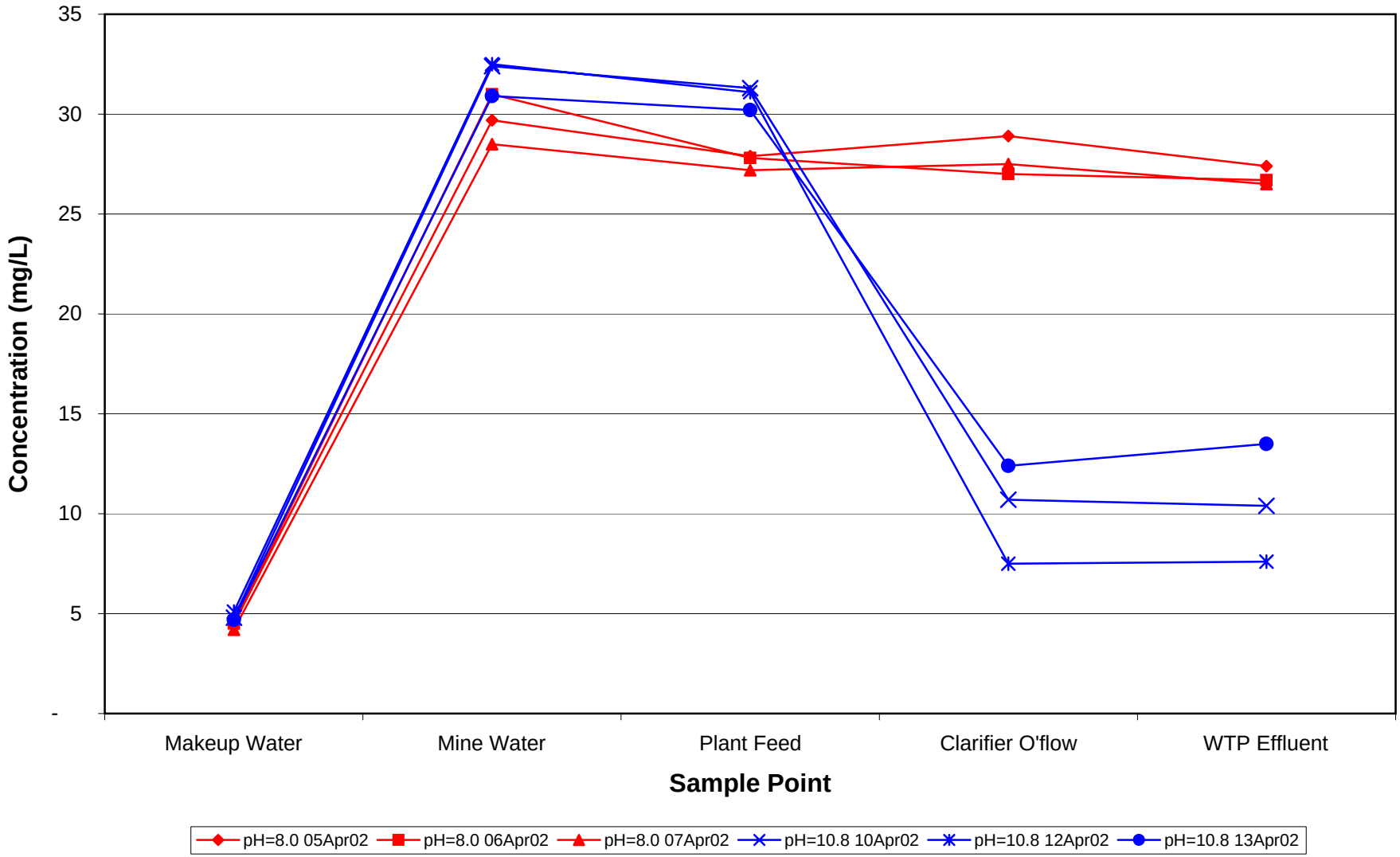
Teck-Pogo Inc.
Lime Softening Investigation

Conductivity



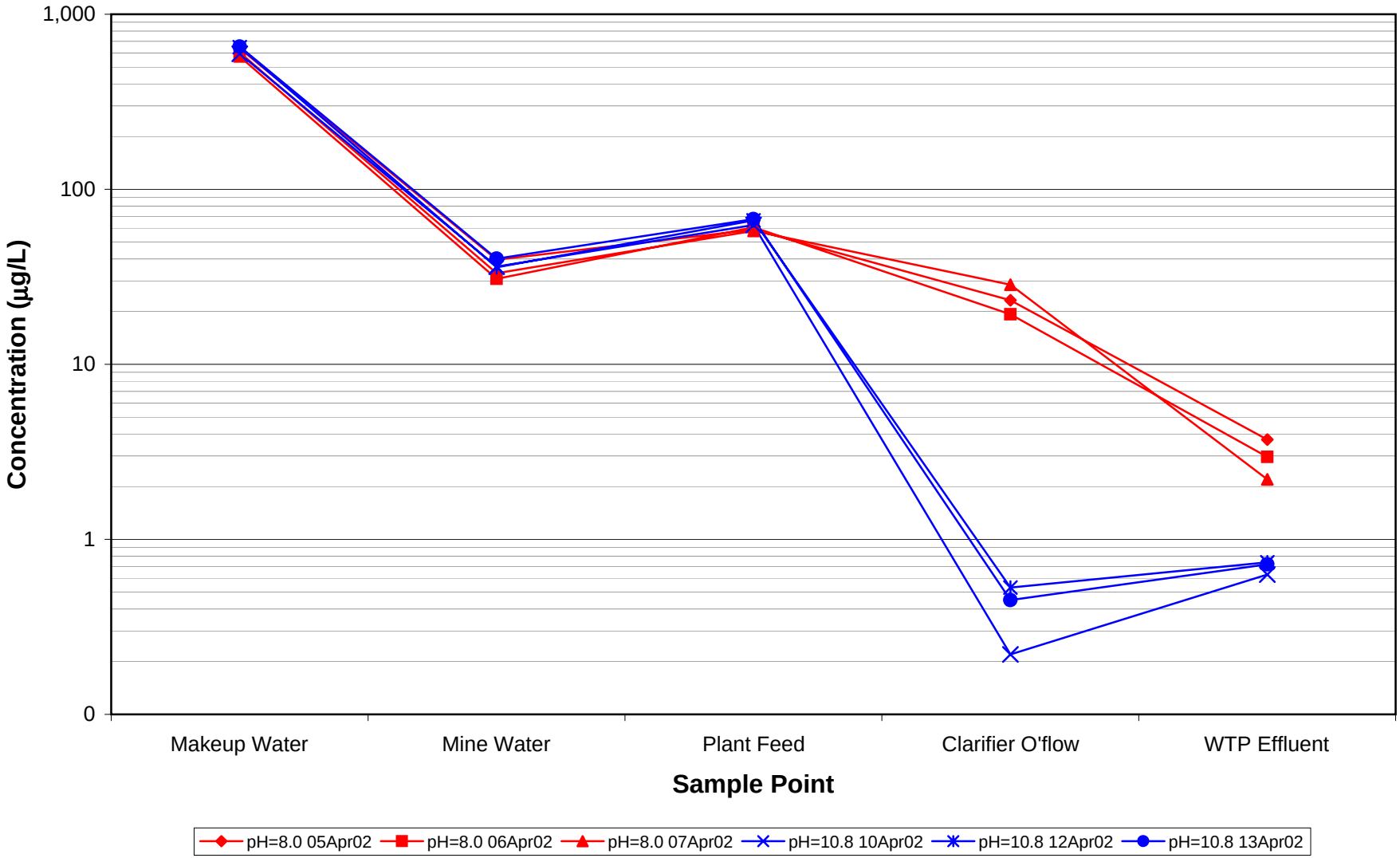
Teck-Pogo Inc.
Lime Softening Investigation

