

Appendix E

Memo (27 July 2000) – Soil Absorption System: Candidate Sites

Column Study Report

Memo (27 July 2000) – Review of Treatment of Mine Effluent by Land Application

Memo (30 May 2001) – Absorption System Modeling

Memo (24 January 2002) – Pogo SAS Freeze Protection Thermal Analysis

Memo (22 January 2002) – SAS Freeze Projection Wells: Summary of MODFLOW Modeling



AGRA

ENGINEERING GLOBAL SOLUTIONS

**AGRA Earth &
Environmental Limited**
2227 Douglas Road
Burnaby British Columbia
Canada V5C 5A9
Tel (604) 294-3811
Fax (604) 294-4664

POGO PROJECT MEMORANDUM

DATE: July 27, 2000

FILE NO: VM00172 II-2

TO: FILE

COMPANY: POGO PROJECT - Teck Corporation

c: As Required

FROM: Michael Davies

SUBJECT: Soil Absorption System - Candidate Sites

As part of the overall project water management, a soil absorption system will be developed to receive water from the water treatment plant. The system will be constructed to allow sufficient hydraulic conductivity to handle more than the upper bound of incoming flows – the NAD of approximately 218 gpm. The hydraulic conductivity will be achieved through selection of appropriate materials and development of sufficient areal size to the system.

The soil absorption system should be placed in an area where there is sufficient in-situ hydraulic conductivity. This sufficiency requires appropriate surficial geology without undue influence on flow potential by permafrost. Moreover, the water should be able to be reintroduced to the receiving environment so as to not negatively influence the project water balance (e.g. by placing the water upgradient of the RTP catchment area).

Three candidate locations have been identified from the evaluation of the general site area:

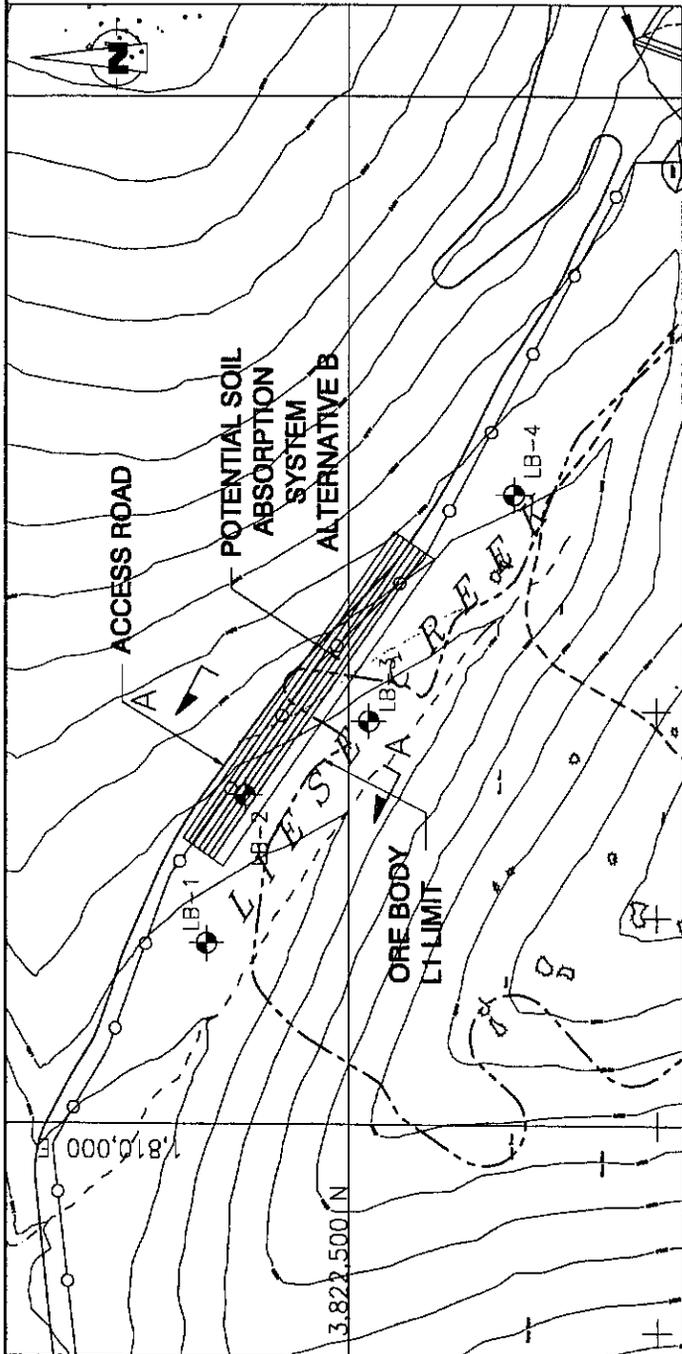
- Lower Liese within the floodplain of the Goodpaster River – this location would be developed away from permafrost (e.g. not too close to the hillslope) and would be raised above predicted infrequent flood levels (e.g. a 200 year flood level).
- Liese Creek Bench area – this is an area below the RTP and above the Goodpaster floodplain on the south facing side of Liese Creek. The area is relatively gently sloping with colluvial cover.
- Upper Liese area – on the south-facing slope on a saddle above the proposed plantsite. Drainage of the treated water would be away from the mining activity.

These three candidate locations present the range of possible sites for project area – upland, mid-valley and floodplain. Optimized locating of the chosen site would come during detailed site engineering and following collection of more site-specific subsurface information.

These locations and a general indication of approximate system size are shown on Figure 1. Figures 2 to 4, inclusive, show approximate plan and cross-section details for each site. The

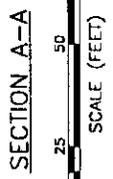
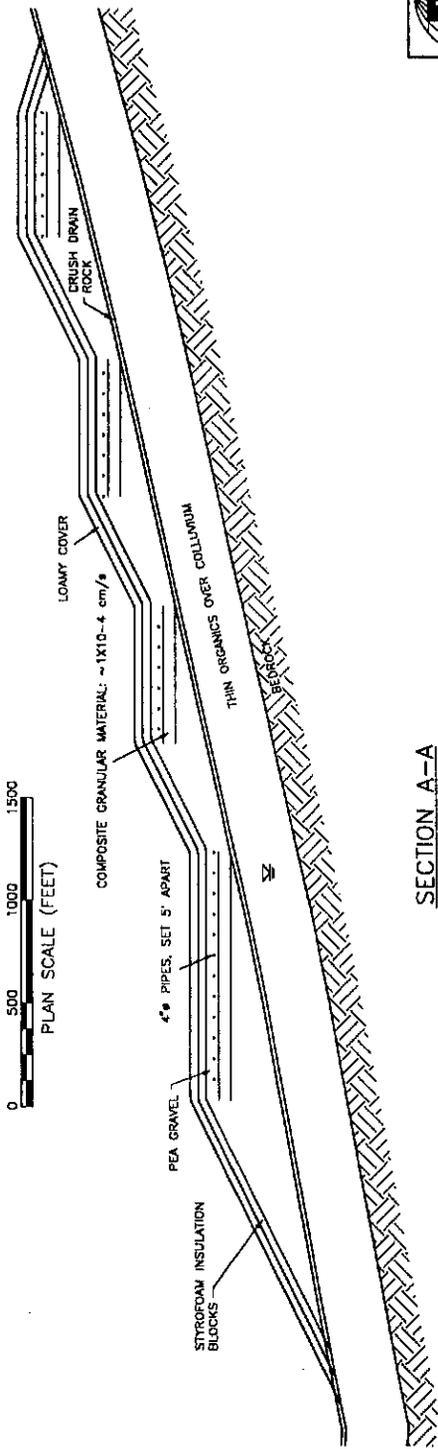
engineering details for the absorption system are not complete and await completion of current column tests on mixtures of site available soils.

The 2000 field investigation program will include drilling several holes in each candidate location to characterize subsurface conditions. The results of this subsurface characterization work will assist in ranking the candidate sites for technical suitability. We understand that Teck will identify the selected location in consultation with regulatory agencies.



LEGEND:
 PLANNED BOREHOLES

NOTES:
 1. SECTION GEOLOGY INFERRED
 2. COMPOSITE GRANULAR MATERIAL = ENGINEERED MIXTURE OF SAND/GRAVEL/SILT/ORGANICS

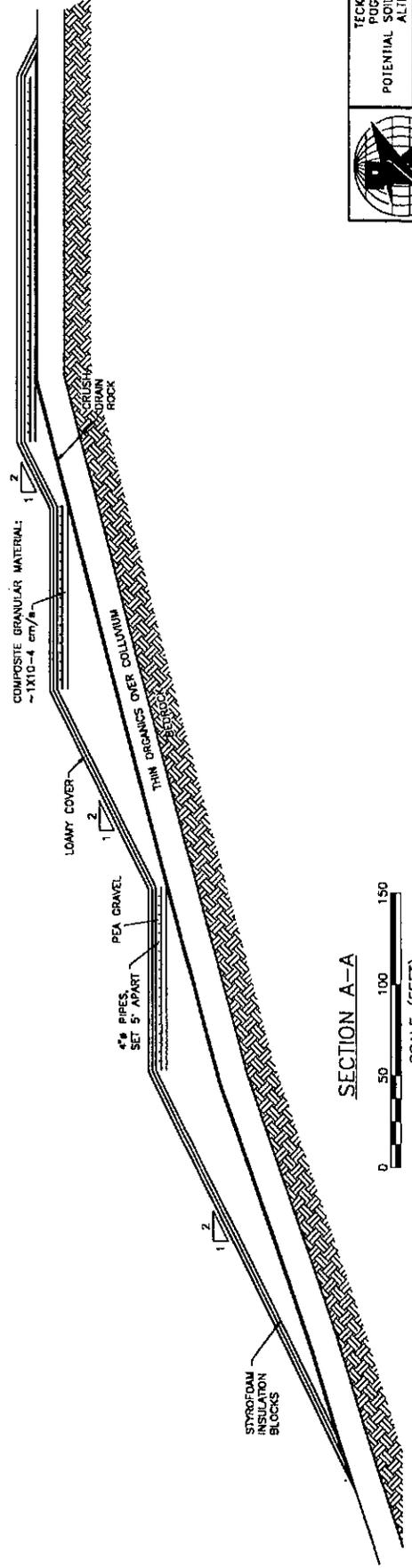
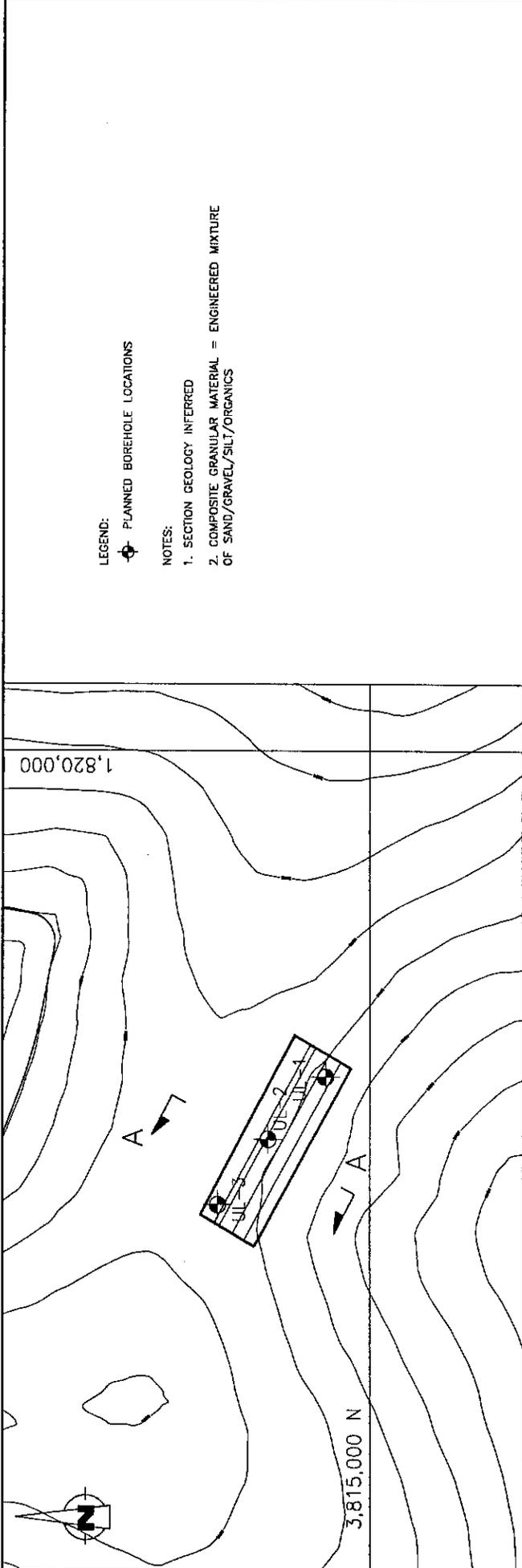




TECK-POGO INC.
 POGO PROJECT
 POTENTIAL SOIL ABSORPTION SYSTEM
 ALTERNATIVE B

DATE: 02/28/88	DRAWN BY: WJL/BR/CA/WH/STW/STW/STW/STW
PROJECT NO. 00133B	SHEET NO. 3 OF 3
FIGURE 3	

1810,000
 3,822,500 N
 0 500 1000 1500
 PLAN SCALE (FEET)
 0 25 50 75
 SCALE (FEET)
 SECTION A-A
 STYROFOAM INSULATION BLOCKS
 PEA GRAVEL
 4" PIPES, SET 5' APART
 COMPOSITE GRANULAR MATERIAL: ~1X10⁻⁴ cm/s
 LOAMY COVER
 CRUSH ROCK
 THIN ORGANICS OVER COLLUMMUM
 ACCESS ROAD
 POTENTIAL SOIL ABSORPTION SYSTEM ALTERNATIVE B
 ORE BODY LI LIMIT
 LB-1
 LB-2
 LB-3
 LB-4
 LEGEND:
 PLANNED BOREHOLES
 NOTES:
 1. SECTION GEOLOGY INFERRED
 2. COMPOSITE GRANULAR MATERIAL = ENGINEERED MIXTURE OF SAND/GRAVEL/SILT/ORGANICS
 TECK-POGO INC.
 POGO PROJECT
 POTENTIAL SOIL ABSORPTION SYSTEM
 ALTERNATIVE B
 DATE: 02/28/88
 DRAWN BY: WJL/BR/CA/WH/STW/STW/STW/STW
 PROJECT NO. 00133B
 SHEET NO. 3 OF 3
 FIGURE 3



TECK-POCO INC.
 POGO PROJECT
 POTENTIAL SOIL ABSORPTION SYSTEM
 ALTERNATIVE C

DATE	SCALE	FIG. NO.	SHEET NO.
02/27/00	U4139	041	10

FIGURE 4



Teck Resources Inc.
Pogo Project
Column Study Report

TECK RESOURCES INC. - 2000-01-01

DISCLAIMER

This report was prepared exclusively for Teck Corporation by AGRA Simons (Simons). The quality of information, conclusions and estimates contained herein is consistent with the level of effort involved in Simons' services and based on: i) information available at the time of preparation, ii) data supplied by outside sources, and iii) the assumptions, conditions and qualifications set forth in this report. This report is intended to be used by Teck Corporation only, subject to the terms and conditions of its contract with AGRA Simons. Any other use of, or reliance on, this report by any third party is at that party's sole risk.



Table of Contents

1.0	LABORATORY STUDY OF SOIL ABSORPTION SYSTEM.....	1
1.1	Objectives	1
1.2	Methods	1
1.2.1	Soils.....	1
1.2.2	Columns	2
1.2.3	Feed Solutions	3
1.2.4	Sample Collection, Frequency and Solution Assays	4
2.0	ANALYTICAL METHODS AND DETECTION LIMITS	4
3.0	QA/QC PROGRAM	4
4.0	RESULTS AND OBSERVATIONS	5
4.1	Columns A to H.....	5
4.1.1	Cyanide, CN	5
4.1.2	Thiocyanate, SCN	5
4.1.3	Ammonia, NH ₃	6
4.1.4	Nitrate, NO ₃	6
4.1.5	Sulfate, SO ₄ , and Total Dissolved Solids (TDS)	7
4.1.6	pH and ORP	7
4.1.7	Metals	7
4.1.8	Manganese.....	8
4.1.9	Attenuation Rate Estimates.....	8
4.1.10	End Test Columns A through H - Culture Enumeration	9
4.2	Columns I and J.....	10
4.2.1	pH and ORP	10
4.2.2	Metals.....	10
4.2.3	End Test - Columns I and J.....	12
4.2.4	Metal Absorption Capacity	13
5.0	CONCLUSIONS.....	13



List of Abbreviations

Aerate	Introduce oxygen/air
Aerobic	Presence of free oxygen
Anoxic	Condition of insufficient oxygen supply or accessibility
Denitrification	Reduction of nitrate or nitrite to nitrogen, nitrous, or nitric oxide
Nitrification	Oxidation of ammonium salts to nitrates and oxidation of nitrites to nitrates by certain bacteria
ORP	Oxidation-Reduction Potential
SWEP	Special Waste Extraction Process – procedure used in BC similar to EPA TCLP
TCN	Total cyanide
WAD	Weak Acid Dissociable



1.0 LABORATORY STUDY OF SOIL ABSORPTION SYSTEM

1.1 Objectives

As presented in the Water Management Report, the proposed plan is to discharge treated effluent from the treatment plant through a soil infiltration and land treatment system before final release to the environment. The primary objective of the soil absorption system will be the removal of complex ions, which include cyanide, thiocyanate and ammonia. The secondary objective of the system is the polishing and removal of metals. Additional information from the literature on the mechanisms utilized by soil infiltration systems to polish mine effluent are reviewed and discussed in the paper entitled "Soil Effluent Treatment by Land Application" located in Appendix VIII of the Water Management Plan.

The feasibility of using a soil absorption system was evaluated using a laboratory soil-column testing program as described in the following report. The program evaluated the impact of variations in organic content and feed composition on the removal efficiency for major ions such as cyanide (CN^-), ammonia ($\text{NH}_3 \rightarrow \text{NH}_4^+$) and thiocyanate (CNS^-) as well as metals.

The objectives of the test program were (1) to demonstrate the feasibility of the land treatment system for compliance with the proposed project water quality objectives as listed in Table 4.5 of the Water Management Plan and (2) to provide data to aid in the design of the soil absorption field.

1.2 Methods

1.2.1 Soils

The soils used in the study were selected as being representative of the on-site materials available at Pogo by Agra Earth and Environmental staff (Agra E&E). The samples were bagged, labelled and shipped to Process Research Associates Ltd's (PRA) laboratory, 9145 Shaughnessy Street, Vancouver, B.C. The soil samples consisted of:

- coarse sand
- aeolian silt
- surficial organic peat.



The above soils were tested in the lab by Agra E&E to verify estimated permeability and finalize the test column mixtures. Based on Agra E&E instructions, PRA blended the soils as received from Pogo to generate two mixtures.

Mixture A was a low organic content material consisting of 10% organics, 10% silt and 80% sand.

Mixture B was a high organic content material consisting of 20% organics, 10% silt and 70% sand.

Two cycle modified SWEP tests were conducted on each of the two soil mixtures. The results showed the following elements being leached: Al, Ca, Fe, Mg, Mn, Si, Na, and Zn. Assay details are tabled in Appendix A.

1.2.2 Columns

The laboratory set-up consisted of 4 inch diameter clear plexiglass columns approximately 48 inches in length with a 36 inch bed depth. The media was supported by a perforated plexiglass grid with glass wool to retain fines. See Appendix B for photographs of the actual columns. Columns A through H were inoculated with 100 mL of solution containing organisms capable of degrading NH_3 , NO_3 , CN and SCN.

A total of 10 columns were set-up as duplicates of five different configurations of soil mixtures and feed solutions. The column set-ups and conditions were as follows:

Column	Soil Mixture	Feed Solution
A and B	A	Synthetic Mine Water
C and D	B	Synthetic Mine Water
E and F	A	Treated Mine Water
G and H	B	Treated Mine Water
I and J	A	Treated Mine Water Spiked with Metals



1.2.3 Feed Solutions

Three solution tests were tested: synthetic mine water (Columns A to D), treated mine water (Columns E to H) and treated mined water spiked with metals (Columns I and J).

The objective of running a synthetic solution through the soil column was to investigate the removal and polishing of metals and complex ions from the solution. Synthetic mine water was generated by adding chemical reagents to water from the City of Vancouver domestic water distribution system. Chemical reagents containing metal species and complex ions such as CN, SCN, NO₃, and NH₃ were added proportionally to simulate the effluent quality from the current water treatment plant.

The second solution tested was treated mine water. Chemical reagents containing complex ions such as CN, SCN, NO₃, and NH₃ were added proportionally to simulate elevated complex ion levels. The purpose of running this solution through the soil column was to investigate the removal of complex ions in the soil systems. Using actual mine water collected from the existing underground water treatment plant at the Pogo site as the stock solution removed the unknown chemical interaction relationships between the species contained in the synthetic solution and the soil systems. The mine water was collected on June 17, 2000 and shipped to Vancouver for the test program.

The third solution generated was treated mine water spiked with metals. In this case, selected chemical reagents were added to simulate elevated metals content or 'off spec' effluent quality. These metals were Ag, Al, As, Cd, Cr, Cu, Fe, Mn, Ni, Pb, Sr, and Zn. The purpose of running these tests was to investigate the effect of metal concentration on metals removal/polishing as well as determining the capacity of the two soil mixtures tested for metals removal. The results for the spiked mine solution tests can be found in section 4.2.

The compositions of the above three feed solutions are provided in Appendix C. The chemical reagents used in solution makeup are also provided in Appendix C.

All feed solutions were metered into the columns using peristaltic pumps at a rate of 100 mL/h. This flowrate was selected to simulate a typical surface loading rate of 1 gpd/ft².



1.2.4 Sample Collection, Frequency and Solution Assays

The leach solutions from each column were collected in containers placed under each column. The volume of leach solution being generated was measured daily. The samples were collected, split, archived, preserved and submitted directly to either PRA or IPL for the assays. Since the leach solutions contained some visible particulate material, all samples were assayed for both total and dissolved metals. The initial leach solutions contained measurable levels of particulate metals, namely iron and aluminum, since these materials were being rinsed from the soil media. Once this initial release was complete, particulate metals levels dropped, although some evidence of post-oxidation and precipitation of Fe and Mn was indicated by the differences between total and dissolved metals. The leach solutions were initially assayed on daily basis for all parameters. Assay frequency was however reduced on a weekly basis after the data trends could be clearly established from the results. The transition from daily to weekly assaying occurred after 7 to 10 days of the start of the program for the metals, while assaying for the major ions (TCN, WAD-CN, NH₃, NO₃, SCN, SO₄ and TDS) continued daily for approximately 21 days and was then dropped back to 2 to 3 times per week. Measurements for the physical parameters, namely pH, conductivity, and ORP, were conducted daily throughout the program. Columns A through H were operated between 69 and 72 days while Columns I and J were operated for a total of 70 days.

2.0 ANALYTICAL METHODS AND DETECTION LIMITS

Analyses were carried out jointly by PRA and IPL (International Plasma Laboratories). The analytical methods and detection limits for the study used by PRA and IPL are summarized in Appendix D.

3.0 QA/QC PROGRAM

A quality assurance and control program (QA/QC) was completed on metal and complex ion analyses for the soil column testwork. The primary objective of the program was to determine the level of precision/repeatability in the test laboratories and to determine the accuracy/reproducibility of assaying between laboratories. The QA/QC program demonstrated that there was some variability in the precision of assays between the laboratories used in the study, as expected. However, the QA/QC program results also demonstrated that the precision of assays was sufficient to validate the data collected during the study and support conclusions with respect to attenuation of the major ions and metals investigated.



4.0 RESULTS AND OBSERVATIONS

4.1 Columns A to H

The tabulated analytical results for Columns A through H are provided in Appendix F while the graphical plots of the data for these columns are provided in Appendix G.

Columns A through H, which were designed to assess removal of complex ions and metals from both a synthetic and real treated effluent using two different soil mixtures, are presented in Section 1. Trends and relationships associated with the individual parameters and the different test conditions were sufficiently defined by the data set to draw conclusions with respect to probable removal mechanisms and rates. The overall findings from the data generated from Columns A through H are summarized in the following sections.

4.1.1 Cyanide, CN

Columns A thru H demonstrated that both total cyanide and WAD cyanide were effectively being removed to low concentrations under all test conditions. Although there were outliers in the data set, (potentially due interference from organic matter in the leach solutions), by the end of the test (70 days) TCN values were typically less than 10 ppb (0.01 mg/L) while WAD-CN levels were in the 1 to 5 ppb (0.001 to 0.005 mg/L) range. Initial TCN feed concentrations were approximately 50 ppb (0.05 mg/L). The mechanisms for cyanide removal would include (1) precipitation of iron complexes (2) adsorption to organic material and (3) aerobic biological uptake. Discussion of the mechanisms responsible for cyanide removal in soil were presented in Appendix E of the Water Management Report. It is assumed that precipitation of cyanide complexes and adsorption to organic matter would be the dominant removal mechanisms relative to biological mechanisms. Differences in the soil mixtures did not appear to have an impact on removal efficiency.

4.1.2 Thiocyanate, SCN

All columns demonstrated effective removal of SCN to concentrations of less than 0.2 mg/L. Based on its chemistry, it is assumed that SCN was being removed by aerobic biological uptake. Both Columns C and D and



Columns G and H, which contained lower permeability materials and higher organic contents appeared to be slightly less effective in SCN removal during the first 30 days of the study. This difference in performance was deemed due to the relative lower availability of oxygen in the high organic content materials. The results indicate that once a biological culture is established in a soil media, SCN should be effectively removed.

4.1.3 Ammonia, NH₃

All columns exhibited similar trends with respect to ammonia. Concentrations were initially low (< 0.5 mg/L) at start-up and then increased to peak values of 3 to 4 mg/L, after one to two weeks of operation. Following the observed peaks, leachate NH₃ concentrations dropped to less than 0.03 mg/L after three weeks of operation. It was concluded that initially ammonia was being physically absorbed by the soil and then subsequently released to generate the peak concentrations, once the limited absorptive capacity of the soil materials for NH₃, had been exceeded. It is assumed that biological nitrification (ammonia oxidation) was responsible for the drop in ammonia concentration after three weeks of operation. This phenomenon is to be expected since some time would be required for the organisms responsible for nitrification to become established in the column materials. This biological activity would ensure that the soil absorption system should have a significant capacity for removal of ammonia. Columns G and H containing lower permeability materials and higher organic contents appeared to be less effective initially in NH₃ removal, potentially due a reduction in the availability of oxygen. However by the end of the study the leach solution NH₃ concentrations in Columns G and H had reached similar concentrations to that demonstrated by the columns containing lower amounts of organic materials.

4.1.4 Nitrate, NO₃

Nitrate data was variable and not consistent between the duplicates. All columns released NO₃ due to leaching of the partially decomposed organic material in the soil media during the first week of the program. After this point, nitrate levels increased as the biological nitrification process became established. Due to the fact that nitrate was generated from ammonia oxidation it is expected that the leachate should contain some NO₃ (as was the case with Columns A, B, C and E where NH₃ was approximately 6 mg/L). However NO₃ concentrations in Columns D, F, G and H were all low after six weeks, indicating that if NO₃ was being released via nitrification it was



subsequently being removed either to supply nitrogen for biological activity under aerobic conditions or through denitrification to generate N₂ gas under anoxic conditions (oxygen limited). Denitrification would be favoured in those columns where oxygen availability was restricted by lower permeability. Although not supported by results from the duplicates, a general conclusion that can be drawn with respect to nitrate is under anoxic conditions some denitrification and loss of nitrate can be expected. However this condition should be avoided since anoxic conditions could potentially inhibit the nitrification process and reduce ammonia removal efficiency as well.

4.1.5 Sulfate, SO₄, and Total Dissolved Solids (TDS)

Sulfate and TDS varied throughout the study without any notable trends. The initial leach solutions however contained elevated TDS since some dissolved salts were being leached from the column media. Sulfate was typically in the 450 to 600 mg/L range while TDS varied from 700 to 900 mg/L. Significant changes in sulfate or TDS would not be expected based on the feed chemistry.

4.1.6 pH and ORP

pH remained in the slightly acidic range of 6.5 to 6.8, indicating that the soil material has limited alkalinity. ORP was typically in the +200 to +300 mV range, indicating oxidizing conditions. Some samples exhibited lower ORP values of less than +100 potentially due to the slightly reduced conditions created by the higher organic content media.

4.1.7 Metals

Heavy metals of environmental concern such as Ag, Hg, Cu, Pb and Cd were removed to low concentrations of less than the assumed discharge specification while the alkali metals, such as Ca, K, Sr and Na were not removed and may have in fact been leached from column materials in some cases. Non-metals such as As, Sb and Se, assumed present as anions, were being effectively removed, potentially due to the presence of Fe in the feed and column material that would assist with precipitation of these species. Leachate concentrations for Zn and Ni were low but variable in some cases potentially due to variation in leachate pH. Reducing conditions and low pH's in columns with high organic contents resulted in some dissolution of metals (namely Mn as discussed below) from the media during



the first three weeks of the test program. A general observation was that the removal of metals would likely be enhanced if the pore water pH's in the column materials were higher. As noted above, leachate pH's were typically 6.5 to 6.8, and oxygen availability was not limited. It is recommended that the soil absorption system utilize low organic content materials and incorporate an alkaline material in the soil mixtures to increase pore water pH and assist with metal removal.

4.1.8 Manganese

During the column study, dissolved manganese concentrations did increase to between 6 and 7 mg/L, during the first two weeks of the test but then steadily dropped to less than 1 mg/L by the time the study was terminated after 10 weeks. A review of the results indicates that soluble manganese was being generated from the slightly acidic, anoxic environment, created by the presence of the relatively high concentrations of "organics" in the soil mixtures tested. Under the above conditions, both iron and manganese can act as oxidizing agents in the presence of "organics" and thereby be released into solution as reduced species. Once the leachate from the column study were exposed to oxygen, iron readily oxidized and precipitated as ferric hydroxide while manganese remained in solution as soluble manganous ion (Mn^{++}) due to the slightly acidic pH conditions in the leachate. The column study has demonstrated the potential need to incorporate two features in the design of the soil absorption system; (1) a reduction in the organic content of the soil mixture to control anoxic conditions and (2) maintaining alkaline conditions in the soil column through either incorporation of alkaline material, such as limestone into the soil mixture or through ensuring that the discharge has sufficient alkalinity to assist with precipitation of metals, including manganese. It should be noted that reductions in organic content from that used in the column study should help to maintain pH in the alkaline range in the soil absorption system.

4.1.9 Attenuation Rate Estimates

The attenuation rates for the major ions for Columns A thru H are presented in Table 4.1. The data in this table was generated by comparing the feed and final discharge concentrations at the end of the test program and then expressing removal as the mass removed per day on an equivalent surface area basis. For comparative purposes, removal rates are also expressed on a percent removal basis. It should be noted however, that the attenuation rates on both a mass per unit area basis and on a percent removal basis



would have been higher if the feed concentrations used in the column study had been greater. Chemical and biological treatment systems typically reduce contaminant concentrations to baseline or residual concentrations irrespective of feed concentration as long as the loading capacity of a particular treatment system has not been exceeded. Performance for chemical treatment systems are governed by solubility limits while biological systems are typically controlled by retention times and loading rates not feed concentrations. The feed concentrations in this study mirrored the expected maximum water treatment effluent concentrations generated from the water quality modelling work presented in Section 4.0 of the Water Management Plan (August, 2000). These concentrations were low relative to the maximum concentrations that a typical soil absorption system could treat. Regardless of the low feed concentrations, Table 4.1 demonstrates that the media had significant capacity to remove CN, NH₃ and SCN. The attenuation rates represented in Table 4.1 can be used to evaluate the proposed design of the soil absorption system.

Table 4.1 Column A to H Attenuation Rates (kg/ha/da)

Column	CN (Total)		NH ₃		SCN	
	Loading ¹	% ²	Loading ¹	% ²	Loading ¹	% ²
A	0.12	82	8.70	87	1.18	53
B	0.14	94	8.85	88	1.92	87
C	0.12	84	9.15	91	1.81	81
D	0.12	92	9.09	90	2.10	95
E	0.12	80	8.76	90	0.92	46
F	0.12	82	8.38	86	1.78	90
G	0.12	84	8.29	85	1.95	99
H	0.13	80	8.56	88	1.66	84
Average	0.12	84	8.72	88	1.67	79

¹ Loading expressed as kg/ha/d.

² % - Percent Removed based on feed concentration used in the testwork program.

4.1.10 End Test Columns A through H - Culture Enumeration

Once the operation of Columns A through H was discontinued, a 250 cc sample of the media at the surface of Columns A, E, G and I were collected for microbial culture enumeration. This samples were placed in a standard jar



with an air space, left un-refrigerated and shipped to Microbial Technologies Inc for enumeration and cell counts for NH_3 , CuCN, SCN and NO_3 degraders. The results of the Microbial Technologies report is provided in Appendix H. Bacterial populations of nitrifying bacteria and SCN-degrading bacteria were high in all soil samples, except for Column I (nitrifiers) and Column G (SCN-degraders). Populations of denitrifying bacteria were moderately high in all but Column A. No copper-cyanide degrading bacteria were detected in any of the samples tested.

4.2 Columns I and J

The tabulated analytical results for Columns I and J are provided in Appendix I while the graphical plots of the data for these columns are provided in Appendix J.

Columns I and J were designed to assess the removal capacity of the soil media for metals when the feed metal concentrations were elevated above expected metal concentrations from the proposed water treatment system. The study was conducted using a feed consisting of treated mine water spiked with metals. The target feed metal concentration for Columns I and J was 10 times the concentrations used in Column E through H, however the actual ratio varied due to limitations such as metal solubility and the contaminant metal content of the lab reagents used to produce the feed solution. The composition of the feed solution is provided in Appendix C. Columns I and J were operated until breakthrough was observed, indicating the capacity of the soil for metals removal had been consumed. At the end of study Columns I and J were rinsed with distilled water on a weekly basis to examine the potential re-release of metals from the media. The overall findings from the data generated from Columns I and J are summarized in the following sections.

4.2.1 pH and ORP

Similar to Columns A through H, pH remained in the slightly acidic range of 6 to 6.8 while ORP ranged from +200 to +300 mV.

4.2.2 Metals

Although Columns I and J were operated until breakthrough was observed, it did not apply to all metals. Specific metals that had markedly increased in



concentration by the end of the study and had thereby shown signs of breakthrough included B, Cd, Hg, Na, Ni and Zn. Metals that remained at low concentration at the end of the study, indicating that removal was still occurring included Ag, Al, As, Cr, Cu, Fe, Pb, Sb, and Se. Ca levels continued to drop during the study likely due to enhanced conditions for CaCO_3 precipitation. The behavior of Mn was similar to Columns A through H in that initially Mn concentrations increased after the first three weeks then was continuing to decrease when the study was terminated.

A comparison of the metal feed concentrations and the resultant product water concentrations and removal efficiency values for Columns I and J are provided in Table 4.2. This table provides data for Day 16 and 70. It should be noted that the removal efficiency calculation used the three previous readings in each case to reduce the impact of sampling and assay errors. Both columns exhibited exceptional removal efficiencies (>90%) for the first 16 days of testing, after which a minor loss of removal efficiency was noted for some of the parameters. By the time the study was terminated at 70 days, the columns were exhibiting break-through for Zn (i.e. product concentration approaching feed concentration). The columns were also exhibiting significant loss of Cd removal efficiency, dropping from 99% removal at Day 16 to approximately 55% at Day 70. Metals that continued to exhibit very high removal efficiencies at Day 70 and no break-through included Ag, As, Fe, Pb and Se. The basic conclusion was that the soil absorption column had significant capacity to remove metals even at feed concentrations an order of magnitude greater than current treated minewater.



Table 4.2 Metal Removal Summary

Table Summaries of Metal Removal Results Columns I and J

Metal	Total/ Dissolved	Feed Concentration mg/L	Column I			Column J					
			Concentration After 16 Days (1)	Percent Removal at 16 Days (2)	Concentration After 70 Days (1)	Percent Removal at 70 Days (2)	Final Concentration (1)	Percent Removal at 70 Days (2)	Concentration After 70 Days (1)	Percent Removal at 70 Days (2)	
Al											
Ag	Total	0.0617	0.0006	98	<0.0001	99	0.0007	98	<0.0001	99	
	Diss	0.0209	0.0002	98	<0.0001	99	0.0002	98	<0.0001	99	
As	Total	0.49	<0.03	94	<0.03	94	<0.03	94	<0.03	94	
	Diss	0.35	<0.03	91	<0.03	91	<0.03	91	<0.03	91	
Cd	Total	0.139	0.0009	99	0.0565	54	0.0005	99	0.0688	60	
	Diss	0.133	0.0009	99	0.0496	56	0.0004	99	0.0688	59	
Cu	Total	0.13	<0.01	92	0.05	80	<0.01	92	0.05	80	
	Diss	0.13	<0.01	90	0.01	92	0.01	87	0.01	90	
Fe	Total	5.33	<0.01	99	0.71	98	<0.01	99	0.11	98	
	Diss	3.02	<0.01	99	<0.01	99	<0.01	98	0.03	99	
Pb	Total	0.257	0.015	93	0.004	97	0.018	92	0.01	96	
	Diss	0.179	0.012	92	0.0003	97	0.017	90	0.0006	97	
Se	Total	0.66	0.001	98	0.0075	99	0.0015	98	0.0052	99	
	Diss	0.29	<0.0005	96	0.0048	99	<0.0005	96	0.0058	99	
Zn	Total	5.54	0.076	99	3.248	17	0.067	99	3.997	10	
	Diss	5.68	0.064	99	3.267	20	0.064	99	3.92	14	

1- Measured concentration at Day 16 or 70

2- Percent Removal calculated using the feed concentration and the average of the three previous samples in the series.



4.2.3 End Test - Columns I and J

The metal absorption and retention efficiency of the columns was assessed using the following procedure.

- Columns I and J were allowed to sit for one week after the end of the leaching program, then leached on a weekly basis using 400 mL of aerated distilled water to simulate precipitation events of approximately 50 mm.
- The leachate was collected and assayed for pH, Eh, conductivity and total and dissolved metals.
- Leaching was conducted for four weeks.

4.2.4 Metal Absorption Capacity

Metal uptake efficiency was assessed by calculating the total quantity of metals removed by the columns during the 70 day study and comparing this value with the quantity of metal released during the End Test. The results of these calculations for the metals designated as potential permit parameters are presented in Appendix K.

The results indicate the columns had the capacity to removal significant amounts of metals without re-releasing these metals during the rinsing portion of the study. Metals being removed by media are potentially being removed and retained in the media as insoluble species.

5.0 CONCLUSIONS

A summary of findings are provided below.

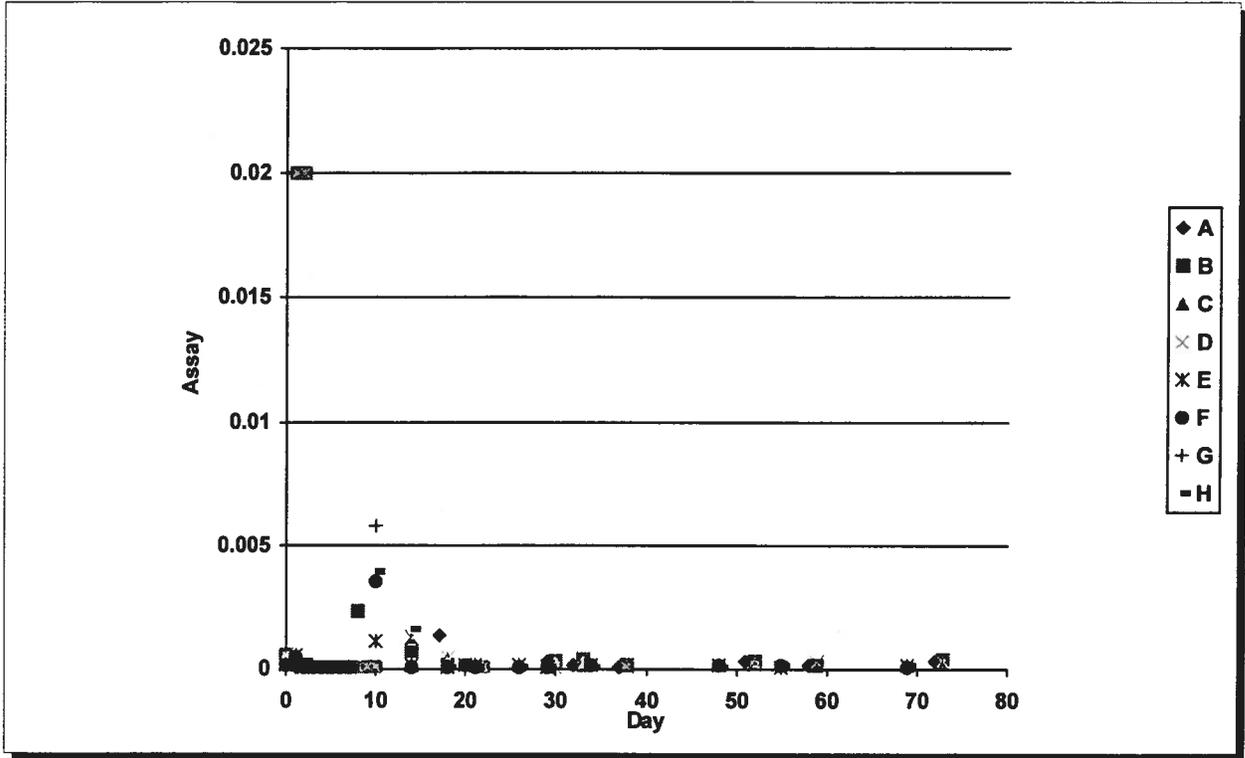
- All columns were effective in the removal of both TCN and WAD-CN to concentrations below the assumed discharge specifications, subject to feed concentrations being in the range of 0.05 mg/L TCN. The mechanisms responsible for removal were assumed to be precipitation and adsorption, since no copper cyanide degraders were detected during culture enumeration. Factors that would enhance attenuation of cyanide in the soil would therefore be (1) the presence of minerals in the media containing iron (2) organic matter and (3) adequate retention time.
- SCN was removed effectively by all columns with the exception of some inhibition noted with the higher organic matter, lower oxygen availability materials. Biological degradation was assumed to be the primary



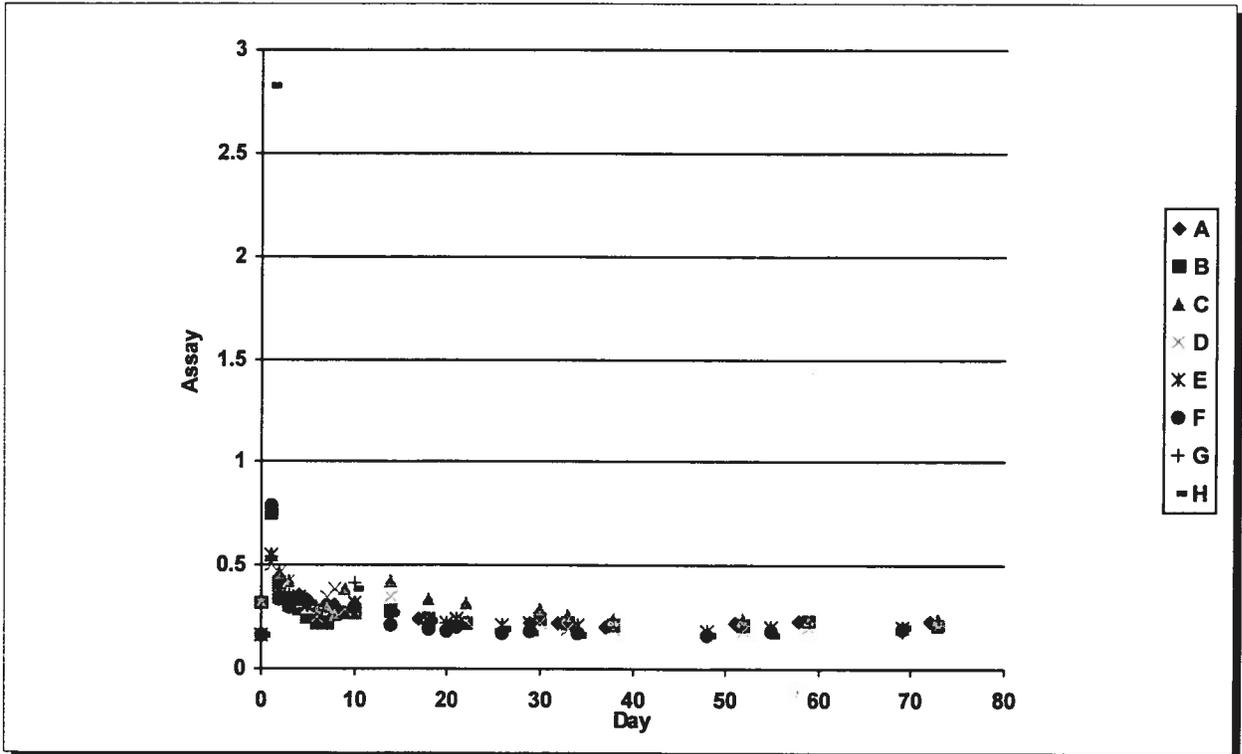
removal mechanism based on the detection of high concentration of SCN-degrading bacteria in all columns. Factors that would be expected to enhance the attenuation of SCN, would therefore include (1) oxygen availability and (2) adequate surface area to support biological growth.

- Ammonia was effectively removed by all columns once the biological cultures became established and the organic material in the media had stabilized. Columns with higher organic matter and limited oxygen availability required longer times to stabilize than the columns with lower organic contents. Factors that would be expected to enhance ammonia removal would therefore include (1) good oxygen availability (2) adequate surface area and (3) adequate retention time.
- The general conclusion with respect to NO_3 is that anoxic conditions can result in removal of NO_3 but should be avoided due to the potential impact on nitrification.
- All metals of concern, namely arsenic, cadmium, selenium, lead, mercury, and silver are consistently removed from solution to below the proposed water quality objectives. The column media demonstrated relatively high capacities for metal removal even when loaded using elevated feed metal concentrations. These metals, once loaded on the media, were immobilized and not available for re-leaching. Factors that should be enhanced to optimize attenuation would include (1) the provision of adequate alkalinity to assist with metal precipitation (2) adequate oxygen availability to avoid reduce conditions and metal re-solubilization, (3) the presence of minerals in the media containing iron and other metals to assist with anion precipitation and (4) high surface areas to provide precipitation sites.