Magnesium, Total



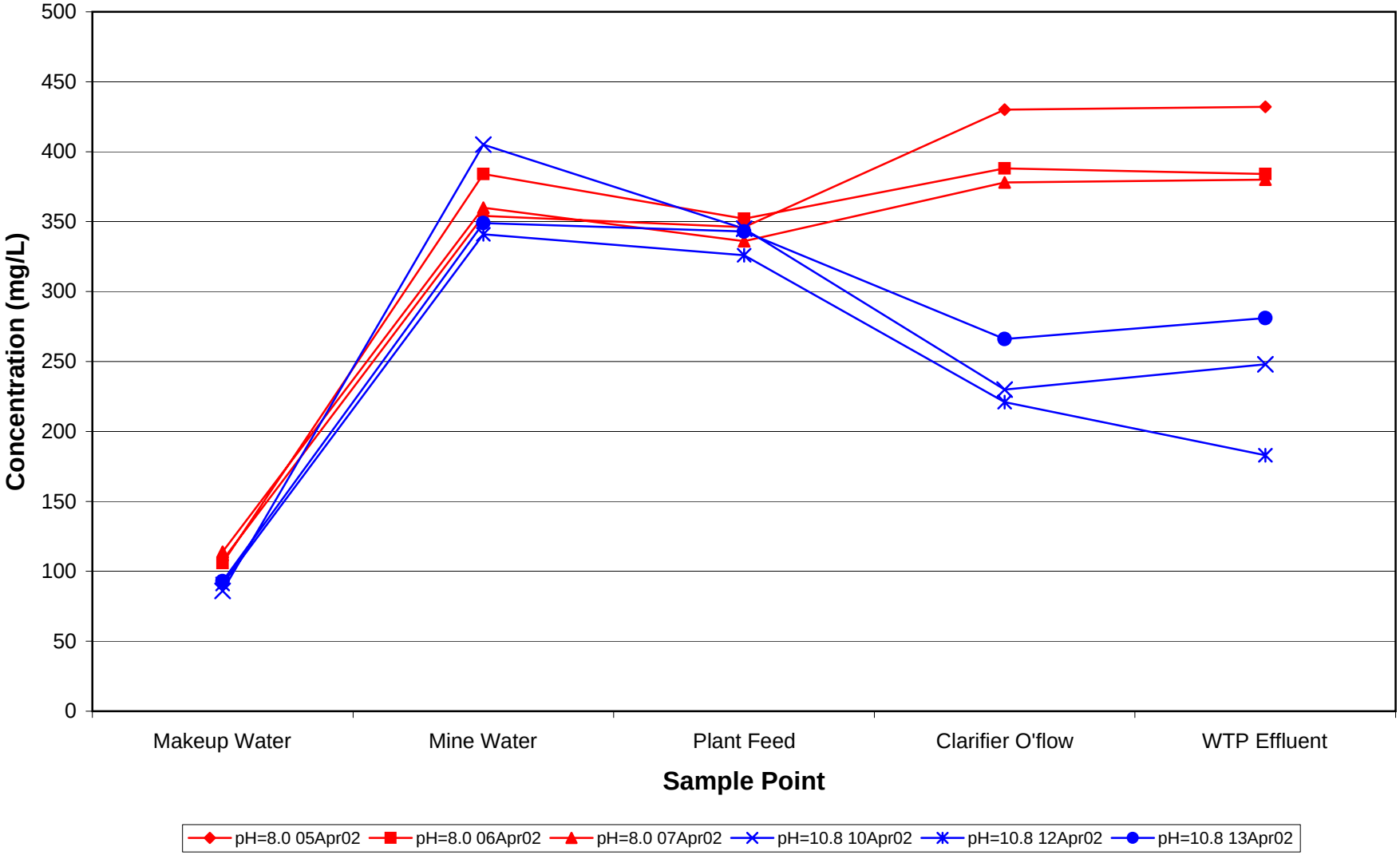
Teck-Pogo Inc.
Lime Softening Investigation

Manganese, Total



Teck-Pogo Inc.
Lime Softening Investigation

Total Dissolved Solids (TDS)



Appendix B

Review of Water Treatment Plant (WTP) Performance Data

Pogo Conclusions

Metal	Influent *			Effluent **					Goodpaster Criteria (mg/L)	Conclusion
	Mean (mg/L)	Std Dev (mg/L)	Total Data Points	Mean (mg/L)	Std Dev (mg/L)	95th Percentile	Total Data Points	Detection Limit		
Ag-T	-	-	2 points (1 Non-Detect) Detect = 0.00003 mg/L	-	-	-	3 points (3 Non-Detects)	100% Data are Non-Detects Lowest Detection Limit = 0.00001 mg/L	**0.00012**	- 100% Non-detects = Inconclusive - However, lowest detection limit of Effluent is less than Criteria - Criteria is achievable
Ag-D	-	-	2 points (2 Non-Detects)	-	-	-	1 point (1 Non-Detect)	100% Data are Non-Detects Lowest Detection Limit = 0.00001 mg/L	**0.00012**	- 100% Non-detects = Inconclusive - However, lowest detection limit of Effluent is less than Criteria - Criteria is achievable
As-T	0.4	0.18	22 points (0 Non-Detects)	0.00917	0.00851	0.02619	32 points (2 Non-Detects)	6% Data are Non-Detects (< 50% Data) Result: Assume DL/2 Lowest Detection Limit = 0.0005 mg/L	**0.05**	- Average and 95th Percentile is lower than Criteria. - Criteria achievable.
As-D	0.393	0.275	5 points (0 Non-Detects)	0.0106	0.00564	0.02188	4 points (0 Non-Detects)	No Detection Limits	**0.05**	- Average and 95th Percentile is lower than Criteria. - Criteria achievable.
Cd-T	0.0000441	0.000048	22 points (16 Non-Detects)	0.0000343	0.0000203	0.0000749	32 points (19 Non-Detects)	59% Data are Non-Detects (> 50% Data) Lowest Detection Limit = 0.00002 mg/L MLE mean = 0.0000306 mg/L Use DL/2 or MLE Mean	**0.0004**	- Cd Influent levels are rather low to begin with. - Influent and Effluent levels are lower than Criteria.
Cd-D	0.0000356	0.0000147	5 points (3 Non-Detects)	0.0000425	0.0000318	0.0001061	4 points (2 Non-Detects)	50% Data are Non-Detects (= 50% Data) Result: Assume DL/2 Lowest Detection Limit = 0.00005 mg/L	**0.0004**	- Cd Influent levels are rather low to begin with. - Influent and Effluent levels are lower than Criteria.
Cr-T	0.0018	0.00244	22 points (11 Non-Detects)	0.00393	0.00519	0.01431	32 points (12 Non-Detects)	38% Data are Non-Detects (< 50% Data) Result: Assume DL/2 Lowest Detection Limit = 0.00005 mg/L	**0.071**	- Cr Influent levels are rather low to begin with. - Influent and Effluent levels are lower than Criteria.
Cr-D	0.00119	0.000888	5 points (2 Non-Detects)	0.000674	0.000818	0.00231	4 points (3 Non-Detects)	75% Data are Non-Detects (> 50% Data) Lowest Detection Limit = 0.0005 mg/L MLE mean = 0.000294 mg/L Use DL/2 or MLE Mean	**0.071**	- Cr Influent levels are rather low to begin with. - Influent and Effluent levels are lower than Criteria.
Cu-T	0.00139	0.00101	22 points (0 Non-Detects)	0.00122	0.000926	0.003072	32 points (1 Non-Detect)	3% Data are Non-Detects (< 50% Data) Result: Assume DL/2 Lowest Detection Limit = 0.009 mg/L	**0.0039**	- Cu Influent levels are rather low to begin with. - Influent and Effluent levels are lower than Criteria.
Cu-D	0.0005	0.000212	5 points (0 Non-Detects)	0.0007	0.000216	0.001132	4 points (0 Non-Detects)	No Detection Limits	**0.0039**	- Cu Influent levels are rather low to begin with. - Influent and Effluent levels are lower than Criteria.
Fe-T	1.095	0.233	2 points (0 Non-Detects)	0.18	0.133	0.446	3 points (0 Non-Detects)	No Detection Limits	**0.3**	- Average is lower than Criteria, but the 95th percentile is higher
Fe-D	-	-	2 points (1 Non-Detect) Detect = 0.05 mg/L Non-Detect = 0.03 mg/L	-	-	-	1 point (0 Non-Detect) Detect = 0.07 mg/L	No Detection Limits	**0.3**	- Fe Influent levels are rather low to begin with. - Influent and Effluent levels are lower than Criteria.
Hg-T	-	-	22 points (21 Non-Detects) Detect = 0.000002 mg/L	-	-	-	32 points (32 Non-Detects)	100% Data are Non-Detects Lowest Detection Limit = 0.000001 mg/L	**0.000012**	- 100% Non-detects = Inconclusive - Range between Non-detects is high (0.000001 mg/L to 0.0002 mg/L) - However, lowest detection limit of Effluent is less than Criteria - Criteria is achievable
Hg-D	-	-	5 points (5 Non-Detects) Lowest Non-Detect= 0.00001 mg/L	-	-	-	4 points (4 Non-Detects)	100% Data are Non-Detects Lowest Detection Limit = 0.00001 mg/L	**0.000012**	- 100% Non-detects = Inconclusive - However, lowest detection limit of Effluent is less than Criteria - Criteria is achievable
Mn-T	0.0735	0.0144	2 points (0 Non-Detects)	0.442	0.352	1.146	3 points (0 Non-Detects)	No Detection Limits	**0.05**	- Effluent levels were initially at 0.455 mg/L (Aug 99) and 0.788 mg/L (Jan 00) - Effluent levels decreased dramatically in June 2001 to 0.0848 mg/L
Mn-D	0.068	0.0132	2 points (0 Non-Detects)	0.0856	-	-	1 point (0 Non-Detect)	No Detection Limits	**0.05**	- More data is required = Inconclusive.
Ni-T	0.0025	0.00099	2 points (0 Non-Detects)	0.00791	0.00263	0.01317	3 points (1 Non-Detects)	33% Data are Non-Detects (< 50% Data) Result: Assume DL/2 Lowest Detection Limit = 0.02 mg/L	**0.052**	- Ni Influent levels are rather low to begin with. - Influent and Effluent levels are lower than Criteria.
Ni-D	0.0023	0.00099	2 points (0 Non-Detects)	0.005	-	-	1 point (0 Non-Detects)	No Detection Limits	**0.052**	- More data is required = Inconclusive.
Pb-T	0.000514	0.000633	22 points (2 Non-Detects)	0.000103	0.0000984	0.0002998	32 points (9 Non-Detects)	28% Data are Non-Detects (Test MLE) Lowest Detection Limit = 0.00002 mg/L MLE mean = 0.0000742 mg/L Use DL/2 or MLE Mean	**0.0006**	- Average and 95th Percentile is lower than Criteria. - Criteria achievable.

Pogo Conclusions

Metal	Influent *			Effluent **					Goodpaster Criteria (mg/L)	Conclusion
	Mean (mg/L)	Std Dev (mg/L)	Total Data Points	Mean (mg/L)	Std Dev (mg/L)	95th Percentile	Total Data Points	Detection Limit		
Pb-D	0.00005	0.000046	5 points (3 Non-Detects)	0.00011	0.0001	0.00031	4 points (0 Non-Detects)	No Detection Limits	**0.0006**	- Average and 95th Percentile is lower than Criteria. - Criteria achievable.
Se-T	-	-	6 points (6 Non-Detects)	-	-	-	5 points (5 Non-Detects)	100% Data are Non-Detects Lowest Detection Limit = 0.001 mg/L	**0.005**	- 100% Non-detects = Inconclusive - However, lowest detection limit of Effluent is less than Criteria - Criteria is achievable
Se-D	-	-	6 points (6 Non-Detects)	-	-	-	3 points (3 Non-Detects)	100% Data are Non-Detects Lowest Detection Limit = 0.001 mg/L	**0.005**	- 100% Non-detects = Inconclusive - However, lowest detection limit of Effluent is less than Criteria - Criteria is achievable
Zn-T	0.00725	0.00364	22 points (0 Non-Detects)	0.00483	0.00473	0.01429	32 points (11 Non-Detects)	34% Data are Non-Detects (Test MLE) Lowest Detection Limit = 0.001 mg/L MLE mean = 0.00252 mg/L Use DL/2 or MLE Mean	**0.035**	- Zn Influent levels are rather low to begin with. - Influent and Effluent levels are lower than Criteria.
Zn-D	0.00304	0.00187	5 points (1 Non-Detect)	0.00168	0.0017	0.00508	4 points (1 Non-Detect)	25% Data are Non-Detects (< 50% Data) Result: Assume DL/2 Lowest Detection Limit = 0.001 mg/L	**0.035**	- Zn Influent levels are rather low to begin with. - Influent and Effluent levels are lower than Criteria.

* Influent = Water Treatment Plant Feed Data from Pogo spreadsheet
** Effluent = Effluent Sheet from Pogo spreadsheet

Red Dog Data Conclusions

Metal	Influent *			Effluent **					Goodpaster Criteria (mg/L)	Conclusion
	Mean (mg/L)	Std Dev (mg/L)	Total Data Points	Mean (mg/L)	Std Dev (mg/L)	95th Percentile (mg/L)	Total Data Points	Detection Limit		
Ag	-	-	25 points (25 Non-Detects)	-	-	-	42 points (42 Non-Detects)	100% Data are Non-Detects Lowest Detection Limit = 0.000002 mg/L	**0.00012**	- 100% Non-detects - Range of Non-detects is too big = Inconclusive - Lowest Detection Limit = 0.000002 mg/L which is less than 0.00012 mg/L Criteria
As	0.008784	0.003779	25 points (13 Non-Detects)	-	-	-	2 points (1 Non-Detect)	50% Data are Non-Detects One detection limit = 0.001 mg/L	**0.05**	- Only 2 data points for effluent. - Arsenic levels both input and output are relatively low compared to Criteria.
Cd	2.70955	0.64728	44 points (0 Non-Detects)	0.002515	0.009543	0.021601	93 points (12 Non-Detects)	13% Data are Non-Detects (< 50% Data) Result: Assume DL/2 Lowest Detection Limit = 0.001 mg/L	**0.0004**	- Cd levels are too high compared to Criteria. - Uncertain if 0.0004 mg/L Criteria is achievable with Deflection Limit at 0.001 mg/L. - Inconclusive
Cl	44.206	12.081	16 points (1 Non-Detect)	42.706	37.54	117.786	34 points (2 Non-Detects)	6% Data are Non-Detects (< 50% Data) Result: Assume DL/2 Lowest Detection Limit = 50.0 mg/L	**230**	- Average concentration is well below Criteria. - 95% of data is below 52.205 mg/L, which is well below 230 mg/L Criteria. - Goodpaster Criteria is achievable on a consistent basis.
Cr	0.00751	0.008002	26 points (24 Non-Detects)	0.000468	0.000291	0.00105	89 points (63 Non-Detects)	71% Data are Non-Detects (> 50% Data) Lowest Detection Limit = 0.0002 mg/L MLE mean = 0.000425 mg/L Use DL/2 or MLE Mean	**0.071**	- Average concentration is well below Criteria. - 95% of data is below 0.00625 mg/L, which is well below 0.071 mg/L Criteria. - Goodpaster Criteria is achievable on a consistent basis.
Cu	0.087385	0.09798	29 points (9 Non-Detects)	0.00143	0.00221	0.00585	89 points (70 Non-Detects)	77% Data are Non-Detects (> 50% Data) Lowest Detection Limit = 0.001 mg/L MLE mean = 0.000788 mg/L Use DL/2 or MLE Mean	**0.0039**	- Average concentration is below Criteria, but 95% of data is below 0.0068 mg/L which is higher than the 0.0039 mg/L Criteria. - Goodpaster Criteria is achievable, but not on a consistent basis.
Fe	9.14498	17.71335	46 points (1 Non-Detect)	0.21359	0.43032	1.07423	58 points (16 Non-Detects)	28% Data are Non-Detects (< 50% Data) Result: Assume DL/2 Lowest Detection Limit = 0.020 mg/L	**0.3**	- Average concentration is below Criteria, but 95% of data is below 1.596 mg/L which is higher than the 0.30 mg/L Criteria. - These high values occur in months between July and October of 2000. - Goodpaster Criteria is achievable
Hg	-	-	No Influent Data	0.0001 (See Conclusion)	-	-	59 points (59 Non-Detects)	100% Data are Non-Detects Lowest Detection Limit = 0.0002 mg/L	**0.000012**	- Uncertain if Criteria is reached because lowest Detection limit is 0.0002 mg/L. - The average of Hg conc. in effluent is assumed to be half the lowest detection limit = 0.0001 mg/L
Mn	13.652	1.96768	25 Points (0 Non-Detects)	0.017742	0.070884	0.15951	89 points (15 Non-Detects)	17% Data are Non-Detects (< 50% Data) Result: Assume DL/2 Lowest Detection Limit = 0.003 mg/L	**0.05**	- Average concentration is below Criteria. - 95% of data is below 0.03202 mg/L, which is below the 0.050 mg/L Criteria. - Goodpaster Criteria is achievable on a consistent basis.
Ni	0.6568	0.11047	25 Points (0 Non-Detects)	0.01043	0.01169	0.03381	89 points (34 Non-Detects)	38% Data are Non-Detects (< 50% Data) Result: Assume DL/2 Lowest Detection Limit = 0.0005 mg/L	**0.052**	- Average concentration is below Criteria. - 95% of data is below 0.02536 mg/L, which is below the 0.052 mg/L Criteria. - Goodpaster Criteria is achievable on a consistent basis.
Pb	2.3609	0.6614	30 Points (0 Non-Detects)	0.00127	0.001157	0.003584	88 Points (21 Non-Detects)	24% Data are Non-Detects (< 50% Data) Result: Assume DL/2 Lowest Detection Limit = 0.0004 mg/L	**0.0006**	- Average Pb levels are high compared to Criteria, but the detection limit went as low as 0.0004 mg/L, which is lower than the 0.0006 mg/L Criteria - Goodpaster Criteria is attainable.
Se	0.005133	0.00652	49 Points (25 Non-Detects)	0.00256	0.00177	0.0061	87 Points (34 Non-Detects)	39% Data are Non-Detects (< 50% Data) Result: Assume DL/2 Lowest Detection Limit = 0.001 mg/L	**0.005**	- Average concentration is below Criteria, but 95% of data is below 0.00596 mg/L which is slightly higher than the 0.005 mg/L Criteria. - Goodpaster Criteria is achievable, but not on a consistent basis.
SO4	2273.44	615.55	32 Points (0 Non-Detects)	2105.93	306.74	2719.41	59 Points (0 Non Detects)	No Detection Limits	**250**	- SO4 levels are too high compared to Criteria
TDS	3363.55	235.78	31 Points (0 Non-Detects)	3068.41	388.17	3844.75	87 Points (0 Non-Detects)	No Detection Limits	**100**	- TDS levels are much higher than Criteria
Zn	264.7174	38.25393	46 Points (0 Non-Detects)	0.055417	0.01907	0.093557	89 points (15 Non-Detects)	17% Data are Non-Detects (< 50% Data) Result: Assume DL/2 Lowest Detection Limit = 0.010 mg/L	**0.035**	- Average Zn levels are high compared to Criteria, but there were occasions where the concentration was below Criteria. - Goodpaster Criteria is attainable, but not on a consistent basis.