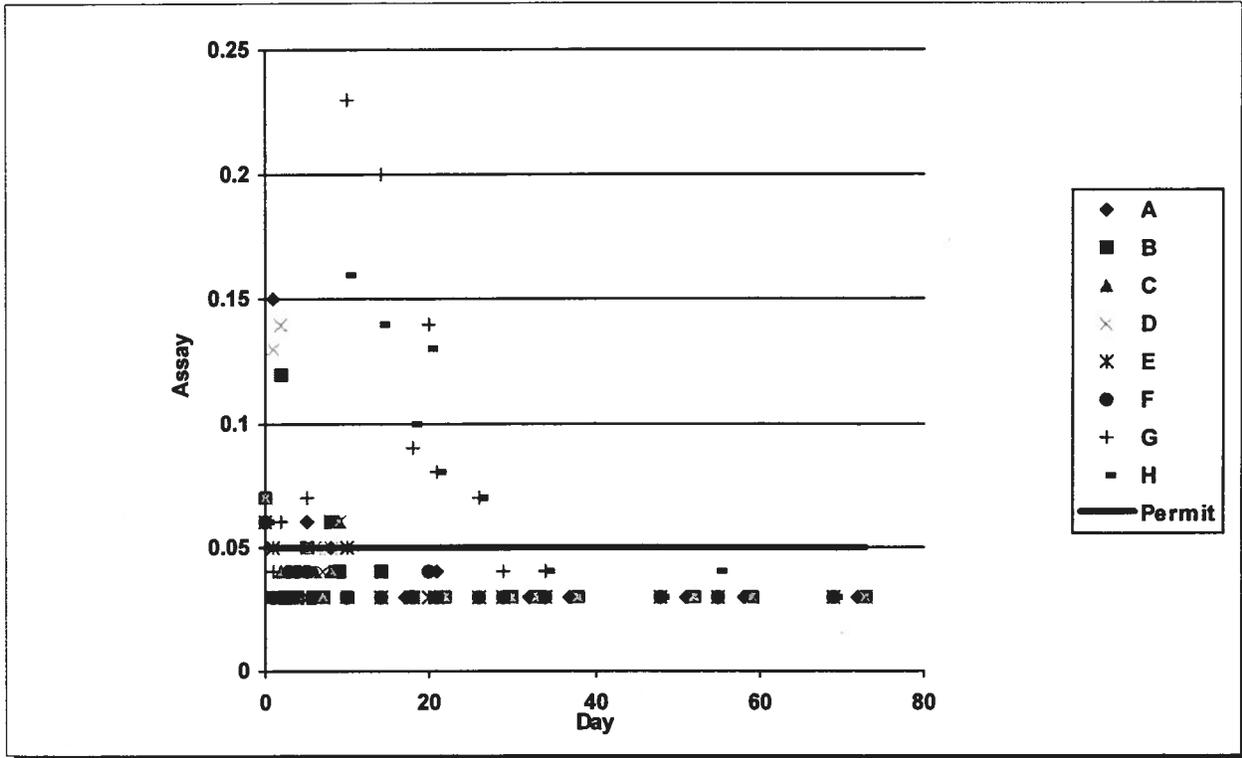
Ag Dissolved mg/L



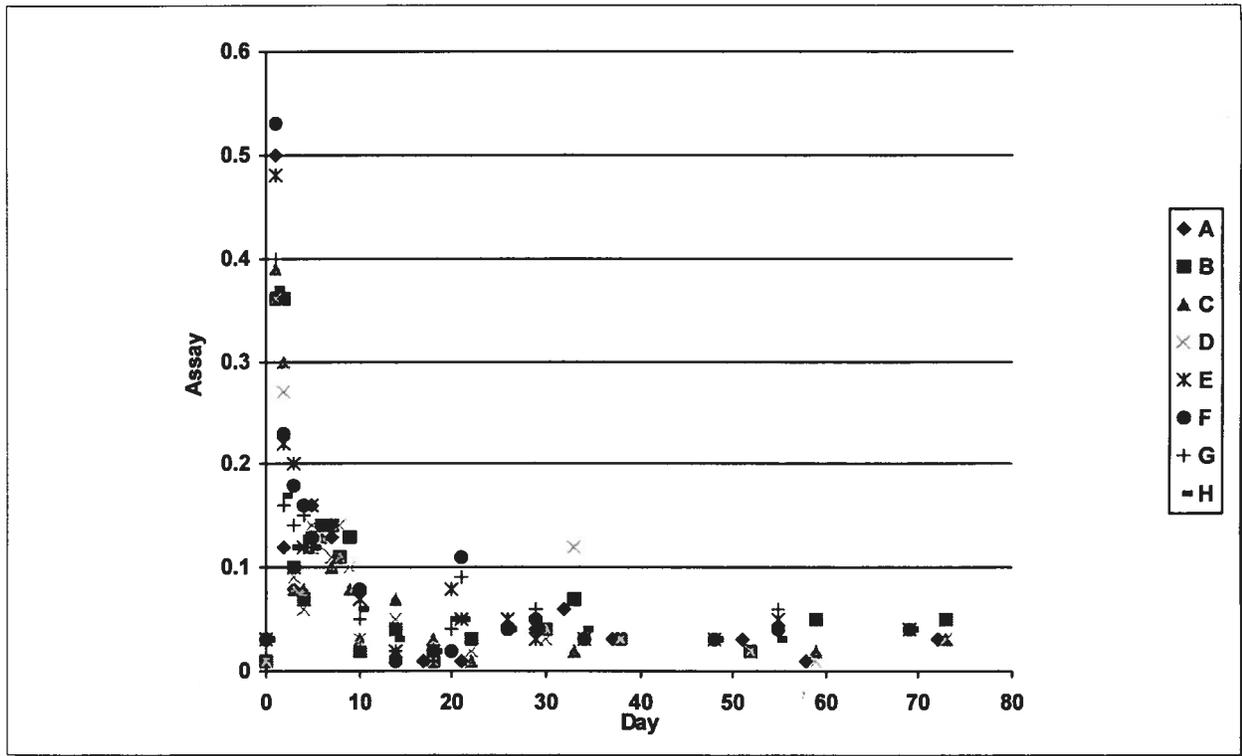
Al Dissolved mg/L



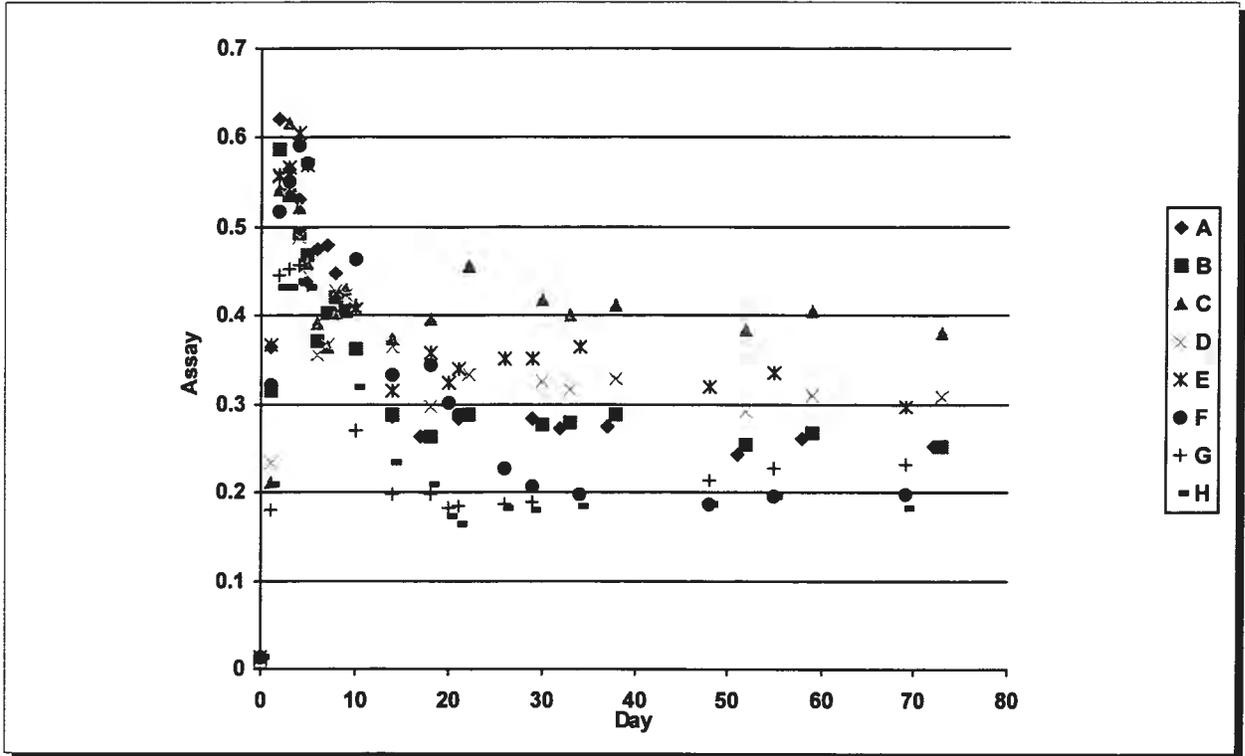
As Dissolved mg/L



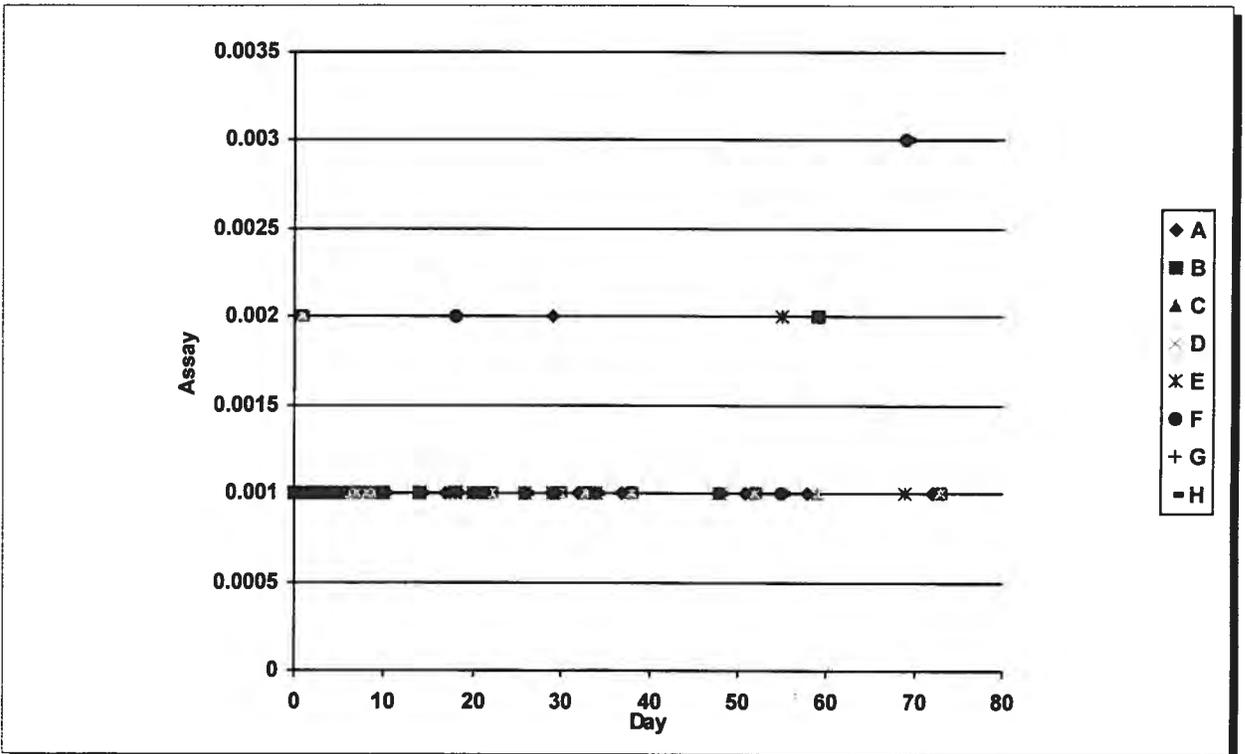
B Dissolved mg/L



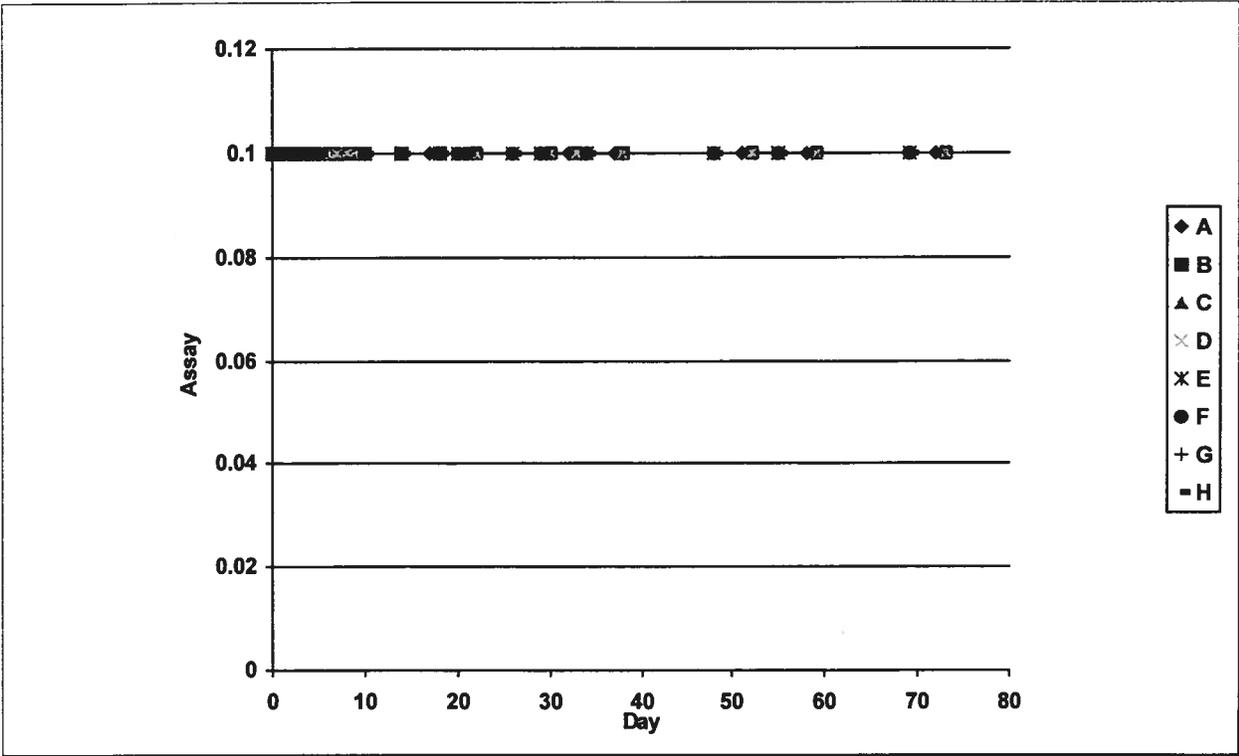
Ba Dissolved mg/L



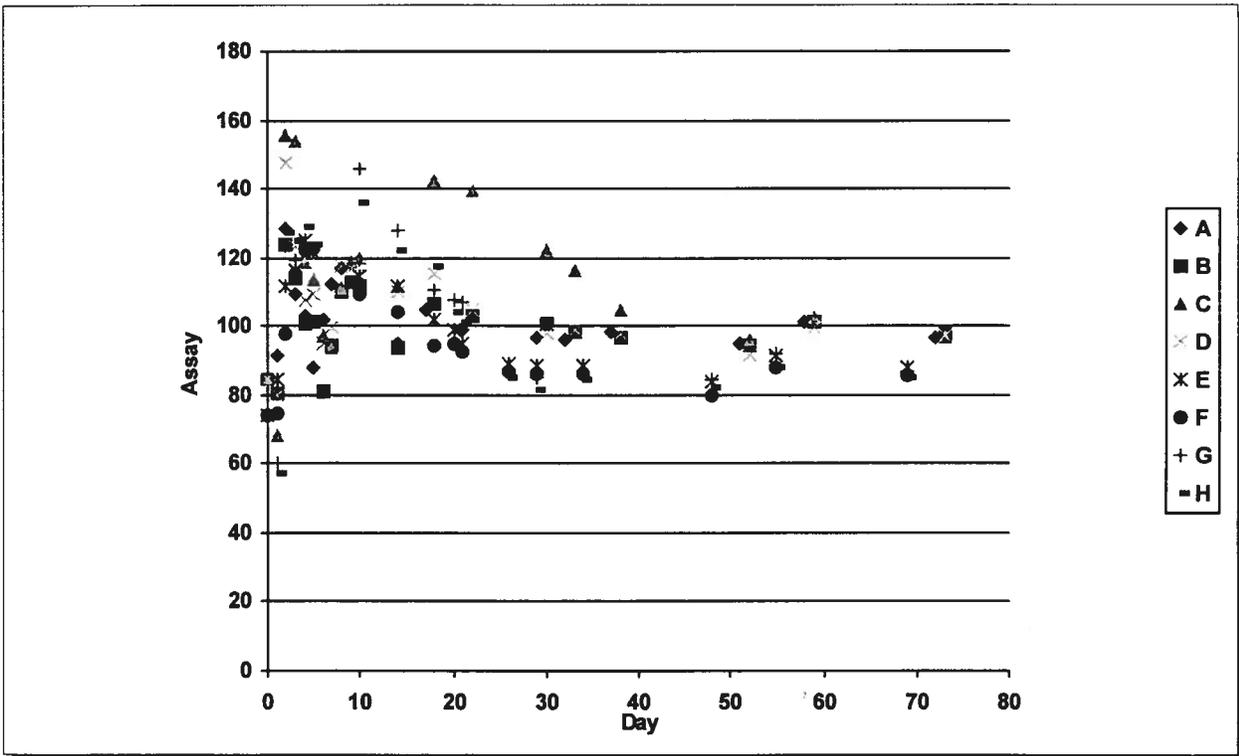
Be Dissolved mg/L



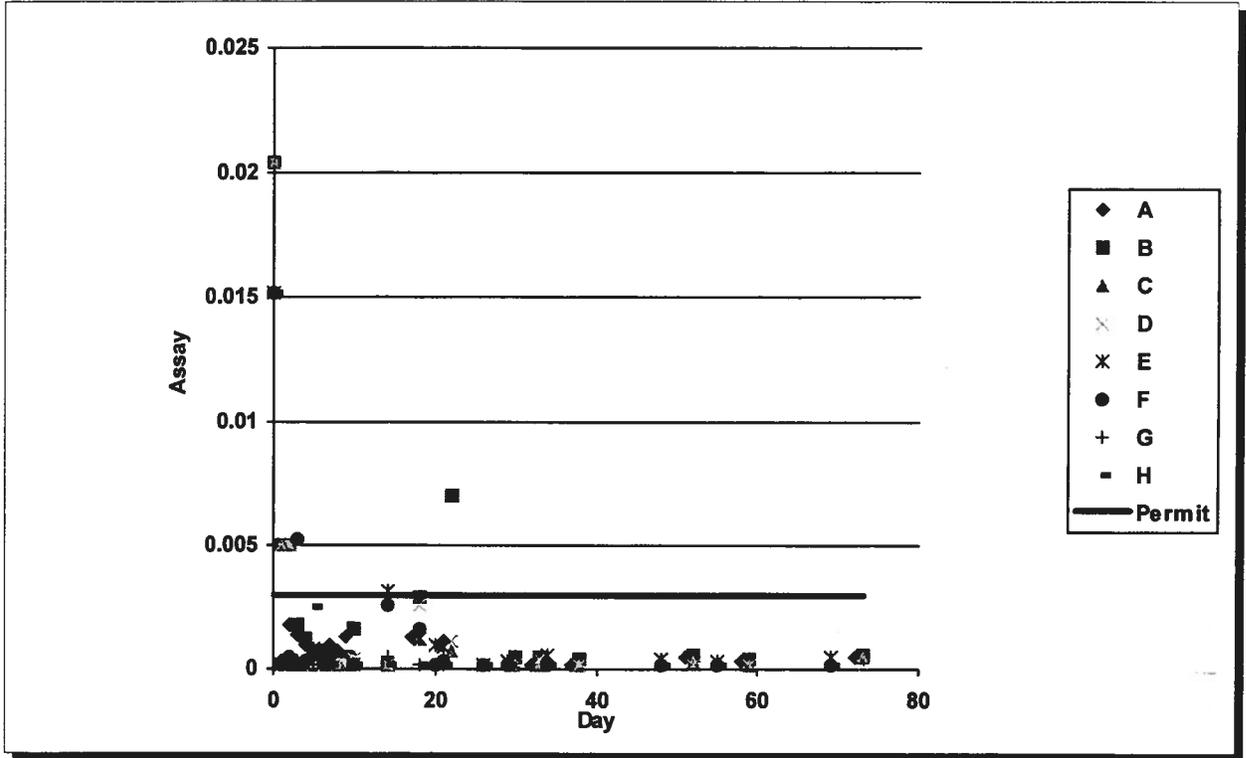
Bi Dissolved mg/L



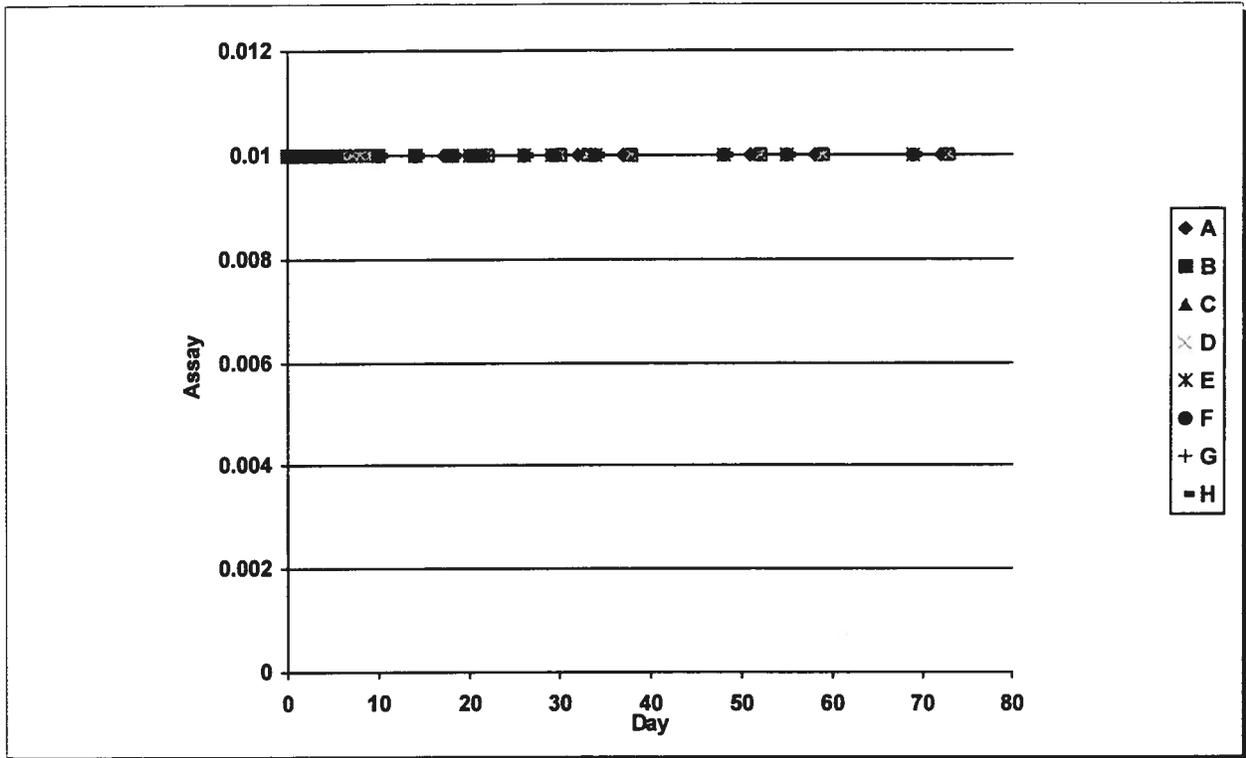
Ca Dissolved mg/L



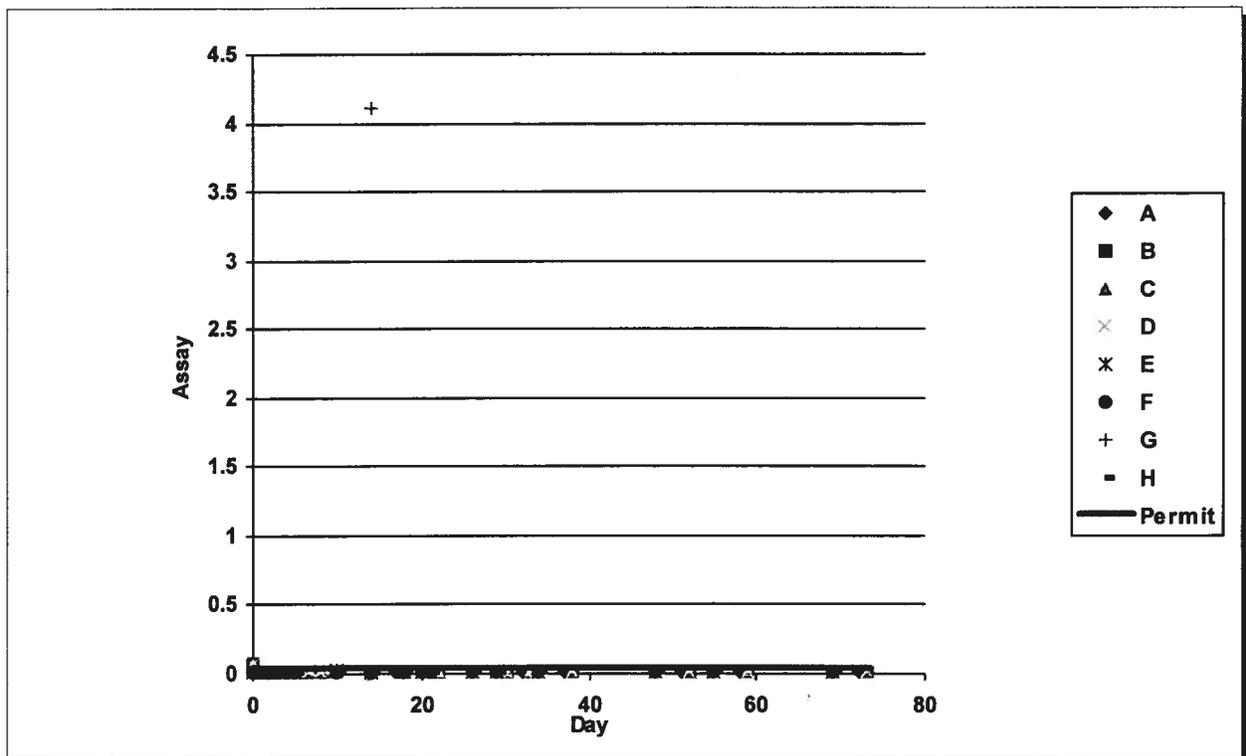
Cd Dissolved mg/L



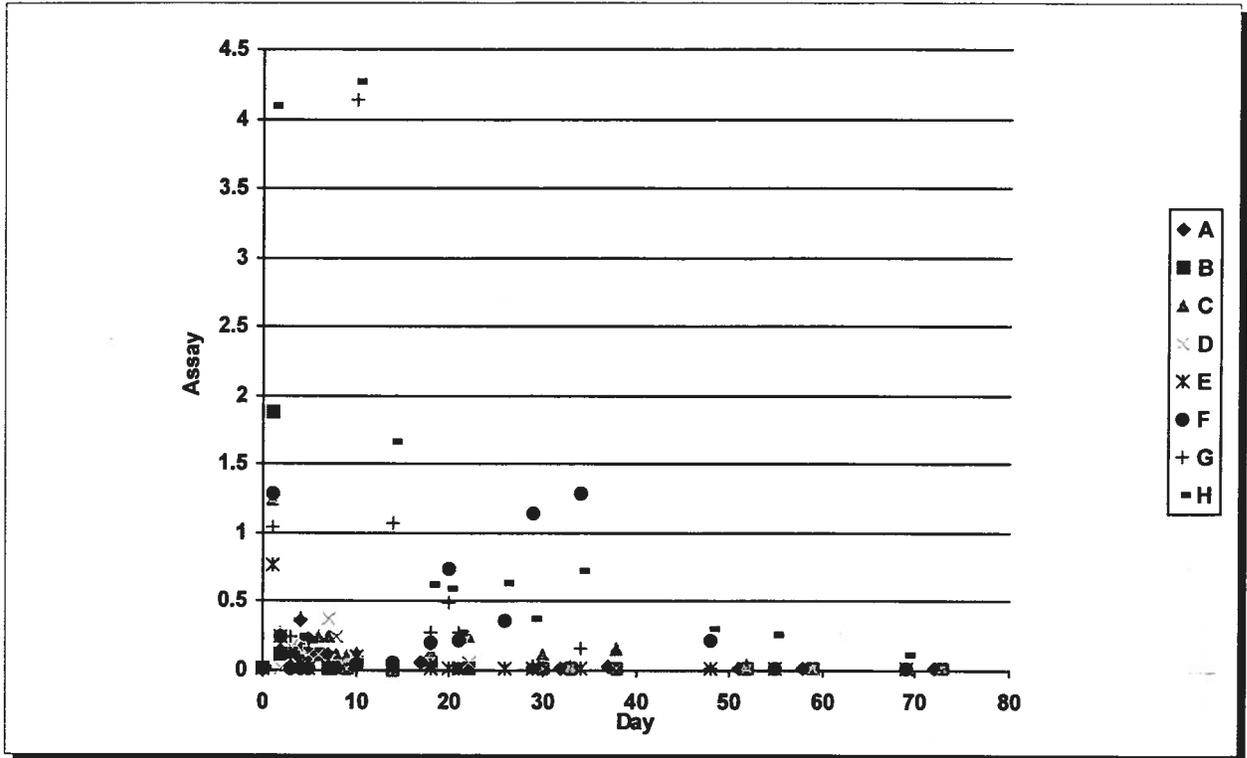
Cr Dissolved mg/L



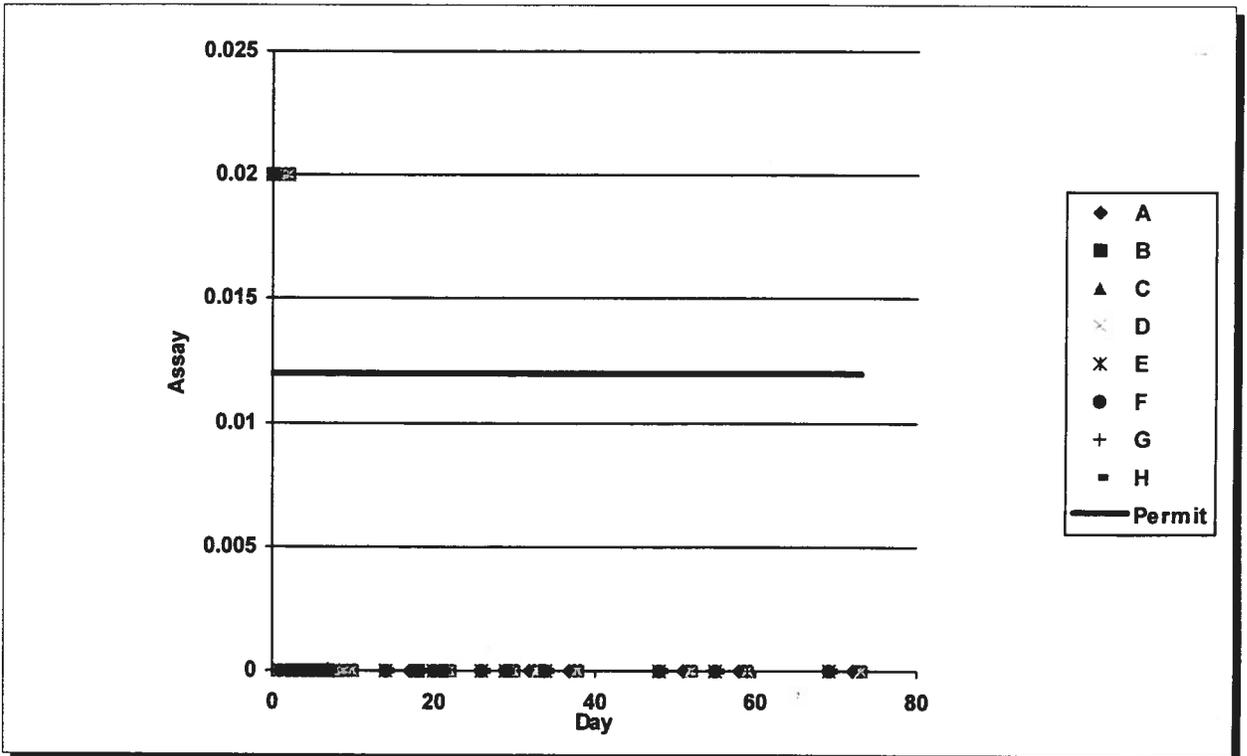
Cu Dissolved mg/L



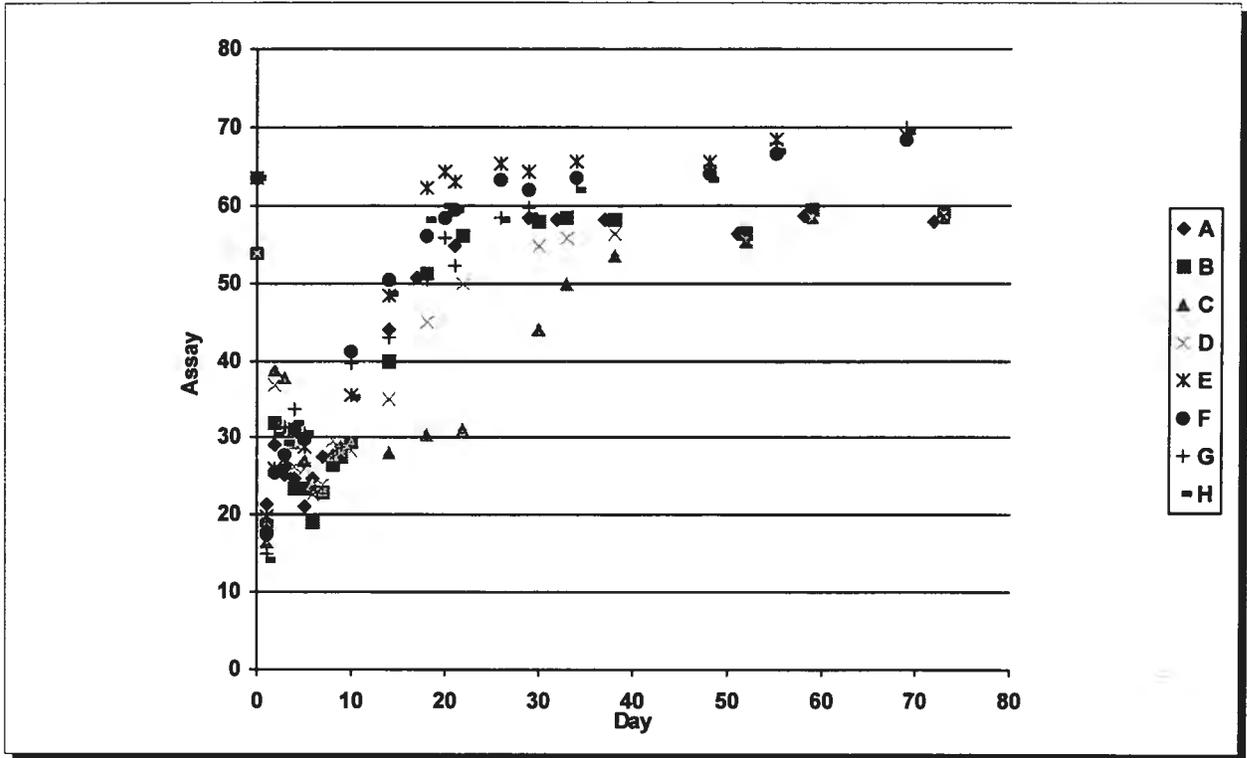
Fe Dissolved mg/L



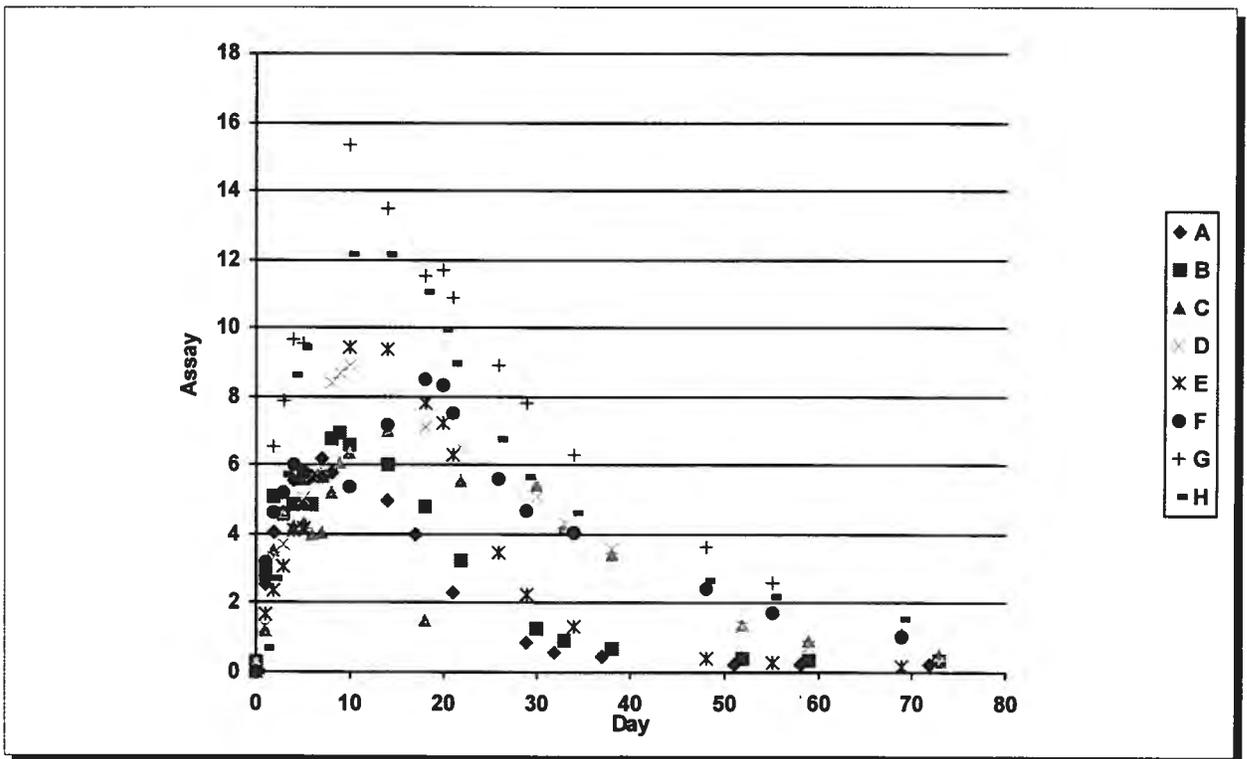
Hg Dissolved mg/L



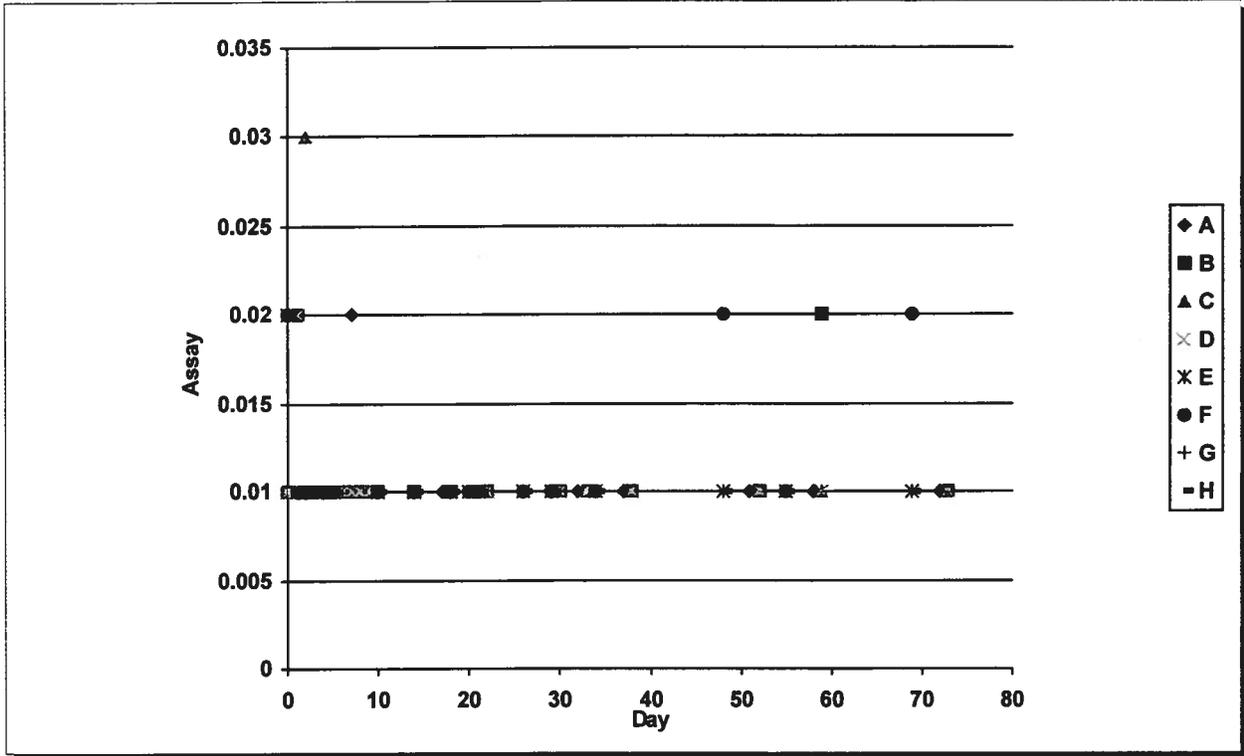
Mg Dissolved mg/L



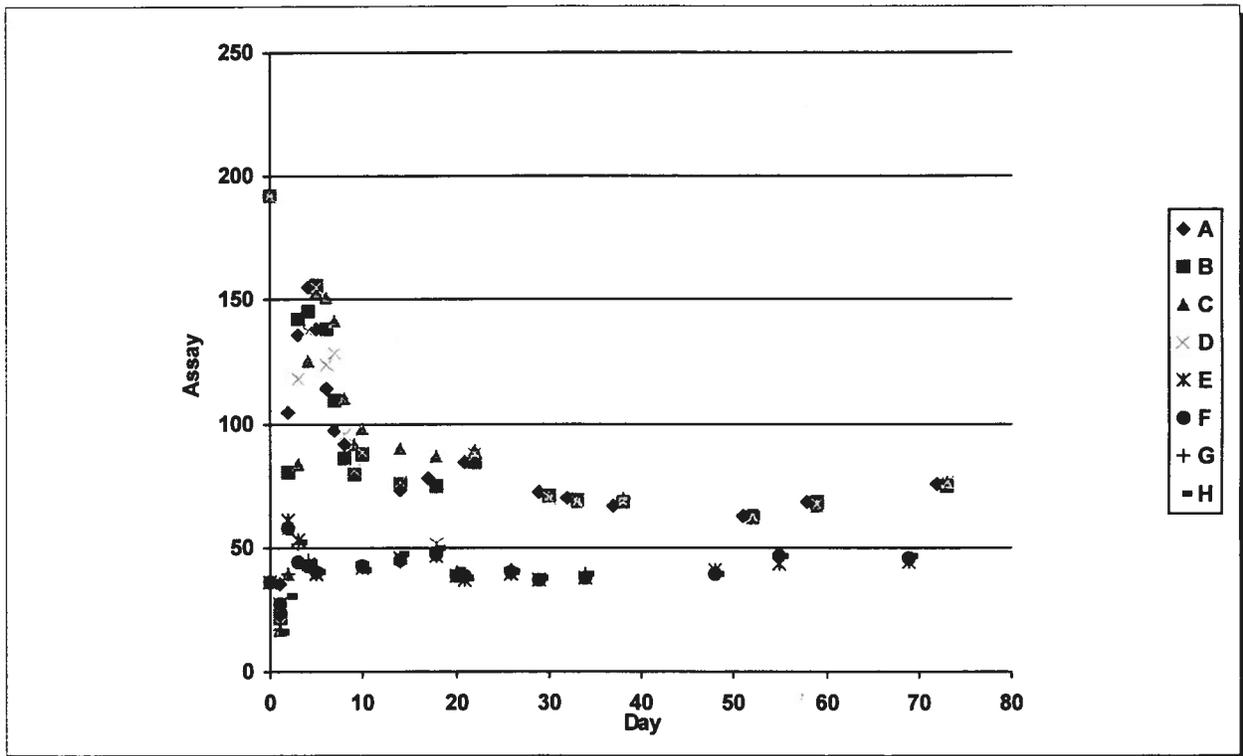
Mn Dissolved mg/L



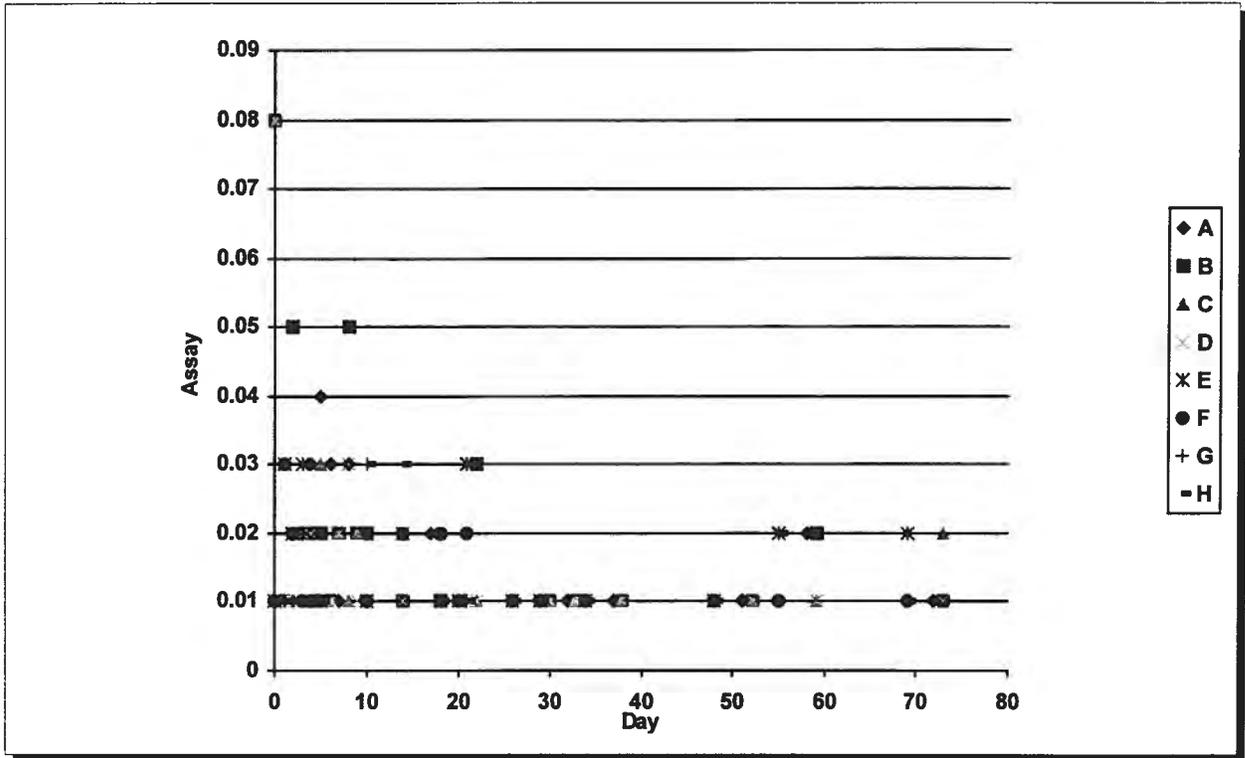
Mo Dissolved mg/L



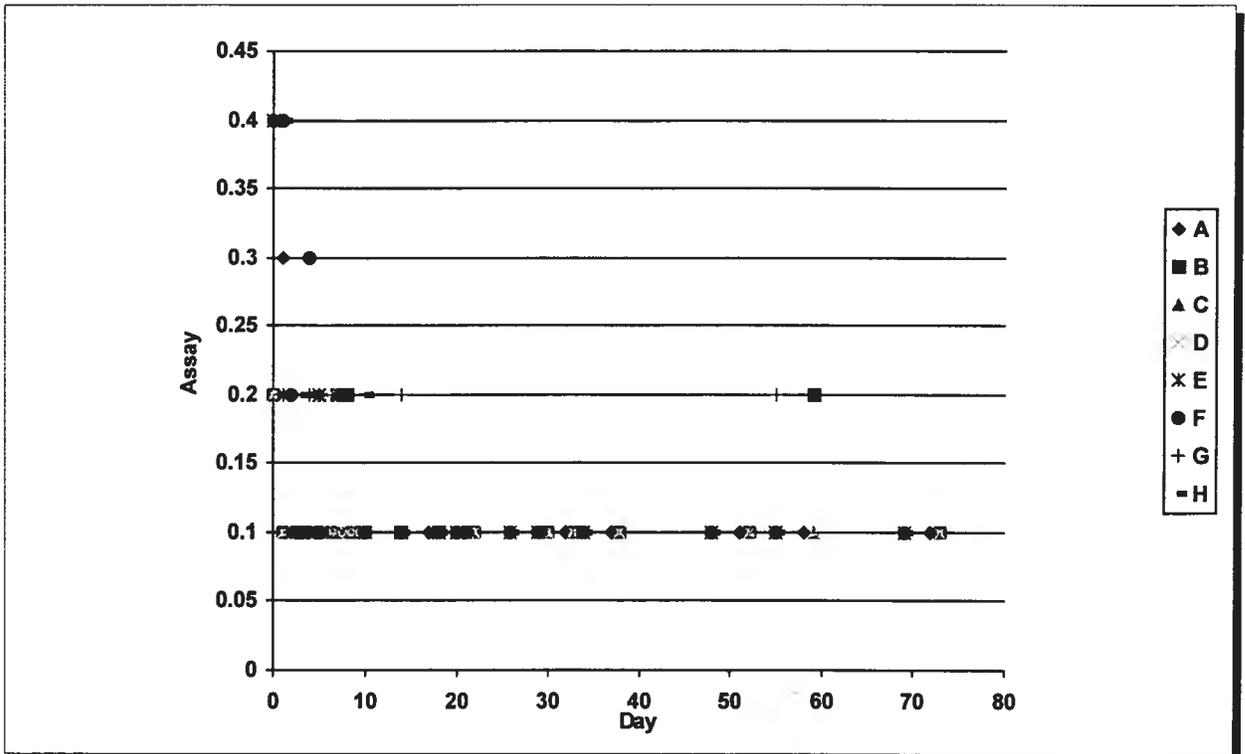
Na Dissolved mg/L



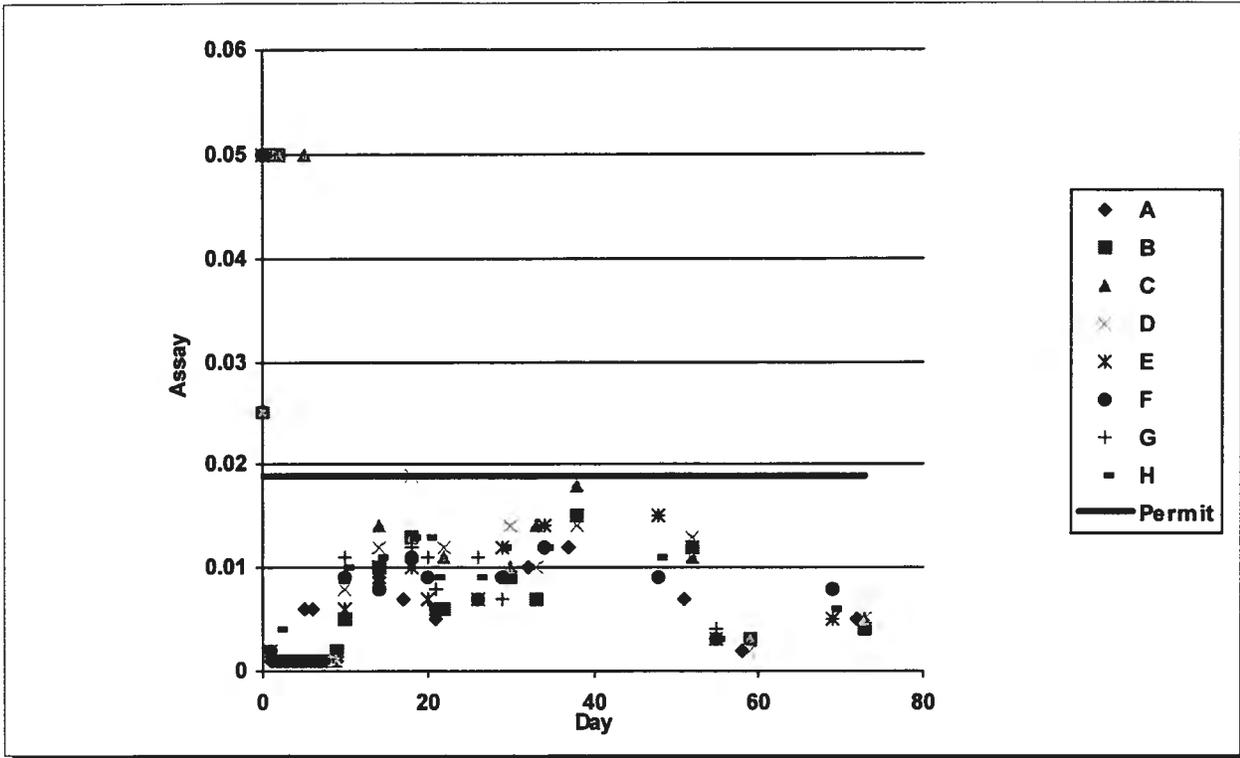