* Influent = Reclaim Water data from Red Dog WTP data set
** Effluent = Mine Discharge (Outfall 001) Data from Red Dog WTP data set

Note: CN & TSS data was ignored as recommended by Walter Kuit of Teck Cominco. See below
"The treated effluent data includes information on cyanide but I suggest that it be ignored as we believe that any measured cyanide at the few ppb level is only "apparent" and not in any way real.

Bear in mind that the plant uses low levels of sulfide addition(about 5 mg/L) to feed to deal with cadmium which has to be under a 2 ppb monthly average level. It also uses gravity feed sand filters. In this regard, also ignore the TSS data as the actual levels ar simply not measureable."

Williams Data Conclusions (Analysis of Data from January 1995 to December 1999 only)

Metal	Influent *			Effluent **					Goodpaster Criteria (mg/L)	Conclusion
	Mean (mg/L)	Std Dev (mg/L)	Total Data Points	Mean (mg/L)	Std Dev (mg/L)	95th Percentile (mg/L)	Total Data Points	Detection Limit		
As-T-HYD	0.107	0.0961	85 points (0 Non-Detects)	0.00077	0.00716	0.015093	101 points (98 Non-Detects)	97% Data are Non-Detects (> 50% Data) Lowest Detection Limit = 0.0025 mg/L MLE mean = 0.0000288 mg/L Use MLE Mean	**0.05**	- No correlation between influent and effluent because there were too many non-detection points in effluent. - As values in effluent are considerably lower than Criteria. - Goodpaster Criteria is attainable on a consistent basis.
Cd-T	-	-	No Influent Data	0.00029	9.7E-05	0.000482	3 points (2 Non-Detects)	67% Data are Non-Detects (> 50% Data) Lowest Detection Limit = 0.002 mg/L MLE mean = 0.000232 mg/L Use MLE Mean	**0.0004**	- No corresponding Influent data. - Only 3 Data points: 1 Detect, 2 Non-detects - Detect point is 0.0004 mg/L which is identical to Criteria. Therefore Criteria is attainable.
CN-T	-	-	No Influent Data	0.0836	0.137	0.3576	264 points (0 Non-Detects)	No Detection Limits	**0.0052**	- No corresponding Influent data. - Criteria is unattainable.
Cr-T	-	-	No Influent Data	-	-	-	4 points (4 Non-Detects)	100% Data are Non-Detects 4 Non-Detects = 0.004, 0.004, 0.005, & 0.0004 mg/L	**0.071**	- No corresponding Influent data - Only 4 Data points: All Non-detects - All 4 Non-Detect points fall below Criteria - Criteria is attainable
Cu-T	-	-	No Influent Data	0.024	0.0246	0.0732	182 points (28 Non-Detects)	15% Data are Non-Detects (< 50% Data) Result: Assume DL/2 Lowest Detection Limit = 0.0031 mg/L	**0.0039**	- No corresponding Influent data. - Criteria is attainable at lowest detection limit of 0.0031 mg/L.
Fe-T	0.187	0.189	85 points (0 Non-Detects)	0.179	0.206	0.591	100 points (0 Non-Detects)	No Detection Limits	**0.3**	- No significant change in Fe concentration from influent to effluent. - Goodpaster Criteria is attainable on a consistent basis for both influent and effluent.
Hg-T	0.137 (µg/L)	0.0476 (µg/L)	85 points (2 Non-Detects)	0.00648 (µg/L)	0.0205 (µg/L)	0.04748 (µg/L)	100 points (94 Non-Detects)	94% Data are Non-Detects (> 50% Data) Lowest Detection Limit = 0.0001 µg/L MLE mean = 0.00138 µg/L Use DL/2 or MLE Mean	**0.012 (µg/L)**	- Hg concentration is reduced in the effluent, and effluent concentration values are well below Criteria. - Criteria is attainable.
Mn-T	-	-	No Influent Data	0.6298	0.0529	0.7356	4 points (0 Non-Detects)	No Detection Limits	**0.05**	- No corresponding Influent data - Only 4 Data points - Criteria is not attainable (dissolved concentrations required)
Ni-T	0.192	0.0577	85 points (0 Non-Detects)	0.122	0.0618	0.2456	182 points (6 Non-Detects)	3% Data are Non-Detects (< 50% Data) Result: Assume DL/2 Lowest Detection Limit = 0.002 mg/L	**0.052**	- There is a positive correlation between the influent and the effluent. - Goodpaster Criteria is attainable only when influent concentrations are low.
Pb-T	-	-	85 points (85 Non-Detects)	-	-	-	182 points (181 Non-Detects)	99% Non-Detects Lowest Detection Limit = 0.0001 mg/L	**0.0006**	- Identical Pb detection limits in influent as in effluent. - More accurate date is required. - Inconclusive
Se-T	-	-	No Influent Data	0.0026	0.0005	0.0036	4 points (2 Non-Detects)	50% Data are Non-Detects (= 50% Data) Lowest Detection Limit = 0.05 mg/L MLE mean = 0.00257 mg/L Use MLE mean	**0.005**	- No corresponding Influent data - Only 4 Data points: 2 Non-detects, 2 Detects - Detect points 0.002 mg/L and 0.0033 mg/L lie below Criteria. Therefore, Criteria is attainable.
SO4-D	1171.91	228.63	85 points (0 Non-Detects)	1362.18	199.44	1761.06	110 points (0 Non-Detects)	No Detection Limits	**250**	- There is a positive correlation between the influent and the effluent. - Sulfate concentration is slightly higher in effluent compared to influent. - Goodpaster Criteria is not attainable
Zn-T	0.0143	0.0063	85 points (11 Non-Detects)	0.00849	0.00879	0.02607	182 points (129 Non-Detects)	71% Data are Non-Detects (> 50% Data) Lowest Detection Limit = 0.0045 mg/L MLE mean = 0.0051 mg/L Use DL/2	**0.035**	- No real correlation between influent and effluent. - Zn levels in influent is already lower than the Criteria. - Goodpaster Criteria is attainable on a consistent basis for both influent and effluent.

* Influent = Effluent Treatment Plant Feed data from Williams WTP Data
** Effluent = Treated Effluent from Williams WTP data set

Kimberley Grab Data Conclusions

Metal	Influent *			Effluent *					Goodpaster Criteria (mg/L)	Conclusion
	Mean (mg/L)	Std Dev (mg/L)	Total Data Points	Mean (mg/L)	Std Dev (mg/L)	95th Percentile (mg/L)	Total Data Points	Detection Limit		
Cd	0.0747	0.041	223 Points (0 Non-Detects)	0.0014	0.00065	0.0027	223 Points (165 Non-Detects)	74% Data are Non-Detects (> 50% Data) Lowest Detection Limit = 0.002 mg/L MLE mean = 0.00174 mg/L Use DL/2 or MLE Mean	**0.0004**	- Data collected beginning from 1997 - Detection Limit of 0.002mg/L is too high compared to 0.0004 mg/L Criteria. - Uncertain whether Criteria is achievable. - Inconclusive.
Cu	0.183	0.249	458 Points (3 Non-Detects)	0.008	0.012	0.032	458 Points (43 Non-Detects)	9% Data are Non-Detects (< 50% Data) Result: Assume DL/2 Lowest Detection Limit = 0.002 mg/L	**0.0039**	- There is a negative correlation between influent and effluent. - Average concentration of 0.008mg/L is slightly higher than 0.0039mg/L Criteria, but concentrations of <0.002mg/L is attainable. - Criteria is attainable, but not on a consistent basis.
Fe	189.63	120.33	458 Points (0 Non-Detects)	0.024	0.017	0.058	458 Points (2 Non-Detects)	0.4% Data are Non-Detects (< 50% Data) Result: Assume DL/2 Lowest Detection Limit = 0.002 mg/L	**0.3**	- There is a positive correlation between influent and effluent. - Average concentration is well below Criteria. - 95% of data is below 0.05 mg/L, which is well below 0.30mg/L Criteria. - Goodpaster Criteria is achievable on a consistent basis.
Pb	3.64	3.28	458 Points (0 Non-Detects)	0.007	0.0053	0.0176	458 Points (44 Non-Detects)	10% Data are Non-Detects (< 50% Data) Result: Assume DL/2 Lowest Detection Limit = 0.002 mg/L	**0.0006**	- Pb levels are too high compared to Criteria. - Uncertain whether 0.0006 mg/L Criteria is achievable with Detection limit at only 0.002 mg/L. - Inconclusive
Mn	18.1	5.15	223 Points (0 Non-Detects)	0.181	0.141	0.463	223 Points (0 Non-Detects)	No Detection Limits	**0.05**	- There is a negative correlation between influent and effluent. - Average concentration of 0.181mg/L is higher than 0.05mg/L Criteria, but concentrations of 0.01mg/L is attainable. - Criteria is attainable, but not on a consistent basis.
SO4	2058.38	548.22	232 Points (0 Non-Detects)	1875.96	393.34	2662.64	234 Points (0 Non-Detects)	No Detection Limits	**250**	- There is a positive correlation between influent and effluent. - SO4 levels are too high compared to Criteria - Inconclusive.
Zn	40.1	18.1	458 Points (0 Non-Detects)	0.017	0.029	0.075	458 Points (6 Non-Detects)	1% Data are Non-Detects (< 50% Data) Result: Assume DL/2 Lowest Detection Limit = 0.002 mg/L	**0.035**	- Average concentration is less than Criteria. - 95% of data is below 0.04 mg/L, which is close to 0.035mg/L Criteria. - Goodpaster Criteria is achievable on a consistent basis.
TSS	39.27	220.22	458 Points (0 Non-Detects)	9.01	5.83	20.67	458 Points (0 Non-Detects)	No Detection Limits	**30**	- Average & 95th Percentile is less than Criteria. - Goodpaster Criteria is achievable.