Ni Dissolved mg/L



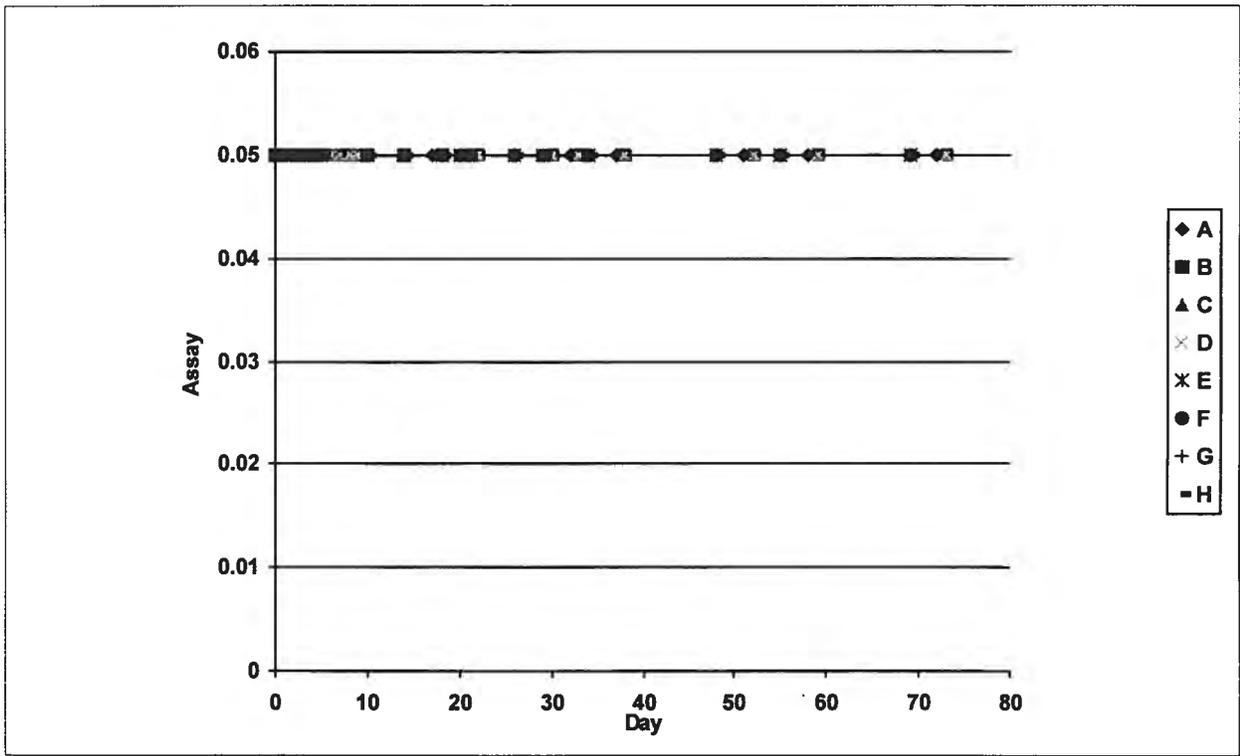
P Dissolved mg/L



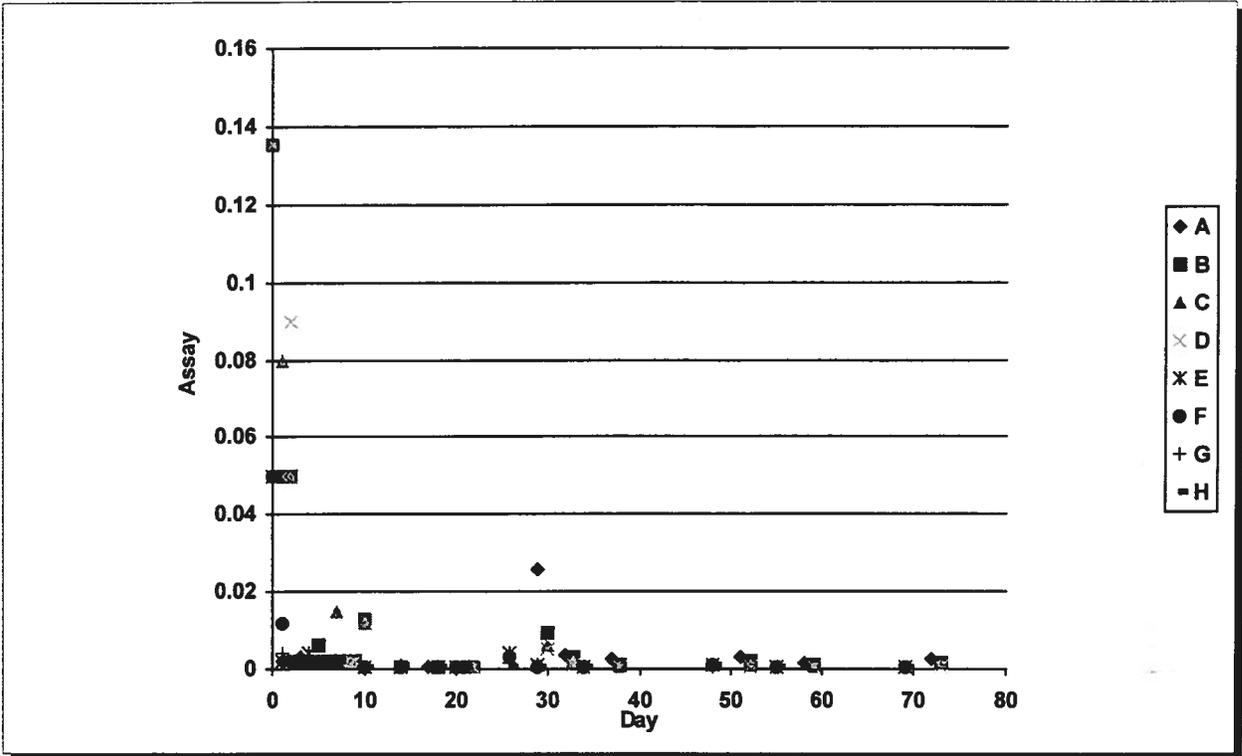
Pb Dissolved mg/L



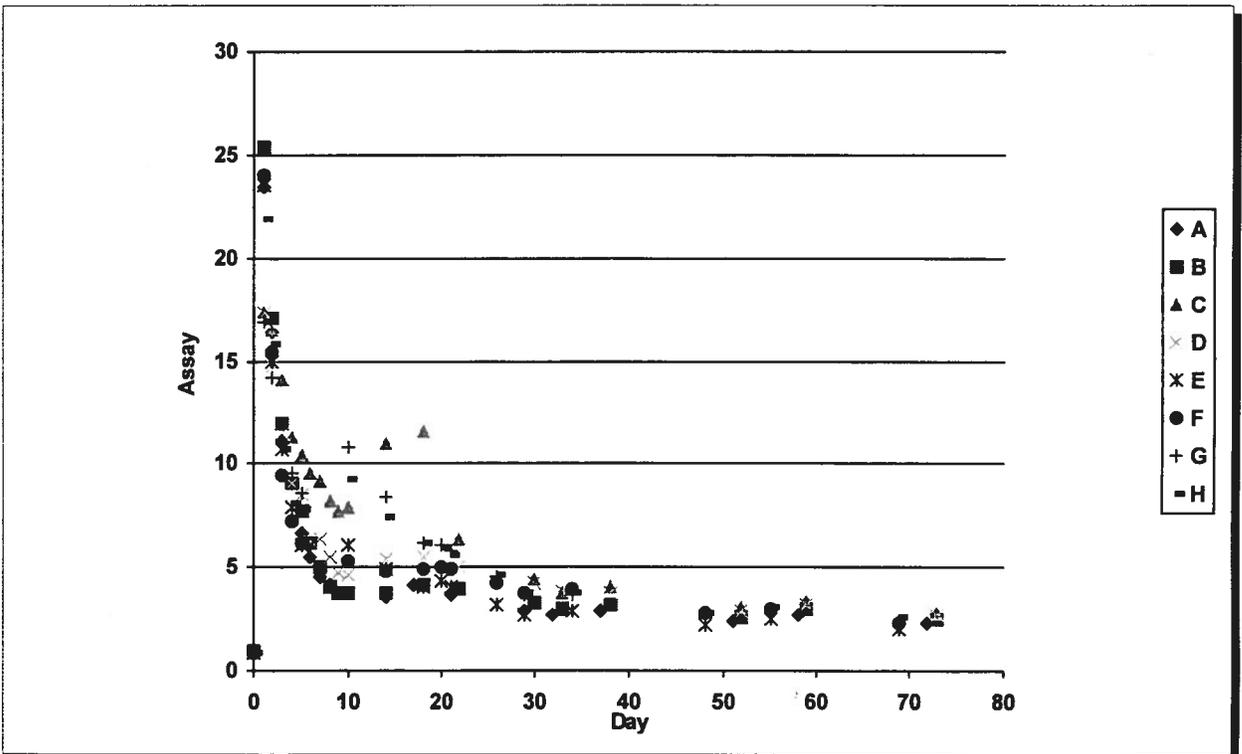
Sb Dissolved mg/L



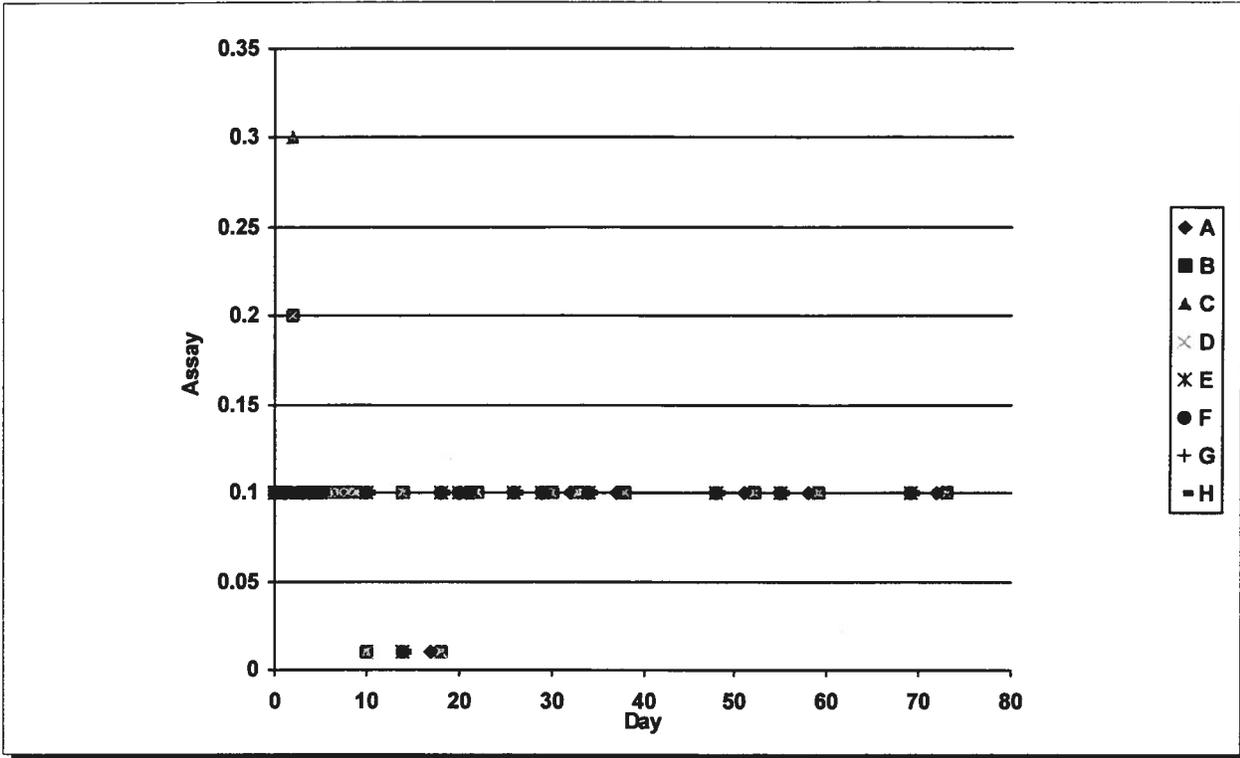
Se Dissolved mg/L



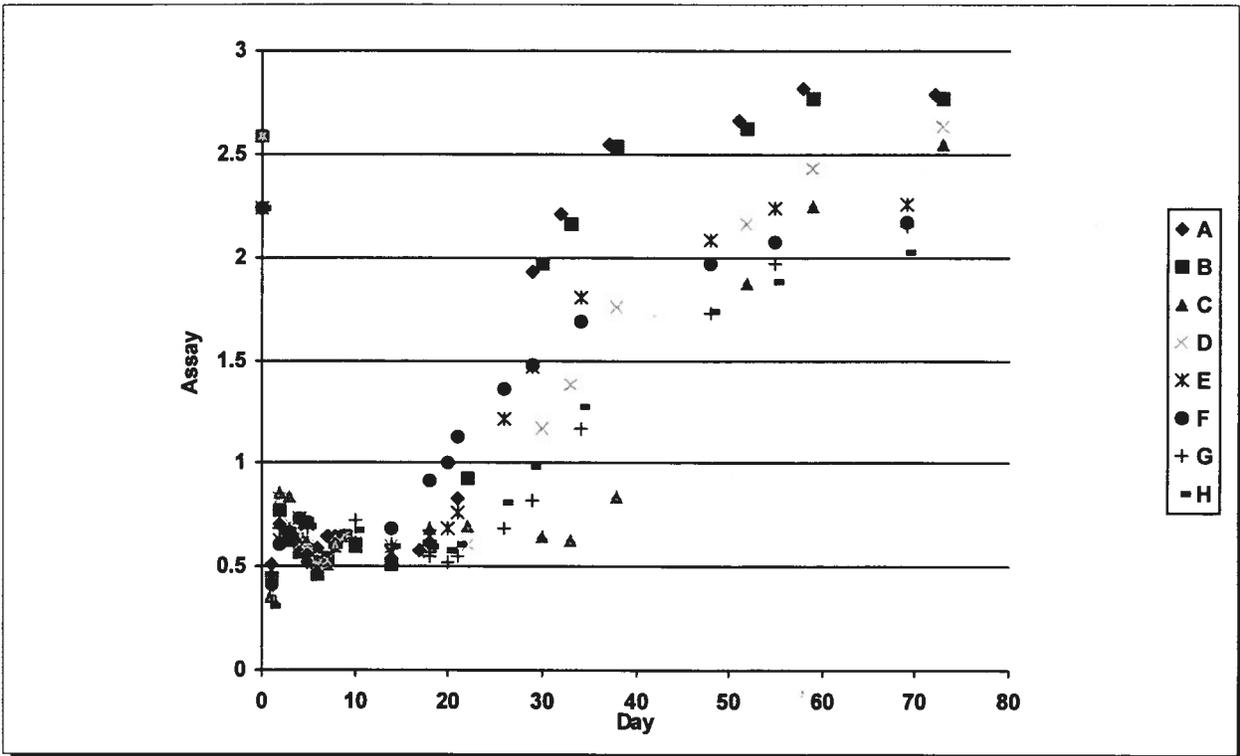
Si Dissolved mg/L



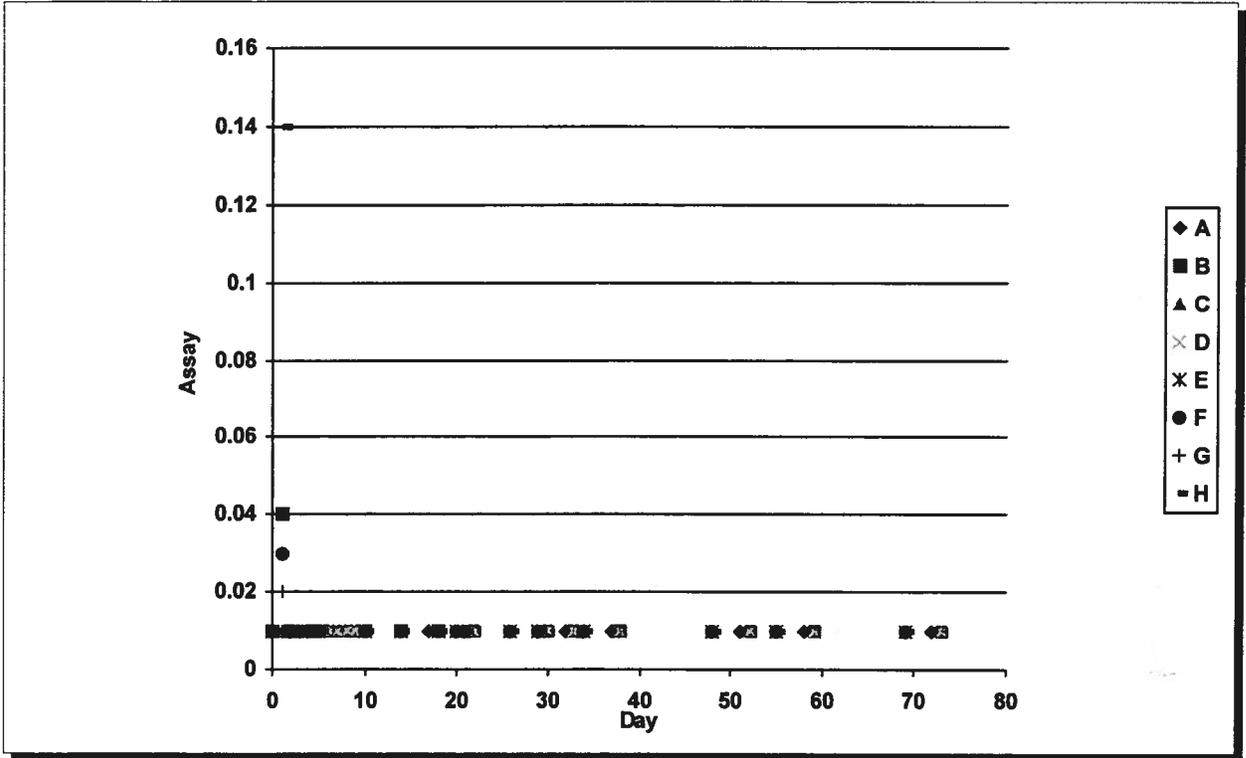
Sn Dissolved mg/L



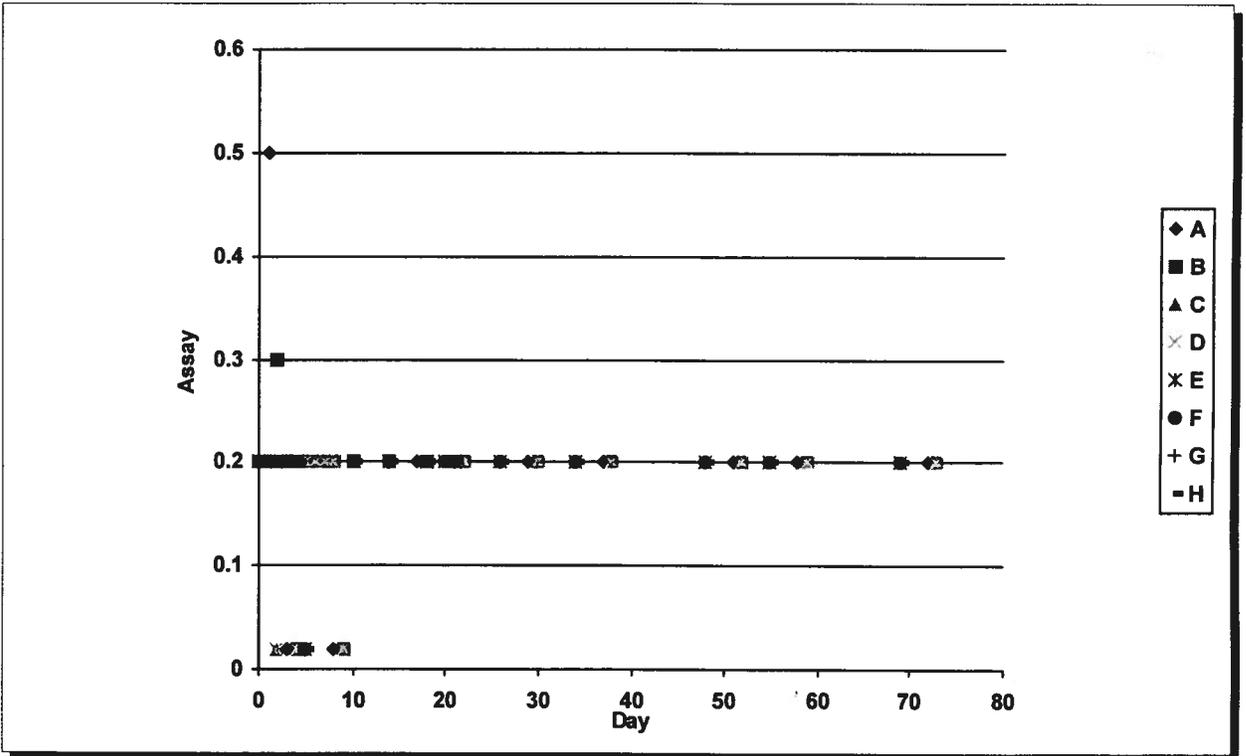
Sr Dissolved mg/L



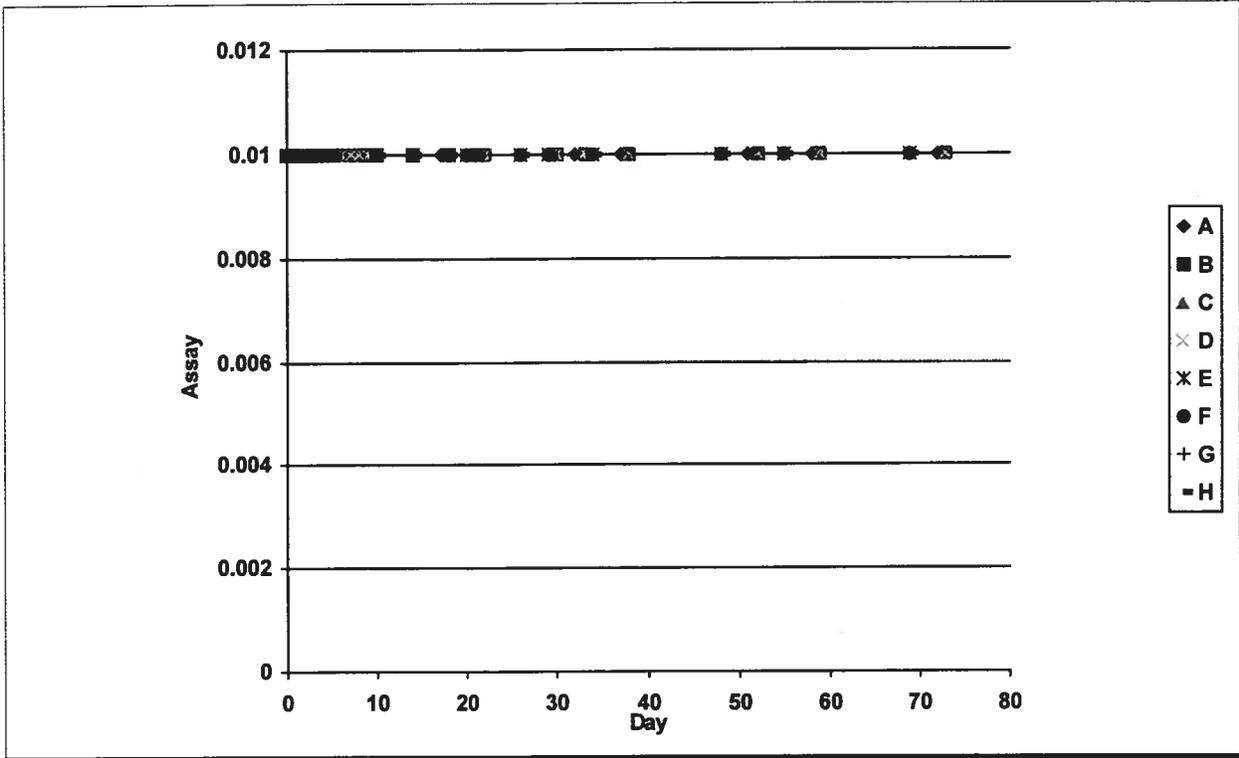
Ti Dissolved mg/L



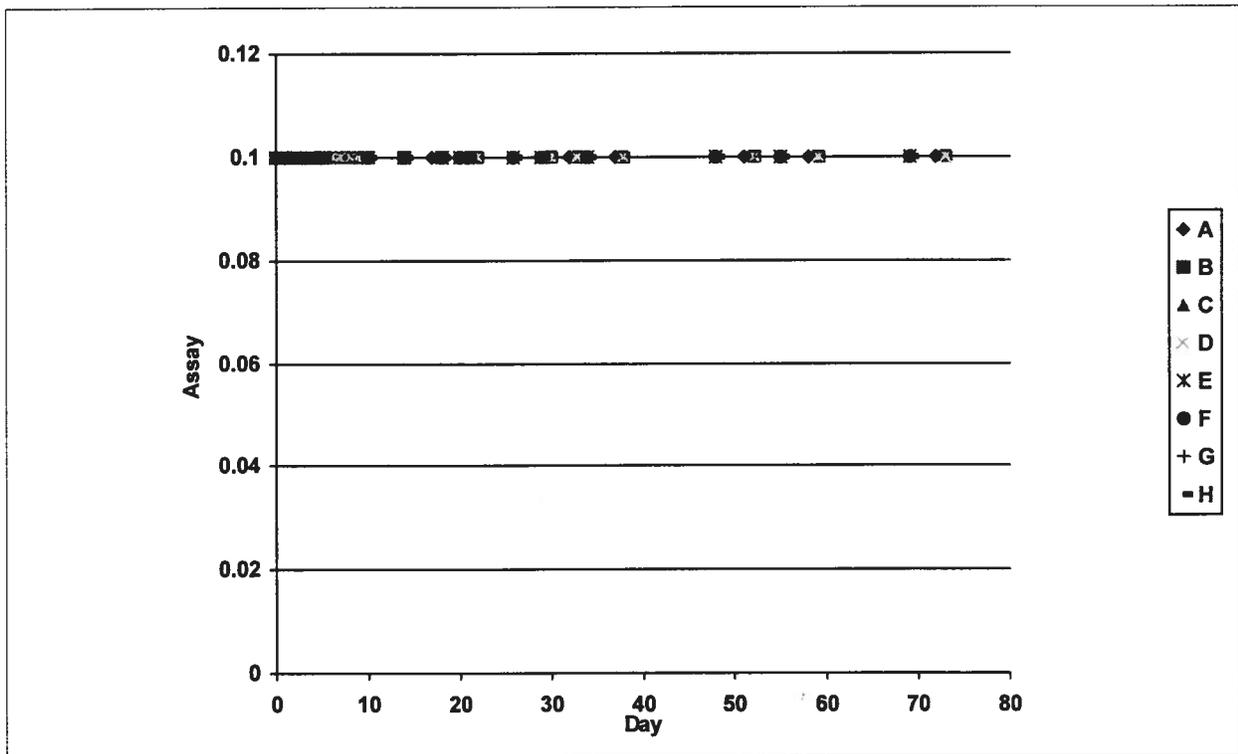
Ti Dissolved mg/L



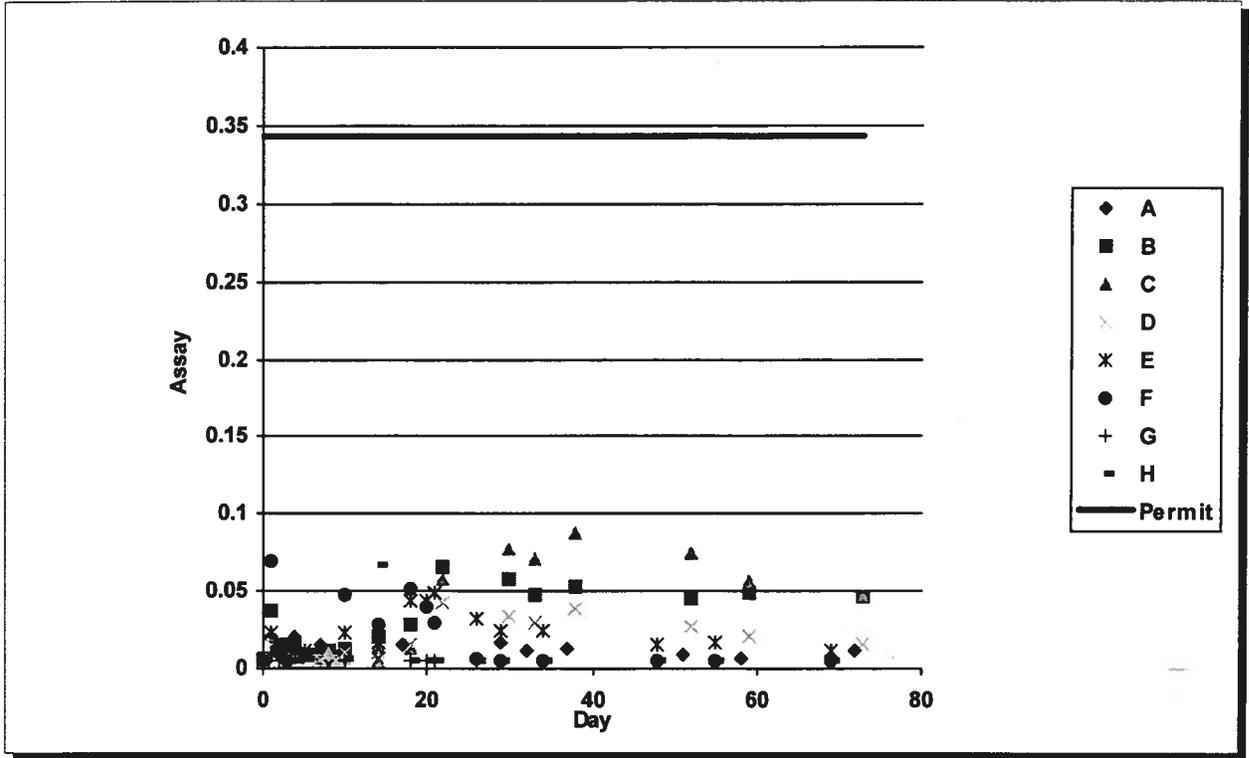
V Dissolved mg/L



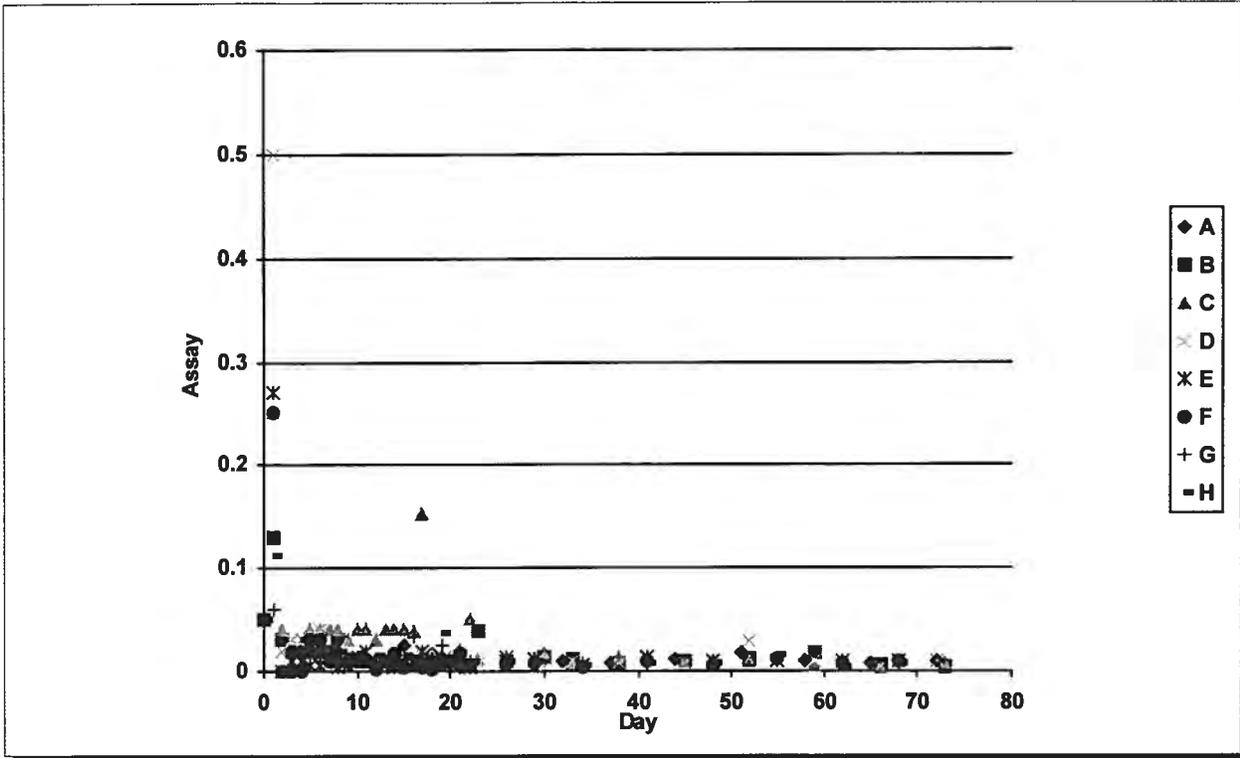
W Dissolved mg/L



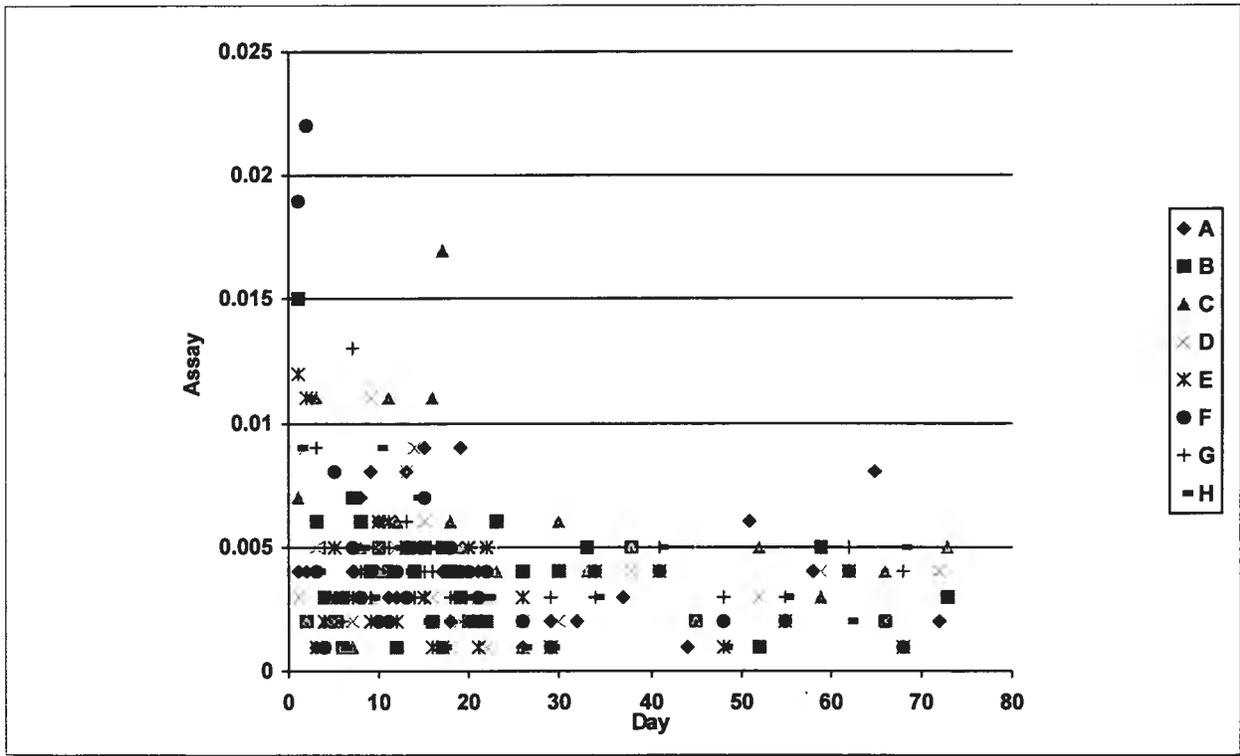
Zn Dissolved mg/L



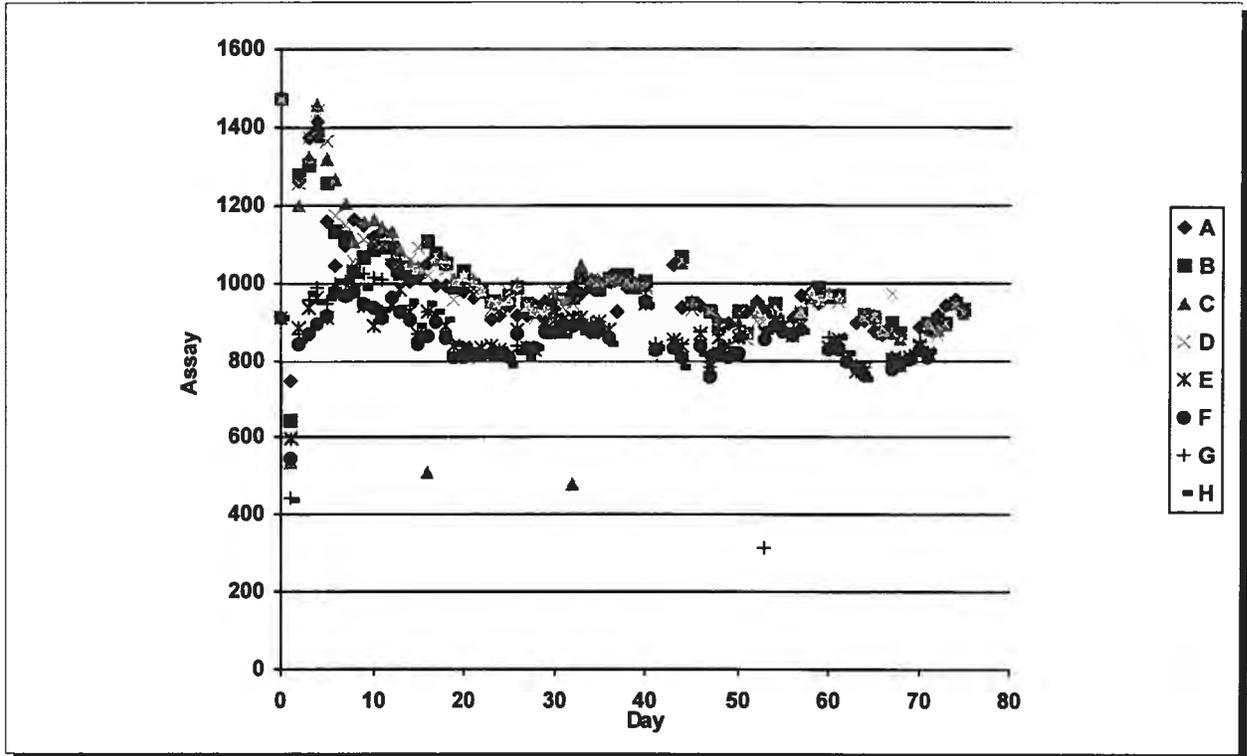
CN(Total) Misc mg/L



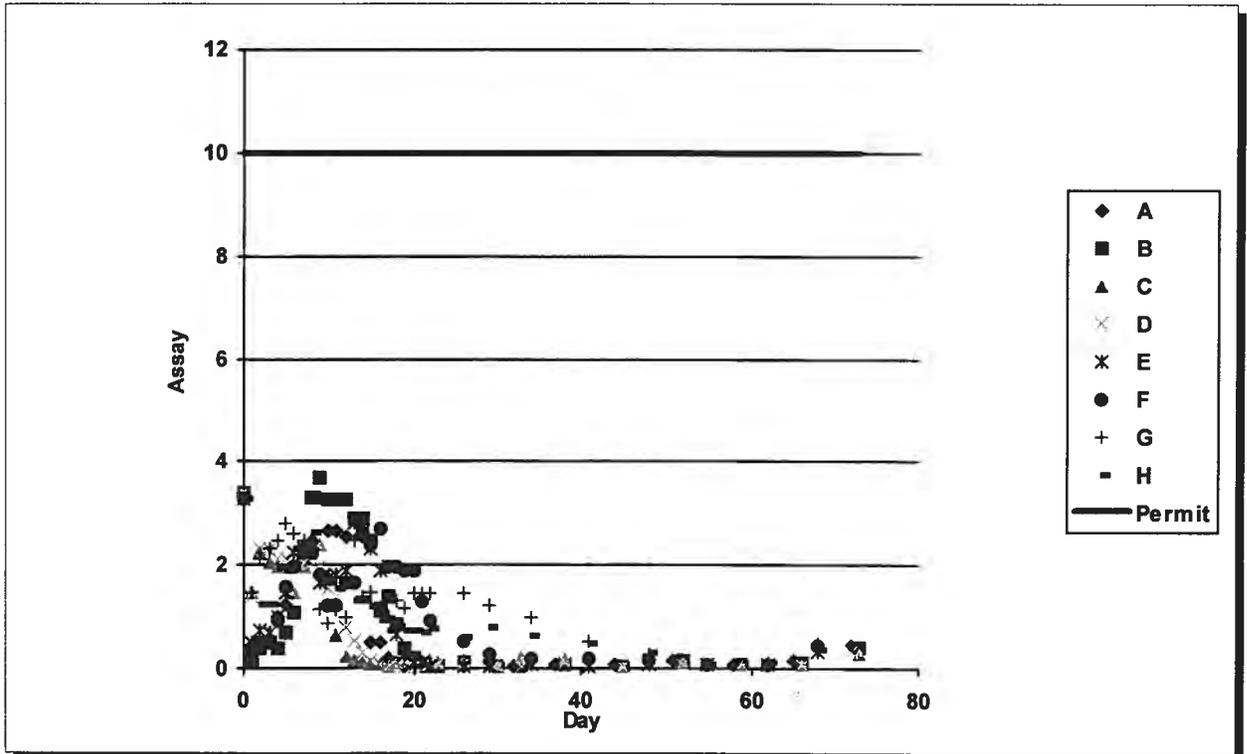
CN(wad) Misc mg/L



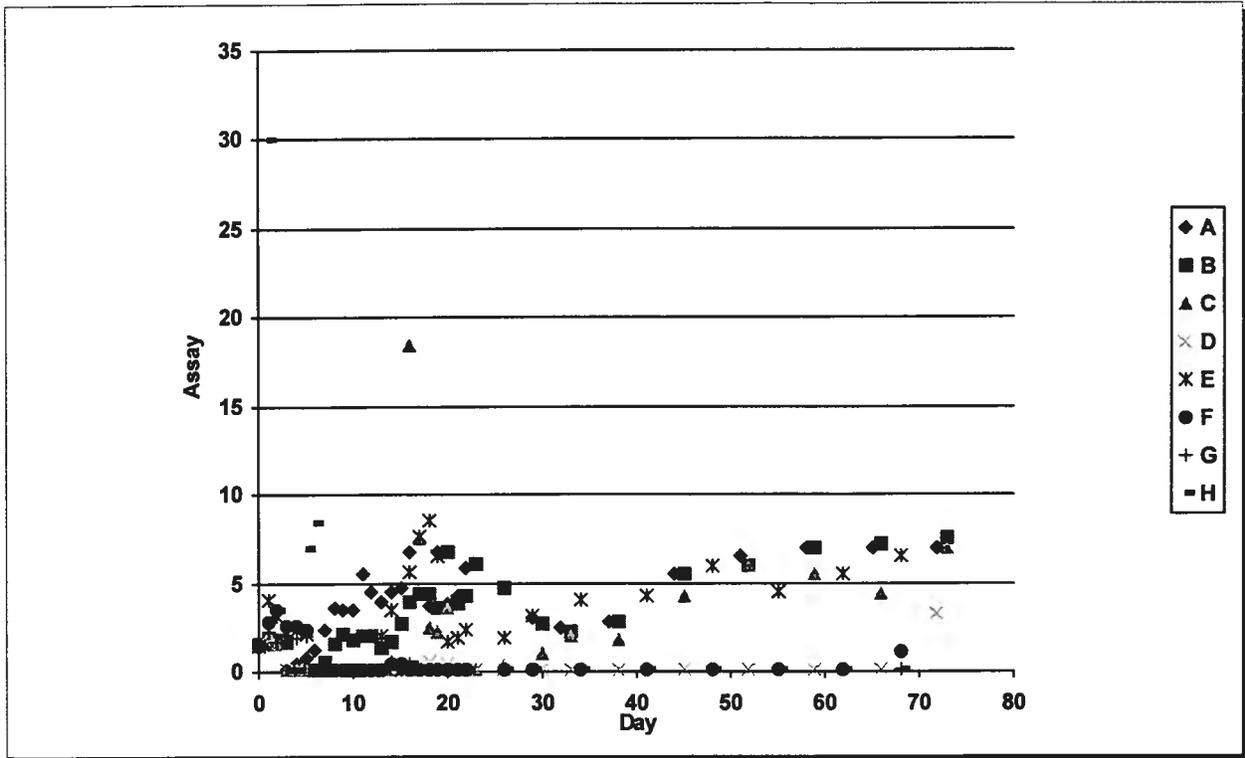
Cond. Misc microS



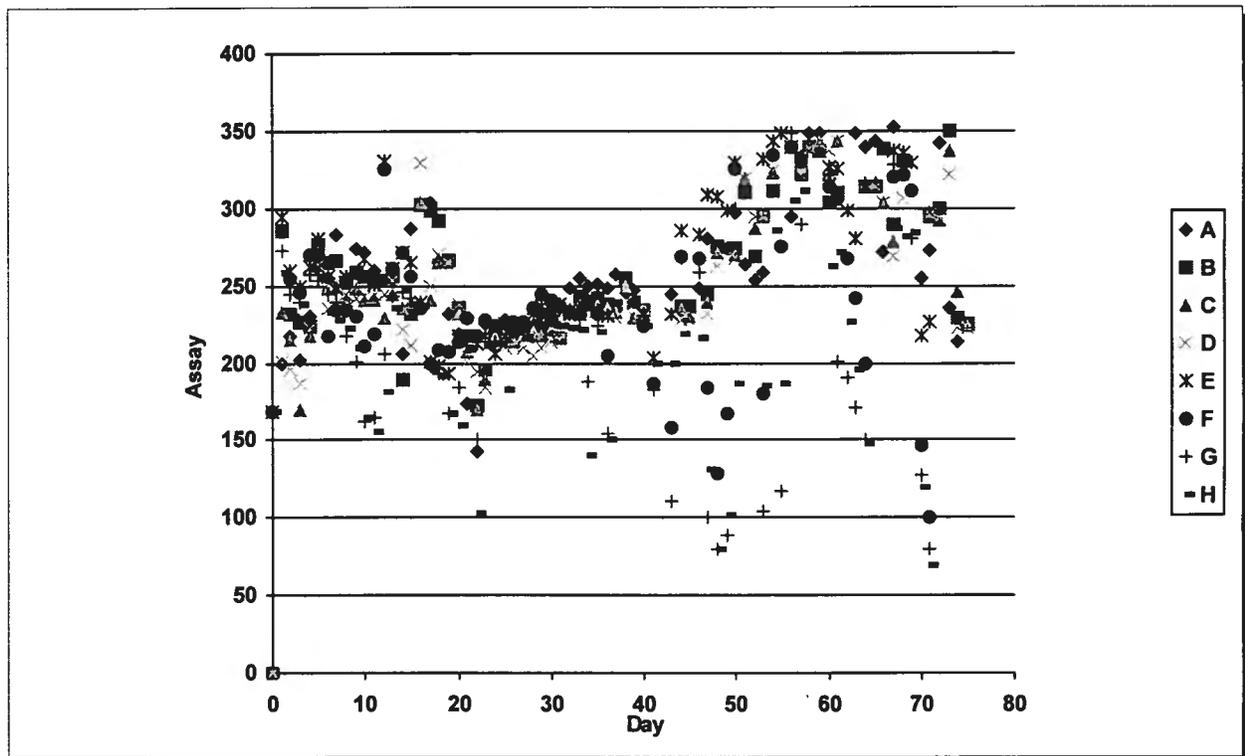
NH3=N Misc mg/L



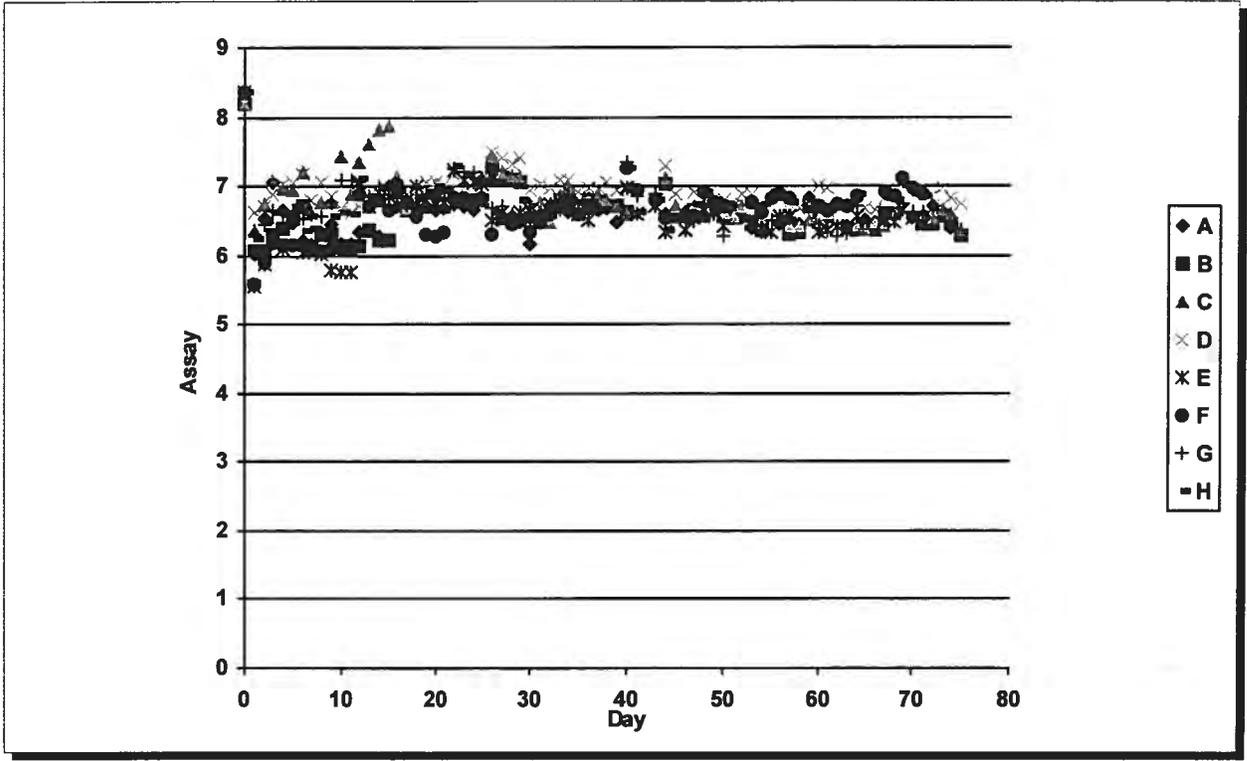
NO₃-N Misc mg/L