*Influent = "In" data from Kimberley Grab data set
**Effluent = "Out" data from Kimberley Grab data set

Kimberley Composite Data Conclusions (Data Analysis from January 1996 to December 2001)

Metal	Influent *			Effluent *										Goodpaster Criteria
				Total					Dissolved					
	Mean (mg/L)	Std Dev (mg/L)	Total Data Points	Mean (mg/L)	Std Dev (mg/L)	95th Percentile (mg/L)	Total Data Points	Detection Limit	Mean (mg/L)	Std Dev (mg/L)	95th Percentile (mg/L)	Total Data Points	Detection Limit	(mg/L)
As	-	-	No Influent Data	0.00153	0.00162	0.00477	72 points (42 Non-Detects)	58% Data are Non-Detects (> 50% Data) Lowest Detection Limit = 0.001 mg/L MLE mean = 0.000936 mg/L Use DL/2 or MLE Mean	0.00116	0.00108	0.00332	72 points (48 Non-Detects)	67% Data are Non-Detects (> 50% Data) Lowest Detection Limit = 0.001 mg/L MLE mean = 0.000725 mg/L Use DL/2 or MLE Mean	0.05
Cd	0.0748	0.0408	223 points (0 Non-Detects)	0.0007	0.0004	0.0015	24 points (3 Non-Detects)	13% Data are Non-Detects (< 50% Data) Result: Assume DL/2 Lowest Detection Limit = 0.0002 mg/L	0.0002	0.00009	0.00038	24 points (17 Non-Detects)	71% Data are Non-Detects (> 50% Data) Lowest Detection Limit = 0.0002 mg/L MLE mean = 0.00016 mg/L Use DL/2 or MLE Mean	0.0004
Cu	0.181	0.207	277 points (3 Non-Detects)	0.013	0.03	0.073	72 points (2 Non-Detects)	3% Data are Non-Detects (< 50% Data) Result: Assume DL/2 Lowest Detection Limit = 0.001 mg/L	0.009	0.0231	0.0552	72 points (3 Non-Detects)	4% Data are Non-Detects (< 50% Data) Result: Assume DL/2 Lowest Detection Limit = 0.001 mg/L	0.0039
CN	-	-	No Influent Data	0.0095	0.016	0.0415	72 points (55 Non-Detects)	76% Data are Non-Detects (> 50% Data) Lowest Detection Limit = 0.01 mg/L MLE mean = 0.0037 mg/L Use DL/2 or MLE Mean	0.00316 (WAD)	0.00642 (WAD)	0.0160 (WAD)	72 points (66 Non-Detects)	92% Data are Non-Detects (> 50% Data) Lowest Detection Limit = 0.01 mg/L MLE mean = 0.00148 mg/L Use DL/2 or MLE Mean	0.0052
Fe	195.74	136.37	277 points (0 Non-Detects)	1.117	0.907	2.931	72 points (0 Non-Detects)	No Detection Limits	0.033	0.044	0.121	72 points (17 Non-Detects)	24% Data are Non-Detects (< 50% Data) Result: Assume DL/2 Lowest Detection Limit = 0.01 mg/L	0.3
NO3	-	-	No Influent Data	-	-	-	-	-	2.437	0.93	4.297	72 points (0 Non-Detects)	No Detection Limits	24.6
NFR	24.77	19.87	277 points (0 Non-Detects)	-	-	-	-	-	7.835	5.399	18.633	72 points (1 Non-Detects)	1% Data are Non-Detects (< 50% Data) Result: Assume DL/2 Lowest Detection Limit = 1 mg/L	40
Pb	3.32	1.71	277 points (0 Non-Detects)	0.033	0.032	0.097	72 points (0 Non-Detects)	No Detection Limits	0.005	0.0057	0.0164	72 points (19 Non-Detects)	26% Data are Non-Detects (< 50% Data) Result: Assume DL/2 Lowest Detection Limit = 0.001 mg/L	0.0006
Zn	45.49	18.9	277 points (0 Non-Detects)	0.276	0.178	0.632	72 points (0 Non-Detects)	No Detection Limits	0.021	0.0238	0.0686	72 points (1 Non-Detect)	1% Data are Non-Detects (< 50% Data) Result: Assume DL/2 Lowest Detection Limit = 0.002 mg/L	0.035

* Influent = "In" data from Kimberley Grab data set
** Effluent = Drainage WTP Montly 4 Hour Composite Sample from Kimberley Composite data set

Metal	Conclusion
As	- Total & Dissolved concentrations are well below Criteria. - Criteria is achievable on a consistent basis.
Cd	- Data collected from 2000 - Average Dissolved concentration is less than Criteria - 95% of Dissolved concentration is below 0.0003 mg/L. which is lower than 0.0004 mg/L Criteria - Goodpaster Criteria is achievable on a consistent basis.
Cu	- Average concentration of 0.009mg/L is slightly higher than the 0.0039mg/L Criteria, but concentrations of <0.002mg/L is attainable. - Criteria is attainable, but not on a consistent basis.
CN	- Uncertain whether 0.0052mg/L Criteria is achievable with a Total concentration detection limit of 0.01mg/L. - Inconclusive
Fe	- Average Dissolved concentration is well below Criteria. - 95% of Dissolved concentration is below 0.081 mg/L, which is well below 0.30mg/L Criteria. - Goodpaster Criteria is achievable on a consistent basis.
NO3	- Average concentration is well below Criteria. - Goodpaster Criteria is achievable on a consistent basis.
NFR	- Average & 95th Percentile is less than Criteria. - Goodpaster Criteria is achievable.
Pb	- Pb Total and Dissolved levels are too high compared to Criteria. - Uncertain whether 0.0006 mg/L Criteria is achievable with Dissolved Detection limit at 0.001 mg/L. - Inconclusive
Zn	- Average Dissolved concentration is less than Criteria. - 95% of Dissolved Concentration is below 0.058 mg/L, which is close to 0.035mg/L Criteria. - Goodpaster Criteria is achievable on a consistent basis.

Appendix C

MODFLOW Analyses of Post SAS Water Quality

Pogo Project Memorandum

To	**Karl Hanneman**	File No.	**VM00172 V-3**
From	**Dan Emerson** **Mike Davies**	cc	
Date	**May 13, 2002**		
Subject	**Pogo Project – MODFLOW Analyses of Post SAS Water Quality**		

This memo is written in response to the request by the regulatory EIS team to conduct a Modflow analysis of the post SAS groundwater quality for the Pogo Project.

A three-dimensional groundwater flow and transport model was constructed with Modflow and MT3DMS using Visual Modflow from Waterloo Hydrogeologic Inc. This model is more detailed than the SAS physical flow model previously developed and presented in Appendix E of the February 2002 Pogo Water Management Plan in order to address numerical issues with contaminant transport.

The model consists of 78 rows and 129 columns with a spacing ranging from 10 feet near the SAS system to 95 feet at the model boundaries. Nine model layers are included with the top layer 20 feet thick and containing the water table and the remaining layers all 10 feet thick and horizontal. The model domain was assumed to be homogeneous and isotropic with the exception of a band of permafrost included near the SAS system, which had a much lower hydraulic conductivity than the remainder of the model.

Boundary conditions for the model include river nodes, constant head nodes, and areally distributed recharge to represent infiltration of precipitation and the recharge from the SAS system.

- The river nodes representing the Goodpaster River were given an imposed gradient from 1352 at the upstream boundary to 1337 at the downstream boundary. The river conductance was calculated based on a riverbed hydraulic conductivity of 3.9×10^{-3} ft/s. River nodes were also used to simulate Liese Creek. These nodes were given a steeper gradient and a lower river conductance.
- Constant head nodes were set at the upstream and downstream boundaries to include base flow into and out of the model domain. These boundaries were set to match the river gradient.
- Areally distributed recharge was included over the entire domain at 0.0018 ft/day with the exception of the permafrost areas. Areally distributed recharge was also used to simulate the recharge of treated water from the SAS system.
- The dispersion modeling assumed a constant dispersivity of 90 ft.

A check on the physical modeling, e.g. predicted travel times and mounding, demonstrated that the more detailed Modflow model provided similar results to the earlier Modflow model.

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Table 5.1 of the February 2002 Pogo Water Management Plan presented the projected post SAS water qualities along with Goodpaster water quality criteria. This memo presents the results of the transport analyses conducted for those parameters that had a post SAS water quality that exceeded the water quality criteria for the Goodpaster River as shown in Table 5.1. These parameters include TDS, NO_3, CN, Cr, Cu, Fe, Pb, Hg, Mn, and Ag.