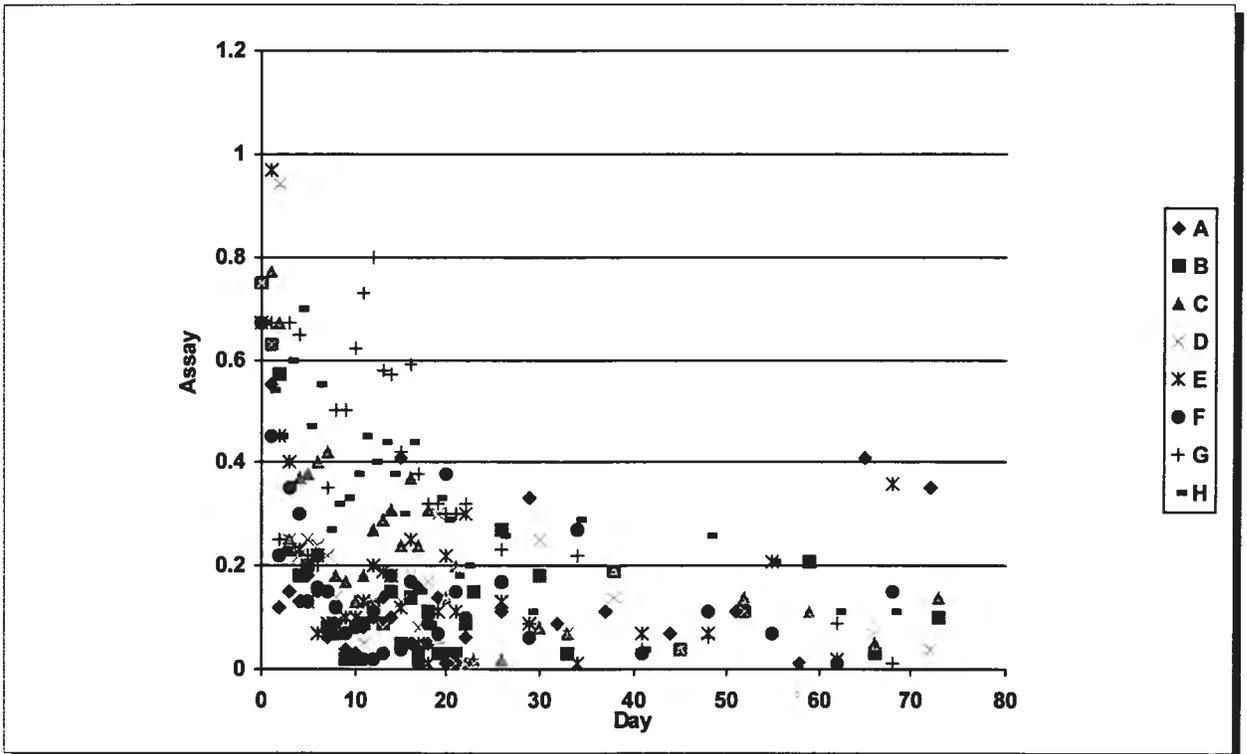
ORP Misc mV



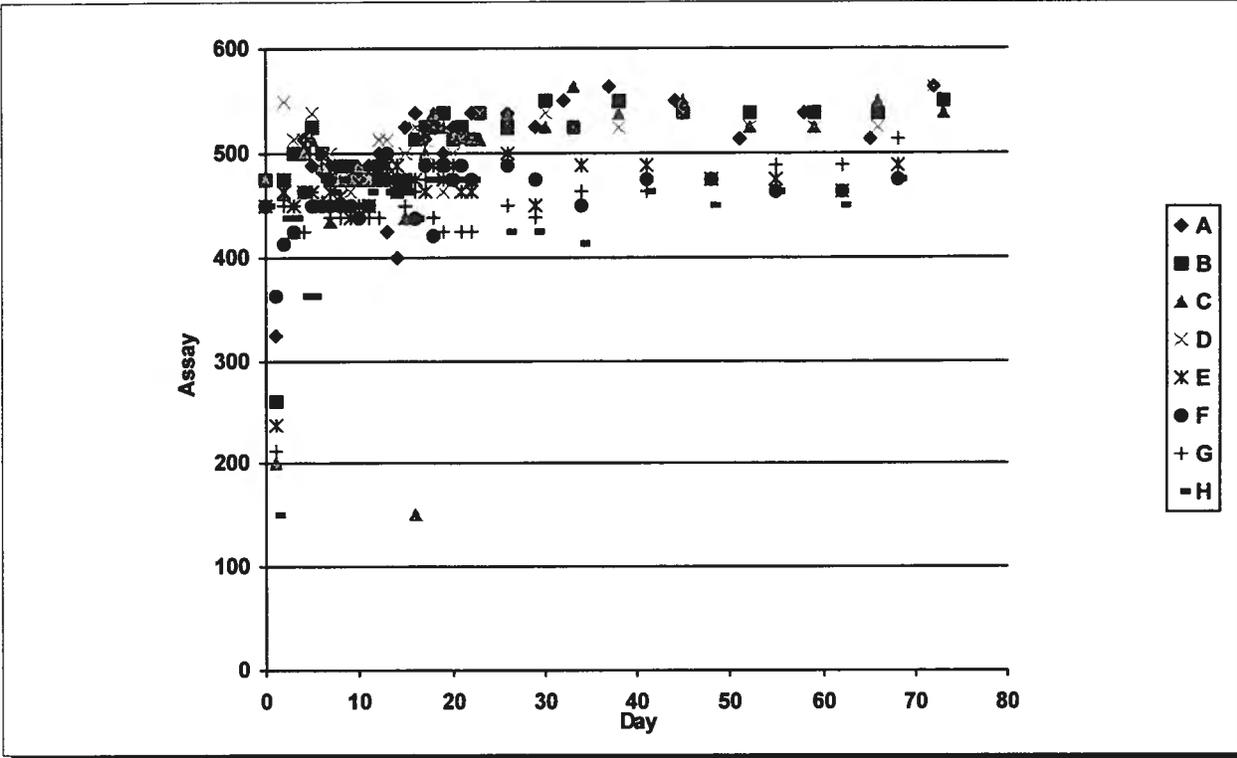
pH Misc



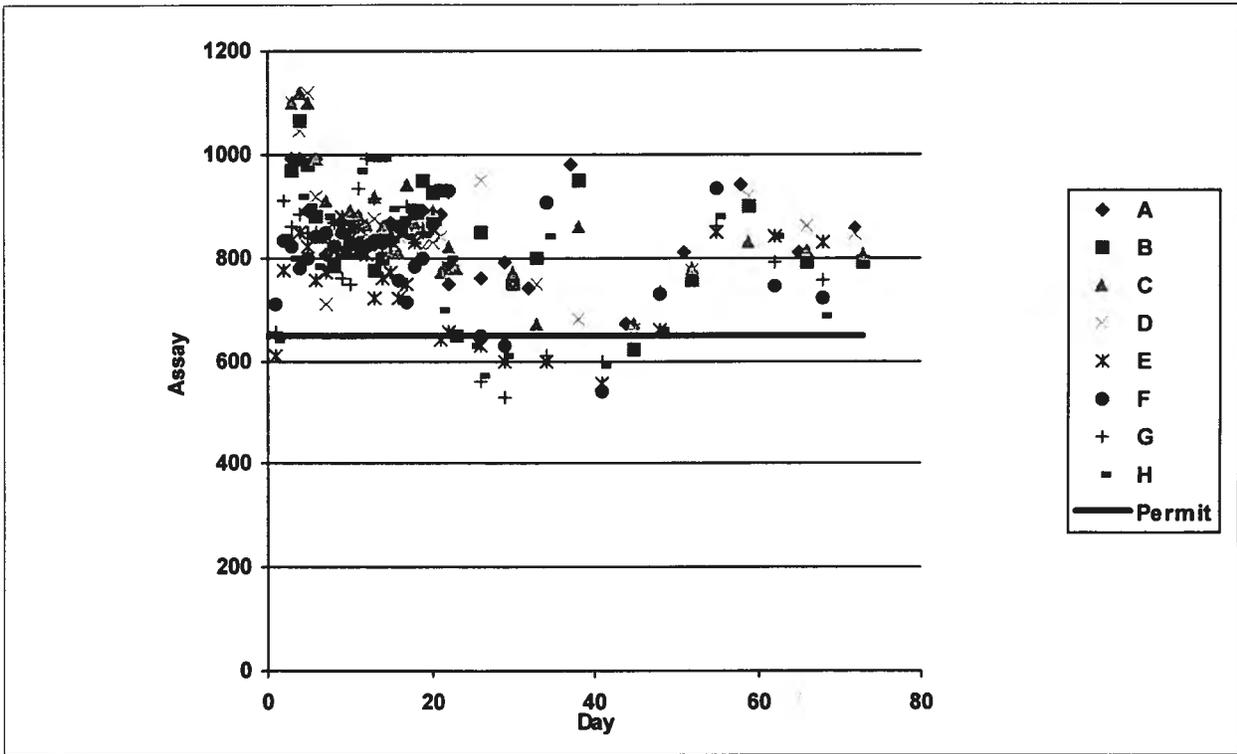
SCN Misc mg/L



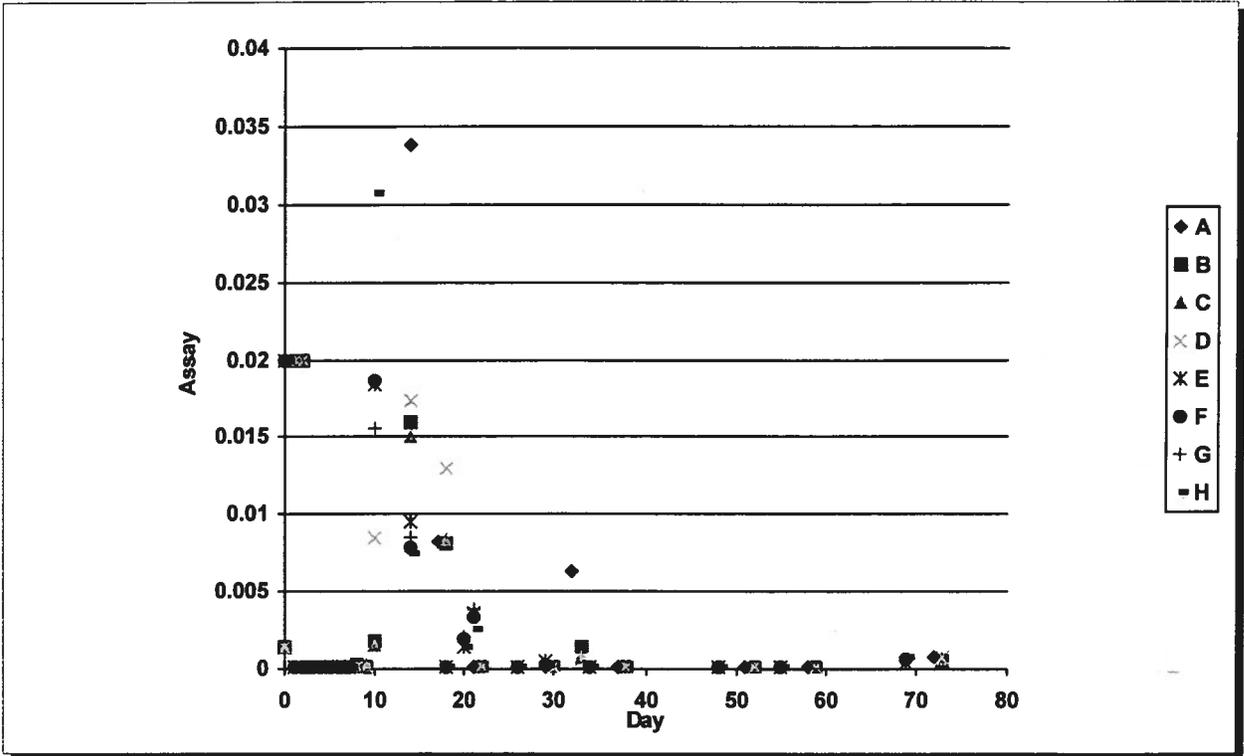
SO4 Misc mg/L



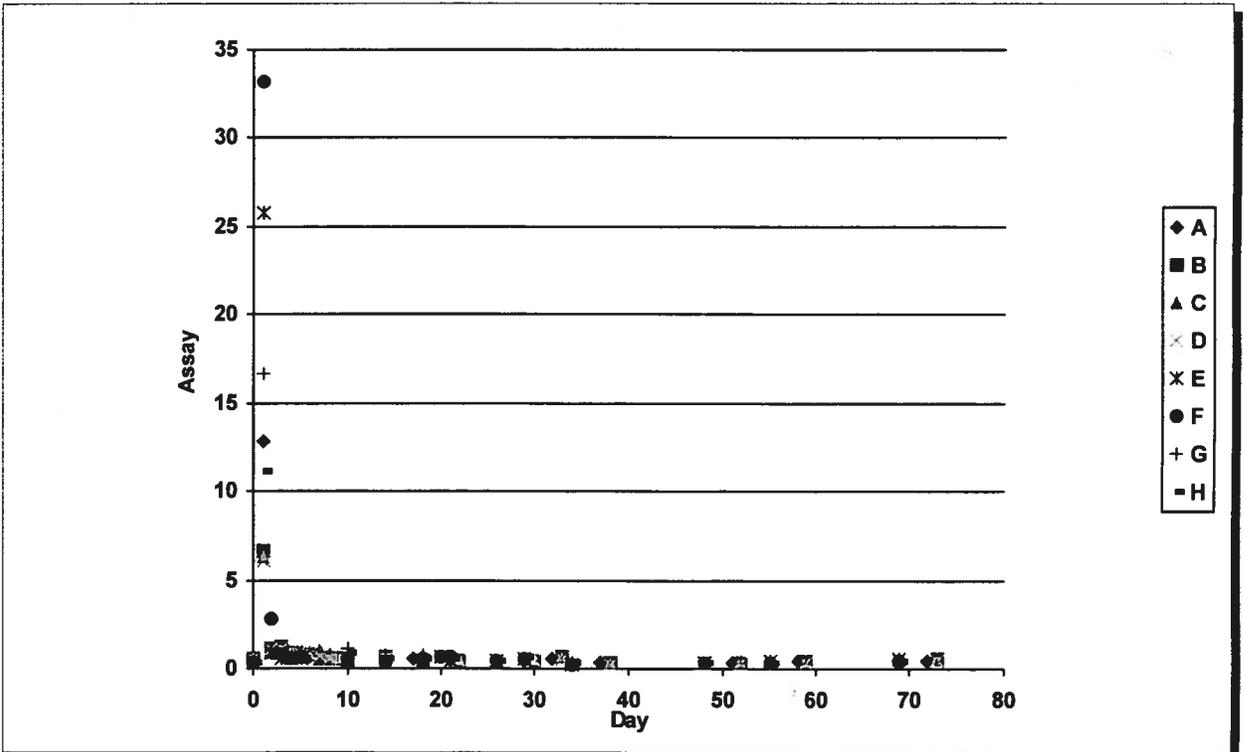
TDS Misc mg/L



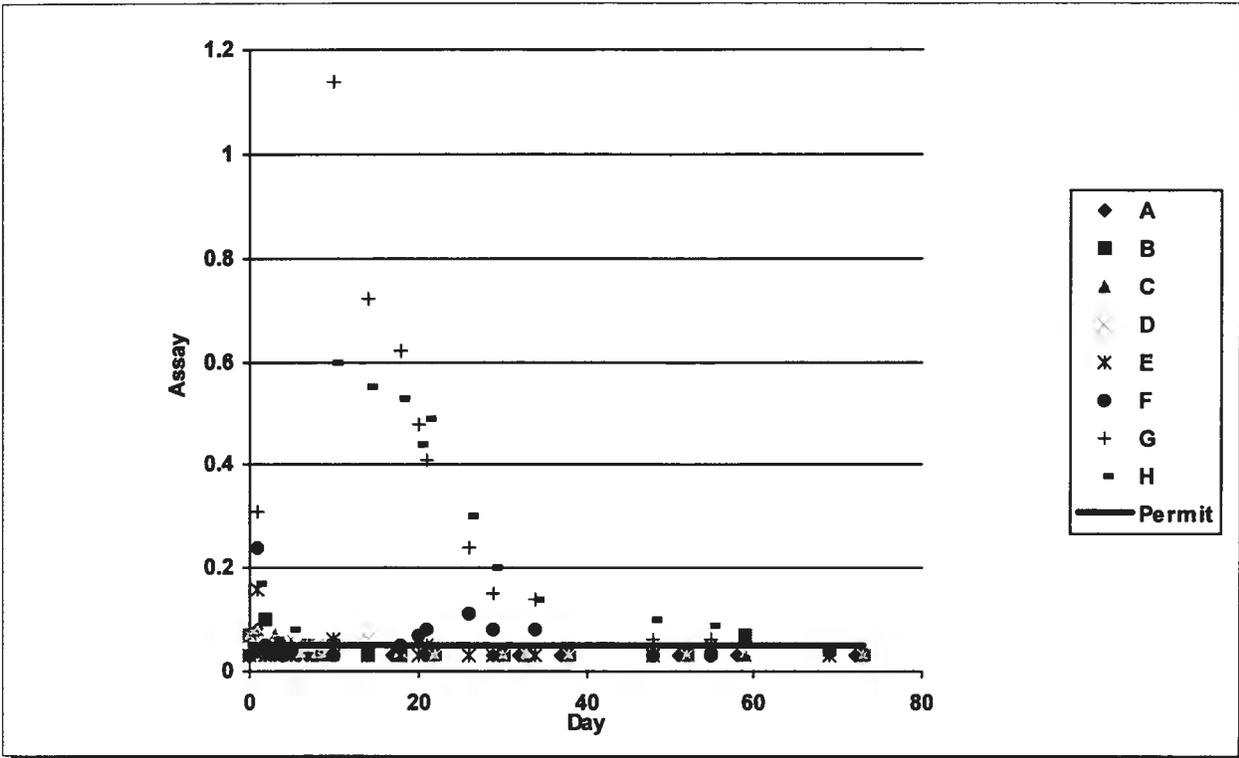
Ag Total mg/L



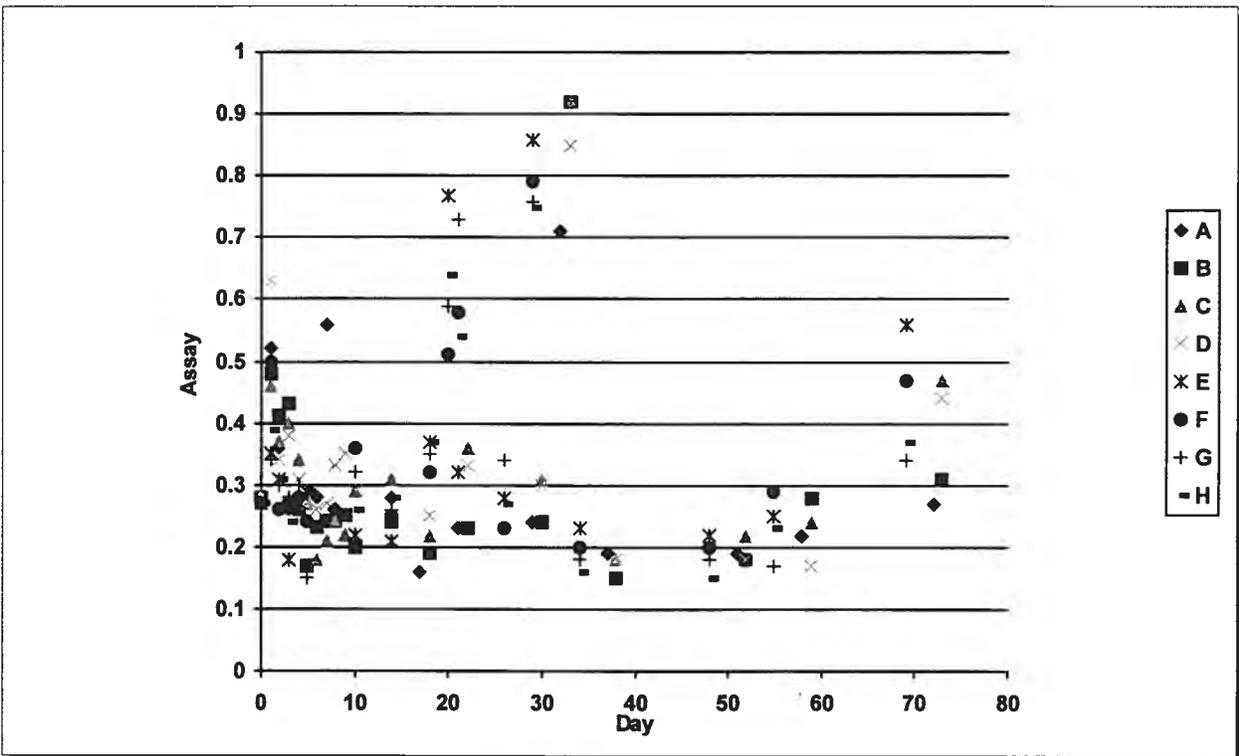
Al Total mg/L



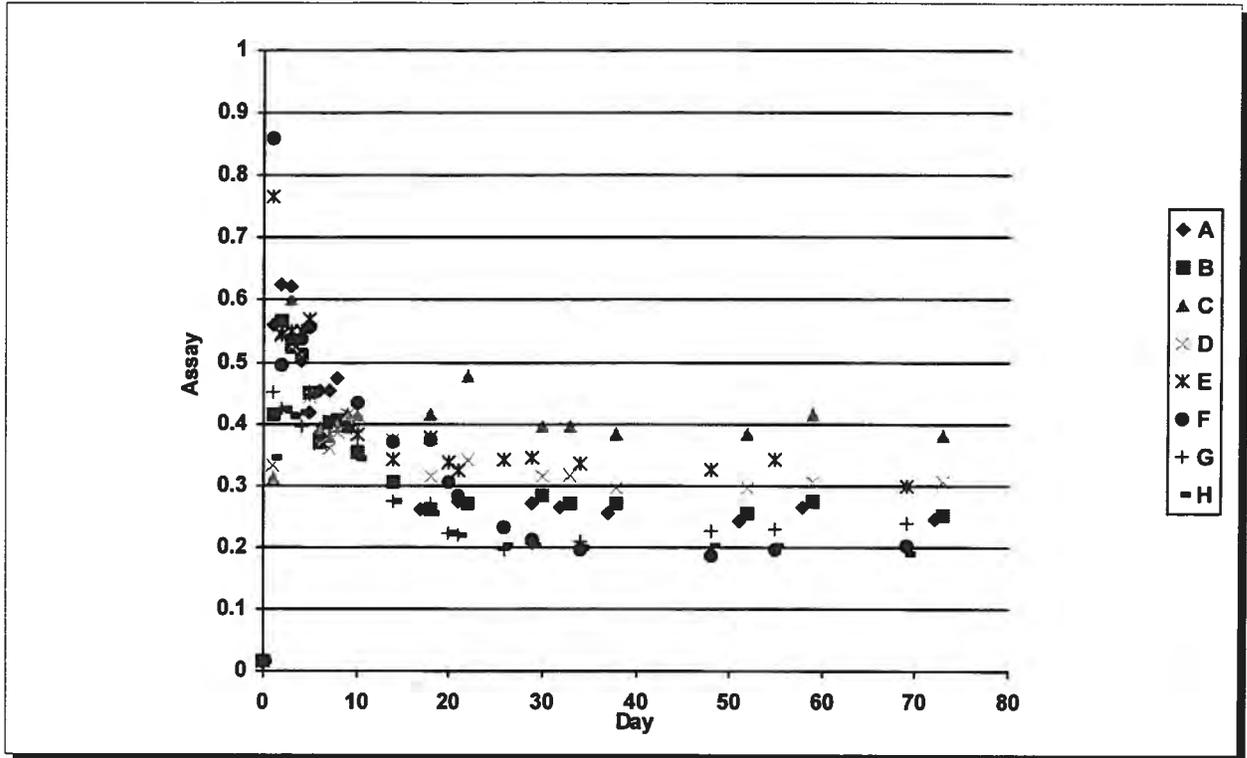
As Total mg/L



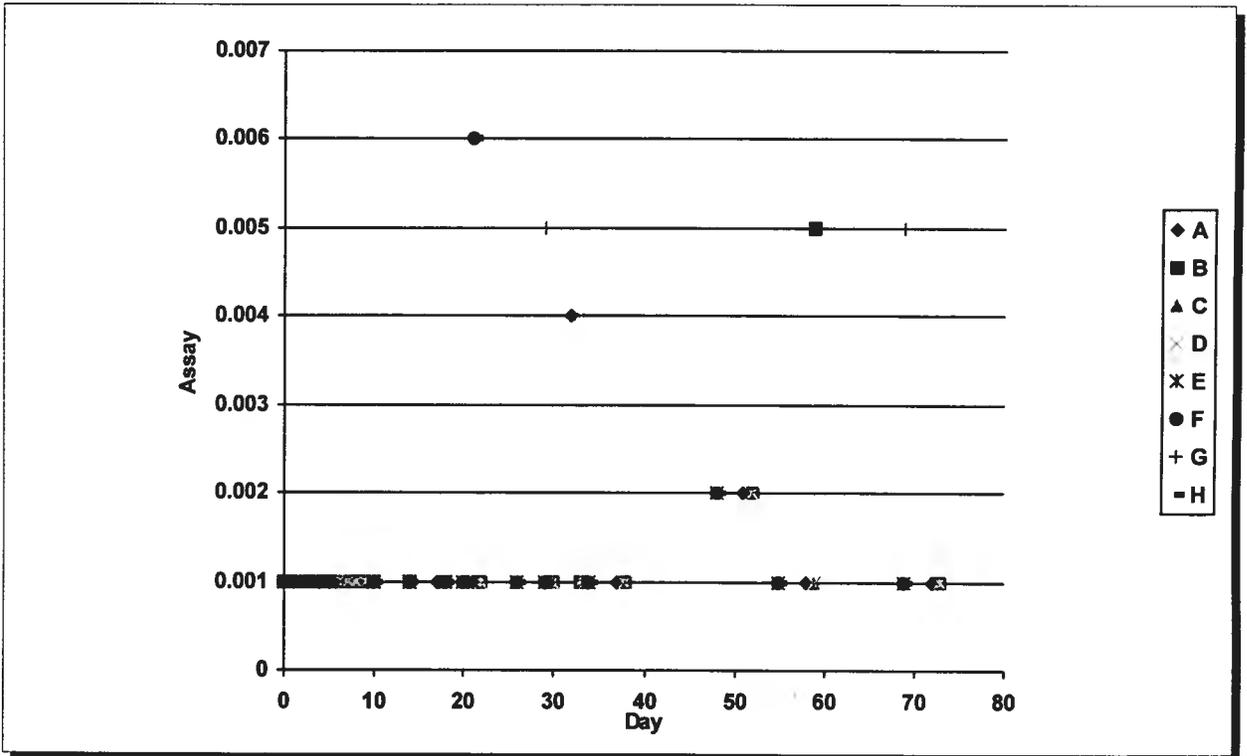
B Total mg/L



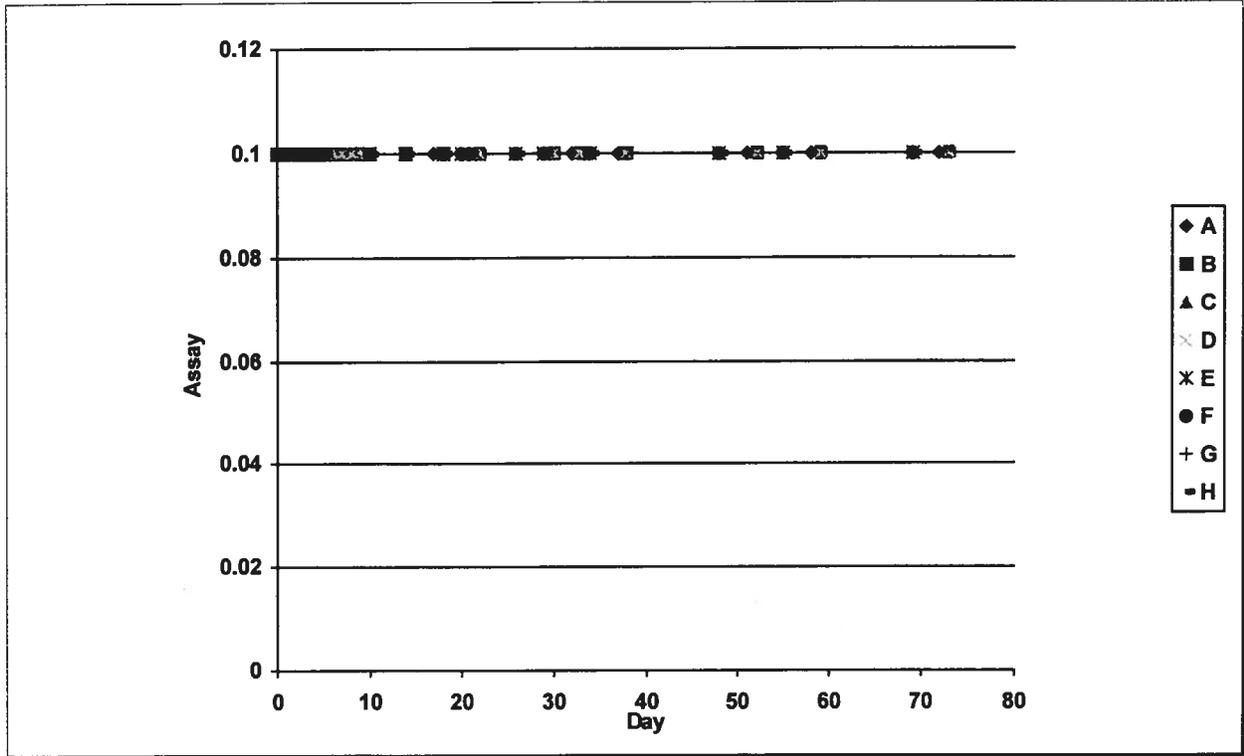
Ba Total mg/L



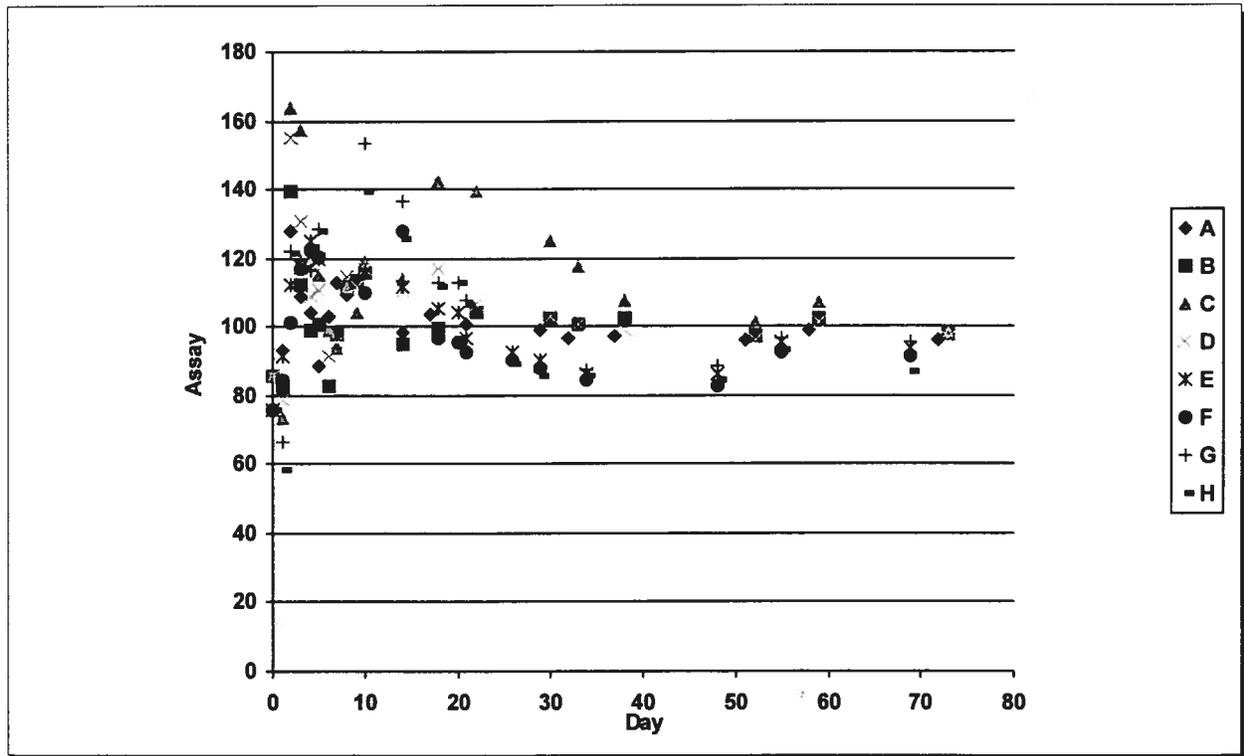
Be Total mg/L



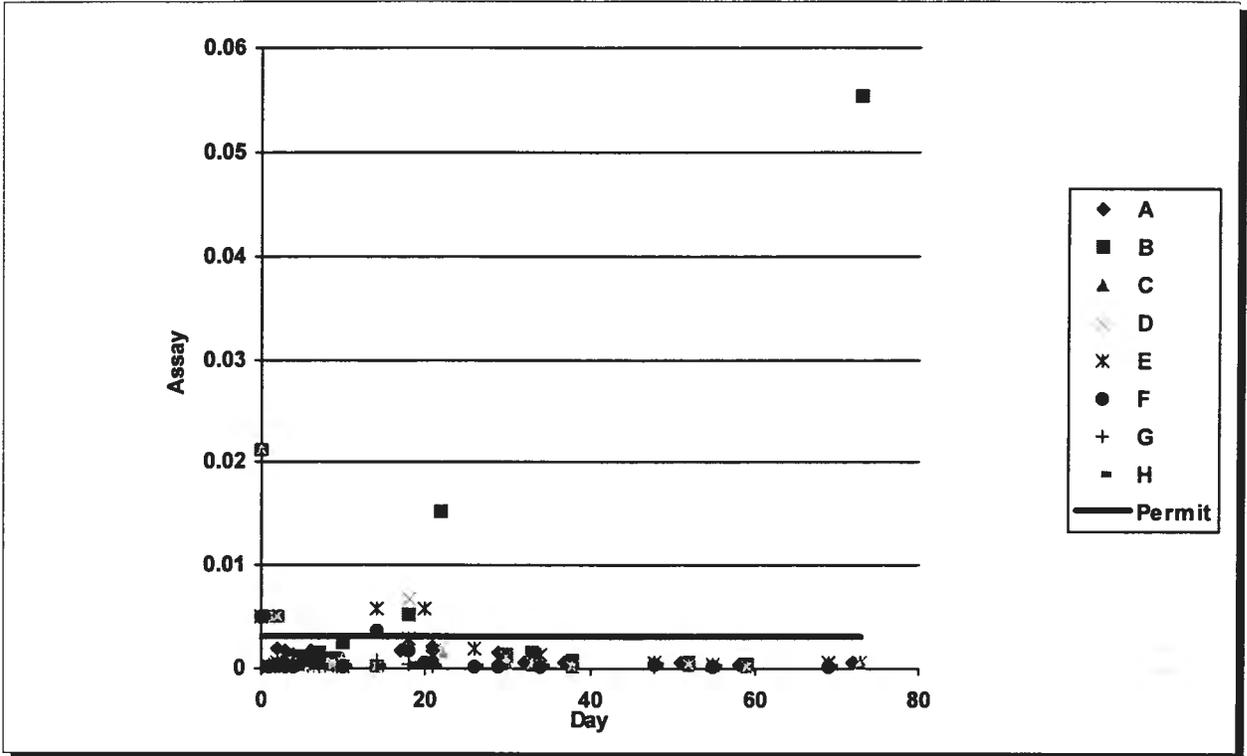
Bi Total mg/L



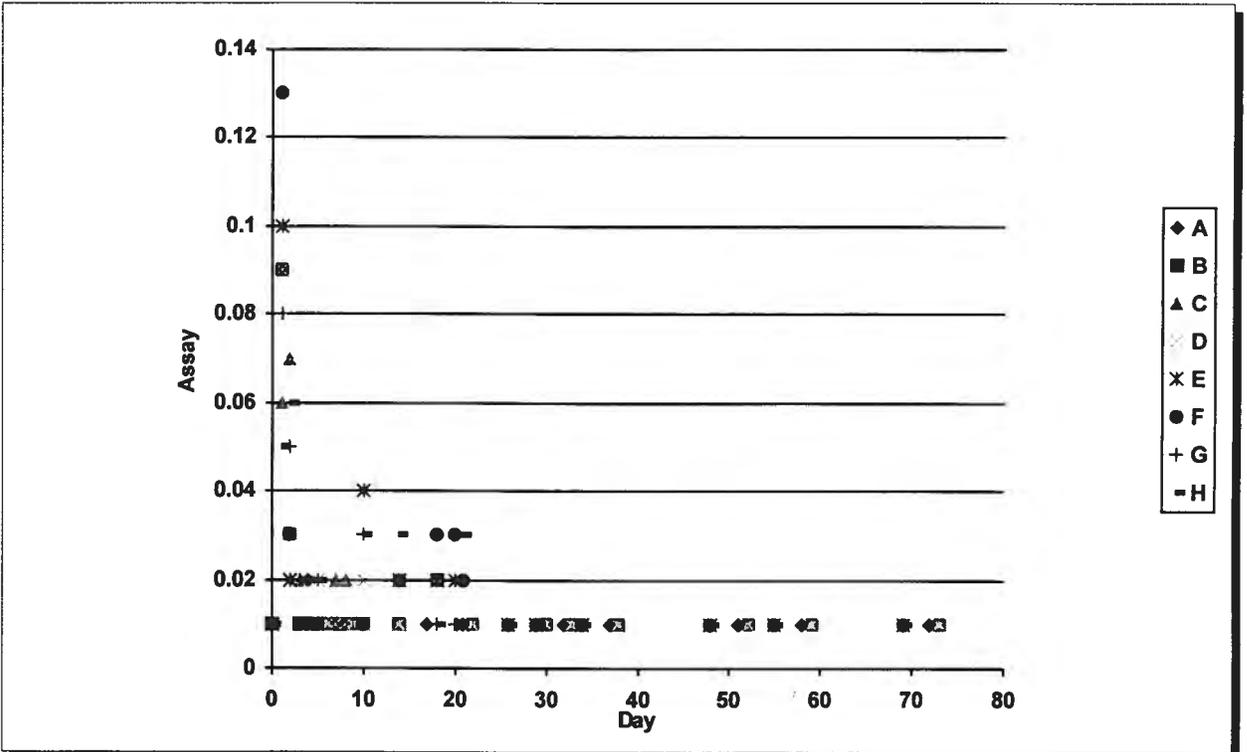
Ca Total mg/L



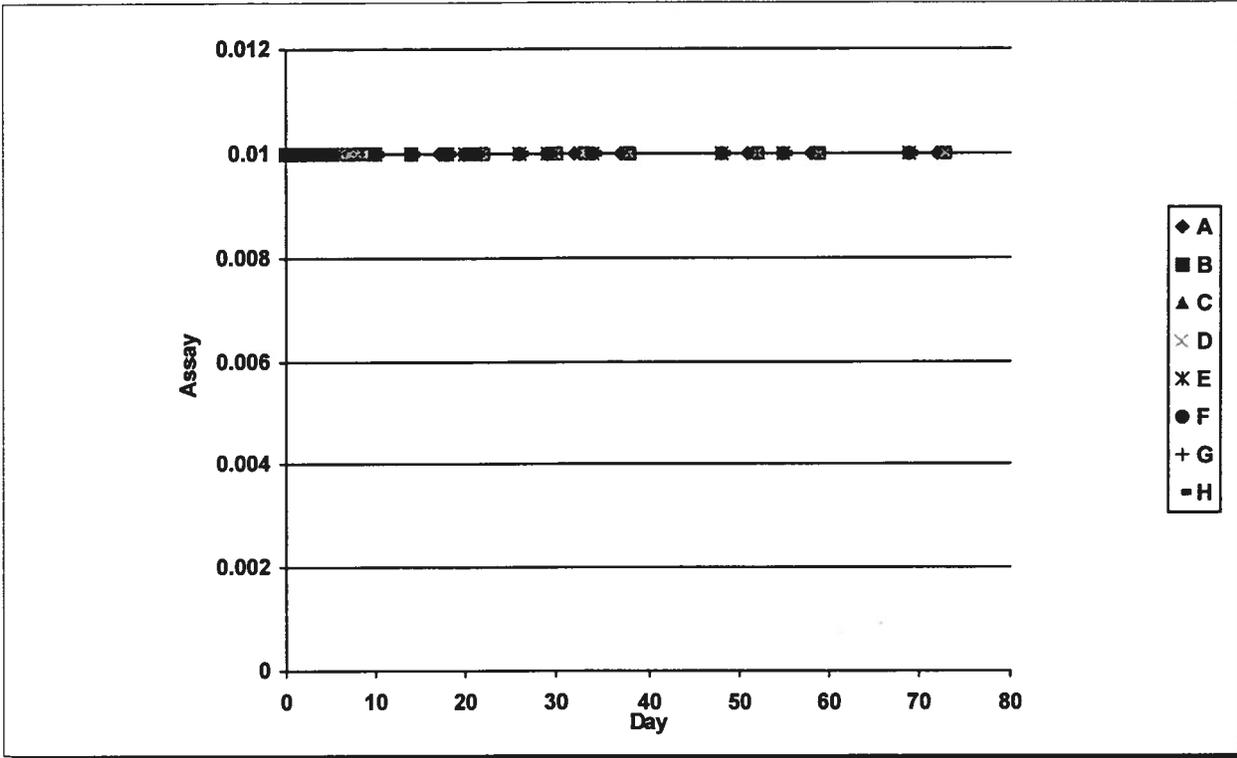
Cd Total mg/L



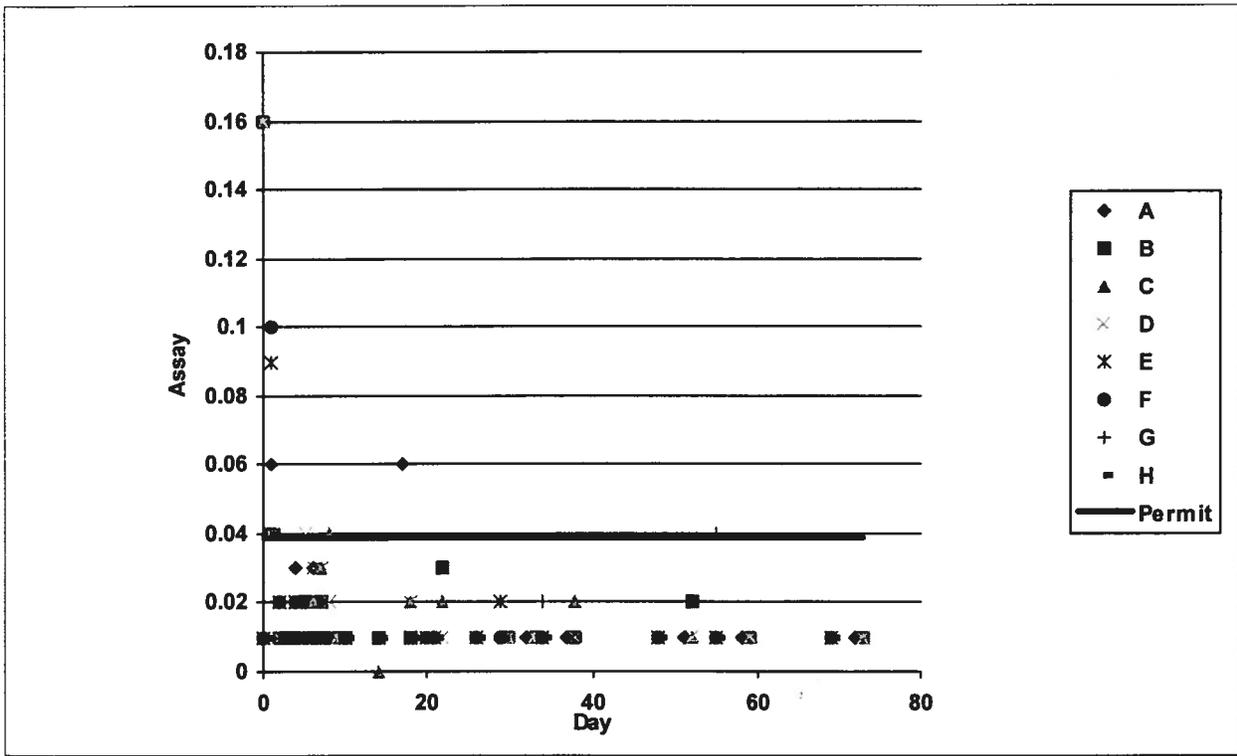
Co Total mg/L



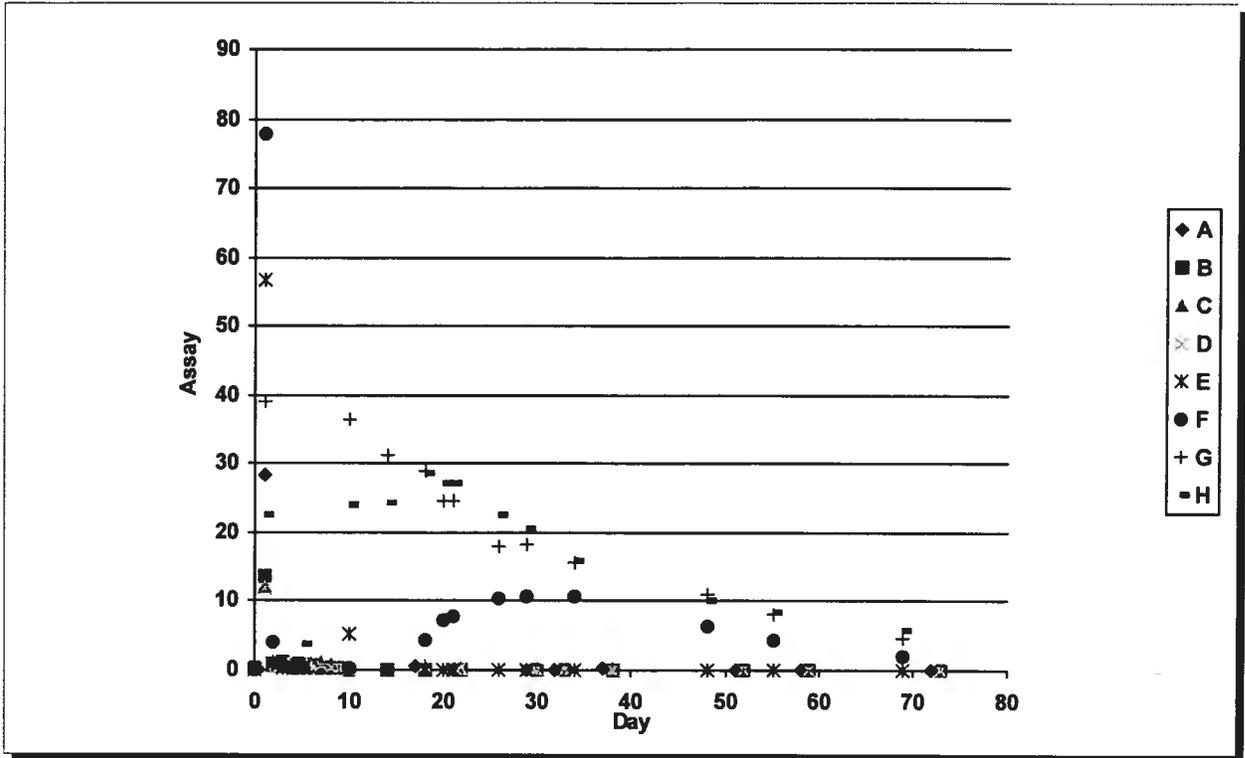
Cr Total mg/L



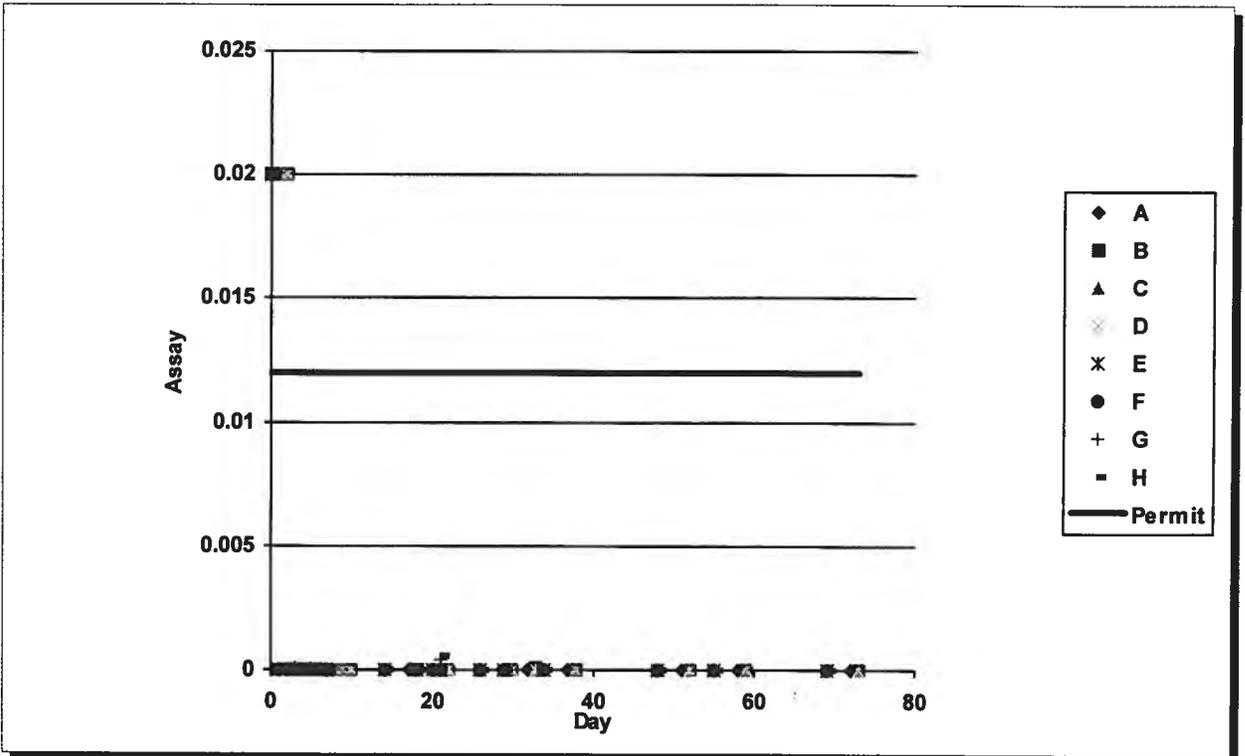
Cu Total mg/L



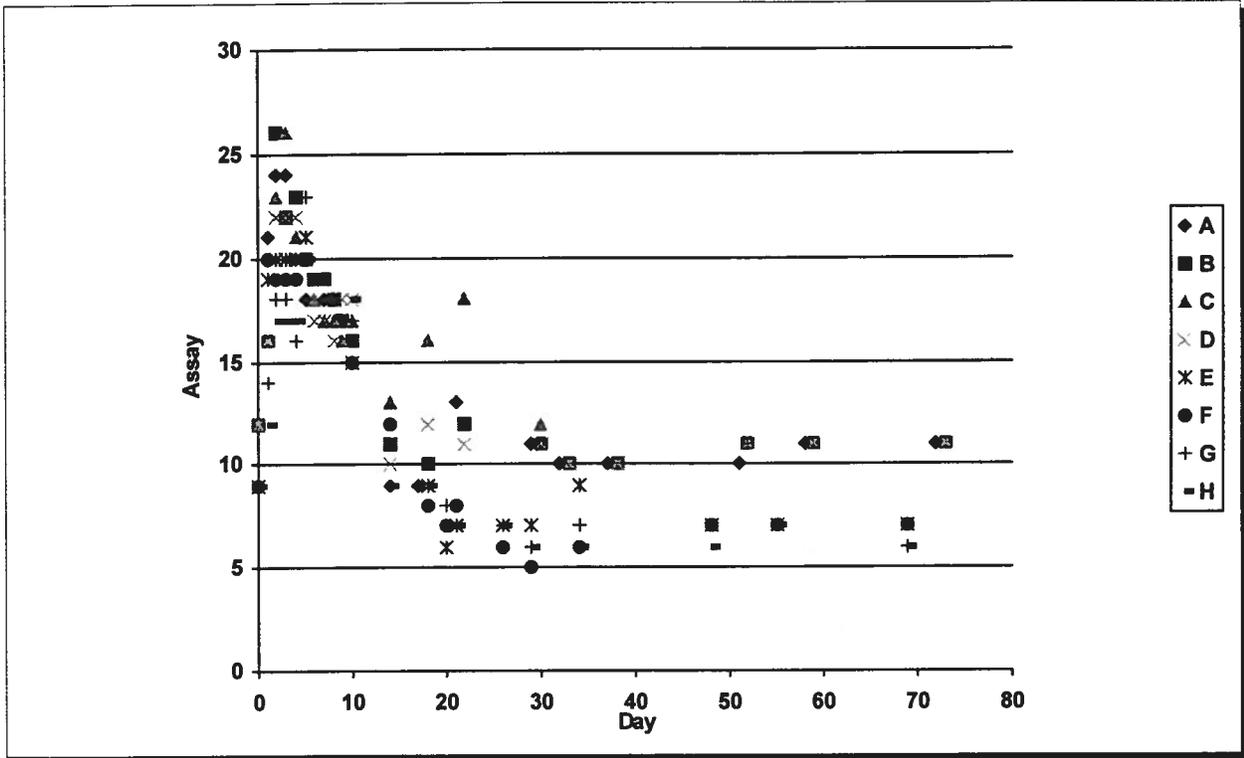
Fe Total mg/L



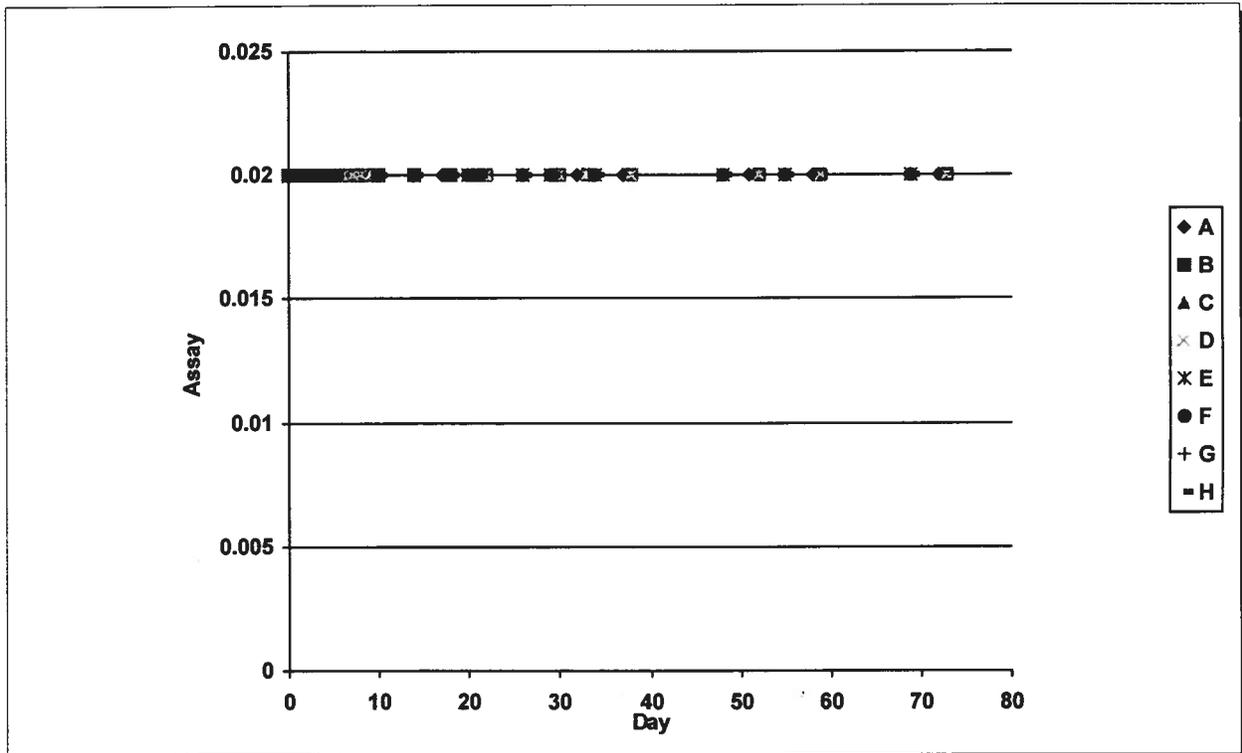
Hg Total mg/L



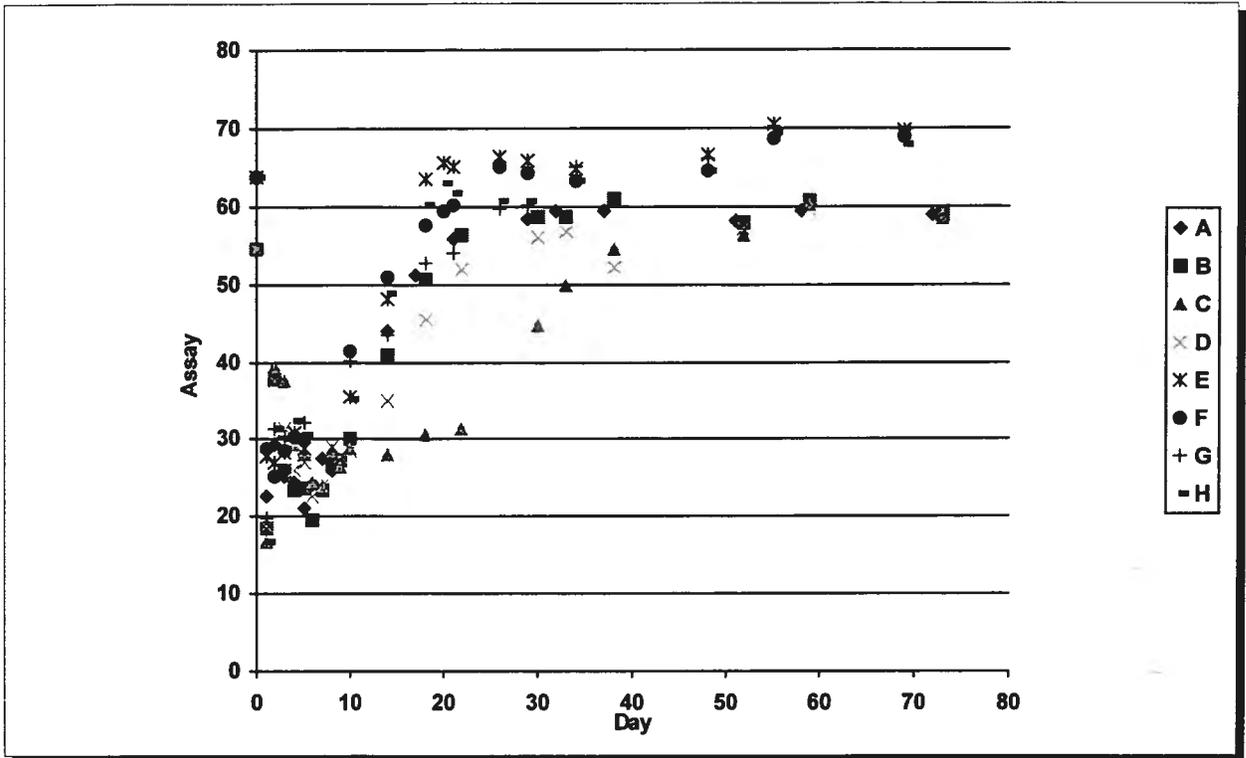
K Total mg/L



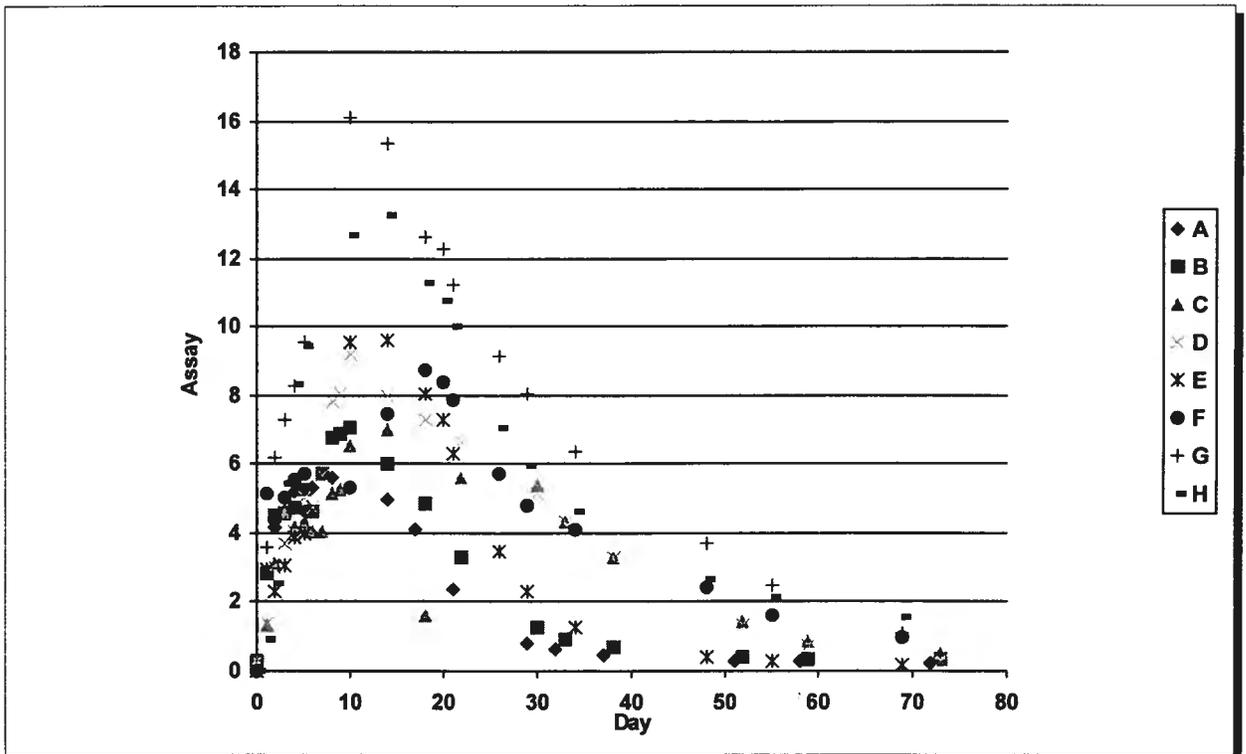
Li Total mg/L



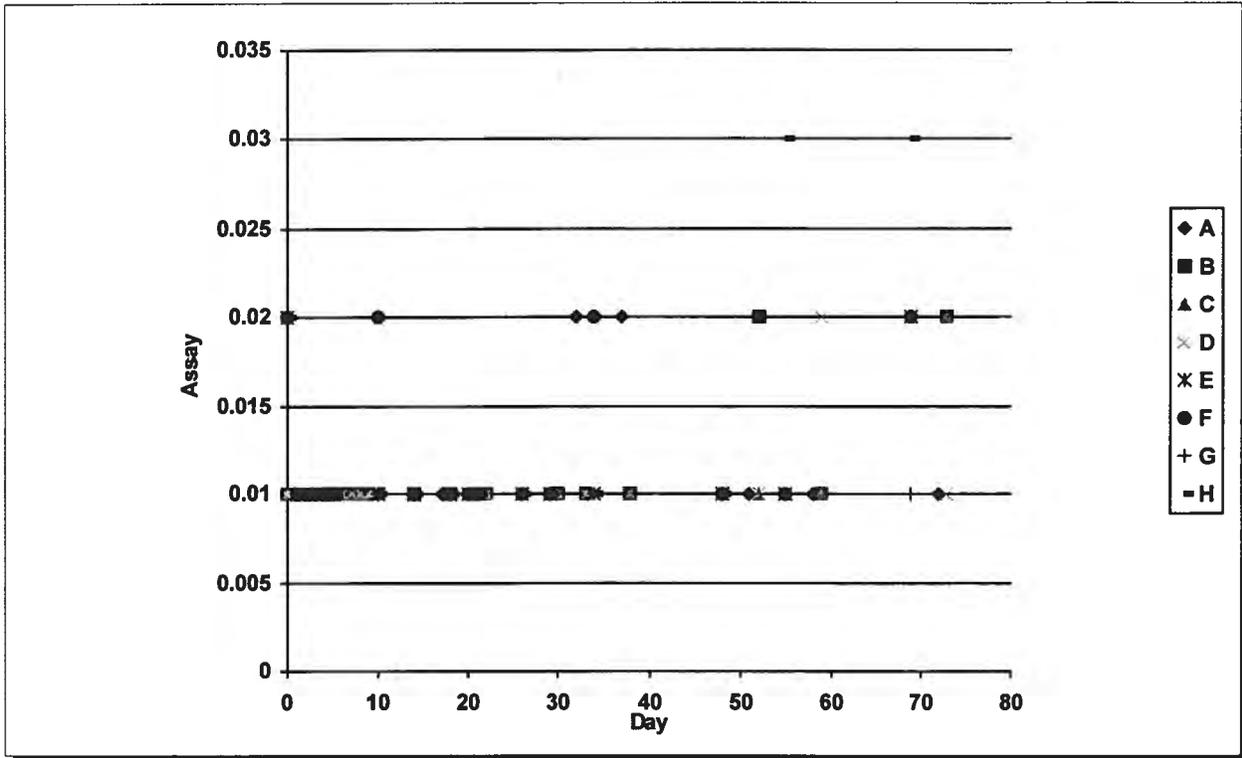
Mg Total mg/L



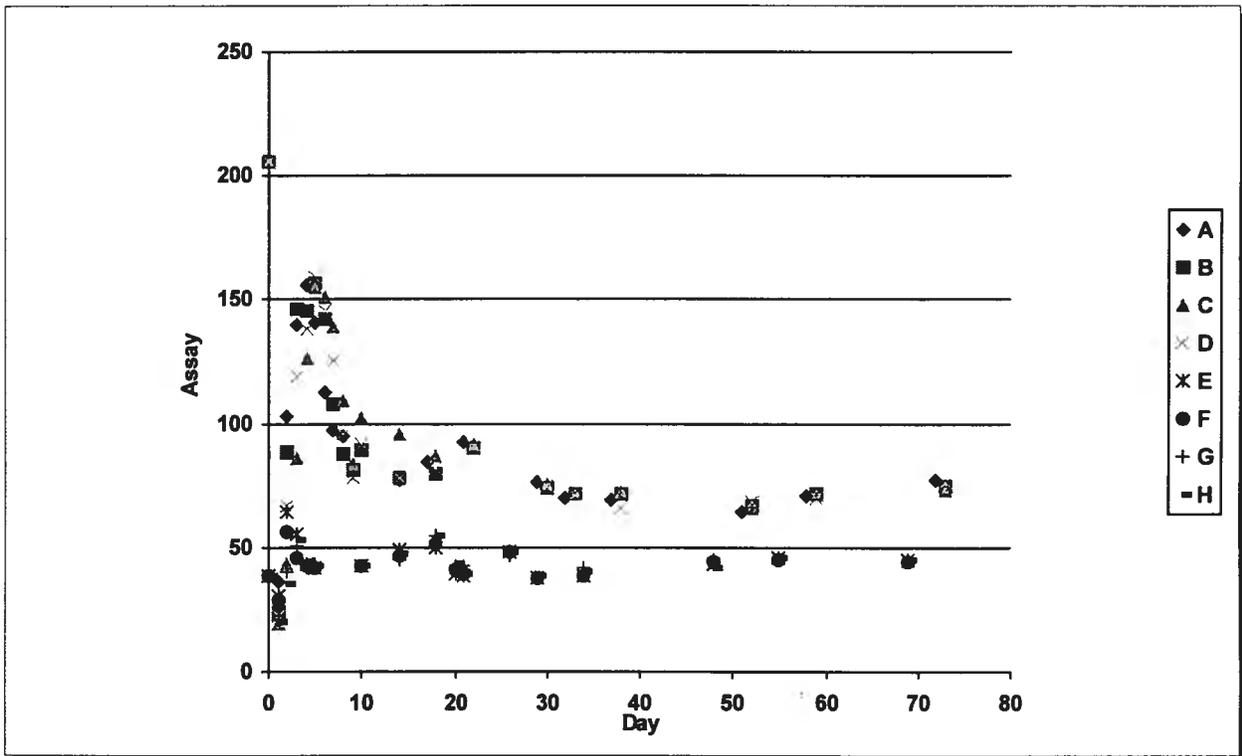
Mn Total mg/L



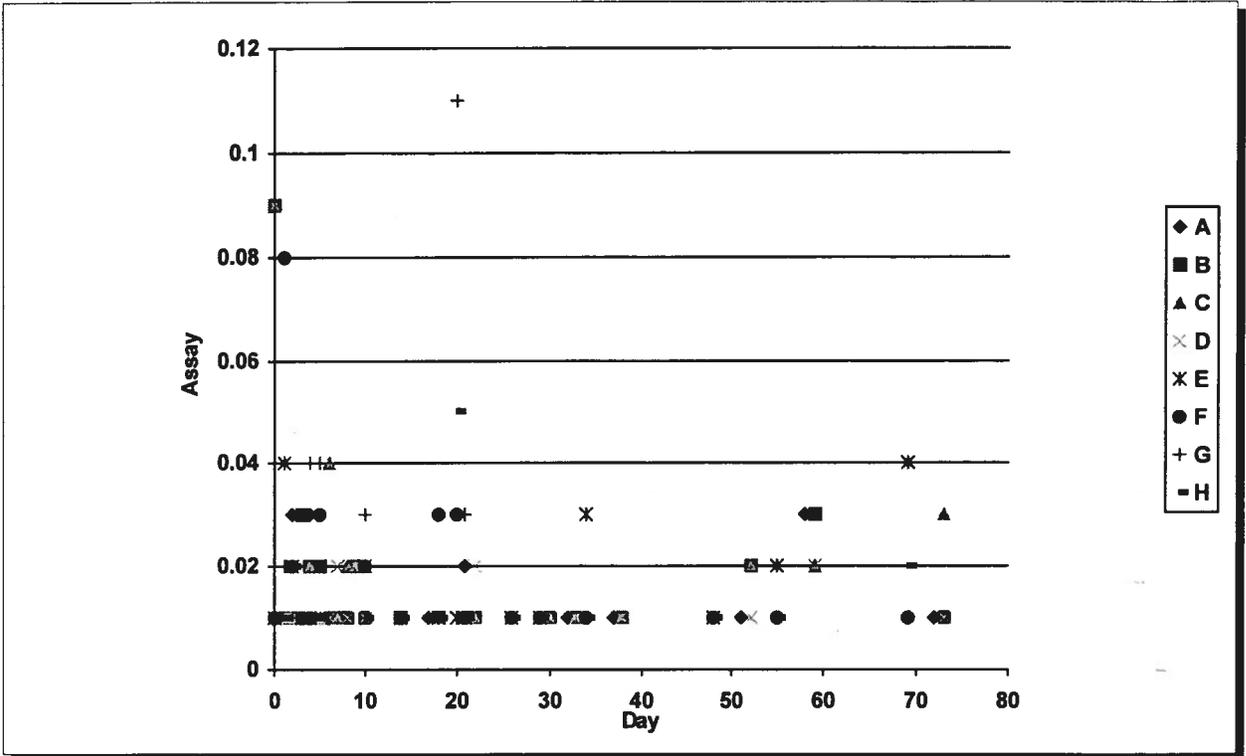
Mo Total mg/L



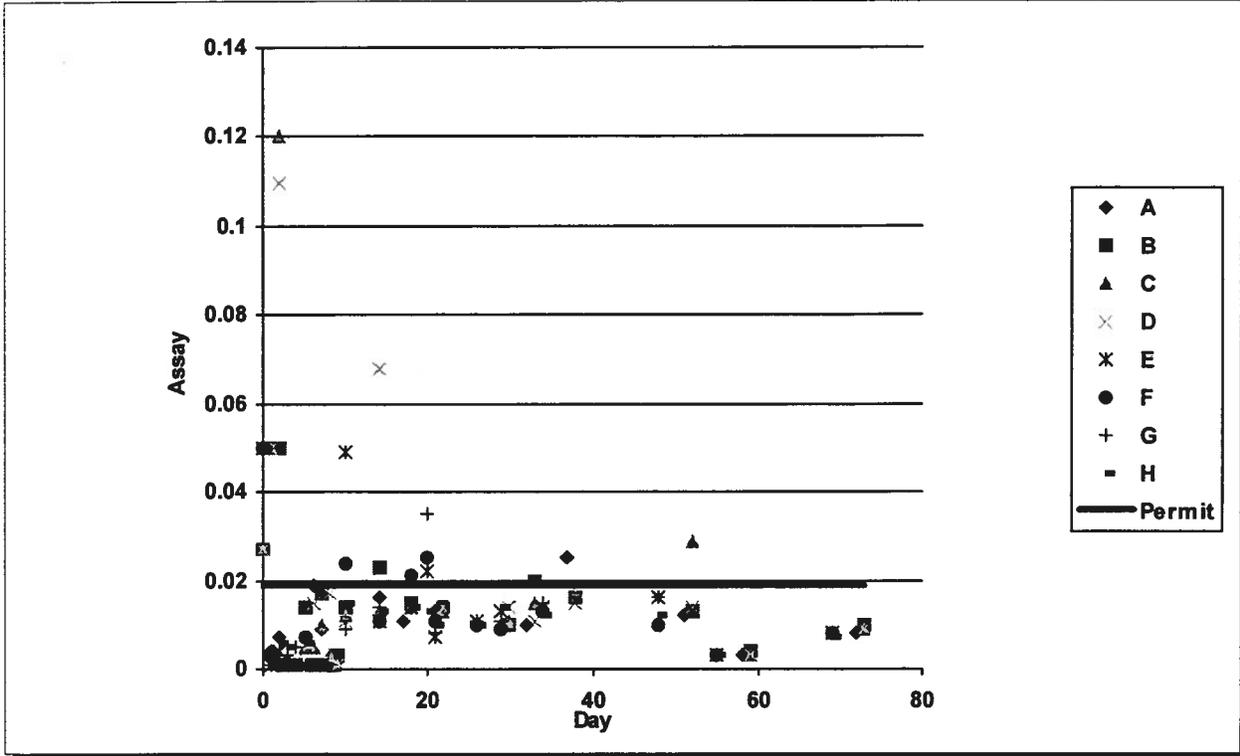
Na Total mg/L



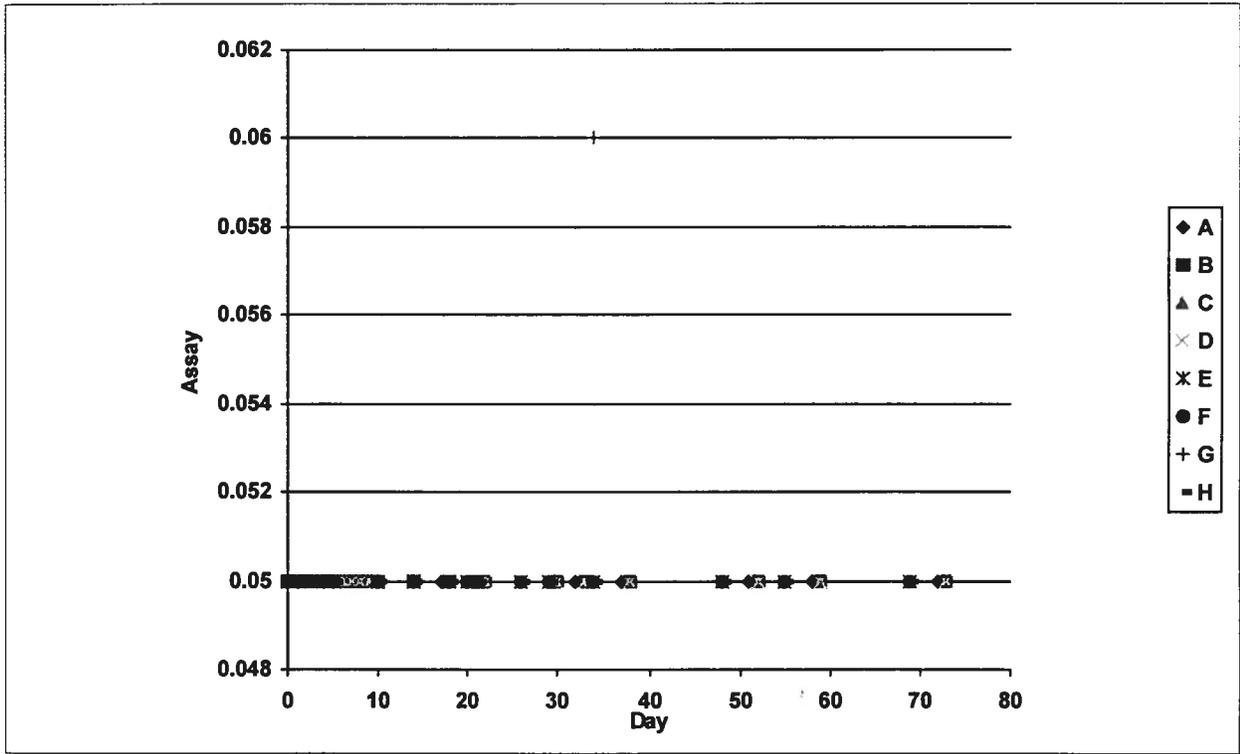
Ni Total mg/L



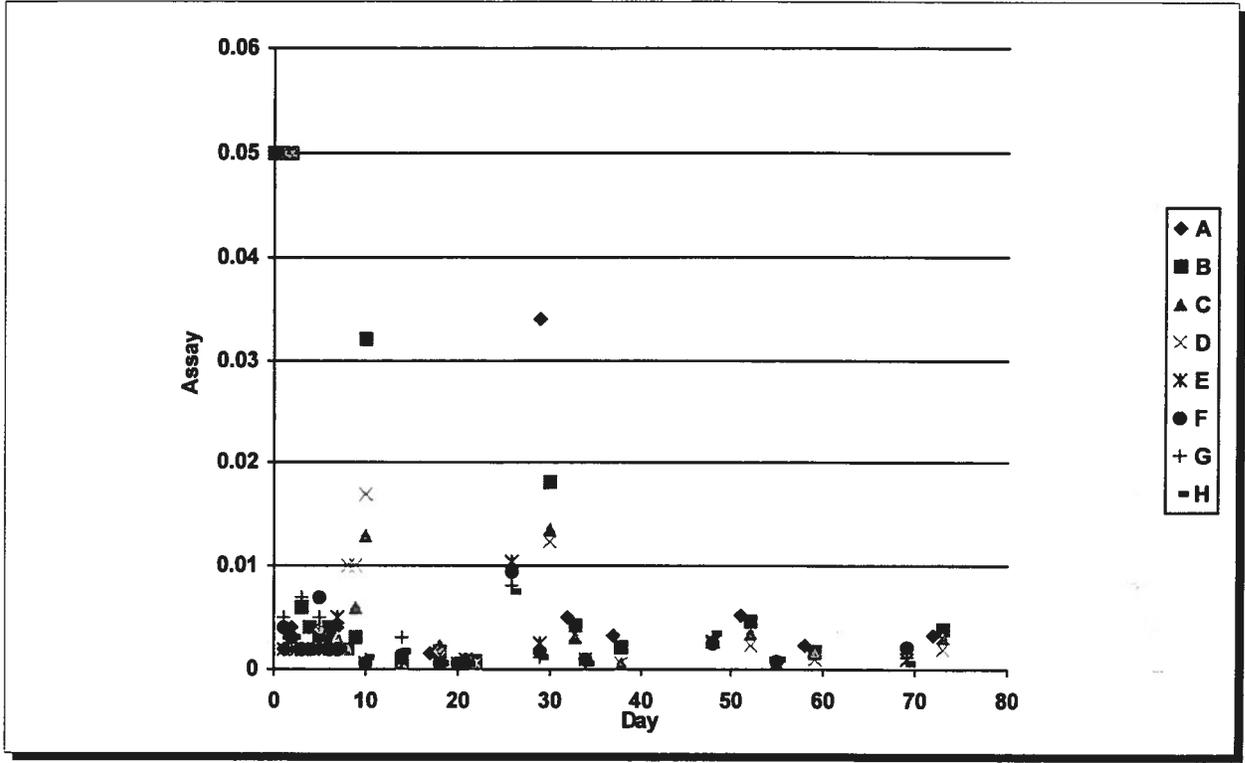
Pb Total mg/L



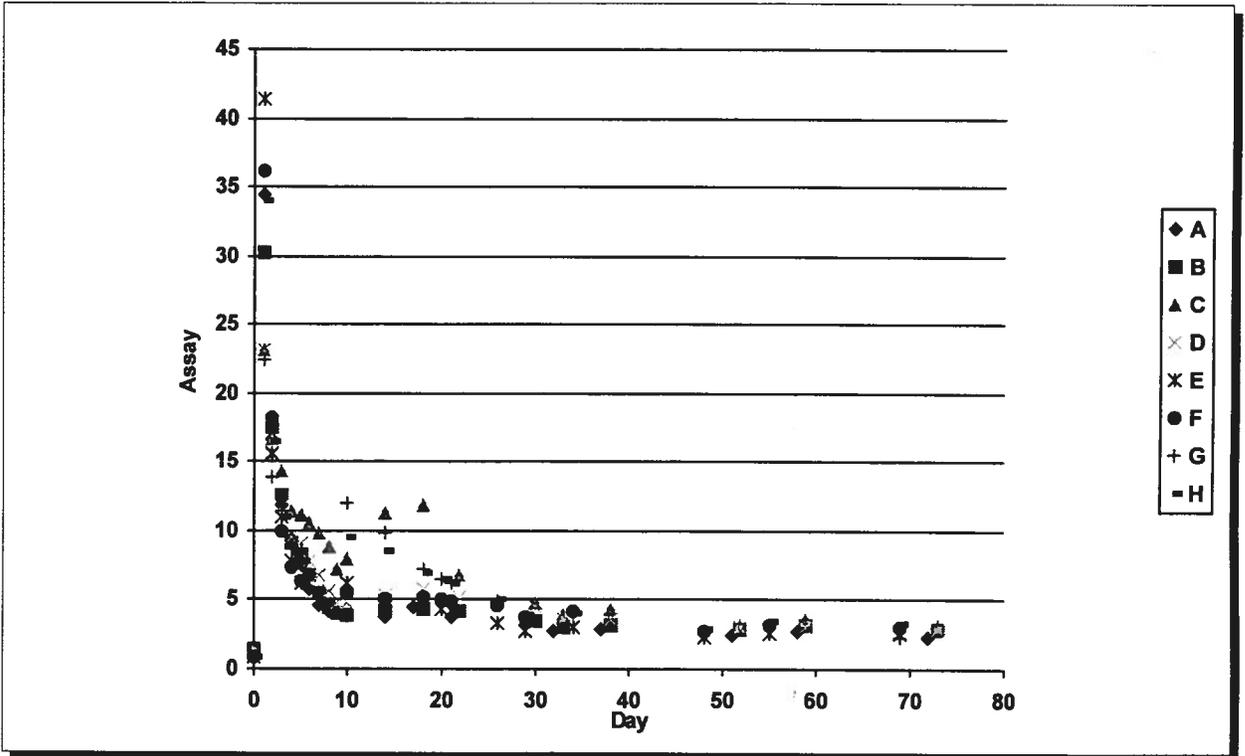
Sb Total mg/L



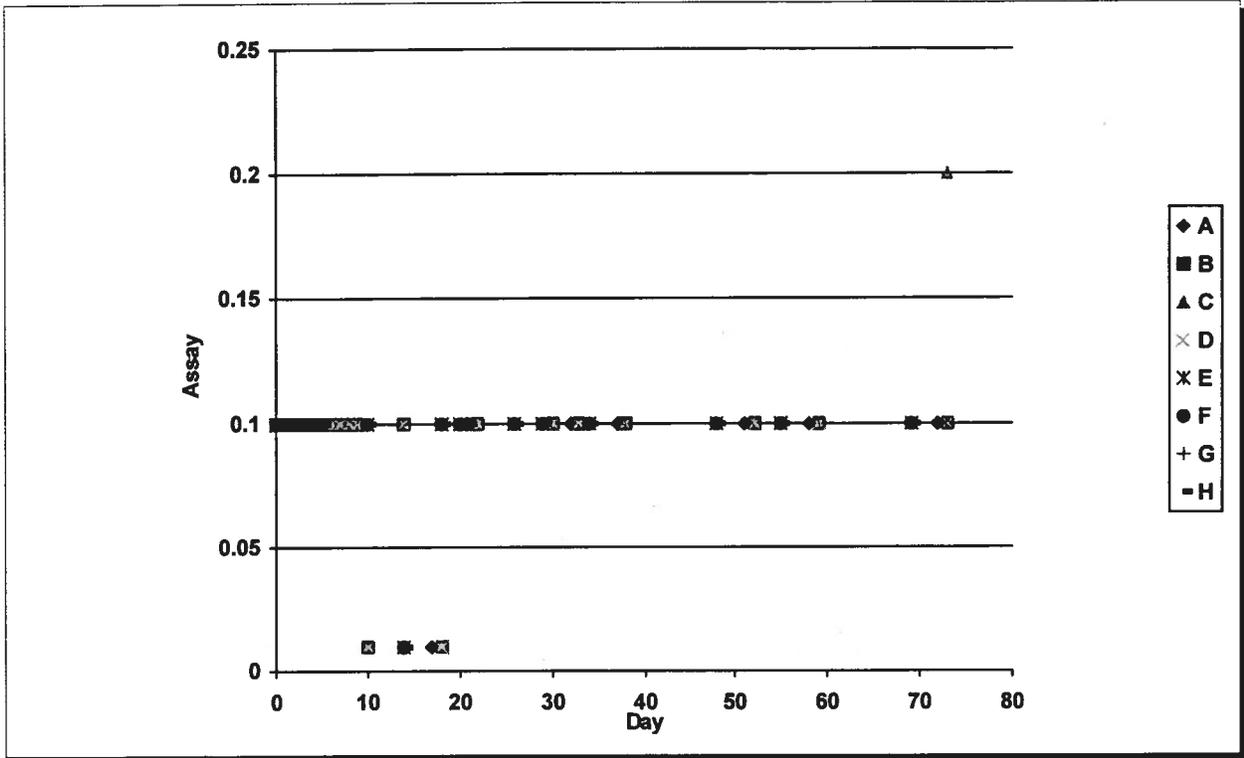
Se Total mg/L



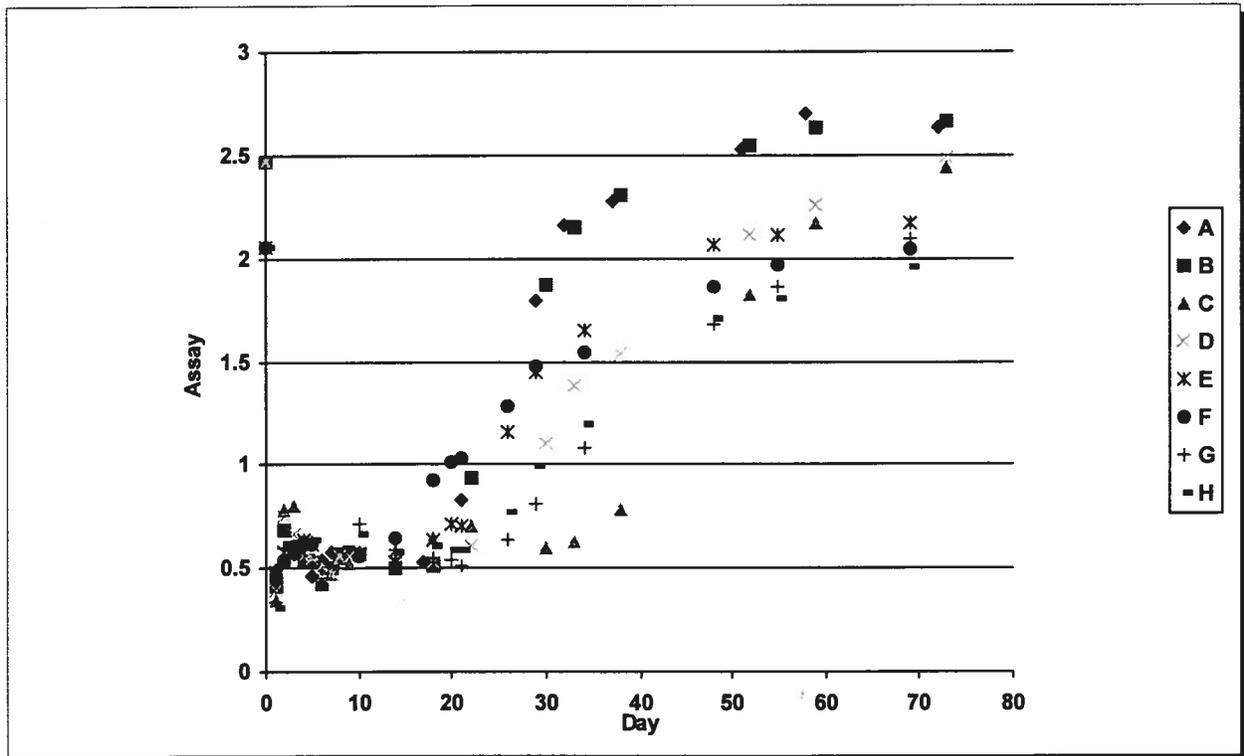
Si Total mg/L



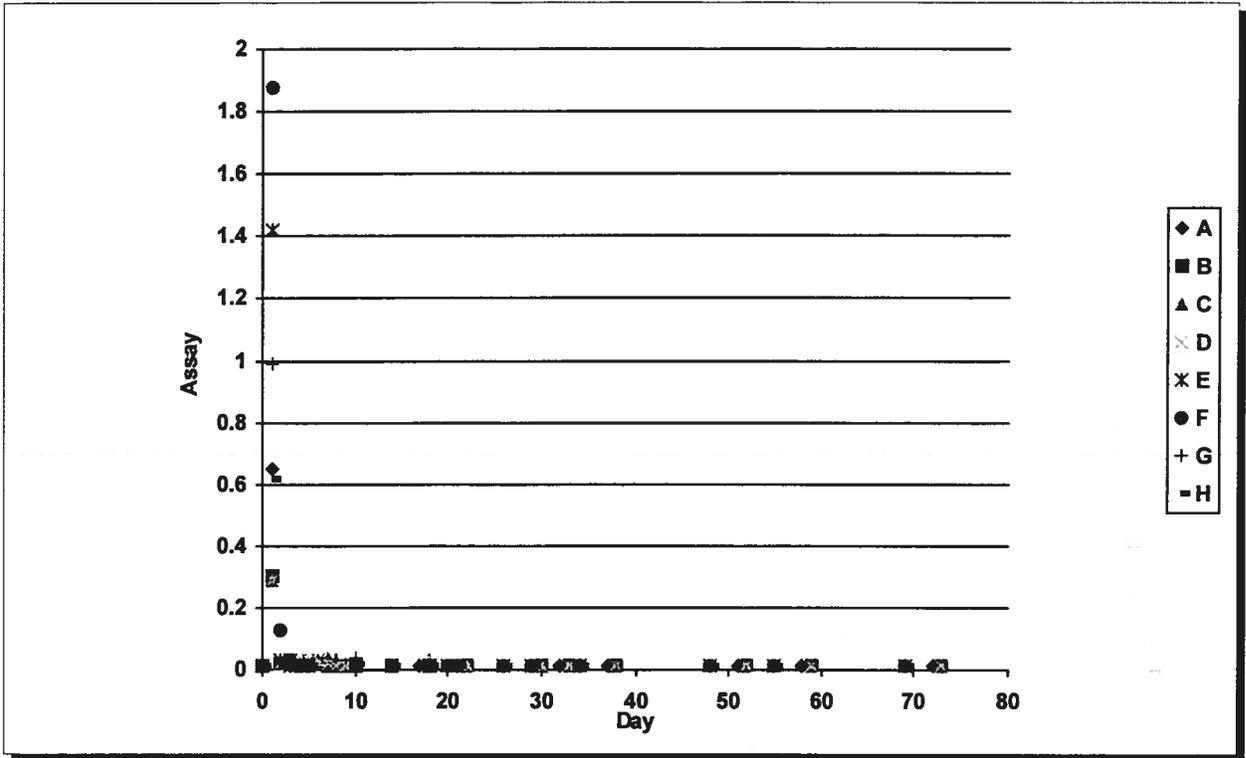
Sn Total mg/L



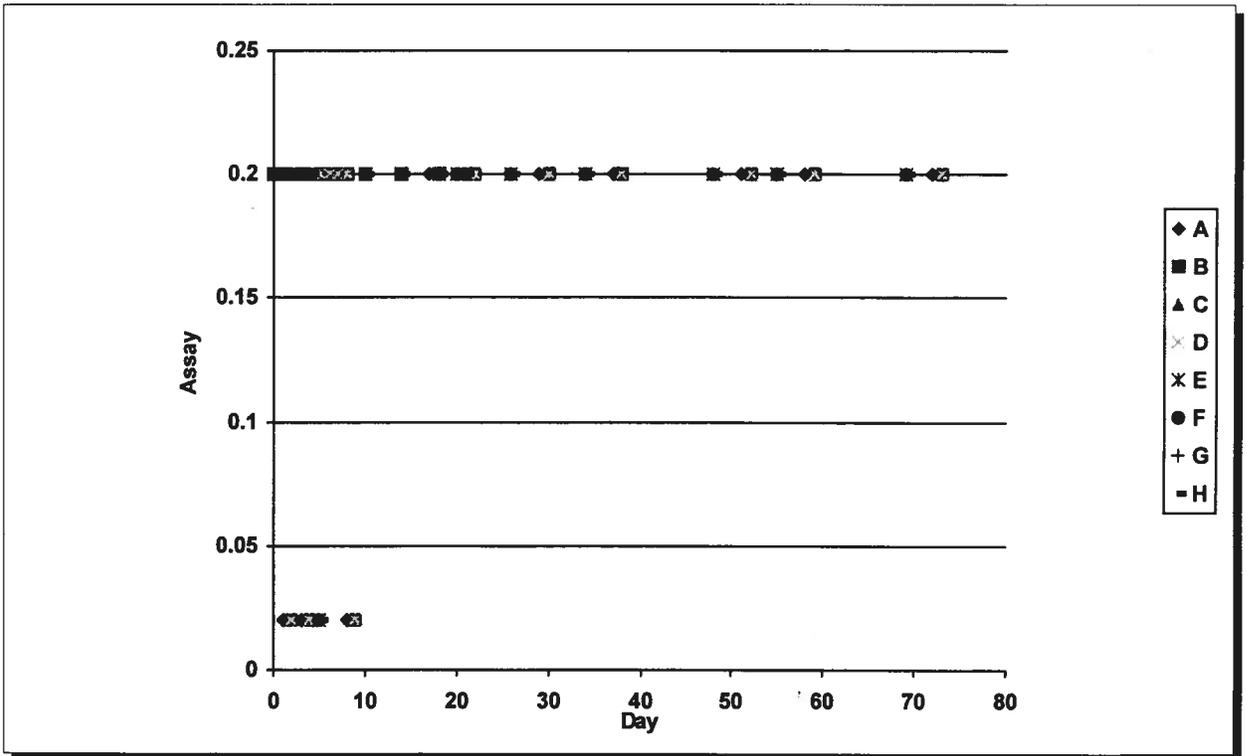
Sr Total mg/L



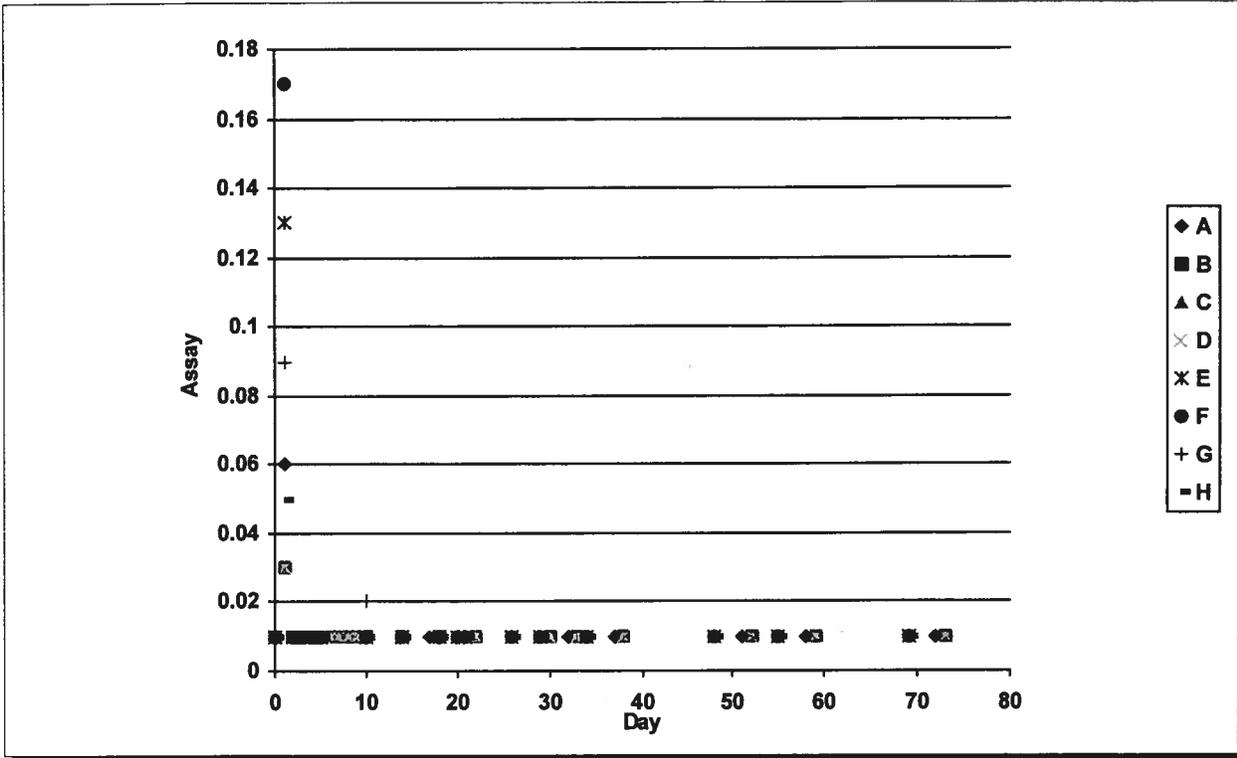
Ti Total mg/L



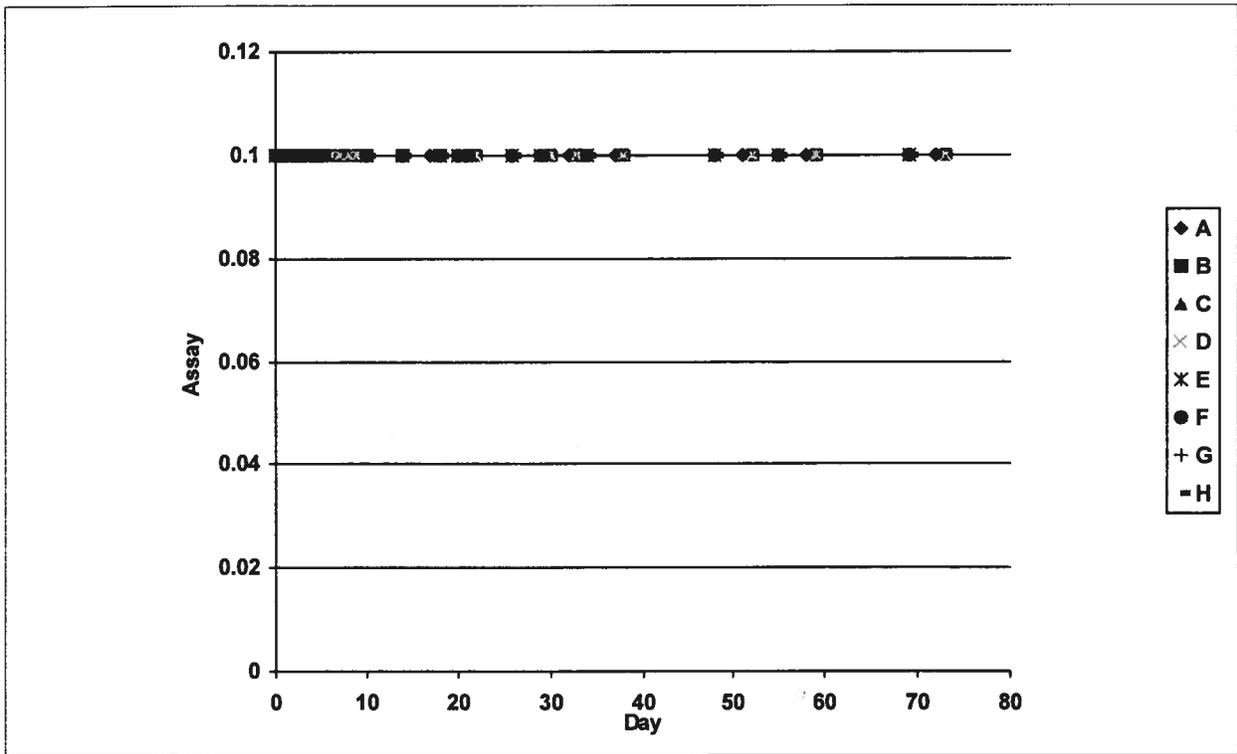
Ti Total mg/L



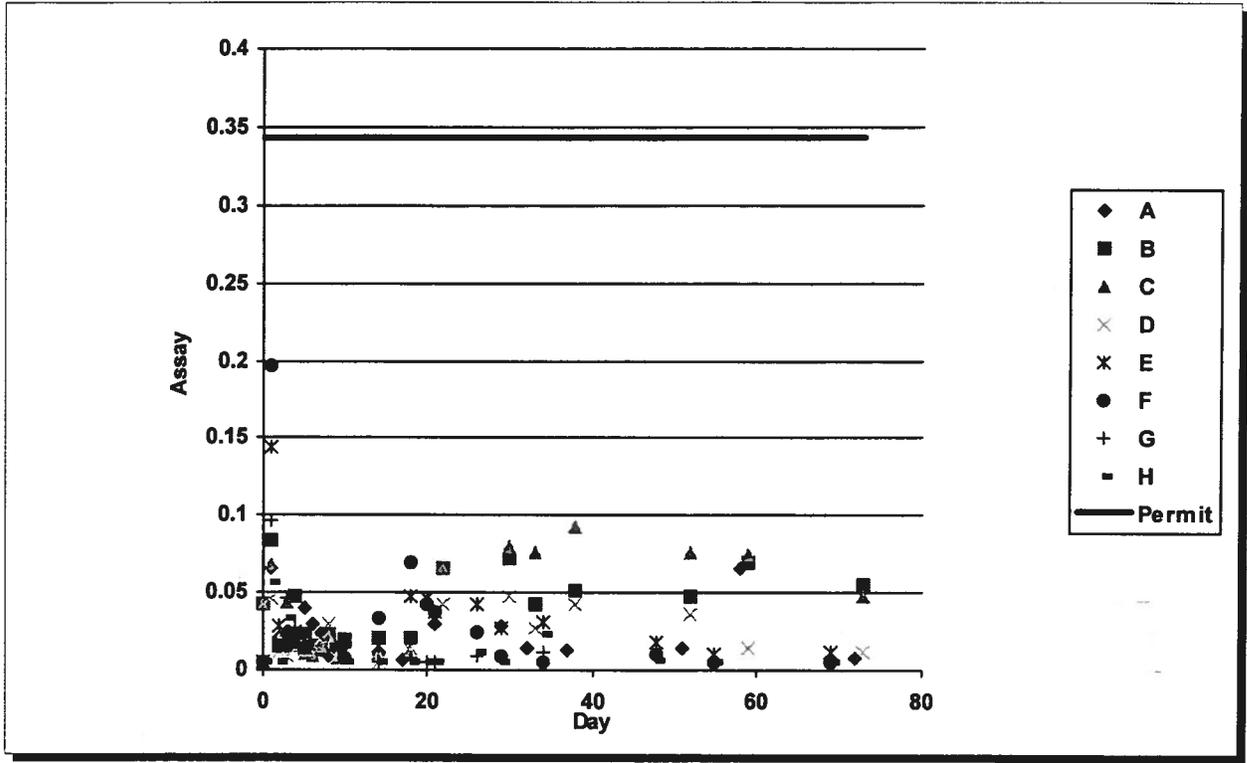
V Total mg/L

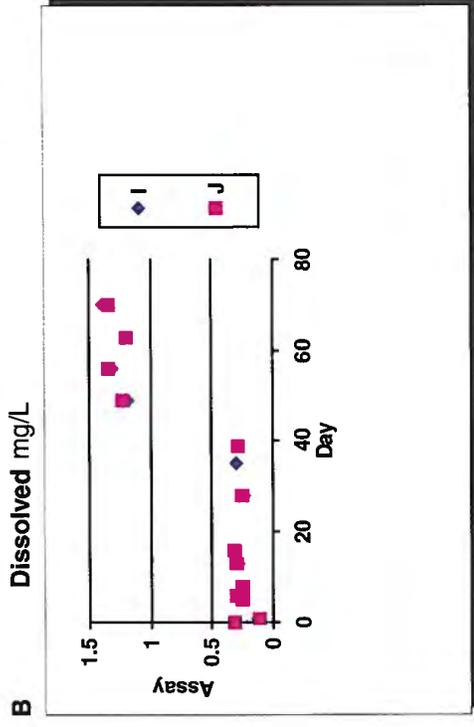
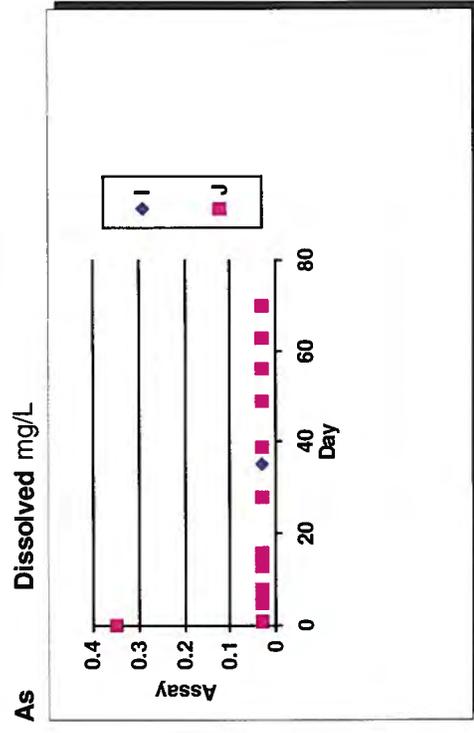
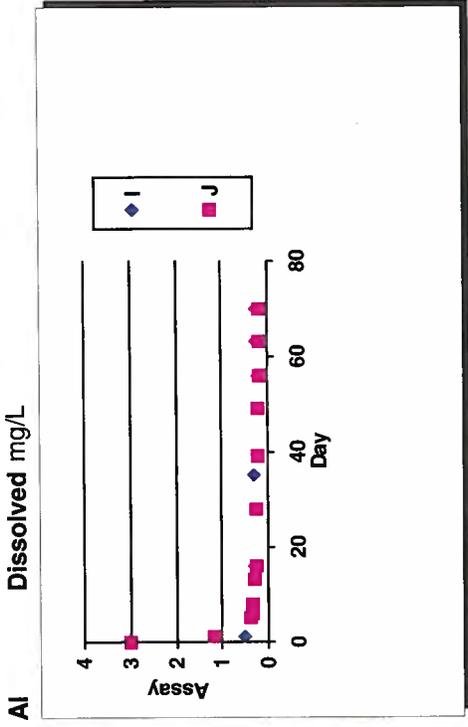
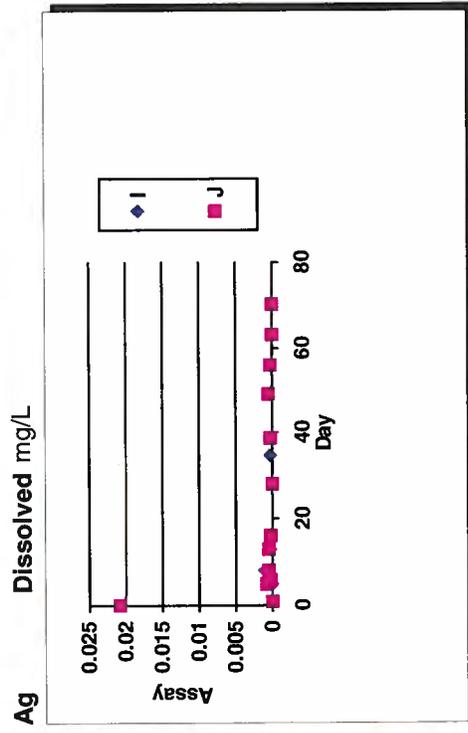