Of these parameters, some are non-reactive (i.e. conservative in that they are not attenuated by chemical processes), while others are reactive. TDS, NO_3, Fe, and Mn are all examples of conservative species. There are no feasible chemical reactions that may occur that could retard or attenuate chemical concentrations along the flow path with the possible exception of Nitrate that can undergo de-nitrification under certain geochemical and biochemical conditions. All the other parameters have some potential for attenuation by some mechanism of sorption. The sorption mechanisms include sorption onto clays or other minerals, adsorption to dissolved organic carbon or suspended organic carbon, complexation with metal hydroxides, biotransformation to organic species and volatilization. These mechanisms are very complex and are dependent on the chemical and physical nature of the aquifer materials and on the chemical species of each reactive parameter, i.e. the valence state and its molecular make up.

Typically, transport analysis of reactive species is simplified through the use of a distribution or partition coefficient, K_d that defines the ratio of adsorbed to dissolved species at chemical equilibrium. Considerable research has been completed by others defining these K_d coefficients for various metals under differing aquifer and geochemical conditions.

The U.S. EPA recently completed a detailed literature review for these values (EPA, 1999). This review uncovered more than a thousand individual K_d values for various parameters in various environments. Table 1 presents a summary of the ranges of the K_d values for metals in soils.

The selection of appropriate distribution coefficients for transport analysis is normally estimated based on analysis of measured distributions in natural or laboratory environments. The range of values reported by the EPA extends over several orders of magnitudes for each parameter. Table 1 presents the range of values and the K_d values used for the post SAS transport simulations. Values in Table 1 were not selected for those parameters that already met Goodpaster River water quality objectives post SAS.

Table 1. Ranges of K_d values from the US EPA (US EPA, 1999)

Parameter	Common Valence State	Distribution Coefficient kg/L		Modeled Distribution Coefficient
		Minimum	Maximum	
TSS	-	-	-	-
TDS	-	-	-	0
Cl	1-	-	-	-
SO_4	2-	-	-	-
TKN	-	-	-	-
NO_3		-	-	0
CNT		0.004	20	0.004
As	3+, 5+	2.00	40000	-
Cd	2+	1.26	100000	-
Cr	3+, 6+	0.20	2000	-
Cu	2+	1.26	3981	1.26
Fe	2+, 3+			0
Pb	2+	5.0	100000	5.0
Hg	2+	20	631000	20
Mn				0
Ni	2+	10.00	6310	-
Se		0.01	251	-
Ag	1+	10.00	32000	10
Zn	2+	0.10	100000	-

Note that in all cases, the lowest value of K_d was utilized to allow a conservative assessment of the aquifer concentrations prior to any effluent entering the Goodpaster River. Further analyses, or site-specific information, would be needed to determine actual K_d values.

Tables 2 and 3 present model predictions assuming average case SAS application rate of 144 gpm and a 95th percentile application rate of 365 gpm, respectively. All cases analyzed assumed 95th percentile parameter concentrations as defined in the February 2002 Pogo Water Management Plan. It should be noted that the combination of the 95th percentile concentration and 95th percentile application rate (365 gpm) is not realistic. The actual results will be closer to the average concentration and application rate.

Figure 1 provides the observation locations used to track the predicted groundwater chemistry adjacent to the Goodpaster River. Figures 2 through 6 show the geochemical profile between OB-1 and OB-14 along the Goodpaster River for various parameters. Along this profile, the modeling indicates two peaks in predicted concentrations near OB-3 and OB-10. The maximum groundwater concentrations in the aquifer immediately adjacent to the Goodpaster River are presented in Tables 2 and 3.

These estimates are all based on a steady state groundwater flow field and SAS input loading. In reality, the flow field will be transient due to fluctuations in the river i.e. freshet in the river, flood events, snowmelt, and increased seasonal precipitation. In addition, the chemical makeup and volume of the post SAS water will vary considerably. The water level in the aquifer will vary in response to the river level, with the river acting alternately as a sink and a source. The effect of this would be to average, or blur, the chemical makeup of the groundwater and flatten out concentration gradients.

As an example, Figure 7 presents iron concentrations along the river similar to Figure 5, except in this simulation, the river stage is not static, but transient. A seasonal fluctuation in river stage was imposed on the model that consisted of nine months of average river stage (equivalent to the steady state model) followed by three months of two feet of flood. This condition was run for 10 years to generate Figure 7. The figure shows a dramatic difference after 10 years of simulated flow and transport between high river stage and low river stage as a result of the gradient between the river and the aquifer reversing during high water.

Therefore, the actual aquifer concentrations will be somewhere between the high and low water simulations presented in Figure 7. The transient river stage, in combination with the transient nature of SAS discharge quality and volume will all tend to bring groundwater concentrations below the steady state predictions. The complexities of all the transient elements are impossible to summarize in a single simulation. The transient river stage is the most simple to implement and probably represents the single most influential transient element.

In summary, transport modeling of post SAS groundwater concentrations has been completed using conservative assumptions:

- 95th percentile concentration levels
- 95th percentile concentration levels and 95th percentile flow levels
- minimum distribution coefficients

For non-reactive ions, the transport modeling indicates attenuation ratios of approximately 1.4:1 compared to the 1:1 ratio assumed for the February 2002 Water Management Plan. For reactive species the chemical attenuation is 100%, resulting in very high dilution ratios with the solute concentration adjacent to the Goodpaster River being essentially the background value in the aquifer.

Inclusion of the transient river effects would reduce the groundwater concentrations at the Goodpaster River during high water periods. Other transient effects would also tend to reduce groundwater concentrations, however, the characterization of these transient elements is difficult. Due to these transient effects, actual groundwater concentrations would be below the maximum steady state values presented in Tables 2 and 3.

Table 2. Maximum predicted groundwater concentrations under average SAS application rate of 144 gpm

Parameter	Groundwater Quality (Dissolved)	Mean Annual Average Discharge (Dissolved)	95th Percentile Annual Average Discharge (Dissolved)	Maximum Groundwater Concentration at River Assuming 95th Percentile Loading (Total)	Goodpaster Criteria (Total)
TSS	7.65	19.2	20	N/A	30
TDS	88.8	317	402	167	100
Cl	0.388	99	139.3	N/A	230
SO4	27.5	139	201	N/A	250
TKN	0.117	3.14	5.28	N/A	10
NO3	0.148	9.6	15.4	6.28	10
CNT	0.0025	0.01143	0.0159	0.0066	0.0052
As	0.00073	0.018	0.018	N/A	0.05
Cd	0.0003	0.00022	0.00029	N/A	0.0004
Cr	0.00036	0.00337	0.0058	N/A	0.071
Cu	0.00063	0.00459	0.00475	0.0006	0.0039
Fe	0.102	0.225	0.225	0.3	0.3
Pb	0.00015	0.00075	0.001	0.00015	0.0006
Hg	0.00519	0.0797	0.1	0.00519	0.012
Mn	0.0323	0.197	0.2	0.094	0.05
Ni	0.00024	0.00751	0.0135	N/A	0.052
Se	0.0005	0.00116	0.0012	N/A	0.005
Ag	0.0001	0.00007	0.0009	0.0001	0.00012
Zn	0.00117	0.0105	0.0106	N/A	0.035

Notes All Concentration in mg/l except Mercury which is µ/l
N/A Input Concentrations less than criteria

Table 3. Maximum predicted groundwater concentrations under 95th percentile application rate of 365 gpm

Parameter	Groundwater Quality (Dissolved)	Mean Annual Average Discharge (Dissolved)	95th Percentile Annual Average Discharge (Dissolved)	Maximum Groundwater Concentration at River Assuming 95th Percentile Loading (Total)	Goodpaster Criteria (Total)
TSS	7.65	19.2	20	N/A	30
TDS	88.8	317	402	289	100
Cl	0.388	99	139.3	N/A	230
SO4	27.5	139	201	N/A	250
TKN	0.117	3.14	5.28	N/A	10
NO3	0.148	9.6	15.4	10.97	10
CNT	0.0025	0.01143	0.0159	0.011	0.0052
As	0.00073	0.018	0.018	N/A	0.05
Cd	0.0003	0.00022	0.00029	N/A	0.0004
Cr	0.00036	0.00337	0.0058	N/A	0.071
Cu	0.00063	0.00459	0.00475	0.0008	0.0039
Fe	0.102	0.225	0.225	0.506	0.3
Pb	0.00015	0.00075	0.001	0.00015	0.0006
Hg	0.00519	0.0797	0.1	0.00519	0.012
Mn	0.0323	0.197	0.2	0.161	0.05
Ni	0.00024	0.00751	0.0135	N/A	0.052
Se	0.0005	0.00116	0.0012	N/A	0.005
Ag	0.0001	0.00007	0.0009	0.0001	0.00012
Zn	0.00117	0.0105	0.0106	N/A	0.035

Notes All Concentration in mg/l except Mercury which is µ/l
N/A Input Concentrations less than criteria