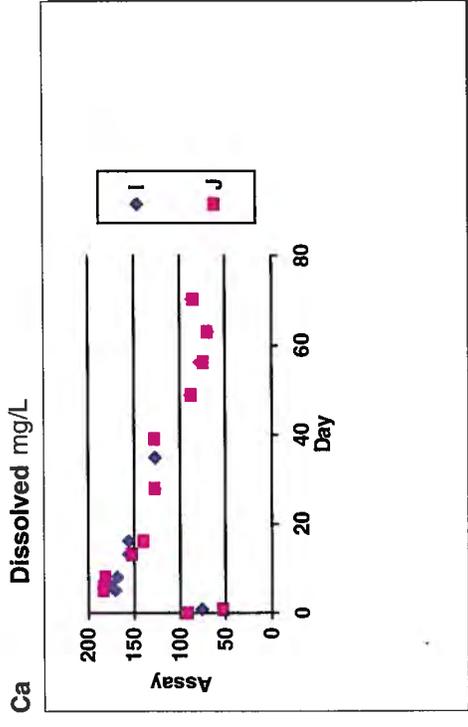
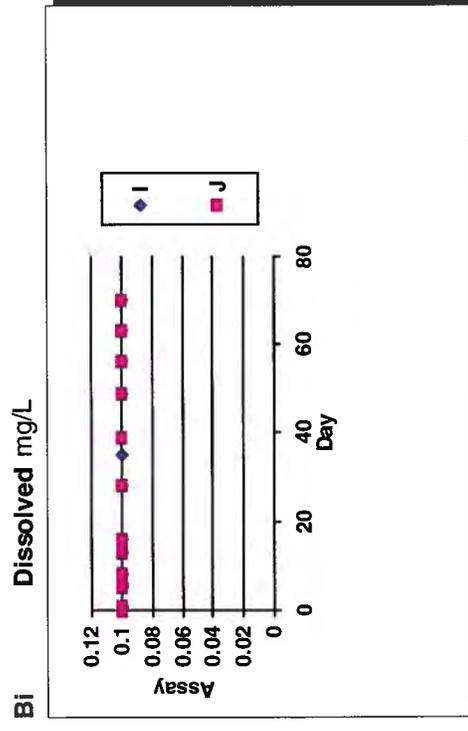
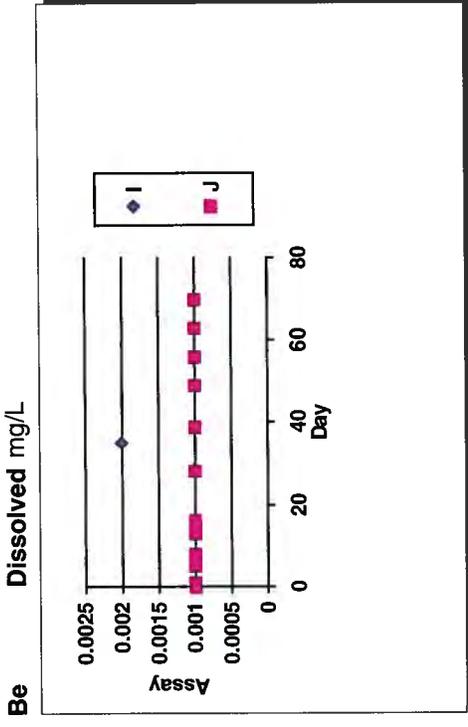
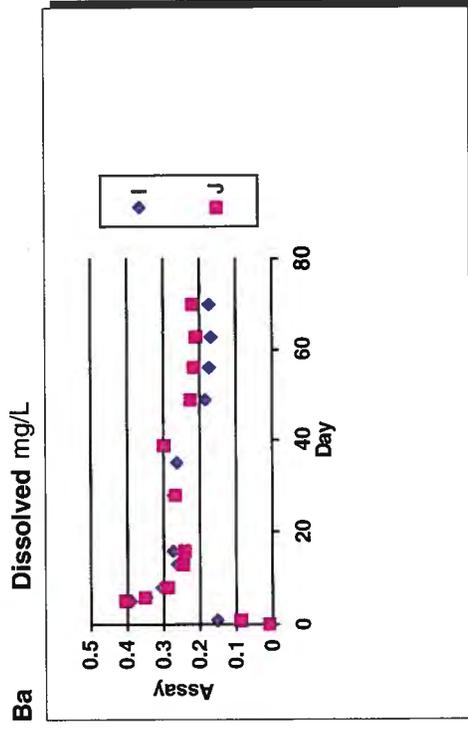
W Total mg/L

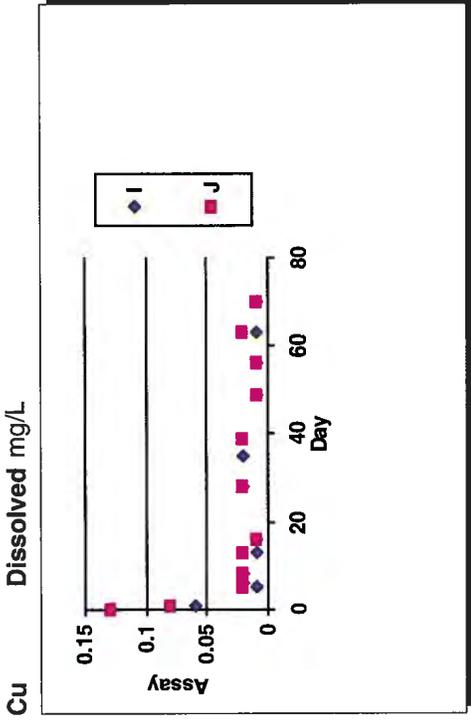
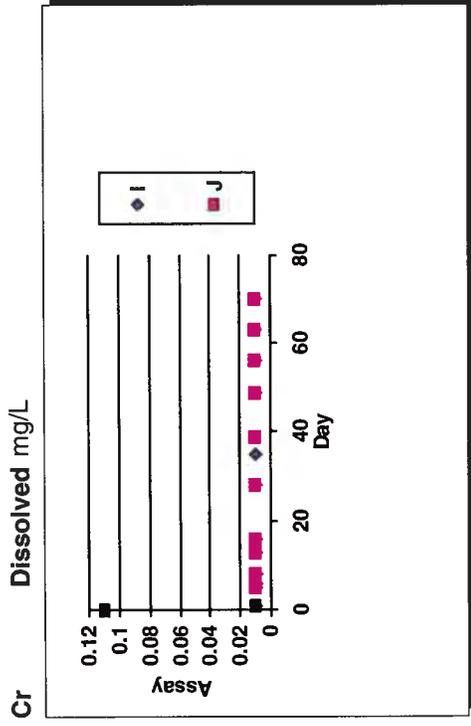
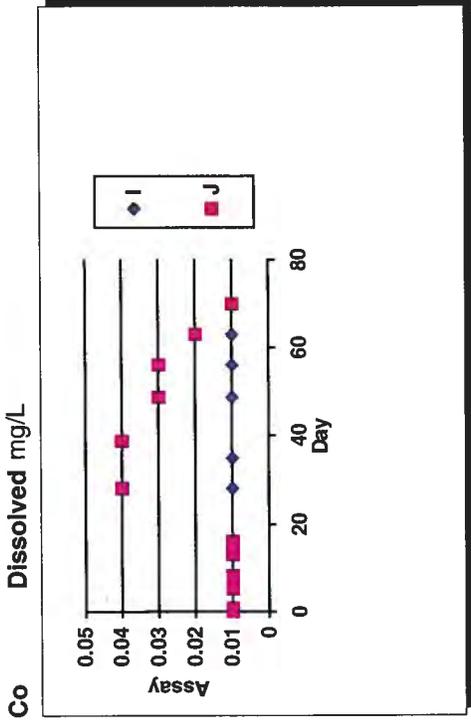
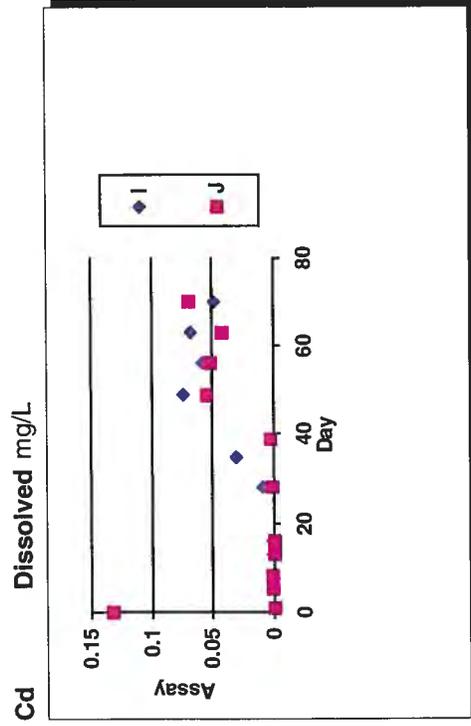


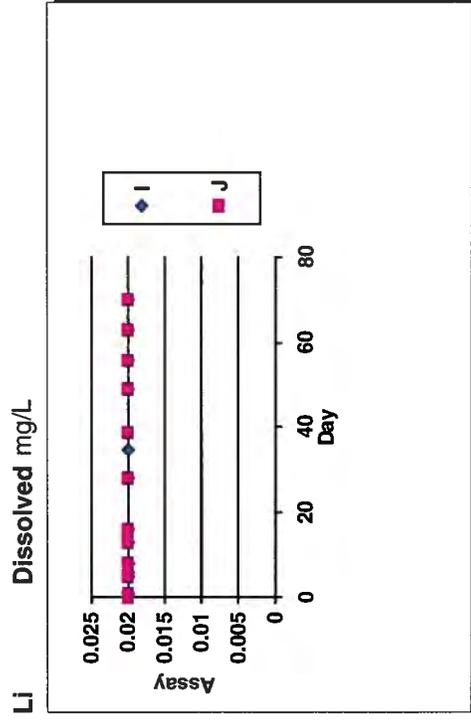
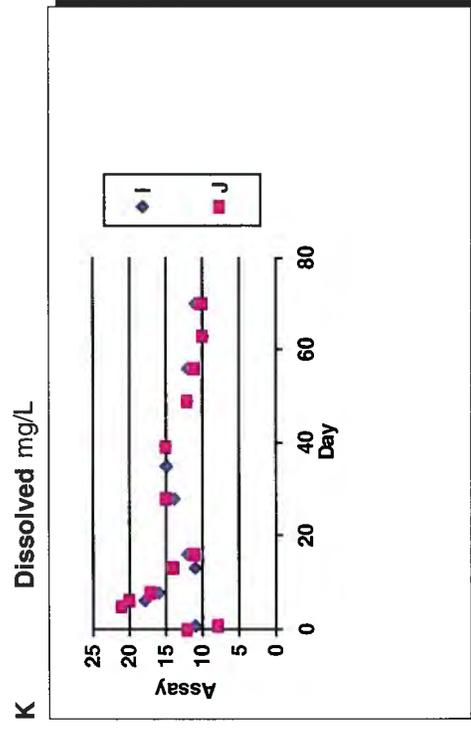
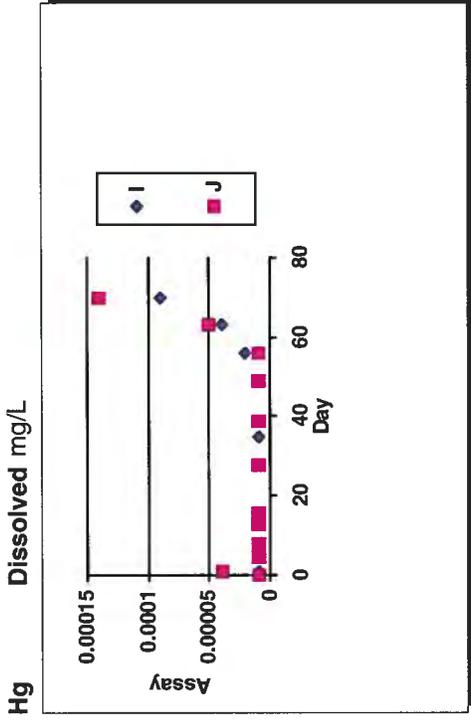
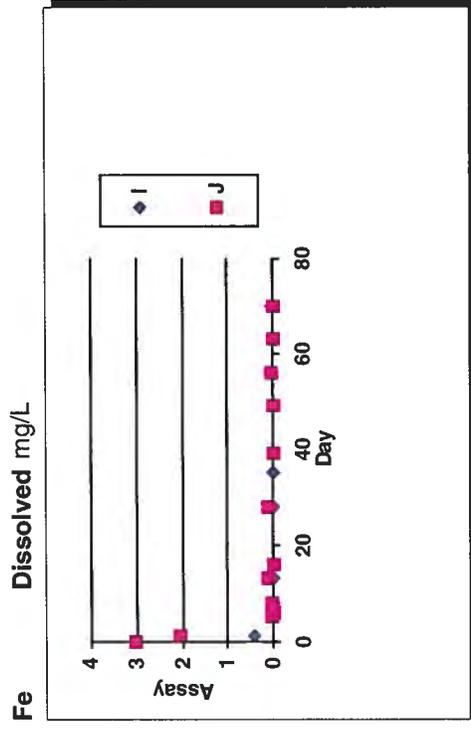
Zn Total mg/L

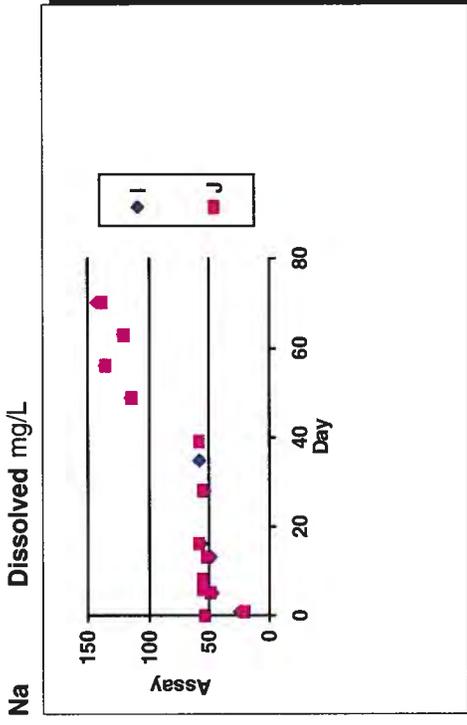
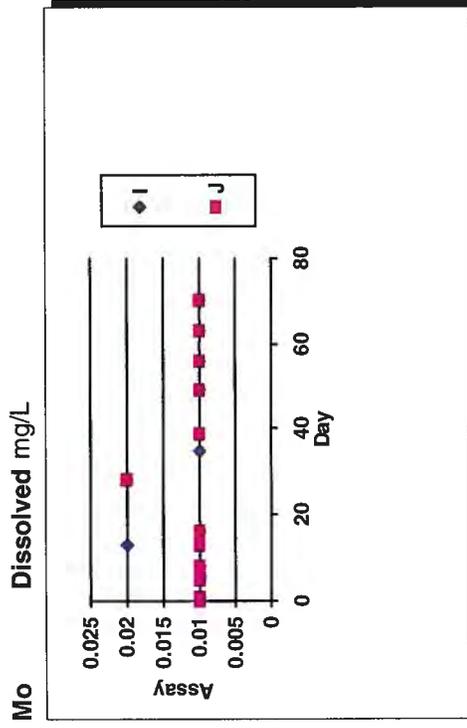
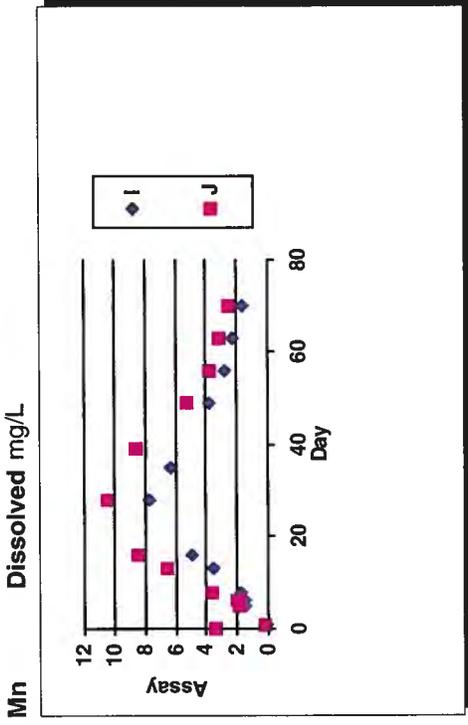
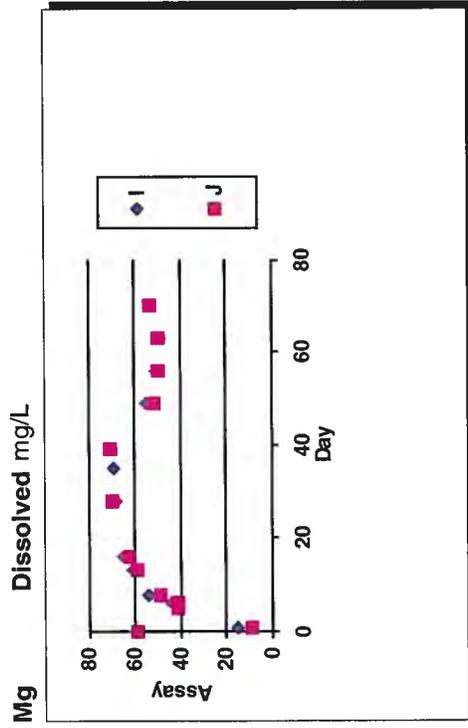


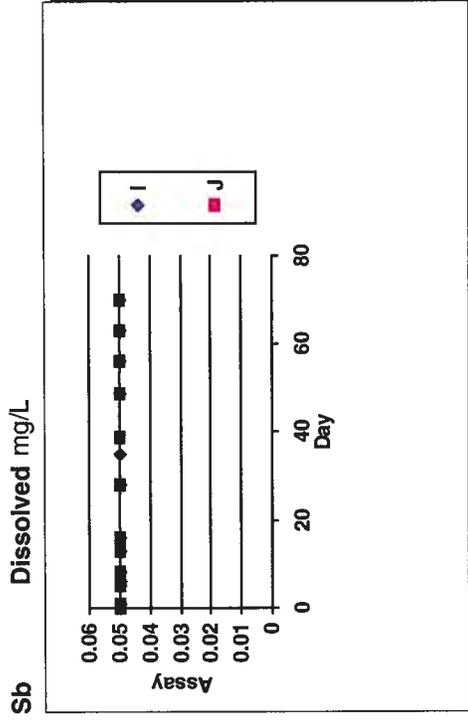
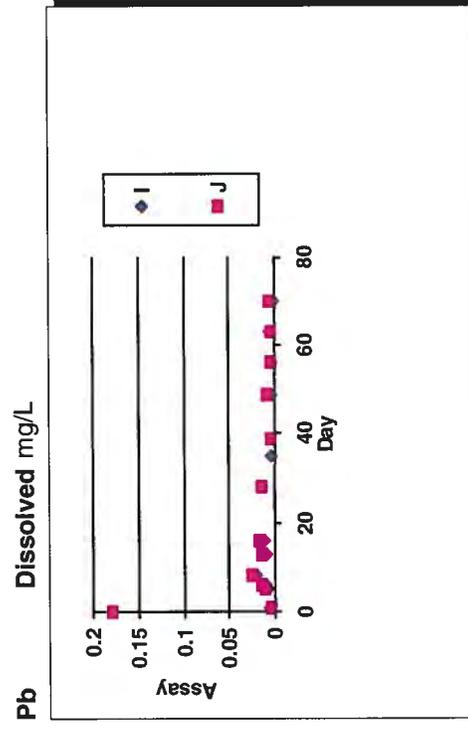
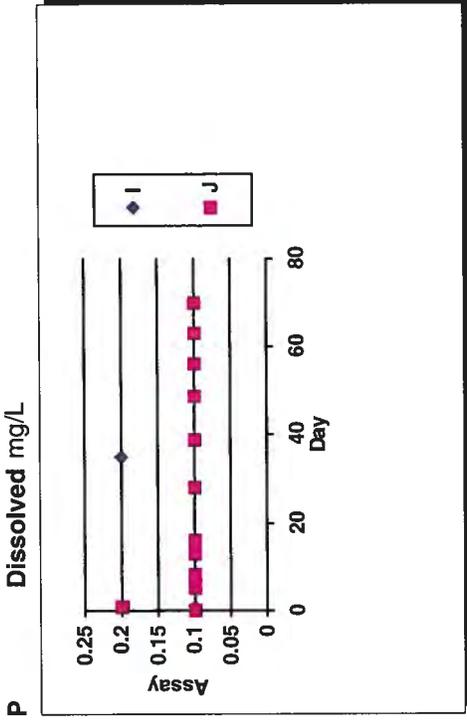
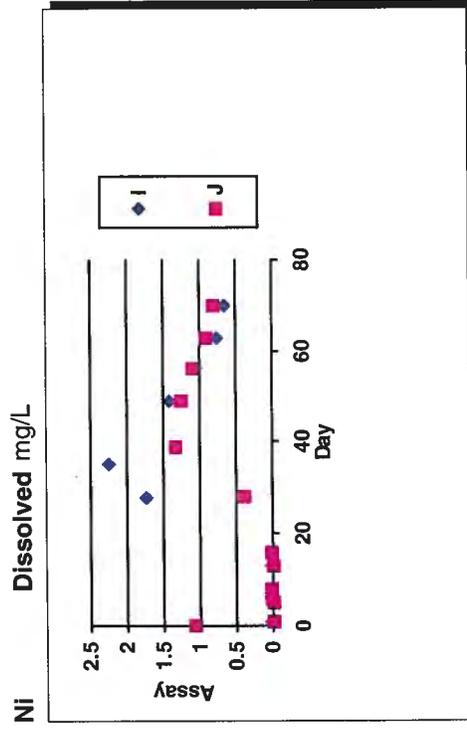


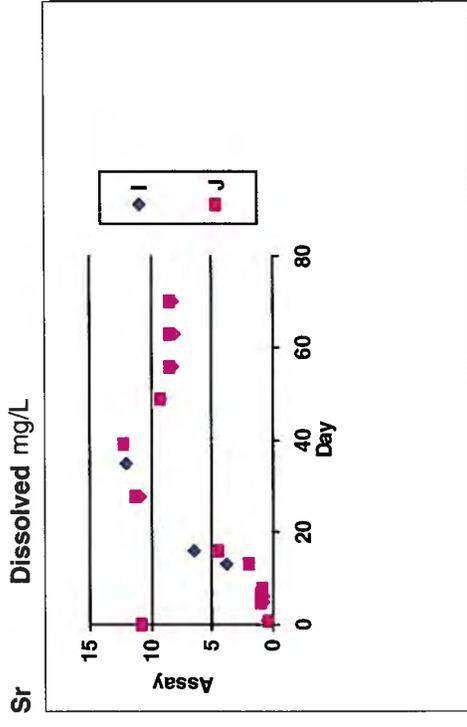
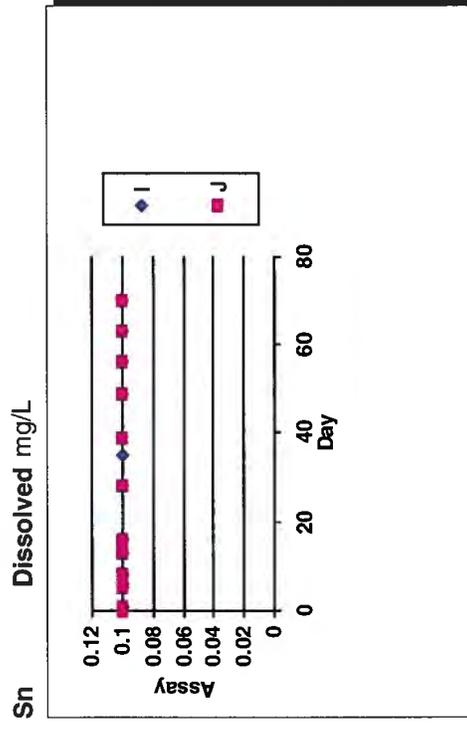
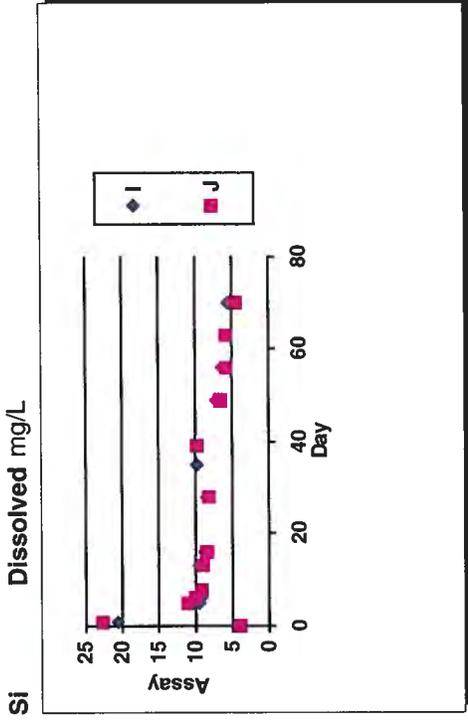
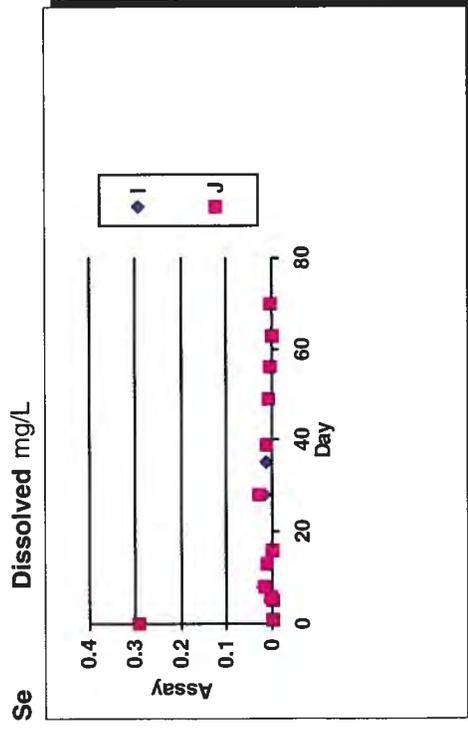


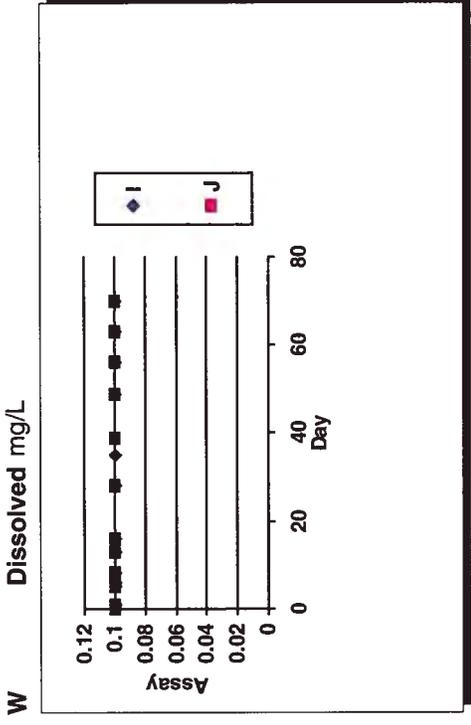
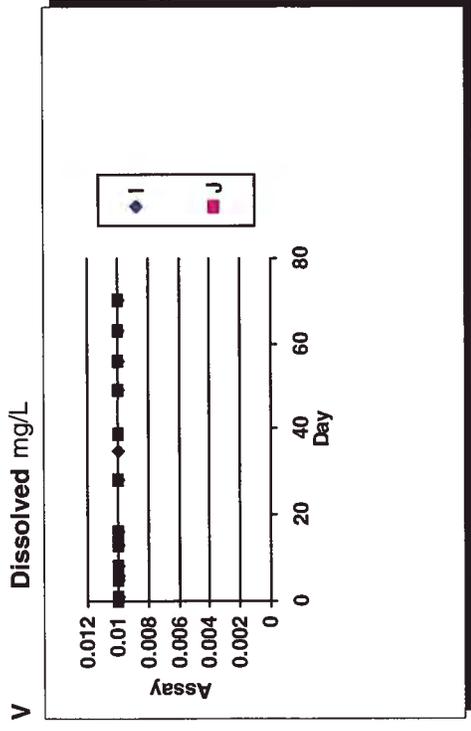
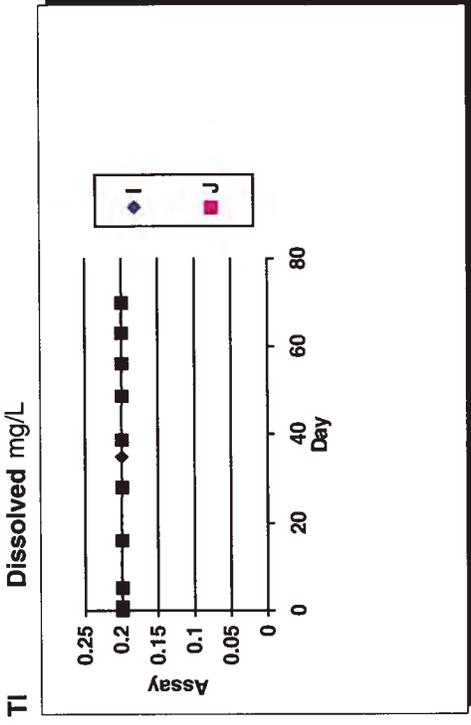
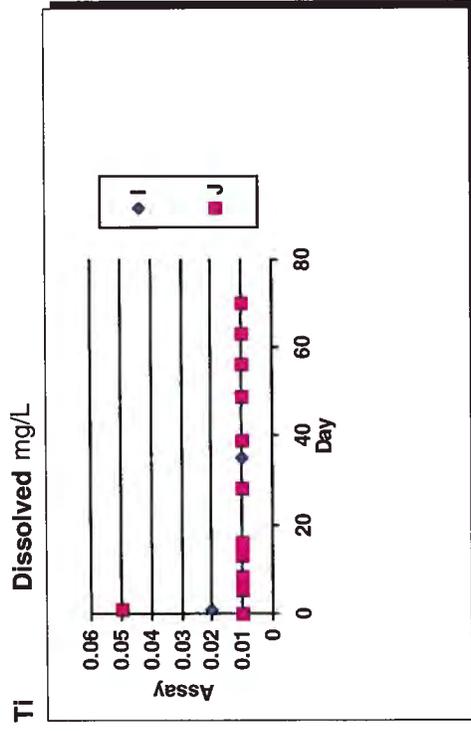


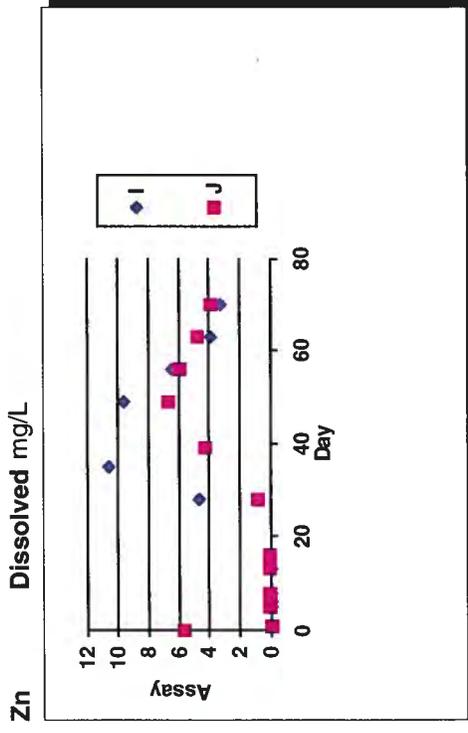


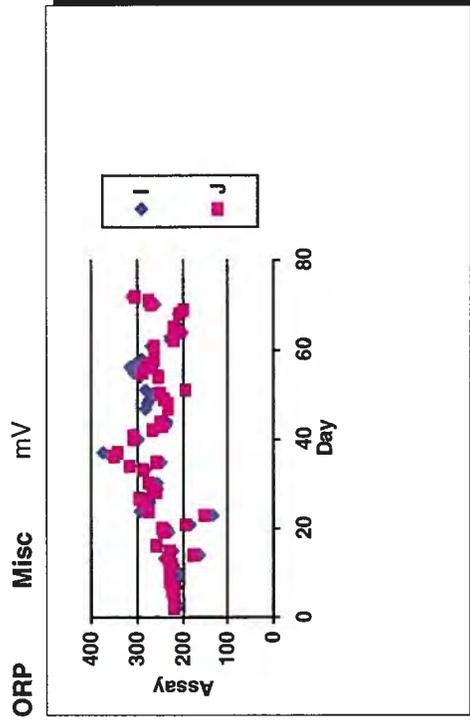
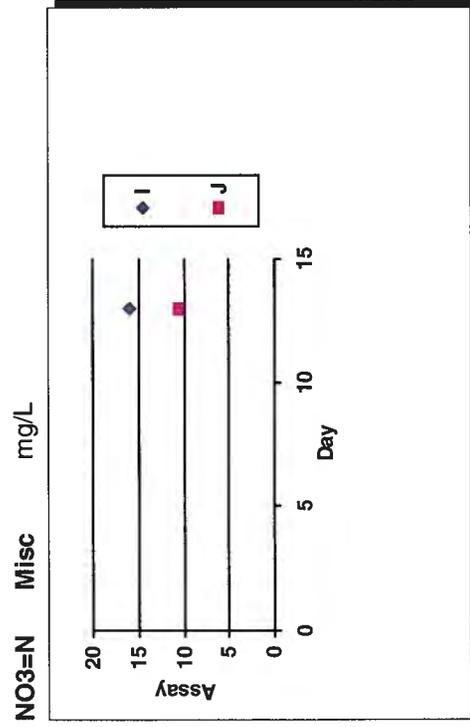
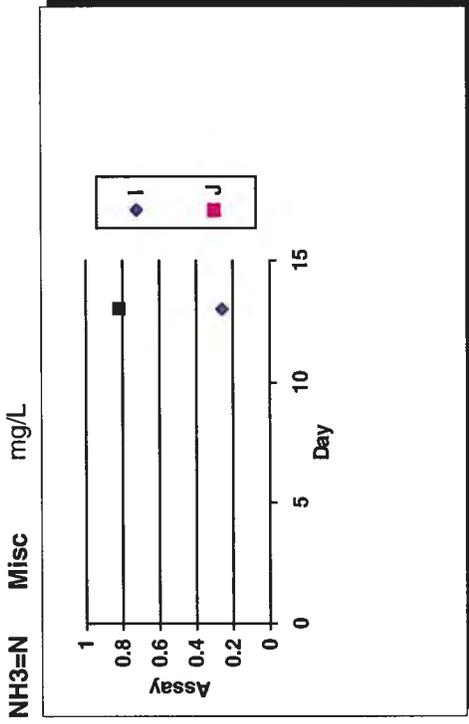
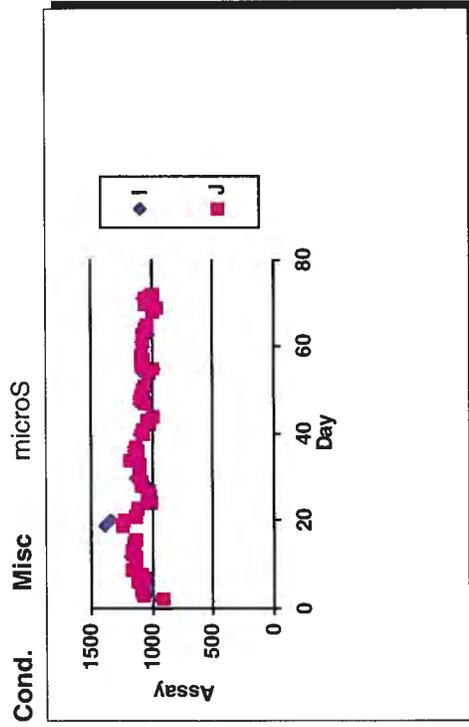


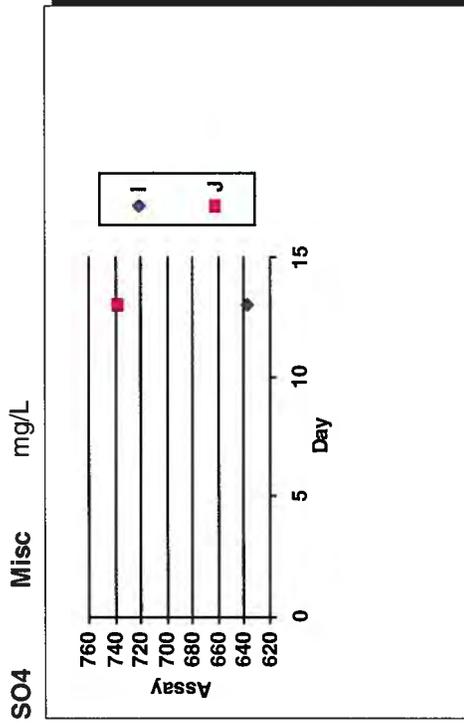
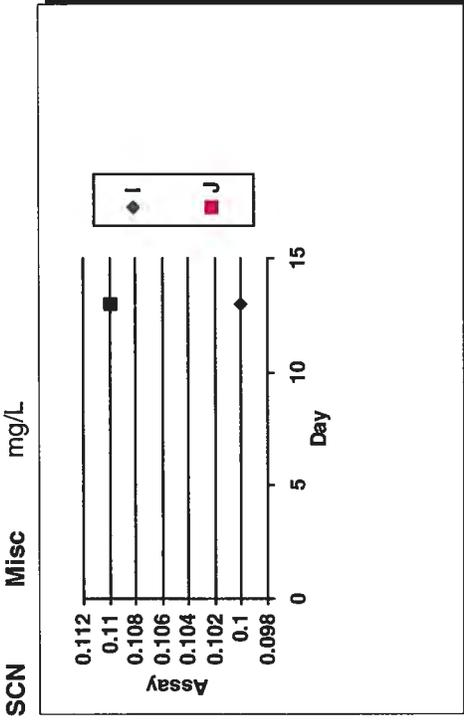
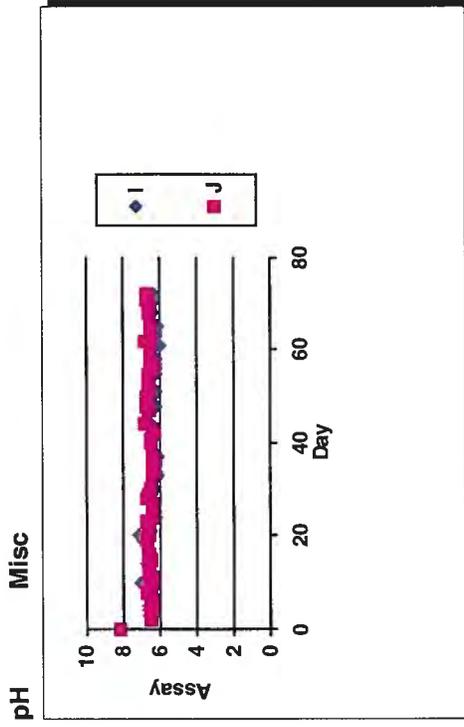


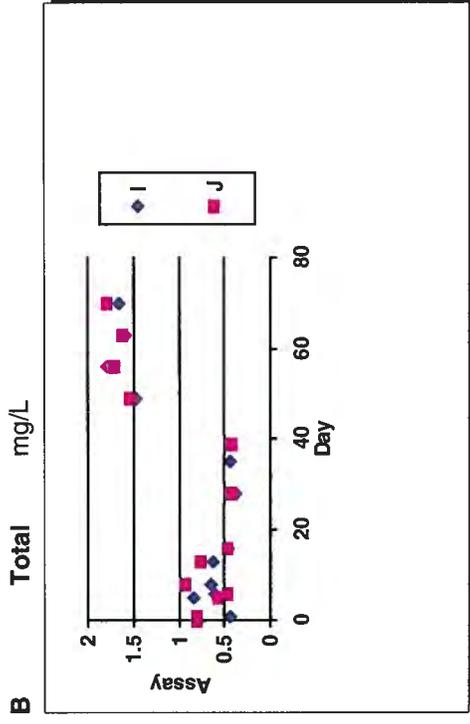
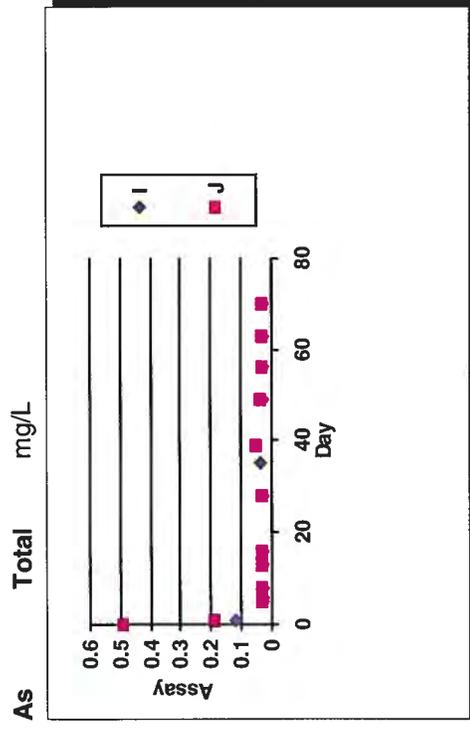
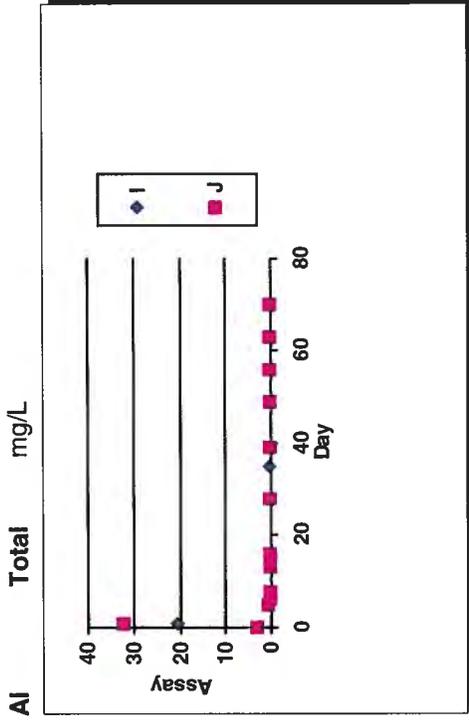
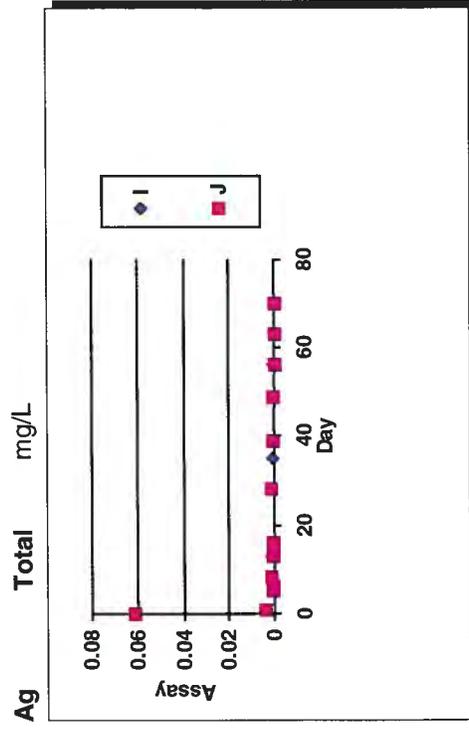


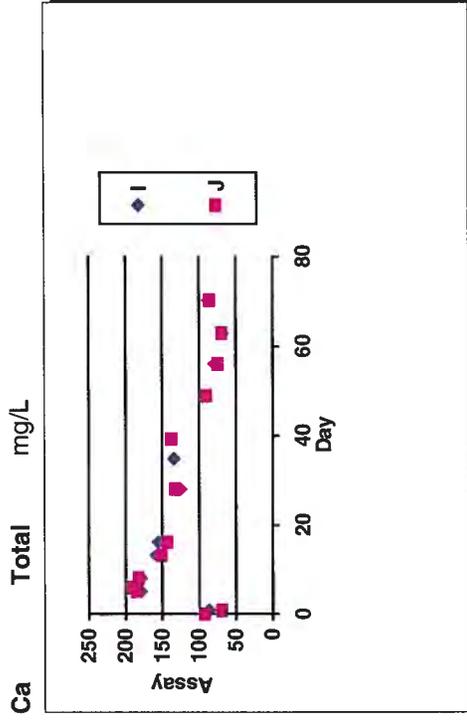
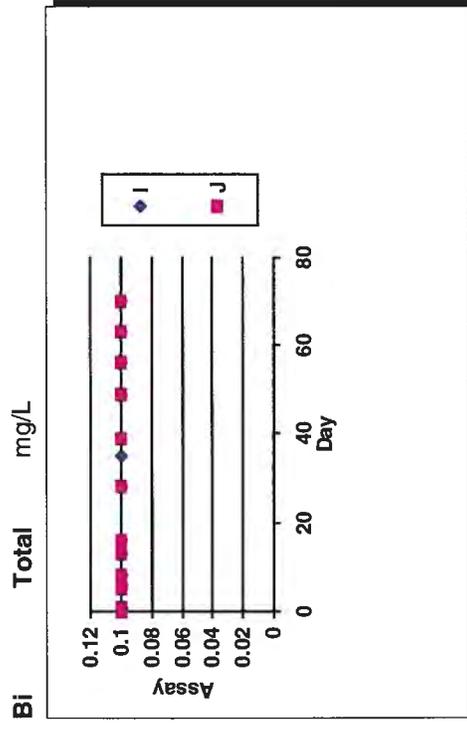
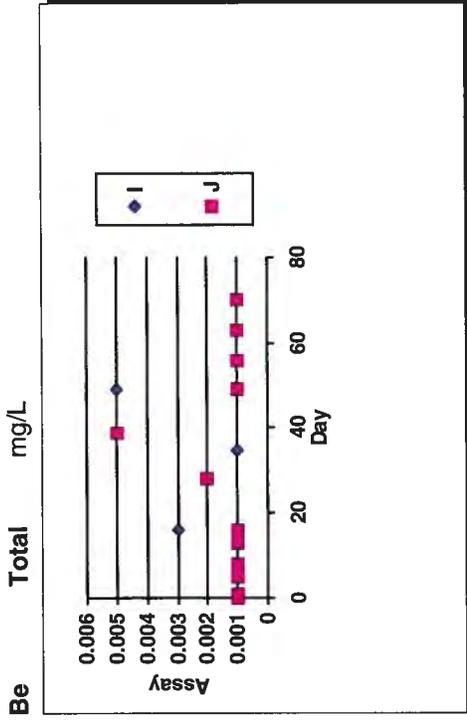
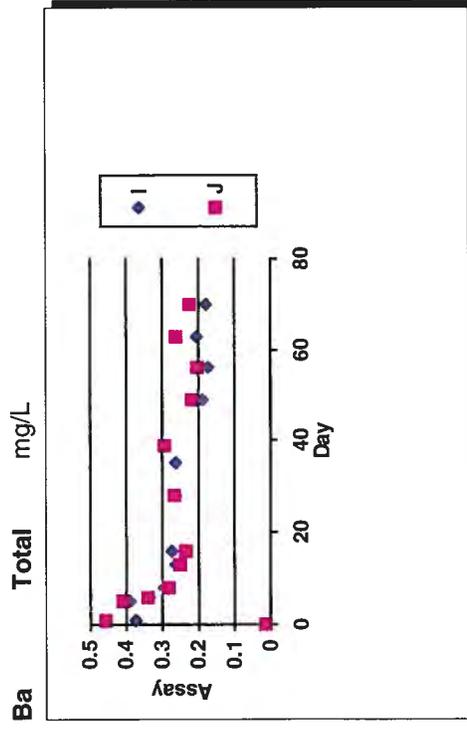


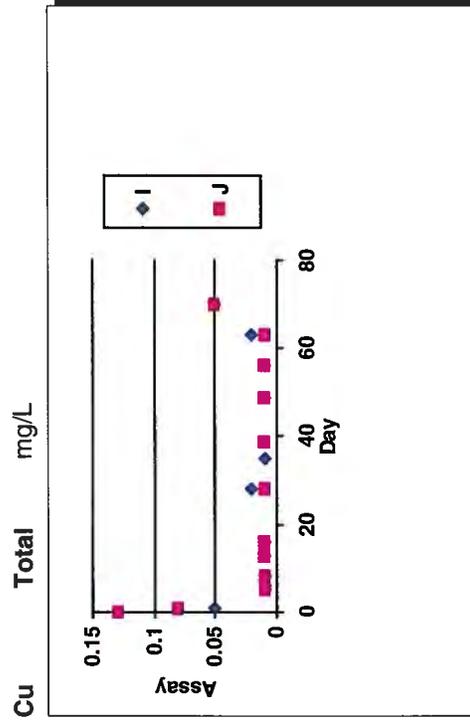
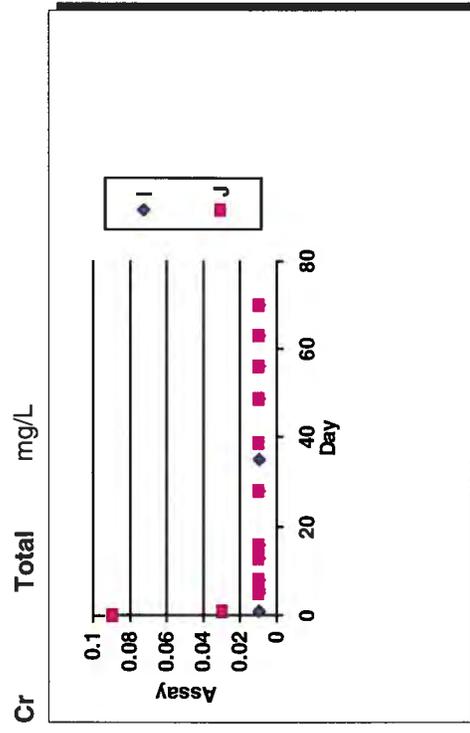
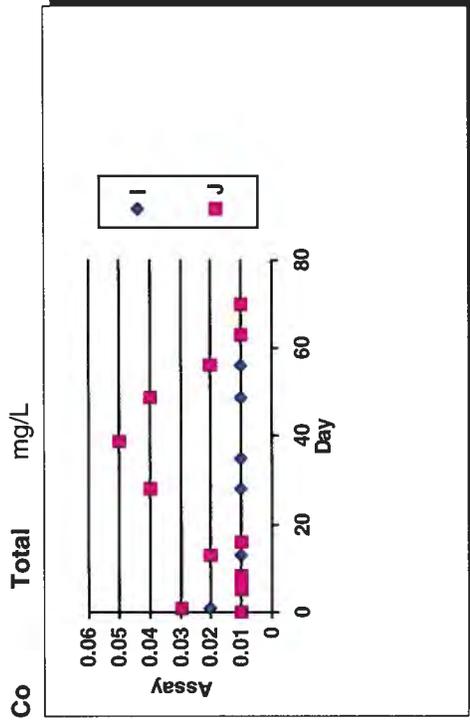
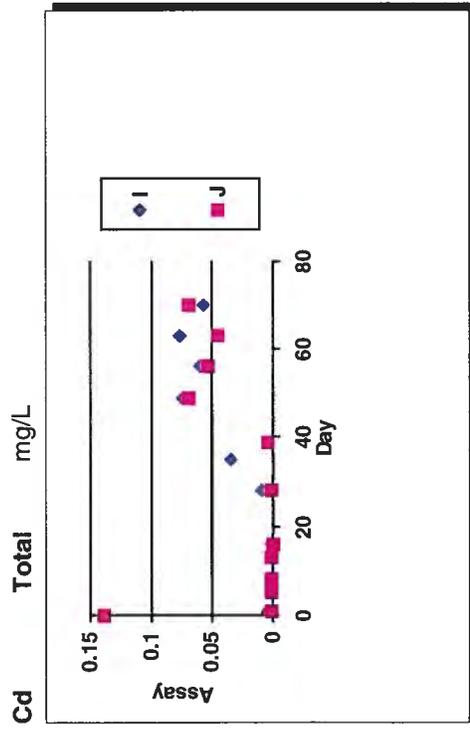


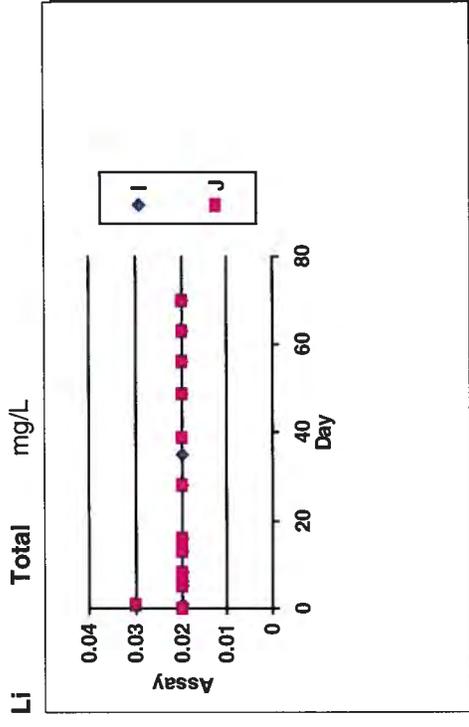
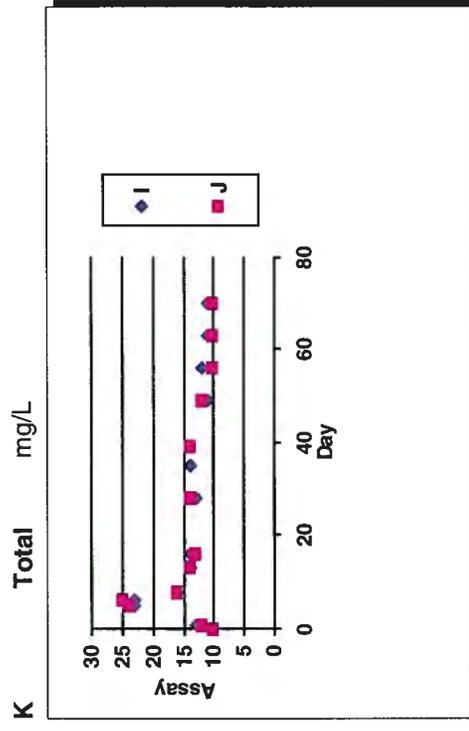
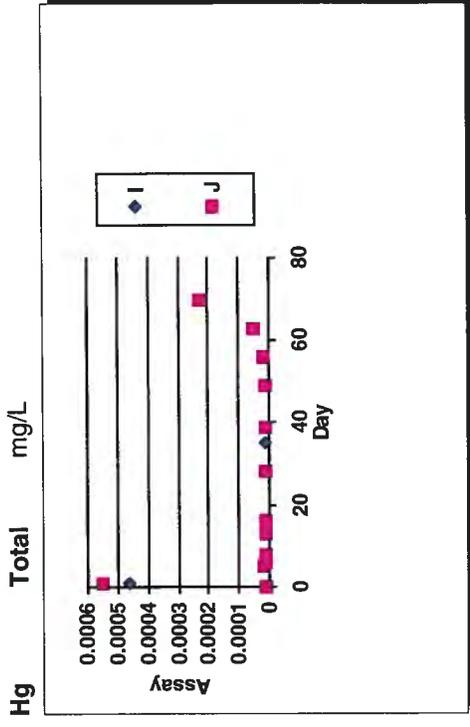
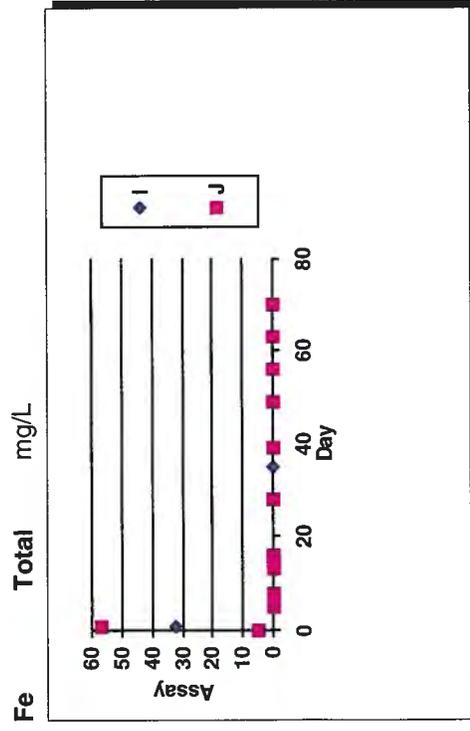


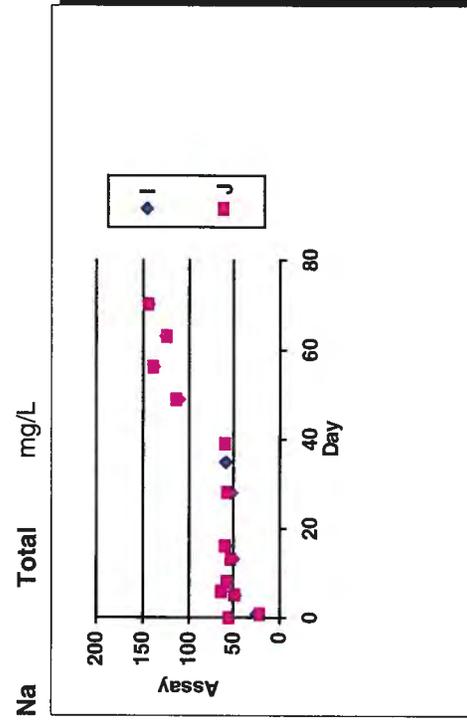
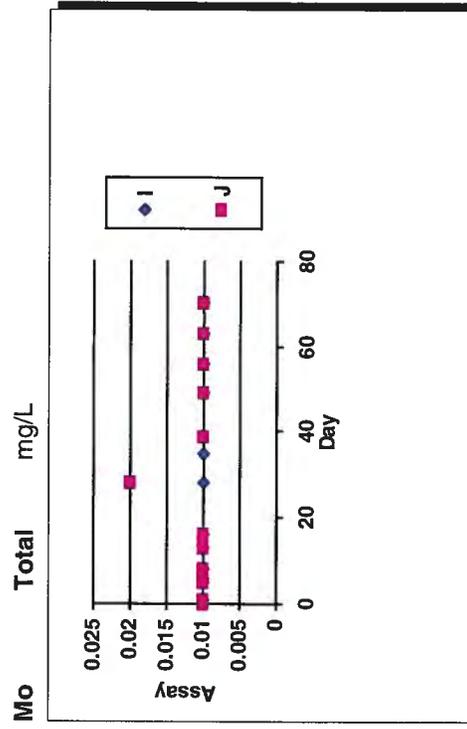
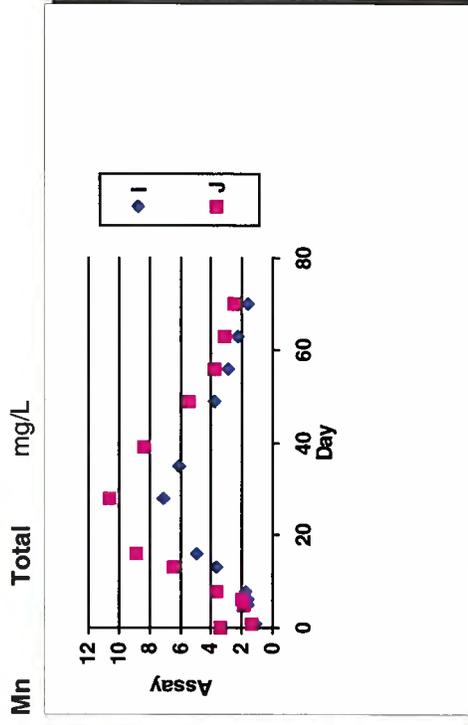
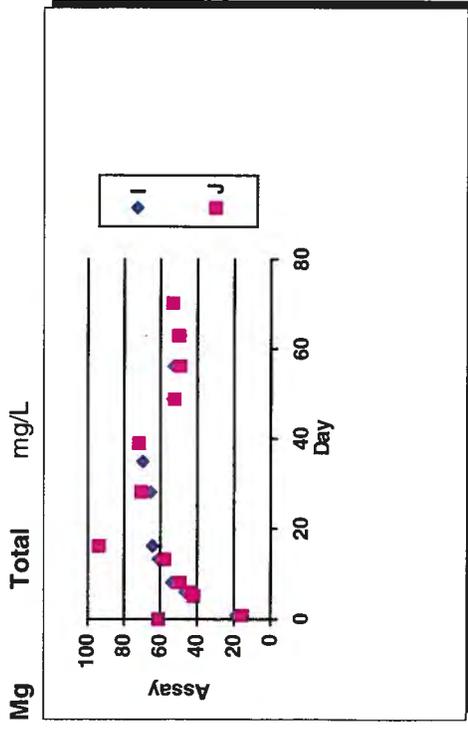


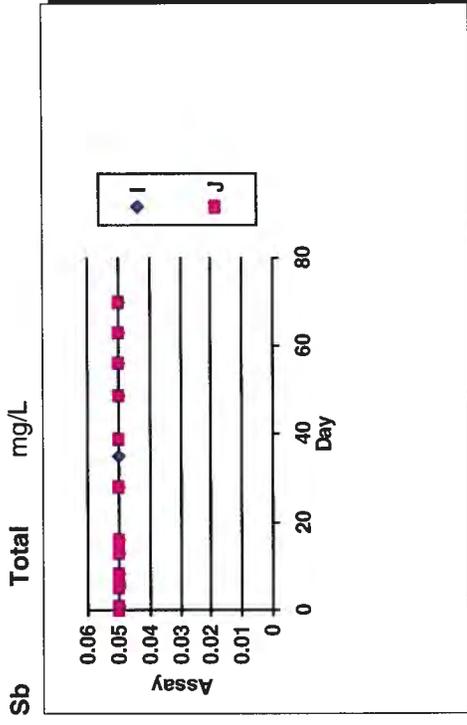
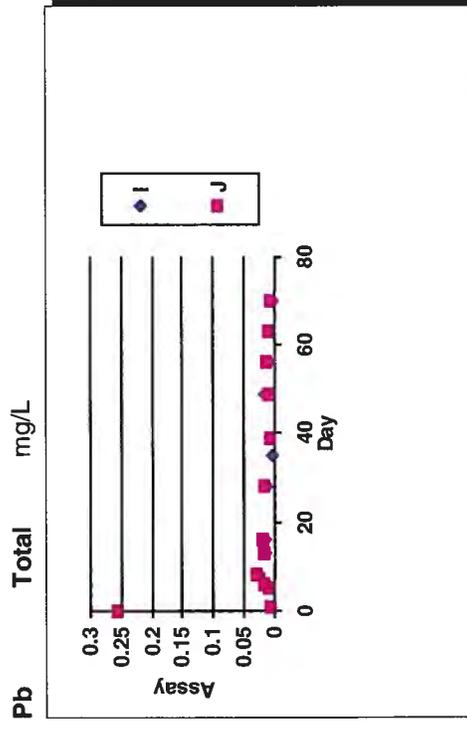
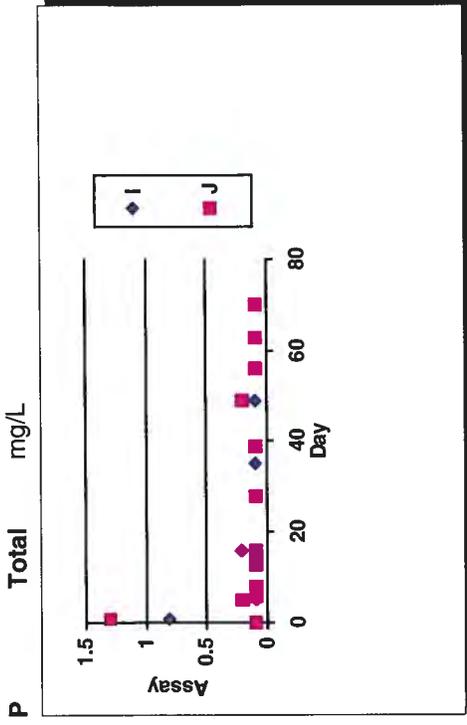
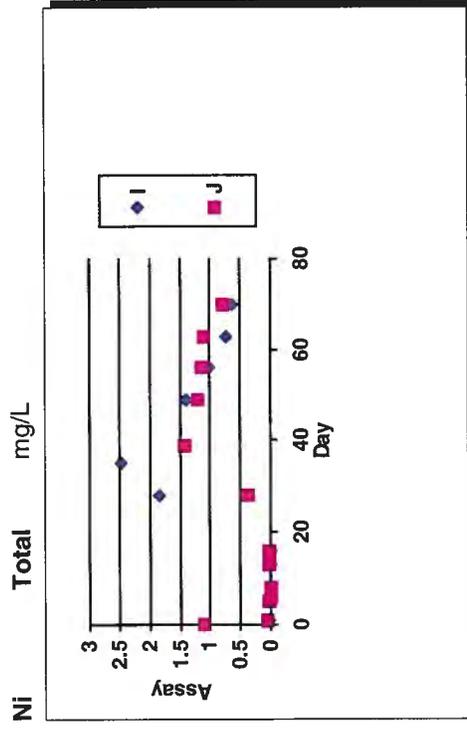


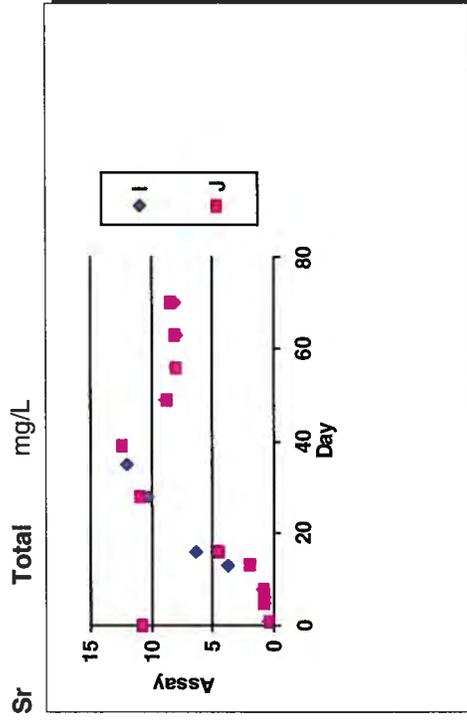
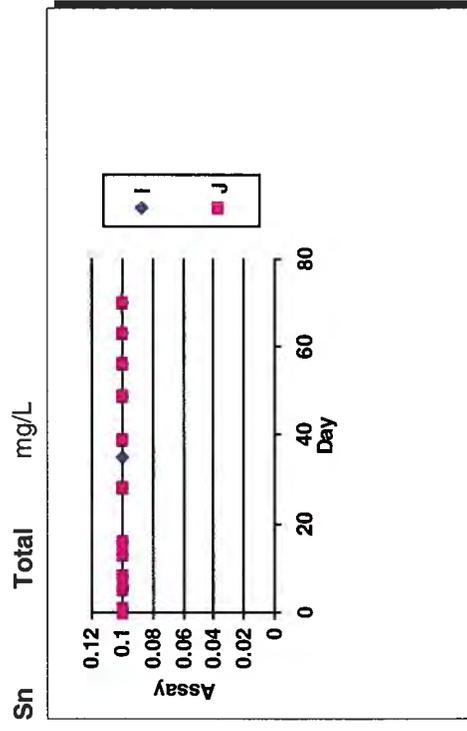
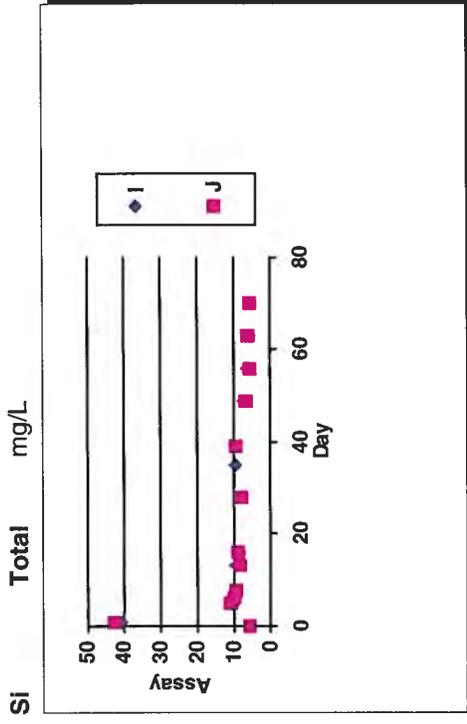
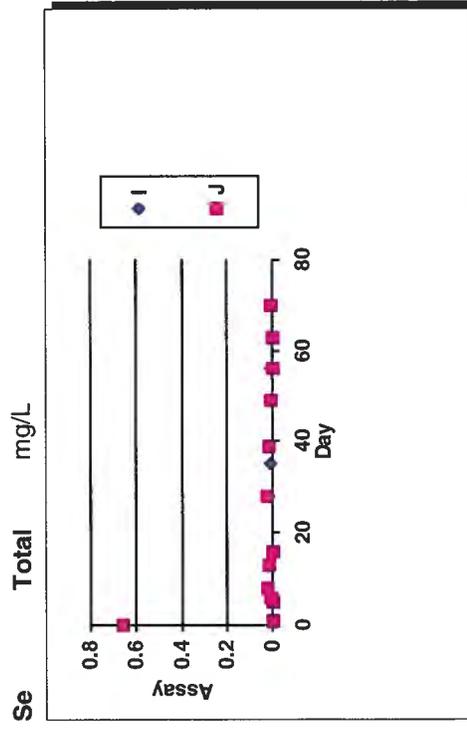


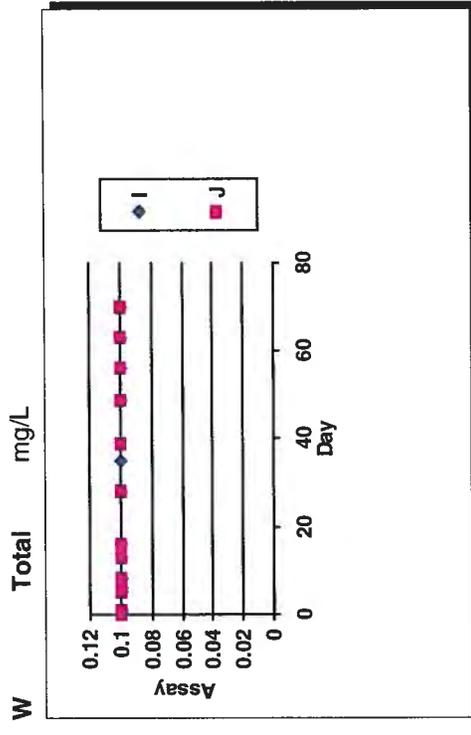
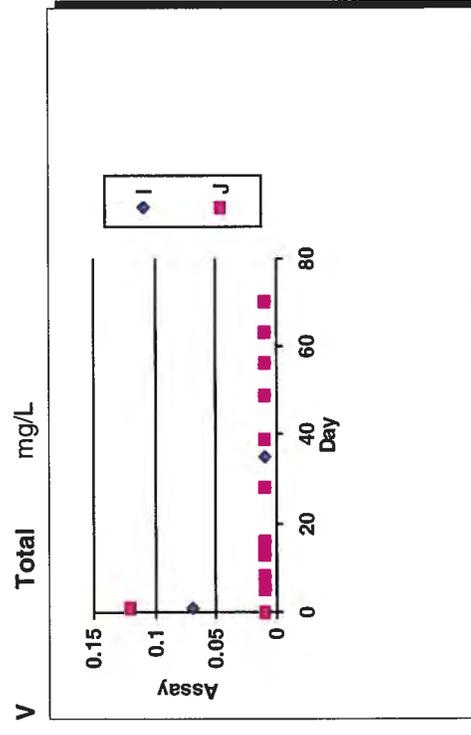
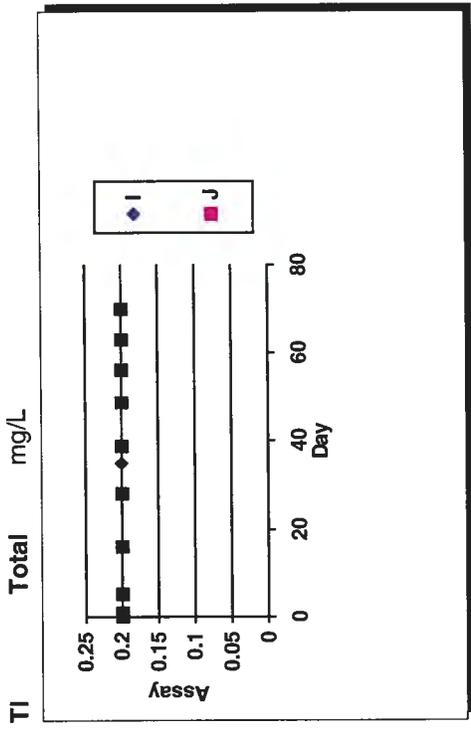
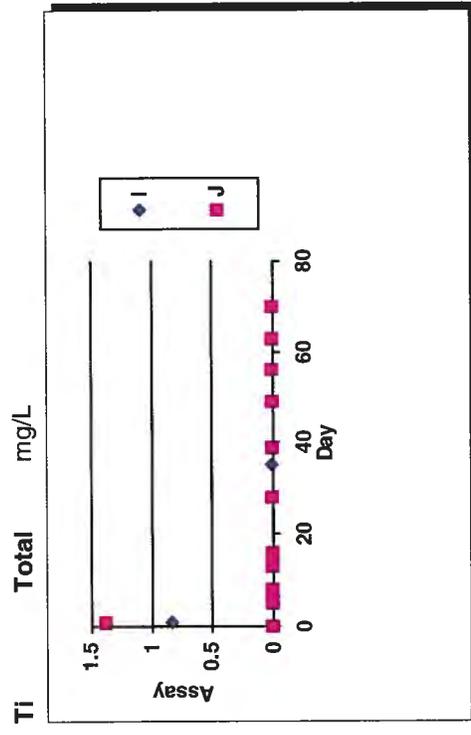


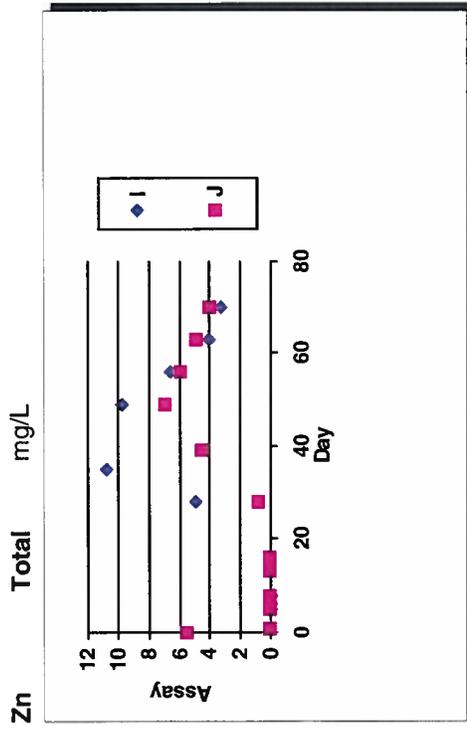












MEMORANDUM

DATE: 27 July 2000 **FILE NO.:** U419B
TO: Bryan Nethery
FROM: Brad McCandlish, and Tom Higgs
SUBJECT: Review of Treatment of Mine Effluent by Land Application

CC:

As requested we have conducted a literature and process review for land application treatment for treated effluent from gold mill operations. The principal contaminants of concern in this review were ammonia, nitrates, trace metals, and cyanide. The main mechanisms of land treatment of these contaminants are adsorption, biological conversion, volatilization and precipitation.

Ammonia and Nitrate

Ammonia and nitrate removal by land application is proven technology. In sewage treatment, these compounds have been treated by land application for well over a hundred years. The processes involved are adsorption, conversion (nitrification), and removal (denitrification, volatilization, and plant uptake). Surface Proximity is important in ammonia and nitrate removal and this often constrains system design.

Some ammonia is volatilized to the atmosphere as ammonia gas (<10%) in natural treatment systems but most is adsorbed through ion exchange reactions on soil particles and charged organic molecules. Adsorbed ammonia is available for plant or microorganism uptake as well as conversion to nitrate through aerobic biological nitrification. Nitrate can also be utilized by plants but is removed primarily by biological denitrification to nitrous oxide and nitrogen gases. Denitrification is maximized in anoxic conditions with a carbon to nitrogen ratio exceeding 1:1 (Metcalf & Eddy). Nitrate exists in solution and if not removed, may escape to pollute the groundwater. The adsorption capacity of a system is finite, so nitrification must occur to convert ammonia and denitrification must occur to remove nitrate. Both of these processes take place near the soil surface.

Ammonia removal in rapid infiltration systems is retarded by colder temperatures. Effluent concentrations of less than 1 ppm were still achieved at temperatures less than 5 °C (Carlson, 1982).

Vast experience with these systems has produced many rules of thumb and conventions. In general, the less oxidized the form of nitrogen entering the system, the more effective the retention and overall nitrogen removal (Reed, 1984). At typical influent ammonia concentrations of 20 ppm, application rates less than 0.305 m/day (1 foot/day) are required to achieve a denitrified effluent. Assuming that nitrification is taking place in the first 4 inches of soil depth, up to 60 pounds per acre of ammonia nitrogen can be converted to nitrate each day. For maximum nitrogen removal in rapid infiltration the application time to drying time ratio should be 1:1 to 1:2. For maximum hydraulic loading or nitrification a ratio of 1:5 to 1:10 is used (Reed, 1984).

An AMEC Company

Nitrogen removal rates of 80% were achieved with application rates of 0.1525 m/day (6 inches/day) but dropped to 30% at an application rate of 0.305 m/day (1 foot/day) (Lance, 1976). The application rate must be carefully tuned to achieve the desired removal with economic results.

Cyanide-Metal Complexes

The fate of cyanide in the soil is linked with that of metals. Cyanide forms very stable complexes with metals. The least mobile complexes are iron and manganese while the most mobile are copper, cobalt, zinc and nickel (Stanton, 1986).

Hexacyanoferrates ($\text{Fe}(\text{CN})_6$ complexes) form double metal cyanide complexes in which metal ions bond to the complex and the whole molecule precipitates into the soil. Most metals (except lead) will form double metal precipitates with ferrocyanide ($\text{Fe}(\text{CN})_6^{3-}$) and ferricyanide ($\text{Fe}(\text{CN})_6^{4-}$). The light metals (Ca, Na, and K) will complex with these iron complexes but the molecule remains soluble. Iron salts are occasionally added to tailings ponds or effluents to help precipitate cyanide and trace metals. Conditions promoting the formation of iron complexes would be expected to attenuate total cyanide concentrations in groundwater (Higgs, 1992).

Retention is one of the key factors in attenuation. The formation of important iron cyanide complexes is slow so soils with short retention times will not attenuate cyanide and metals effectively. Studies of cyanide attenuation of three western subsoils indicated that feldspar and clays could remove about 50 mg of cyanide per kg of mineral (130 mg free cyanide per kg) (Chatwin, 1989).

Some minerals, especially clays, possess exceptional attenuating ability. Soils with high anion exchange capacity attenuate cyanide ions and complexes effectively while cationic minerals are less successful (McLeod, 1989). Illite or smectite and iron hydrous-oxide greatly enhance the ability of earth to attenuate cyanide and heavy metals (Jones, 1991). Jones et al concluded that soils containing poorly crystalline, clay grade illite or palygorskite have the best cyanide attenuating ability while plagioclase, potassium, feldspar, hematite and ilmenite possess some attenuating ability (Jones, 1991).

Cyanide

Cyanide enters the land application system in the form of metal complexes, free cyanide or HCN. The free cyanide and HCN can be volatilized to the atmosphere or converted to metal complexes which in turn are attenuated in the soil matrix as precipitates. These precipitates degrade over time and the free cyanide released is volatilized to the atmosphere while the metals remain in the soil. Biological activity will also oxidize cyanide released from these complexes assuming cyanide concentrations are low. Land application is less successful in treating cyanide at very high concentrations.

The speciation of cyanide is very important since the toxicity of free cyanide is much greater than that of cyanide complexes, cyanate, and thiocyanate. Chemical equilibrium considerations indicate that free cyanide could be abundant in typical soil conditions receiving complexed cyanide but the slow decomposition rate of iron cyanide and other complexes often make these complexes the predominant form. The speciation of cyanide-contaminated groundwater has been studied and the conclusion was that virtually all cyanide was in iron complexes (Meeussen, 1992). The speciation of cyanide in groundwater is determined by decomposition kinetics and biological uptake rather than chemical equilibrium.

The extent of biodegradation of cyanide to ammonia in soils is unclear. Nutrient limitations (especially phosphorous), oxygen availability and proximity to soil surface limit the activity of cyanide degraders (Metcalf & Eddy).

The effect of volatilization HCN to the atmosphere is uncertain as well. Some studies credited volatilization in soils with up to 10% of total losses (Chatwin, 1989); while others indicated volatilization effects were minimal (Hackl, 1991). At typical groundwater pH values (~pH 7), essentially all of the free cyanide is present in solution as HCN, which is readily volatilized in open groundwater systems (McLeod, 1989).

Iron cyanide complexes dissociate rapidly when exposed to UV radiation (sunlight). This magnitude of this effect is unknown but is postulated that the rate of volatilization of free cyanide exceeds the rate of photolytic decomposition so the danger of free cyanide release to groundwater from this source is likely negligible (Higgs, 1992). Microbial activity slightly accelerates the decomposition of iron cyanide complexes as well (Meeussen, 1992).

Thiocyanate formation in soil depends on the presence of sulfur compounds. Significant amounts of thiocyanate may be retained in soils through inclusion in insoluble iron complexes. Chemical oxidation of thiocyanate to cyanate may be significant in soil, particularly in the presence of clays and copper (Chatwin, 1989; Hackl, 1991).

Oxidation of HCN or CN⁻ to cyanate or hydrogen cyanate is an important mechanism of cyanide degradation. This oxidation process requires an oxidizing agent or catalyst such as sunlight or a mineral or bacteriological catalyst. These products in turn decompose to carbon dioxide and ammonia below pH 8.5 (McLeod, 1989).

Metals

Removal of metals occurs mainly through adsorption and precipitation. Metals are retained in the soil, with the retention capacity of most soils and sediments being generally very high, especially at pH values above 6.5 (Metcalf & Eddy). The removal of metal varies but reported removal efficiencies for most metals range between 80-95%.

If the soil pH drops significantly (< ~pH 3) metals held in the soil matrix as precipitates may dissolve into solution and drain into the ground water. Care must be taken to ensure that the pH doesn't drop that low over the life of the system.

Metals can also complex with soluble organic ligands in a similar process to ion pairing. As the abundance of soluble hydroxide, sulfate, chloride, and organic carbon increases, metal ion solubility also increases.

Summary

The mineralogical content of the soil is most important to adsorption and precipitation processes. The proximity of the system to the surface is important for biological and photolytic processes.

Formation of cyanide-metal complexes is the key to treating those contaminants. Biological processes are key to treating nitrogen compounds.

It is possible with careful management procedures to achieve drinking water levels for nitrates and other constituents in rapid infiltration systems (Reed, 1990).

Bibliography:

Carlson, R.R. et al: 1982. *Rapid Infiltration Treatment of Primary and Secondary Effluents*, Journal WPCF, 54:3.

Chatwin, T.D. 1989. *Cyanide Attenuation/Degradation in Soil*, Resource Recovery & Conservation Company, R2C2, Salt Lake City, Utah.

Hackl, R.P., and Beattie, M.J.V. 1991. *Evaluation of Cyanide Attenuation by Sub-Surface Materials from the Nickel Plate Mine Tailings Impoundment Area*, Unpublished Report, Bacon-Donaldson, Richmond, BC.

Higgs, T.W. 1989. *Metals Removal Technology for Gold Mill Effluent*, Gold Mining Effluent Treatment Seminars, Vancouver, B.C., February 15-16.

Higgs, T.W. Associates Ltd. 1992. *Technical guide for the Environmental Management of Cyanide in the Environment*, British Columbia Technical and Research Committee on Reclamation.

Jones, K. and Staunton, W.P.: 1991. *Cyanide in Gold Mine Tailings—Interaction of Cyanide with Soils*, Randol Gold Forum, Cairns, Australia, April 1991.

Kalin, M. 1987. *Ecological Engineering for Gold and Base Metal Mining Operations in the Northwest Territories*, Minister of Supply and Services Canada.

Lance, J.C., Whisler, F.D., and Rice, R.C.: 1976. *Maximizing Denitrification During Soil Filtration of Sewage Water*, Journal of Environmental Quality, 5:102, 1976

Marchant, P.B.: 1989. *Treatment System Design Considerations in British Columbia*, Gold Mining Effluent Treatment Seminars, Vancouver, B.C., February 15-16, 1989

McLeod, Harvey N.: 1989. *Control of Groundwater Impacts from Cyanide Leach Tailings Ponds*, Gold Mining Effluent Treatment Seminars, Vancouver, B.C., February 15-16, 1989

Meeussen, J.C.L., Kelzer, M.G. and De Haan, F.A.M.: 1992. *Chemical Stability and Decomposition Rate of Iron Cyanide Complexes in Soil Solutions*, Environmental Science Technology, 16:3.

Metcalf and Eddy Inc.: *Water Resources and Environmental Engineering*, 3rd ed., McGraw-Hill, New York, 1991

Reed, S.C., Crites, R.W.: 1984. *Handbook of Land Treatment Systems for Industrial and Municipal Wastes*, Noyes Publications.

Spotts, E. and Schafer, W.: 1994. *Determination of Metal Adsorption Capacity of Soils for Disposal of Mining Process Solutions by Land Application*, International Land Reclamation and Mine Drainage Conference, Pittsburgh, PA, April 24-29, 1994

Stanton, M.D., Colbert, T.A., Trenholme, R.B.: 1986. *Environmental Handbook for Cyanide Leaching Projects*, Energy, Mining and Minerals Division, National Park Service, U.S. Department of the Interior.

S.C. Reed. 1990. Task Force on Natural Systems, : *Natural Systems of Wastewater Treatment*, Water Pollution Control Federation.

Zaidi, A., Schmidt, J.W., Simovic, L., and Scott, J.: 1987. *The Art and Science of Treating Wastewater from Gold Mines*, 19th Annual Meeting of the Canadian Mineral Processors, Ottawa, Ontario, January 20-22, 1987

Appendices

Rapid Infiltration:

Soil permeability of 1 inch/hour is necessary for successful rapid infiltration (Metcalf). Acceptable soils are sand, sandy loams, loamy sands and some gravels. It is desirable to have a bed depth of 15 feet to bedrock and groundwater but successful systems have been used with depths as little as 4-6 feet as most of the chemical and biological processes take place in the first few feet of infiltration (Task Force, Metcalf). Rapid infiltration systems are typically operated on a year-round intermittent wet/dry cycle. This encourages the aerobic restoration of the near-surface profile and allows nitrogen removal through subsequent nitrification-denitrification in this zone. The limiting design parameter for rapid infiltration systems is usually either the hydraulic capacity or the nitrogen assimilation capacity of the soil. Vegetation is usually not a design component of the system but weeds or volunteer grasses do not cause problems and promote plant uptake of nitrogen. Cold weather slows the processes of nitrification, denitrification, oxidation and drying so longer application cycles may be necessary. Any vegetation should be cut in the fall as it reportedly causes surface soil freezing and prevents infiltration in the winter.

Formulas

Surface Area: (Task Force)

$$A = 6E-5 * Q$$

A = area in acres

Q = daily flow in gallons

Surface Area: (Metcalf & Eddy)

$$A = Qs/Rd$$

A = area in acres

Qs = sludge production in dry ton solids per year

Rd = design sludge loading rate in dry ton solids per acre per year

Contaminant Limitation: (Metcalf & Eddy)

$$Rm = Lm/(Cm*2000)$$

Rm = maximum amount of sludge applied over the life of the site in dry ton solids/acre

Lm = maximum amount of sludge that can be applied over the life of the site as established by regulatory requirements in dry ton solids/acre

Cm = percent pollutant in sludge in decimal form (50 ppm = 0.00005)

Tables

Laboratory tests results for the maximum metal loads of soil:

Metal	Maximum Metal Load (kg/ha)	Metal Concentration Of Treated Solution (mg/l)	Maximum Solution Load (m ³ /ha)
Silver	12.83	0.15	85500
Cadmium	3.9	0.02	195000
Copper	783.9	4	196000

(30 cm treatment zone thickness)

(Spotts, 1994. Table 3)

U.S. EPA Recommended Cumulative Limits for Metals Applied to Agricultural Crop Land:

	Soil Cation Capacity (meq/100g)		
	5	5-15	>15
	Sand	Sandy Loam	Silt Loam
Metals	Cumulative Loading (lb/acre)		
Pb	500	1000	2000
Zn	250	500	1000
Cu	125	250	500
Ni	125	250	500
Cd	4.4	8.9	17.8

(Reed, Table 3.10)

Number of Infiltration Beds for Continuous Operation:

Application Period, d	Drying Period, d	# of infiltration beds
1	5-7	6-8
2	5-7	4-5
1	7-12	8-13
2	7-12	5-7
1	4-5	5-6
2	4-5	3-4
3	4-5	3
1	5-10	6-11
2	5-10	4-6
3	5-10	3-5
1	10-14	11-15
2	10-14	6-8
1	12-16	13-17
2	12-16	7-9
7	10-15	3-4
8	10-15	3
8	10-15	3
7	12-16	3-4
8	12-16	3
8	12-16	3

(Metcalf & Eddy, Table 13-17)

Memo

To	Rick Zimmer	File No.	VM00172 V-III
From	Bernadette Lyons Michael Davies	cc	Renata Wood Peter Lighthall
Tel	(604) 294-3811		File
Fax	(604) 294-4664		
Date	May 30, 2001		
Subject	Pogo Soil Absorption System Subsurface Flow Modeling Summary Memorandum		

General

The proposed Soil Absorption System (SAS) will be used as a final polishing step for treated RTP water. The SAS will therefore have somewhere between 200 and 400 gpm of water flowing through it during portions of the year when water release is required based upon the water balance. In drier years, the SAS may not be used at all whereas in wetter years, it may be used for most of the summer and fall months. The water reporting to the SAS will percolate through the engineered soil cover and report to the subsurface. This memorandum summarizes flow modeling to predict the likely characteristics of the subsurface flow resulting from use of the SAS on a full-time basis to see what the effects to the existing hydrogeological regime would be under sustained maximum operating conditions.

Visual MODFLOW v 2.8.2 (Waterloo Hydrogeologic Inc., 1999) was used to model the potential influence of the proposed SAS on the groundwater flow system in the Lower Liese Creek area of the Goodpaster River floodplain (see Figure 1). The model was run in steady state, including MODPATH forward tracking of advective particles, to estimate flow path and travel times from the SAS to the Goodpaster River. SAS input flows of 200 gpm and 400 gpm were used. A description of the model setup, calibration, sensitivity analysis and results is provided in this memorandum.

Visual MODFLOW is a pre-processor and post-processor graphic interface package for the MODFLOW and MODPATH model codes. MODFLOW (Harbaugh 2000, Hill 2000) is a block centered modular three-dimensional finite-difference groundwater flow model developed by the United States Geological Survey. First published in 1984 and updated in 1988, 1996 and 2000, MODFLOW is considered the industry standard in three-dimensional groundwater modeling. MODPATH (Pollock 1994) is a particle tracking code used to simulate advective transport in groundwater based on flow regimes produced by MODFLOW.



Model Setup and Calibration

The MODFLOW setup used is shown in Figure 2. The model is 6,000 ft long (in the direction parallel to the river), 2,400 ft wide (in the direction perpendicular to the river) and 100 ft deep. The grid consists of 9 layers each having 38 rows and 86 columns. The initial grid spacing was 50 ft by 50 ft and was refined in areas of interest such as the SAS and the area of the potential downstream monitoring wells.

The model domain slopes gently from an elevation 1361 ft at the upstream end to 1355 ft at the downstream end. This topography is representative of the topography of the Goodpaster flood plain in the area, as determined from surveys of the borehole locations (AMEC 2001).

The river sediment material and hydraulic properties used for the MODFLOW simulation are summarized in Table 1. One porous medium was used to model the river sediments as little variation in the physical properties of the overburden were noted during the site investigation (AMEC 2001). Table 1 also provides a comparison between the input parameters for the SAS model base case and a previous modeling exercise undertaken by Golder Associates (1998b) for an injection well for water from the underground development located further down the river valley (see Figure 1). As noted later in this memorandum, sensitivity analyses were carried out to determine which of the parameters noted in Table 1 could have a significant impact on estimated results.

Table 1: MODFLOW River Sediment Material and Hydraulic Properties Comparison

Parameter	2001 AMEC Model Base Case	Golder Associates 1998 Model ⁽²⁾	
		< 50 ft depth	> 50 ft depth
Horizontal Hydraulic Conductivity (K) ⁽⁷⁾	3.9×10^{-3} ft/s ⁽¹⁾	2×10^{-3} ft/s	1×10^{-3} ft/s
Average Hydraulic Gradient (i)	3.4×10^{-3} ft/ft ⁽¹⁾	3×10^{-3} ft/ft ⁽³⁾	
Hydraulic Conductivity Ratio K_x/K_y (K ratio)	3 ⁽⁴⁾	2.5	
Specific Yield	0.2 ⁽⁵⁾	0.15	
Effective Porosity (n)	0.4 ⁽⁶⁾	0.25	
Depth to Bedrock	Approx 100 ft	100 ft	
Inflow	200 gpm	50 -200 gpm	
Permafrost	In included as a low permeability zone in the model	Included as inactive cells in model	

⁽¹⁾ (AMEC 2001)

⁽²⁾ (Golder Associates 1998b)

⁽³⁾ (Golder Associates 1998a)

⁽⁴⁾ The model sensitivity to the hydraulic conductivity ratio (K ratio) was analyzed very similar results were obtained for K ratios of 3 and 30.

⁽⁵⁾ Based on typical values referenced in Freeze, R.A and J.A. Cherry (1979).

⁽⁶⁾ Based on field description of the river sediments and typical values referenced in Anderson, M.P. and W.W. Woessner (1992).

⁽⁷⁾ It was assumed that horizontal (i.e. K_x and K_y) were essentially the same. It is possible that there would be some preferential conductivity parallel to the river as a result of grain imbrication and/or ancient channelization. This potential variation was not expected to be significant to the computed results.

During the 2000 site investigation program (AMEC 2001), variable thicknesses of permafrost were observed in the southern portion of the model area. Inclusion of the permafrost zone in the model provides for better calibration of the initial piezometric surface thereby providing a more accurate representation of the field groundwater flow system. For these reasons an area of permafrost in the southeast edge of the model was included (as shown in Figure 2). A hydraulic conductivity of 1×10^{-9} ft/s was used for the permafrost zone, this value was used by Golder Associates (1998a) and is supported by the typical hydraulic conductivity values for various frozen media cited in Freeze and Cherry (1979).

The boundary conditions used in the model are shown on Figure 2. Constant head boundary conditions were used on the east and west edges of the model domain. A river boundary condition, and not a constant head boundary, was used along the north side of the model. Flow was therefore not restricted from flowing either to or under the river. The conductance of the river sediments used was 2,000,000 ft²/day, which was chosen to be consistent with the river valley sediment hydraulic conductivity so that it did not impede the movement of water into the river. Water inputs to the SAS were modeled as recharge. The flow was applied as a recharge flux (q in ft/s) to the updated SAS area of 288,000 ft² (720 ft by 400 ft), which provides a recharge of 2 gal/day/ft² at 400 gpm.

The model was calibrated to the piezometric surface developed during the 2000 field investigation (AMEC 2001). The surface was based on data gathered from some 23 boreholes drilled in the area. The borehole locations, piezometric surface developed during the field investigation and the calibrated MODFLOW setup are shown on Figure 3.

Initial Runs

Preliminary two-dimensional finite element modeling using SEEP/W (GEO-SLOPE 1998) was undertaken to gain a better understanding of the flow system in the model area and to serve as a "logic check" for the three-dimensional model input parameters and results.

The candidate base case, the parameters of which are shown in Table 1, was run as a basis of comparison for the sensitivity analyses discussed below. For the base case, the MODPATH forward tracking particles took approximately 2.5 years to reach the river over a path length of 2,400 ft. The resulting average horizontal velocity is 960 ft/year (3.0×10^{-5} ft/s). Groundwater mounding at the center of the SAS was 0.5 ft. Model output for the base case is shown in Figure 4 and 5.

Sensitivity Analyses

Sensitivity analyses using the model were undertaken to assess the effect of the uncertainty in various input parameters on model results. The parameters investigated were hydraulic conductivity, hydraulic conductivity anisotropic ratio (K ratio), porosity and the inclusion of permafrost in the model. Parameter values were varied within the range of what could be



expected in the model area. A brief discussion of the alternative parameter value choice follows:

- **Hydraulic Conductivity:** As part of the 2000 site investigation, two pump tests were carried out in the model area. Analysis of the pump test data suggested that the bulk hydraulic conductivity of the river sediments ranged from about 3.9×10^{-3} ft/s to about 3.9×10^{-4} ft/s although the higher (more pervious) value is supported by other work in the area (e.g. Golder 1998a) and also appears more consistent with the material gradation as determined from sampled boreholes in the area.
- **K ratio:** The river sediments exhibit some horizontal stratification. As such, the horizontal hydraulic conductivity of the sediments is governed by the hydraulic conductivity of the most permeable layer while the vertical hydraulic conductivity is governed by the most impermeable layer. An analysis of possible layer hydraulic conductivity and layer thickness showed that a K ratio in the order of 3 to 30 is likely representative of the river sediments.
- **Porosity:** Typical porosity values for river sands and gravels range from 0.25 to 0.50 (Freeze and Cherry 1979), lower values are representative of more dense and well-graded materials.