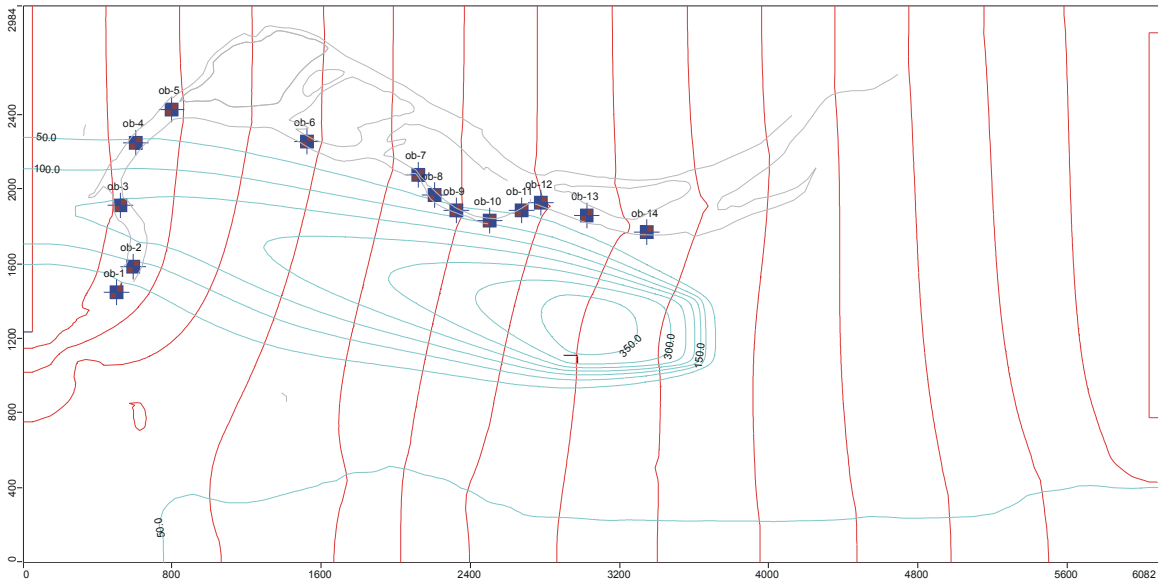

Figure 1. Example of Plume; TDS at 144 GPM and Observation Stations OB1- OB14.

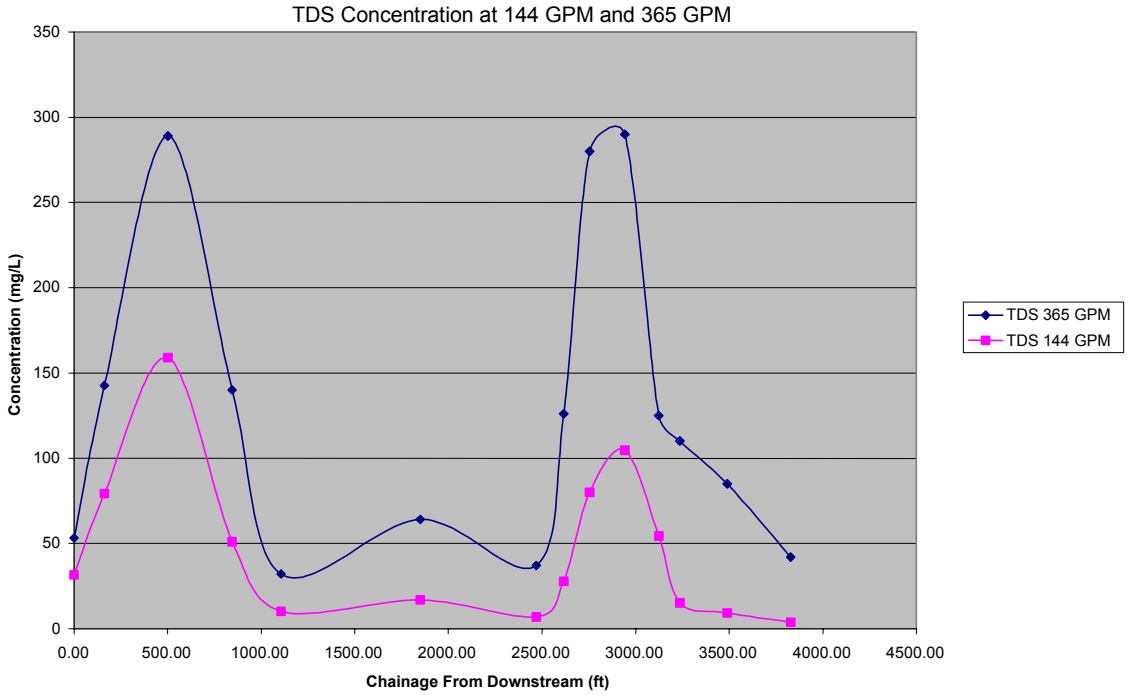

Figure 2. TDS in groundwater at OB1- OB14 at 144 and 365 GPM.

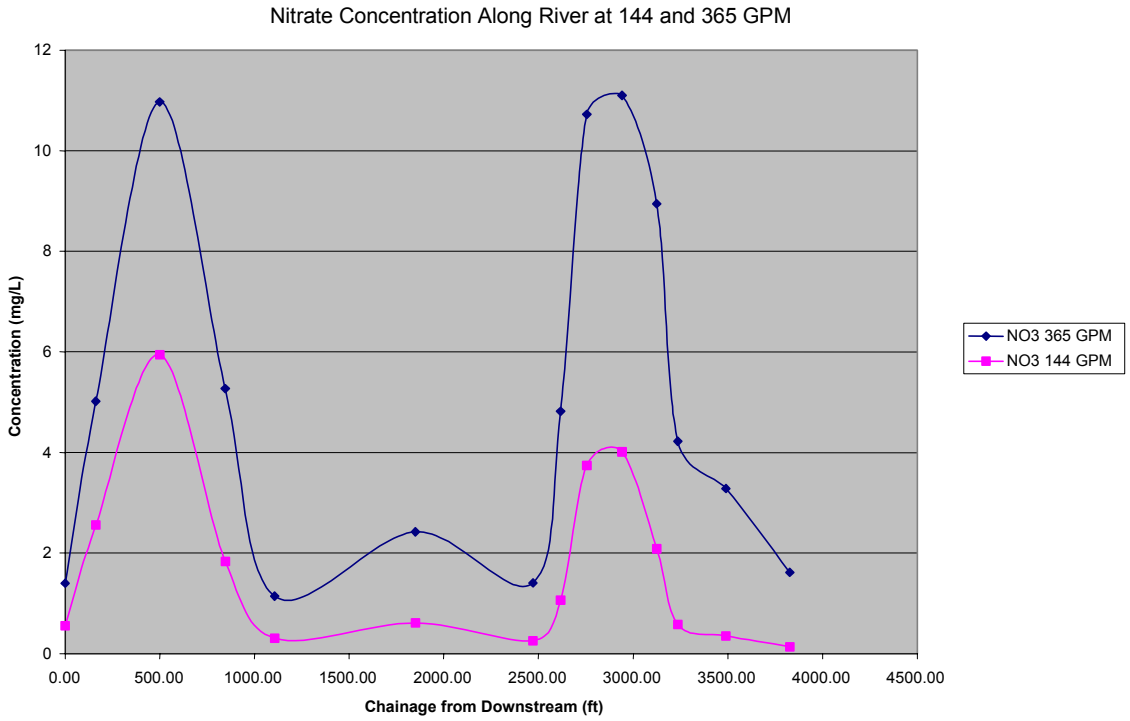

Figure 3. Nitrate along river at OB1- OB14 at 144 and 365 GPM.

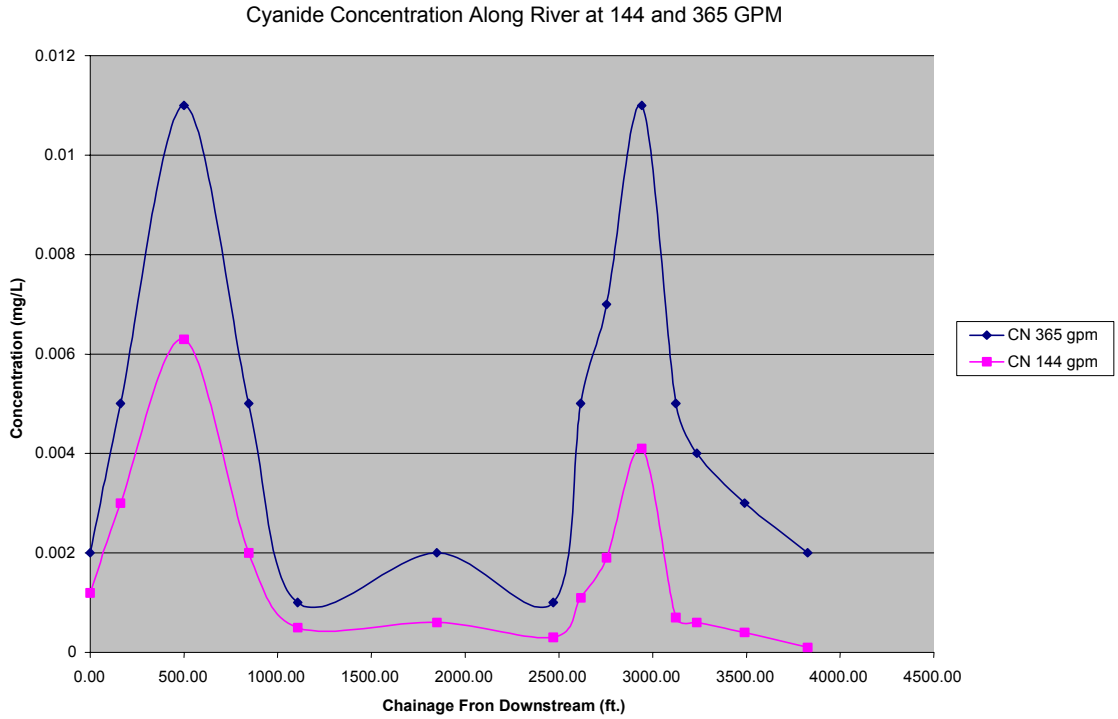

Figure 4. Cyanide along river at OB1- OB14 at 144 and 365 GPM.

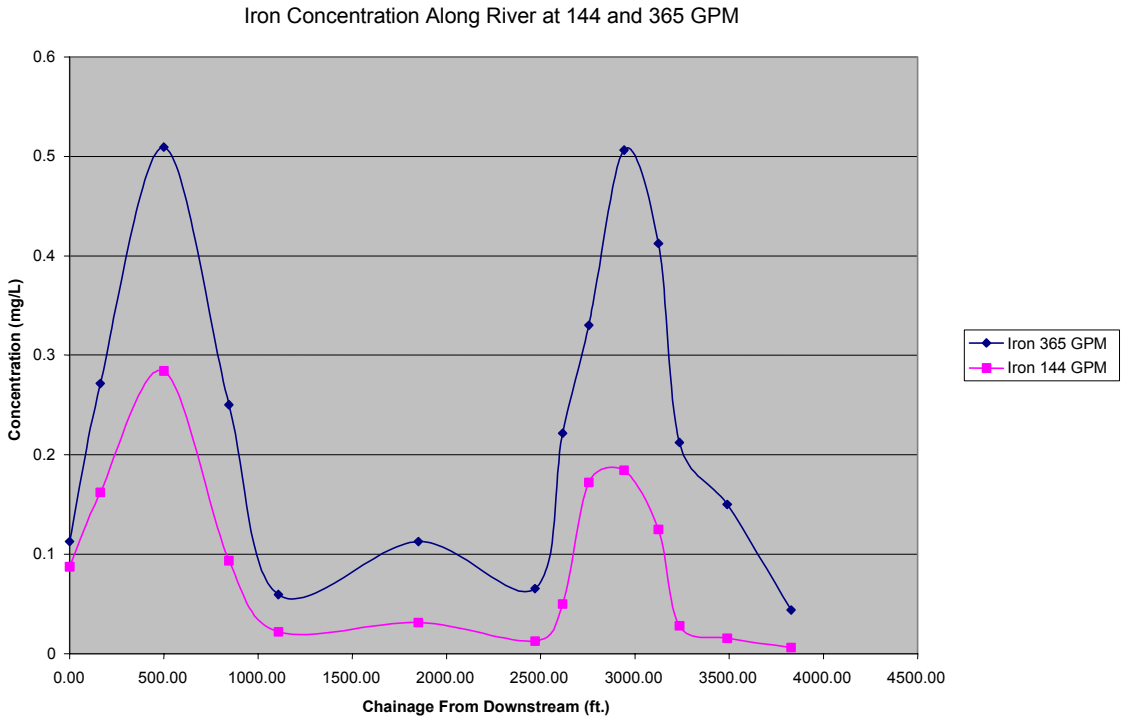

Figure 5. Iron along river at OB1- OB14 at 144 and 365 GPM.

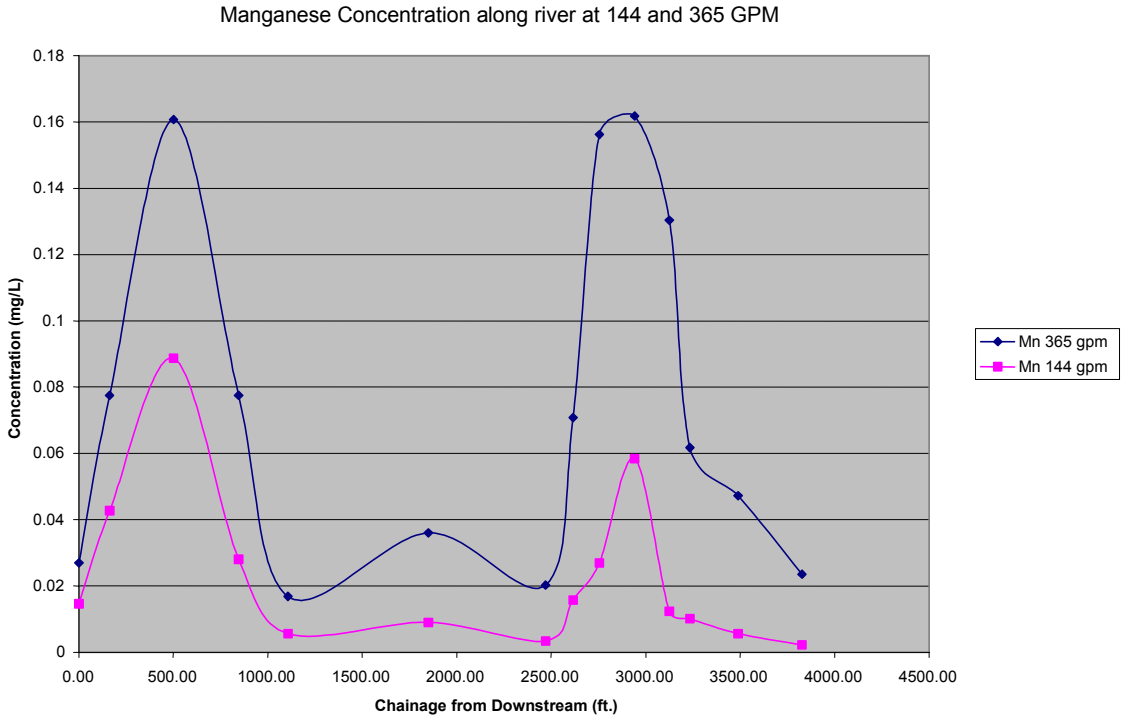

Figure 6 Manganese along river at OB1- OB14 at 144 and 365 GPM.

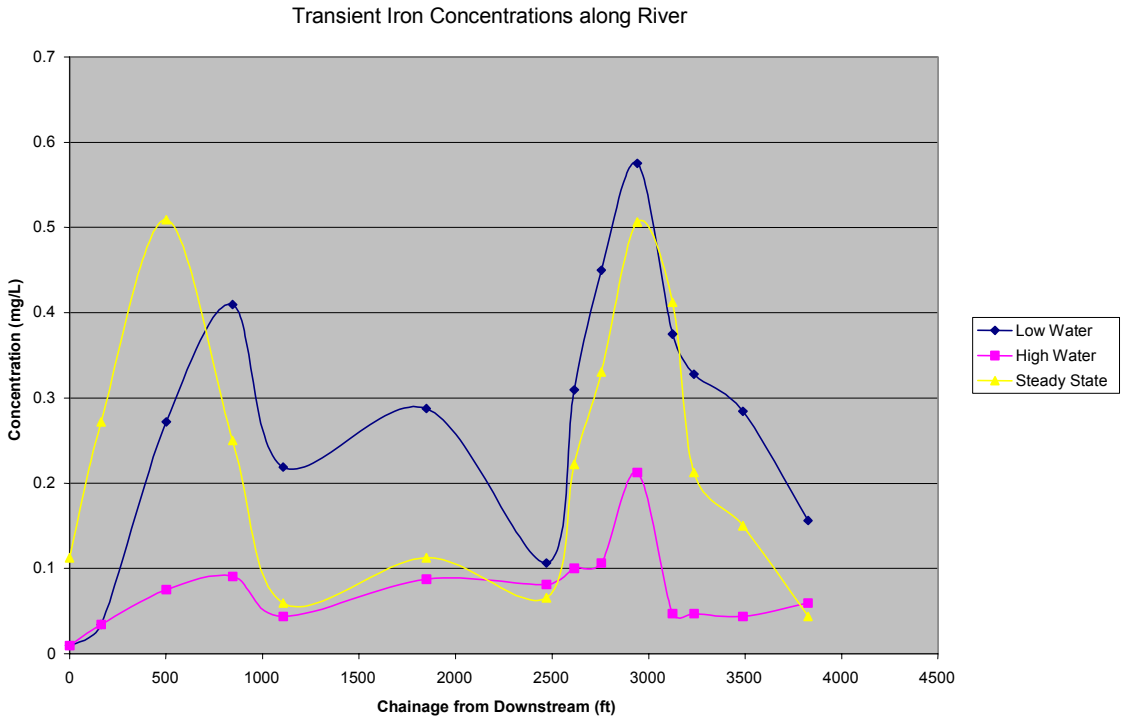

Figure 7. Iron along river at OB1- OB14 during transient simulation.

Respectfully submitted,

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Reference

U.S. Environmental Protection Agency (1999). Partition Coefficients for Metals in Surface Water, Soil, and Waste. US EPA, Office of Solid Waste, June 22.