Table 2: Summary of Sensitivity Analyses

Parameter	Base Case	Sensitivity Case	Sensitivity Analyses Results			
			Time to River	Path Length in Plan	Average Horizontal Velocity	Groundwater Mounding ⁽¹⁾
Hydraulic Conductivity	3.9×10^{-3} ft/s ⁽¹⁾	3.9×10^{-4} ft/s ⁽¹⁾	2.5 years	550 ft	7×10^{-6} ft/s 220 ft/year	5.4 ft
K ratio	3	30	2.25 years	2400 ft	3.4×10^{-5} ft/s 1100 ft/year	0.9 ft
Porosity	0.40	0.30	1.75 years	2400 ft	4.4×10^{-5} ft/s 1400 ft/year	0.4 ft

⁽¹⁾ Value based on water table elevation at the center cell of the SAS

The model sensitivity to changes in hydraulic conductivity, K ratio and porosity are as expected and follow directly from Darcy's Law.

$$q = Ki \quad [1]$$

$$v = q/n \quad [2]$$

The model is most sensitive to the hydraulic conductivity of the river valley sediments. Numerically lowering the hydraulic conductivity results in the logical computed result of the modeled sediments being less able to move water away from the input area causing a localized rise in the water table in the area producing a down-gradient path northwest directly into the river. However, such a lowering of the hydraulic conductivity greatly decreases the groundwater velocity and therefore the travel time to the river is longer. As noted, the information available from extensive field investigations support hydraulic conductivity bulk values in the upper range which results in less mounding yet quicker travel times.



Increasing the K ratio by an order of magnitude decreases the river sediments ability to move water down and away from the injection point, producing a similar but less pronounced effect than that described for lowering the hydraulic conductivity.

Changing the porosity has little effect on groundwater mounding or the path water takes from the SAS to the river. The travel time to the river is reduced as expected from Equation 2.

Results

The results of the base case model properties and SAS inflows of 200 gpm and 400 gpm are given in Table 3. Typical model output in plan and section for the 200 gpm case is shown in Figure 4 and 5 and 400 gpm case is shown in Figure 6 and 7.

Table 3: 200 gpm and 400 gpm Base Case Input Result Summary

Input Flow	Time to River	Path Length in Plan	Average Horizontal Velocity	Groundwater Mounding ⁽¹⁾
200 gpm	2.5 years	2400 ft	3x10 ⁻⁵ ft/s 960 ft/year	0.7 ft
400 gpm	2 years	2400 ft	3.8x10 ⁻⁵ ft/s 1200 ft/year	1 ft

⁽¹⁾ Value based on water table elevation at the center cell of the SAS

Dissipating both the 200 gpm and 400 gpm input flows within the floodplain appear feasible under the base case conditions. The most notable difference between the scenarios is the variation in flow path. The MODPATH results show that well LL-4 and well LL-5 and potential well LL-31 are located so as to cover the potential variation in flowpath and provided downstream monitoring under these conditions.

The results of the model using a hydraulic conductivity of 3.9x10⁻⁴ ft/s for SAS inflows of 200 gpm and 400 gpm are given in Table 4.

Table 4: 200 gpm and 400 gpm, K= 3.9x10⁻⁴ ft/s, Input Result Summary

Input Flow	Time to River	Path Length in Plan	Average Horizontal Velocity	Groundwater Mounding ⁽¹⁾
200 gpm	2.5 years	550 ft	7x10 ⁻⁶ ft/s 220 ft/year	5.4 ft (near surface)
400 gpm	2.5 years	500 ft	1.1x10 ⁻⁵ ft/s 250 ft/year	9.4 ft (above surface)

⁽¹⁾ Value based on water table elevation at the center cell of the SAS

Under the reduced hydraulic conductivity conditions for the entire floodplain, the 200 gpm SAS input may not dissipate to the river sediments without some mounding. However, the modeling has assumed that the SAS would be used constantly throughout any given year. Due to groundwater mounding concerns, the 400 gpm input provides even additional mounding should

the field hydraulic conductivities prove to be in the 3.9×10^{-4} ft/s range. However, as noted, the likelihood of the bulk hydraulic conductivity for the floodplain being in the lower range is very small based upon the extensive drilling to date. In addition, this mounding concern is based upon full use of the field on a year-round basis. If the field were to be used at either 200 gpm or 400 gpm for lesser period, lesser mounding and more rapid dissipation of flows would occur.

Using a K ratio of 30 rather than 3 in the 400 gpm case causes more potential mounding than for the base case with a K ratio of 3. Adrian Brown (personal communication) suggests that a K ratio of about 10 is more realistic for these sediments.

The MODPATH results show that wells LL-4 and LL-5, and at least one other located near the proposed airstrip such as the potential well at LL-31, cover the potential variation in the flowpath and provide downstream monitoring under the conditions evaluated.

Summary

The MODFLOW analyses suggest that for the range of material and hydraulic properties modeled for the Lower Liese Creek area of the Goodpaster River floodplain, a SAS input of 200 gpm appears to be largely acceptable to the aquifer whereas 400 gpm may cause mounding in excess of that considered acceptable should the bulk hydraulic conductivity of the floodplain be in the lower bound range of available information. Measures to reduce the mounding potential, should the combination of parameters modeled be realized in operations, are available but are beyond the scope of this memorandum. However, as noted, it is considered highly unlikely that the bulk hydraulic conductivity of the floodplain could exhibit such a low average hydraulic conductivity.

Based upon the modeling, wells LL-4, LL-5 and something similar to the potential LL-31, appear logical as downstream monitoring locations to obtain representative samples of potential groundwater influence from the SAS prior to the flows potentially entering the Goodpaster River.

AMEC Earth & Environmental Limited



Per
Bernadette M. Lyons MSc.E., E.I.T.
Mining Environmental Engineer



Michael P. Davies, Ph.D., P.Eng., P.Geo.
Senior Geotechnical Consultant

Reviewed By:



pc Peter C. Lighthall, P.Eng.
Vice President, Vancouver



References

AMEC Earth & Environmental Limited (2001), POGO FEASIBILITY STUDY 2000 Geotechnical and Hydrogeological Characterization Program, Delta Junction, Alaska.

Anderson, M.P. and W.W. Woessner (1992), Applied Groundwater Modeling: Simulation of Flow and Advective Transport, Academic Press Inc.

Freeze, A.R. and J.A. Cherry (1979), Groundwater, Prentice-Hall, Inc.

GEO-SLOPE International Inc. (1998), User's Guide SEEP/W: For Finite Element Seepage Analysis, Version 4.

Golder Associates (1998a), Hydrological Regime Goodpaster River Valley and Proposed Exploratory Adit Pogo Project, Alaska. Draft Report submitted to Teck Corporation.

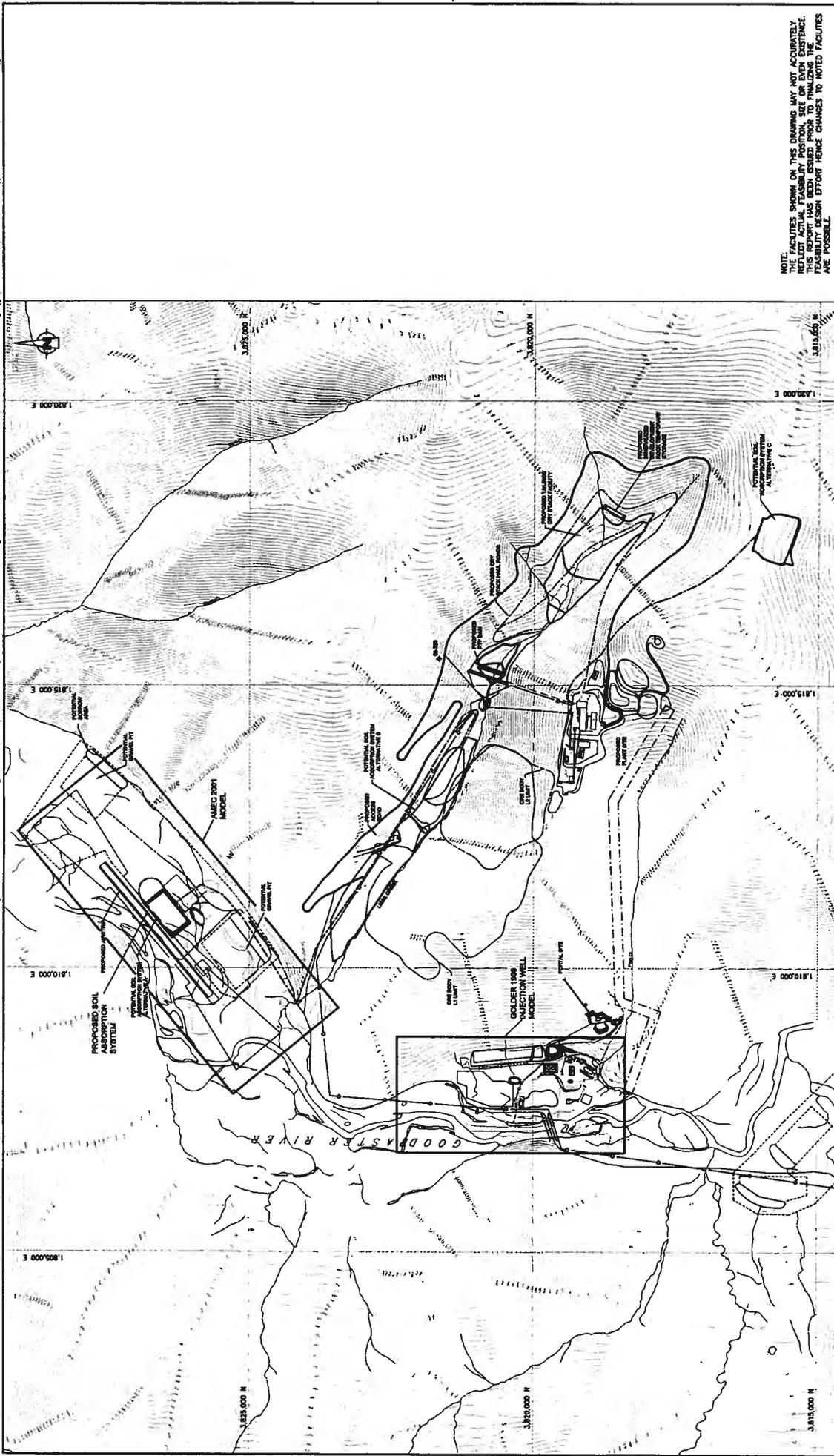
Golder Associates (1998b), Technical Memorandum No. 5 Hydrogeological Modeling of Injection Well Goodpaster River Valley, Pogo Project, Alaska. Draft Report submitted to Teck Corporation.

Harbaugh, A.W., Banta, E.R., Hill, M.C., and McDonald, M.G. (2000), MODFLOW-2000, the U.S. Geological Survey modular ground-water model -- User guide to modularization concepts and the Ground-Water Flow Process: U.S. Geological Survey Open-File Report 00-92, 121 p.

Hill, M.C., Banta, E.R., Harbaugh, A.W., and Anderman, E.R. (2000), MODFLOW-2000, the U.S. Geological Survey modular ground-water model -- User guide to the Observation, Sensitivity, and Parameter-Estimation Processes and three post-processing programs: U.S. Geological Survey Open-File Report 00-184, 210 p

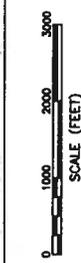
Pollock, D.W. (1994), User's Guide for MODPATH/MODPATH-PLOT, Version 3: A particle tracking post-processing package for MODFLOW, the U.S. Geological Survey finite-difference groundwater flow model: U.S. Geological Survey Open-File Report 94-464, 234 p.

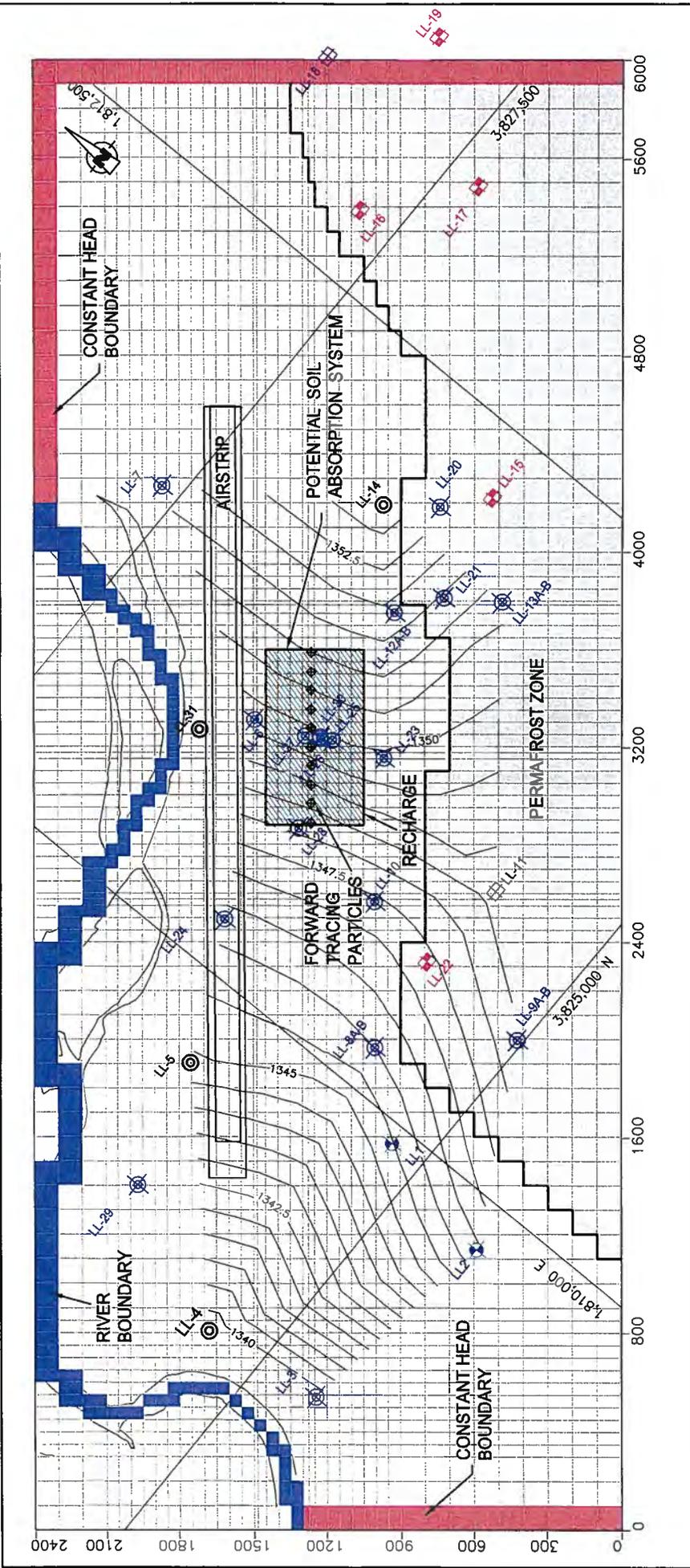
Waterloo Hydrogeologic Inc. 1999, Visual MODFLOW User's Manual.



NOTE: THE FACILITIES SHOWN ON THIS DRAWING MAY NOT ACCURATELY REFLECT ACTUAL FACILITY POSITION. SEE ON-SITE EXISTENCE MAP FOR ACTUAL FACILITY POSITION. FEASIBILITY DESIGN EFFORTS WERE MADE TO NOTED FACILITIES ARE POSSIBLE.

 		AMEC Earth & Environmental Limited 2211 Devonshire Ave. Suite 100 Vancouver, BC V6H 3K9 Tel: 604-261-1811 Fax: 604-261-1812		PROJECT NO: 1480724-04 DATE: 11/11/04 SHEET NO: 11	
PROJECT: SOIL ABSORPTION SYSTEM		SHEET NO: 11		FIGURE: 1	
LOCATION PLAN		DATE: MAY 2001		FIGURE 1	
APPROVED BY: [Signature]		APPROVED BY: [Signature]		FIGURE 1	
TITLE: AS SHOWN		TITLE: AS SHOWN		FIGURE 1	

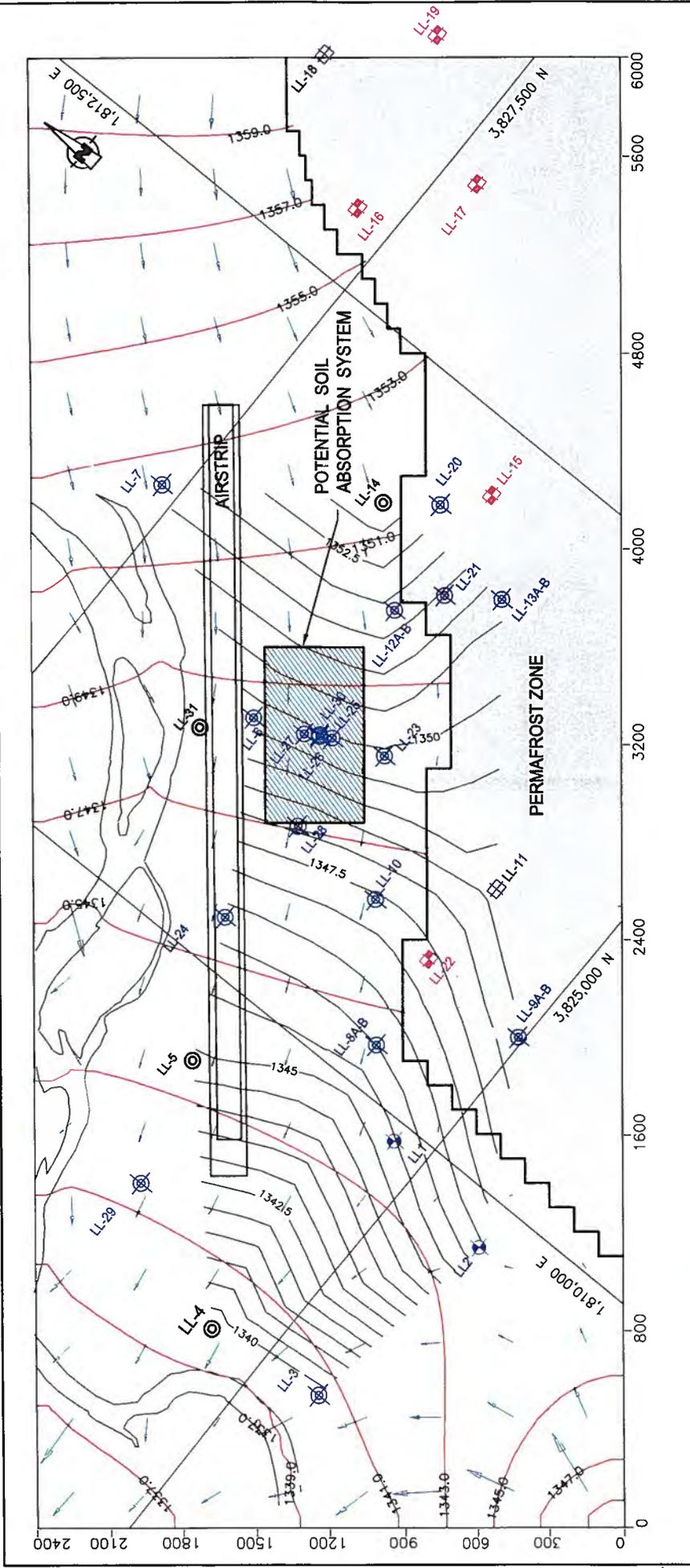




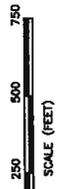
- LEGEND**
- 2000 ABANDONED PORTABLE ROTARY RIG BOREHOLE
 - 1989 EXISTING BOREHOLE (AGRA)
 - 2000 PORTABLE ROTARY RIG BOREHOLE
 - 2000 PORTABLE ROTARY RIG BOREHOLE, WELL INSTALLED
 - POTENTIAL MONITORING WELL LOCATIONS
- NOTE: TOPOGRAPHY APPROXIMATE



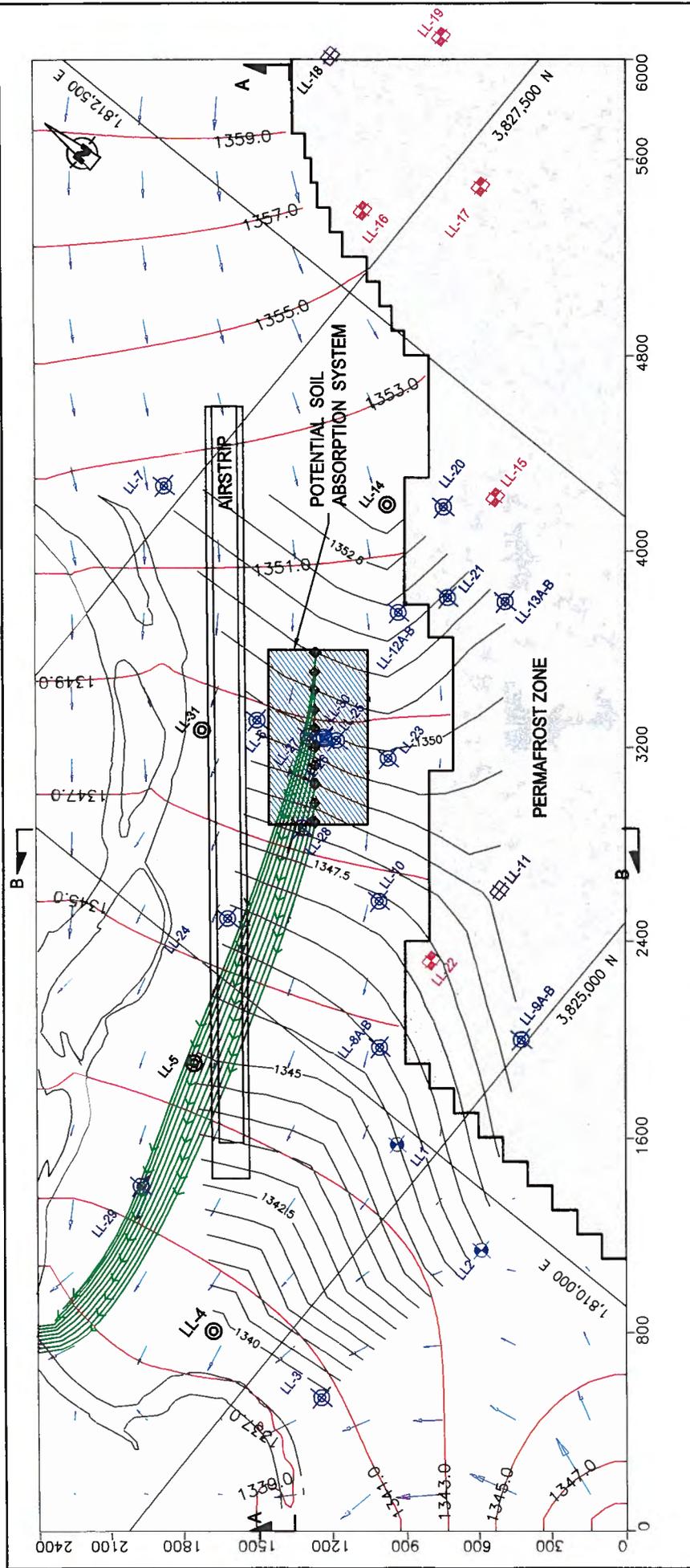
		AMEC Earth & Environmental Limited 227 Douglas Road Burnaby, B.C. V5C 5A6 Tel: 284-3811 Fax: 284-6864		DWN BY: YW CRD BY: BL APP: <i>M. M.</i> SCALE: AS SHOWN	PROJECT: POGO PROJECT SOIL ABSORPTION SYSTEM TITLE:	DATE: MAY 2001 PROJECT NO: VM00172-V-III REV. NO.:
		TECK CORPORATION Client		MODFLOW SETUP		FIGURE NO. FIGURE 2



- LEGEND**
- 2000 ABANDONED PORTABLE ROTARY RIG BOREHOLE
 - 1999 EXISTING BOREHOLE (AGRA)
 - 2000 PORTABLE ROTARY RIG BOREHOLE
 - 2000 PORTABLE ROTARY RIG BOREHOLE, WELL INSTALLED
 - POTENTIAL MONITORING WELL LOCATIONS
 - EQUIPOTENTIALS
 - GROUNDWATER FLOW



	AMEC Earth & Environmental Limited 2227 Douglas Road Billings, MT 59210-5400 Tel. 294-3811 Fax. 294-4884	DATE: MAY 2001 PROJECT NO.: VM00172-V-III REV. NO.:	PROJECT: POGO PROJECT SOIL ABSORPTION SYSTEM	FIGURE NO.: FIGURE 3
		DWN BY: YW CHKD BY: BL SCALE: AS SHOWN	TITLE: CALIBRATION OF TOTAL HEAD EQUIPOTENTIALS	
Client:	TECK CORPORATION			



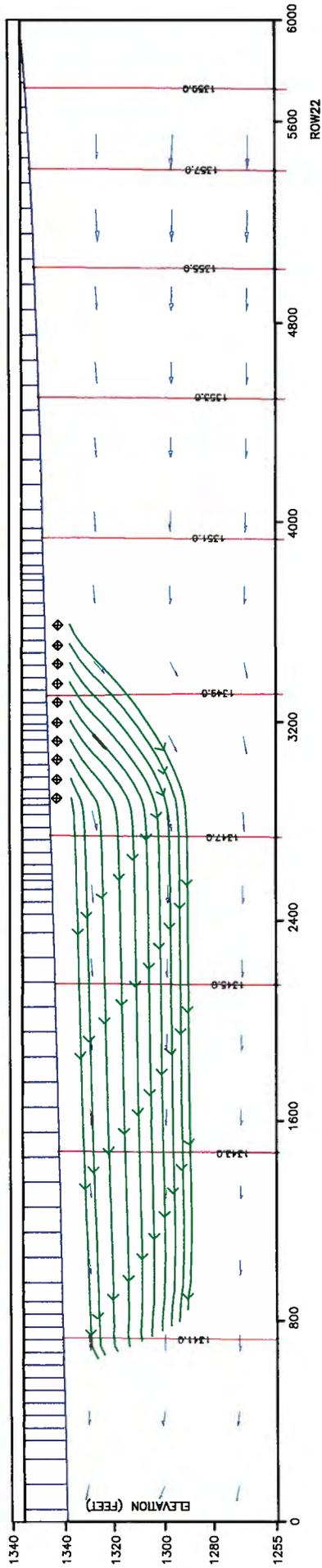
LEGEND

- 2000 ABANDONED PORTABLE ROTARY RIG BOREHOLE
- 1998 EXISTING BOREHOLE (ACRA)
- 2000 PORTABLE ROTARY RIG BOREHOLE
- 2000 PORTABLE ROTARY RIG BOREHOLE, WELL INSTALLED
- POTENTIAL MONITORING WELL LOCATIONS
- EQUIPMENTS
- MIDPATH FORWARD TRACKING PARTICLE FLOW PATH (NOTE: EACH ARROW REPRESENTS 1/2 YEAR TRAVEL)

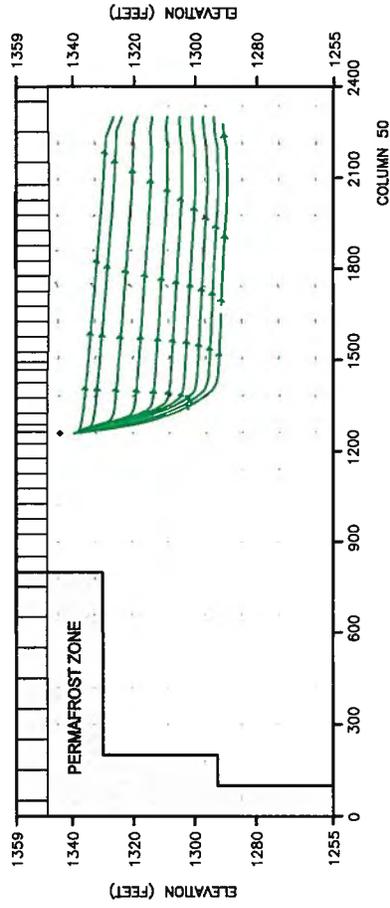
SCALE (FEET)

0 250 500 750

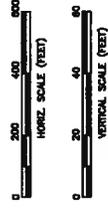
DATE	MAY 2001
PROJECT NO.	VM00172-V-III
REV. NO.	
FIGURE NO.	FIGURE 4
PROJECT:	POGO PROJECT SOIL ABSORPTION SYSTEM
OWN BY:	YW
CHKD BY:	BL
APP.	<i>[Signature]</i>
SCALE	AS SHOWN
AMEC Earth & Environmental Limited 2227 Douglas Road Burnaby, B.C. V5A 2S4 Tel. 294-2811 Fax. 294-0854	TECK CORPORATION
Client	
MODEFLOW STEADY STATE MODEL OUTPUT 200 gpm INPUT FLOW, PLAN K=3.9 x 10 ⁻³ ft/s K _{ratio} =3	



SECTION A-A



SECTION B-B

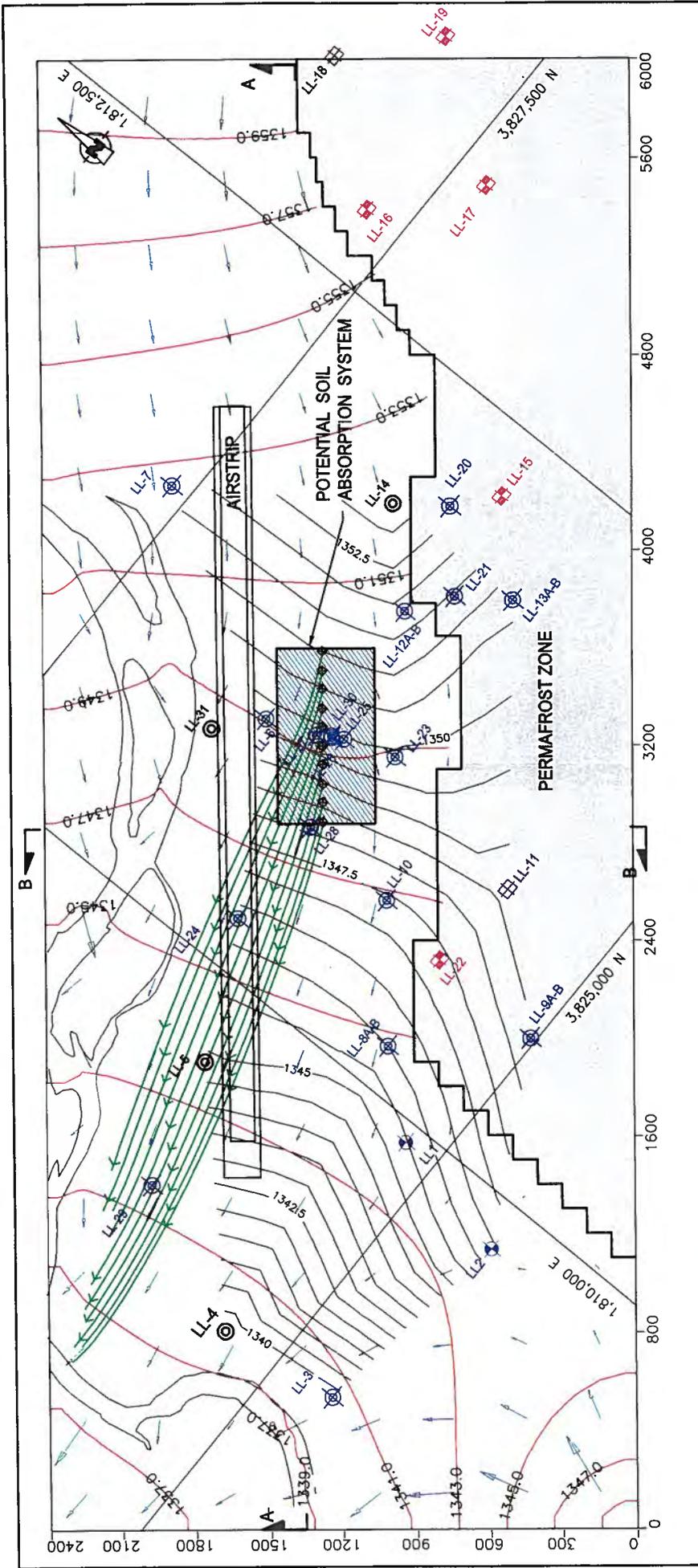


NOTE: 10X VERTICAL SCALE EXAGGERATION

LEGEND

- MODPATH FORWARD TRACKING PARTICLE FLOW PATH (NOTE: EACH ARROW REPRESENTS 1/2 YEAR TRAVEL)
- ◇ MODPATH FORWARD TRACKING PARTICLE
- FLOW
- EQUIPOTENTIALS

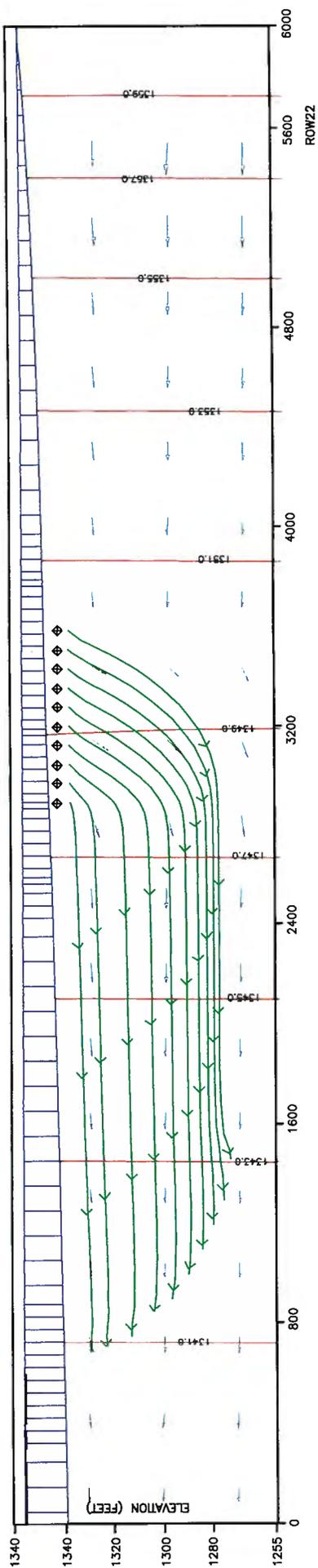
	AMEC Earth & Environmental Limited 2227 Douglas Road Burnaby, B.C. Tel. 294-3911 Fax. 294-4684	DWN BY: BLYW	DATE: MAY 2001
		CHKD BY: BL	PROJECT NO: VM00172-V-III
Client		SCALE: AS SHOWN	REV. NO.: .
TECK CORPORATION		POGO PROJECT SOIL ABSORPTION SYSTEM	
MODFLOW STEADY STATE MODEL OUTPUT 200 gpm INPUT, SECTIONS $K=3.9 \times 10^{-3}$ ft/s, $K_{RATIO}=3$		FIGURE NO. FIGURE 5	



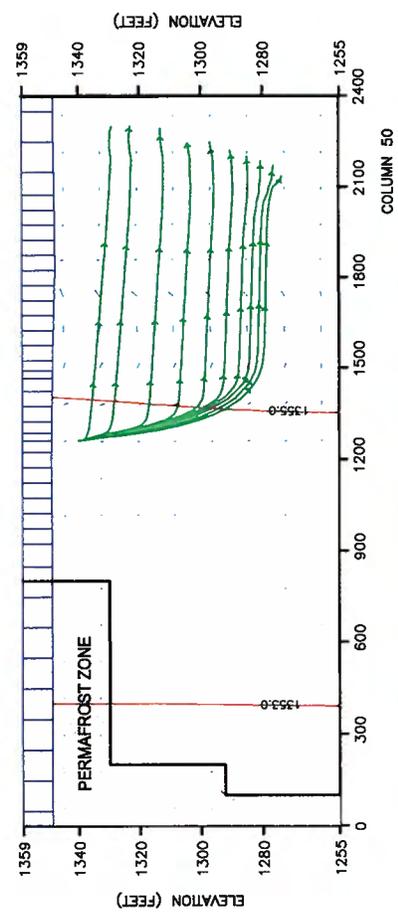
- LEGEND**
- 2000 ABANDONED PORTABLE ROTARY RIG BOREHOLE
 - 1989 EXISTING BOREHOLE (AGRA)
 - 2000 PORTABLE ROTARY RIG BOREHOLE
 - 2000 PORTABLE ROTARY RIG BOREHOLE, WELL INSTALLED
 - POTENTIAL MONITORING WELL LOCATIONS
 - EQUIPMENTS
 - MODPATH FORWARD TRACKING PARTICLE
 - MODPATH FORWARD TRACKING PARTICLE FLOW PATH (NOTE: EACH ARROW REPRESENTS 1/2 YEAR TRAVEL)



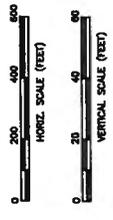
		AMEC Earth & Environmental Limited 2227 Douglas Road Burnaby, B.C. Tel: 294-2811 Fax: 294-4884		DATE: MAY 2001 PROJECT NO: VM00172-V-III REV. NO.
		TECK CORPORATION Client		PROJECT: POGO PROJECT SOIL ABSORPTION SYSTEM TITLE: MODFLOW STEADY STATE MODEL OUTPUT 400 gpm INPUT FLOW, PLAN $K=3.9 \times 10^{-3}$ ft/s $K_{\text{frost}}=3$
DRAWN BY: YW CHECKED BY: BL APPROVED BY: [Signature]	SCALE: AS SHOWN	FIGURE NO. FIGURE 6		



SECTION A-A



SECTION B-B



NOTE: 10X VERTICAL SCALE EXAGGERATION
 LEGEND
 MODPATH FORWARD TRACKING PARTICLE FLOW PATH (NOTE: EACH ARROW REPRESENTS 1/2 YEAR TRAVEL)
 MODPATH FORWARD TRACKING PARTICLE
 FLOW
 EQUIPOTENTIALS

DATE: MAY 2001 PROJECT NO: VM00172-V-III REV. NO.: FIGURE NO: FIGURE 7		POGO PROJECT SOIL ABSORPTION SYSTEM MODFLOW STEADY STATE MODEL OUTPUT 400 gpm INPUT, SECTIONS $K=3.9 \times 10^{-3}$ ft/s, $K_{RATIO}=3$	
DWN BY: BLV/W CHKD BY: BL APP: <i>[Signature]</i> SCALE: AS SHOWN	AMEC Earth & Environmental Limited 2227 Douglas Road Burnaby, B.C. V5C 2R1 Tel: 294-5811 Fax: 294-6864	TECK CORPORATION Client	

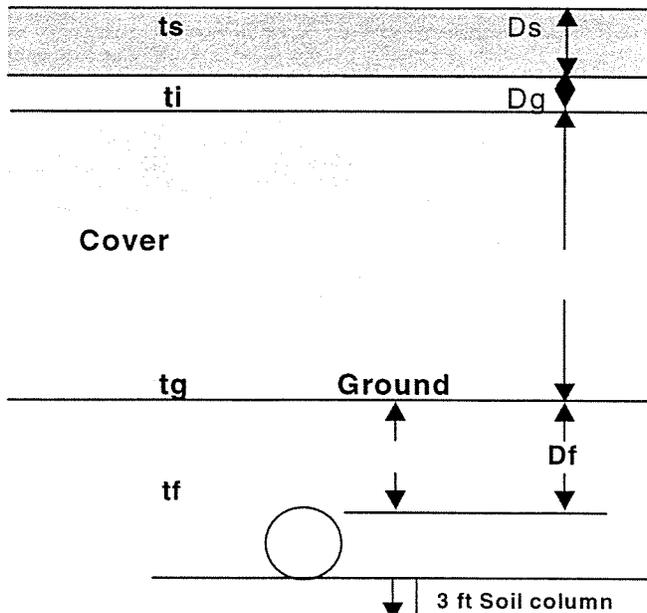
Memo

To **Bryan Nethery** *K. Lamb* File No. **U419G**
 From **Ken Lamb** cc **Rick Zimmer, Karl Hanneman**
 Tel **1-604-664-3276**
 Fax
 Date **Jan 24, 2002**

Subject **Pogo SAS Freeze Protection Thermal Analysis**

The following outlines the requirements, design and calculations for prevention of freezing of the Pogo Soil Adsorption System (SAS).

The SAS requires the capability for year round operation including during periods of sub-zero temperatures during winter. The piping system is shown in the following figure,



A design investigation was carried out to determine the water flow and organic cover thickness required to prevent freezing of water in this piping system located below the cover material.

Calculation Procedure

The water distribution piping will be laid under one foot of gravel, organic matter of a depth to be determined, one foot of top gravel cover and varying snow depths.

Step 1

The first step was to calculate the depth of organic cover that is required to prevent freezing at the pipe location. This calculation is based on Cold Region Engineering procedures using the freezing index and thawing index for the site. The required Material and thermal properties used in the analysis are given in the tables.

Step 2

With the material depths fixed, a thermal conduction calculation was carried out to determine the heat lost from the pipe location to the atmosphere when the atmosphere is at the 1% minimum temperature of -51°F . This is an extreme case and represents the effect of transient low temperatures.

The heat available from water entering "the system" was calculated. It was then assumed that the heat losses to the atmosphere could be increased by an amount equivalent to the heat supplied by the water, and a revised organic cover depth calculated. These calculations were carried out for an entering water temperature of 33.8°F .

A summary of the analysis is given below in Table 1, the first section shows the depth of freezing with no water flow and the chosen depth of mulched organic cover. The second shows the proposed design configuration with the flow of 200 gpm of well water for freeze protection.

Table 1

Freeze Depth with no Water Flow			Material properties
	D		k
	Ft		BTU/hr.ft ² .°F/ft
Ds Depth of Snow	2.5		0.1329
Dg Depth of gravel Cover	0.00		1.2
Dc Depth of Organic Cover	3.40		0.12
Df Depth of Freezing	3.47		1.2
Total Frost Depth (Excl Snow), ft		6.87	
Design with Water Flow			Material properties
Water Supplied at, °F	33.8		K
	D		K
	Ft		BTU/hr.ft ² .°F/ft
Ds Depth of Snow	2.50		0.1329
Dg Depth of gravel Cover	0.00		1.2
Dc Depth of Organic Cover	3.40		0.12
Df Depth of Freezing (i.e.Pipe Depth)	1.00		1.2
Total Cover Depth above Pipe (Excl Snow), ft		4.4	

The low thermal conductivity of the organic cover provides reasonable insulation, but is insufficient to prevent freezing under severe conditions. The freeze protection water would be pumped during the colder part of winter from November to April to prevent freezing and to keep the SAS field active and available.

The moisture content of the organic layer is a major determinant of the depth of freezing, the higher the moisture the less freezing depth. This calculation has assumed a moisture content of 2.5%, which is at the low end of the anticipated range of 2.5 -10%. If this value is increased to 5%, which is more likely, the depth of organic cover required is reduced to 2.5 feet.

From the above we conclude that a mulched organic cover of approximately 3 feet is appropriate for freeze protection when combined with the use of a 200 gpm freeze protection water flow, and snow depth of 30 ins.

The appended calculations show the methodology used in carrying out the calculations.



Calculation of Freeze Depth

From Fig. 6-9	Average Mean Soil Temperature	Units °F	32.58	Input or Use Cell I7
From Fig. 6-11	Air Freezing Index, nFI	°F. days	6600	Air Thawing Index, nFI
From Fig. 6-8	Surface Freezing Index, nFI	°F. days	0.7	Surface Thawing Index, nFI
	Freezing Duration	days	4620	
	Initial Estimate for Freezing Depth (Excluding Snow Depth)	ft	228	Goal Seek
			6.87	

Soil Description	Snow	1 Sand & Gravel	2 Organics	3 Sand & Gravel
Depth	30	0.00	3.40	3.47
Soil Density, Dry	2.50	110	50	110
Moisture Content	0	2.5	2.5	2.5
Thermal Conductivity, k	or BTU/hr.ft. °F/ft			
R Value	0.1329	1.2	0.12	1.2
Average, kavg		57.1	9.4	20.8
Volumetric Specific Heat, c		Sand & Gravel	0.17	
Average, cavg	0.50			
Volumetric Latent Heat, L		396	180	396
C, Combined Layers		57.1	9.4	15.2
L, Combined Layers		396	180	289
Thermal Ratio (Alfa)		0.028	0.028	0.028
mu(1)		2.920	1.062	1.062
lamda for each Layer		0.83	0.87	0.89
No Freezing Days required to freeze each Layer		0	1111	3509
Remaining Degree Days		4620	3509	0
			Goal Seek	Change Cell G8

The Lower the moisture content
The greater will be the freeze depth

AMEC E&C Services Limited
 111 Dunsmuir Street, Suite 400
 Vancouver, B.C. V6B 5W3
 Tel (604) 664-4315
 Fax (604) 669-9516
 www.amec.com



Temperatures	
ts Minimum Surface Temperature	-51
tg Ground Temperature	tg
tf 32° F-Freezing Temperature	32

Temperatures	
ts Minimum Surface Temperature	-51
tg Ground Temperature	tg
tf 32° F-Freezing Temperature	32

For Depth of Snow Cover of 30 ins					
Original Design			Design with Water Added & organic cover depth reduced		
Water Supplied at, °F	D	Material properties		Water Supplied at, °F	Material properties
	ft	k			k
		BTU/hr.ft2.°F/ft			BTU/hr.ft2.°F/ft
Ds Depth of Snow	2.50	0.1329		Ds	2.50
Dg Depth of gravel Cover	0.00	1.2	Saving	Dg Depth of gravel Cover	0.00
Dc Depth of Organic Cover	6.65	0.12	3.25 ft	Dc Depth of Organic Cover	3.40
Df Depth of Freezing (i.e.Pipe Depth)	1.00	1.2		Df Depth of Freezing (i.e.Pipe Depth)	1.00
Depth above Pipe (Excl Snow), ft	7.65		Total	Depth above Pipe (Excl Snow), ft	4.40

Heat Loss $Q = \frac{If-ts}{(Ds/Ks.A)+(Dg/Kg.A)+(Dc/Kc.A)+(Df/Kf.A)}$

hr.°F/BTU (per ft2)

For the Snow Mat'l Rg = 18.811
 For the Cover Mat'l Rg = 0.000
 For the Organic Cover Mat'l Rc = 55.41446361
 For the Subsurface Mat'l Rss= 0.833333333

R = 75.059

Heat Loss $Q = \frac{If-ts}{(Ds/Ks.A)+(Dg/Kg.A)}$

hr.°F/BTU (per ft2)

For the Cover Mat'l Rg = 18.811
 For the Cover Mat'l Rg = 0.000
 For the Cover Mat'l Rc = 28.29409777
 For the Subsurface Mat'l Rss= 0.833333333

R = 47.939

Heat Loss/ft2 $Q = 1.11$ BTU/hr/ft2

Area of One Cell 48000 ft2
 Heat Loss per Cell 53,078 BTU/hr

Total Area 288000 ft2
 Total Heat Loss 318,470 BTU/hr lost to Atmos

Heat Loss/ft2 $Q = 1.73$

Area of One Cell 48000 ft2
 Heat Loss per Cell 83,106 BTU/hr

Total Area 288000 ft2
 Total Heat Loss 498,638 BTU/hr lost to Atmos
 Net Heat Loss if pile same freeze depth

For the Individual Layers

Temp diff. between Surface & Ground 61.28 °F
 tg 10.28 °F

Temp diff. between Freeze Location & Ground 0.92 °F
 tg 31.08 °F

For the Individual Layers

Temp diff. between Surface & Ground 48.99 °F
 tg -2.01 °F

Temp diff. between Freeze Location & Ground 1.44 °F
 tg 30.56 °F

Heat Content of Water

Flowrate 200 USgpm
 100093.6 lb/hr

Temperature incoming Water 33.8 °F
 Temperature discharge Water 32 °F

Total Heat Supply 180,168 BTU/hr
 Assumed Evenly distributed across full area

Heat Content of Water

Flowrate 200 USgpm
 100093.6 lb/hr

Temperature incoming Water 33.8 °F
 Temperature discharge Water 32 °F

Total Heat Supply 180,168 BTU/hr

AMEC E&C Services Limited
 111 Dunsmuir Street, Suite 400
 Vancouver, B.C. V6B 5W3
 Tel (604) 664-4315
 Fax (604) 669-9516
 www.amec.com

Pogo Project Memorandum

To **Rick Zimmer** File No. **VM 00172 V-3**
From **Michael Davies** cc **FILE**
Date **22 January 2002**
Subject **SAS Freeze Protection Wells – Summary of MODFLOW Modeling**

Further to previous hydrogeological assessment work carried out in the Goodpaster floodplain for the proposed Soil Absorption System (SAS), this memorandum summarizes modeling done to support a recommendation on the optimum location for placement of water supply wells needed to operate a freeze-protection system for winter operation of the SAS. As per previous modeling work, Visual MODFLOW v 2.8.2 (Waterloo Hydrogeologic Inc., 1999) was used to model the potential influence of freeze-protection water to the SAS on the groundwater flow system in the Lower Liese Creek area of the Goodpaster River floodplain.

The general concept to provide added freeze protection to the SAS beyond soil insulation alone is to provide continuous water flow through the SAS during the winter months. Water balance modeling for the project indicates that the water treatment plant may have a range of winter water for SAS discharge ranging from 0 gpm to about 150 gpm. Under normal operating conditions, winter use of the SAS would appear to be minimal necessitating the requirement for freeze protection.

Two different scenarios were considered, one using the minimum (0 gpm) water treatment plant contribution and one using an approximately maximum (150 gpm) winter water treatment rate. For the assessment, it was assumed that 200 gpm was the nominal amount of freeze protection flow required, regardless of water treatment plant influent, although that value will have to be more precisely determined by detailed engineering.

Four potential locations for wells to provide the nominal 200 gpm freeze protection water are shown on Figure B0172-07-001. This figure also includes the MODFLOW discretization grid in plan view consistent with the previous modeling for the SAS (AMEC Earth & Environmental, 2001). The model was run in steady state for each well location, i.e. it was assumed that the winter scenario could operate indefinitely so that the maximum potential physical effect of the flow regime could be assessed. The base model was identical to that used in previous flow modeling for the SAS. A description of the model setup, calibration, and sensitivity analysis for the base model was provided in AMEC Earth & Environmental (2001).

As noted, two scenarios were evaluated for each of the four well locations. Scenario one has one of the various wells pumping 200 gpm and injecting all of that flow into the SAS distribution system at that same 200 gpm (no use of SAS for treated mine water in excess of plant requirements). The second scenario has the same well operation, with an additional 150 gpm injected into the SAS for a total rate of injection of 350 gpm. The latter scenario, though



modeled as a steady state condition, would likely be more indicative of a peak operating condition.

Table 1 presents an evaluation of the well locations and their effect on the estimated travel time to the Goodpaster River. Note that the minimum travel times for Wells 3 and 4 are significantly shorter than their average times or the minimum predicted times for Wells 1 and 2 because Wells 3 and 4 tend to short-circuit some, but not all, of the flow from the SAS.

Table 1 – Summary of MODFLOW Modeling for Potential Freeze Protection Wells

Well Location	Injection Rate (gpm)	Travel Time (Days)		
		Max	Min	Avg.
Well #1	200	1150	692	890
	350	1132	590	811
Well #2	200	1172	699	903
	350	1149	658	835
Well #3	200	1175	71	743
	350	1128	83	711
Well #4	200	1168	171	792
	350	1146	167	754

Previous modeling (AMEC Earth & Environmental, 2001) showed approximate average travel times to the Goodpaster River of about 800 to 900 days for the SAS under normal operating conditions. Based upon the current modeling work, it appears that wells located upgradient from the SAS would be preferred from the standpoint of keeping the previously projected time about the same.

The actual rate of flow required for freeze protection has not been established by engineering and the 200 gpm value used is therefore preliminary only. However, the upgradient trends indicated by the modeling would not change for different flow rates

Respectfully submitted,

AMEC Earth & Environmental Limited

Reviewed by:

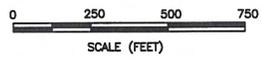
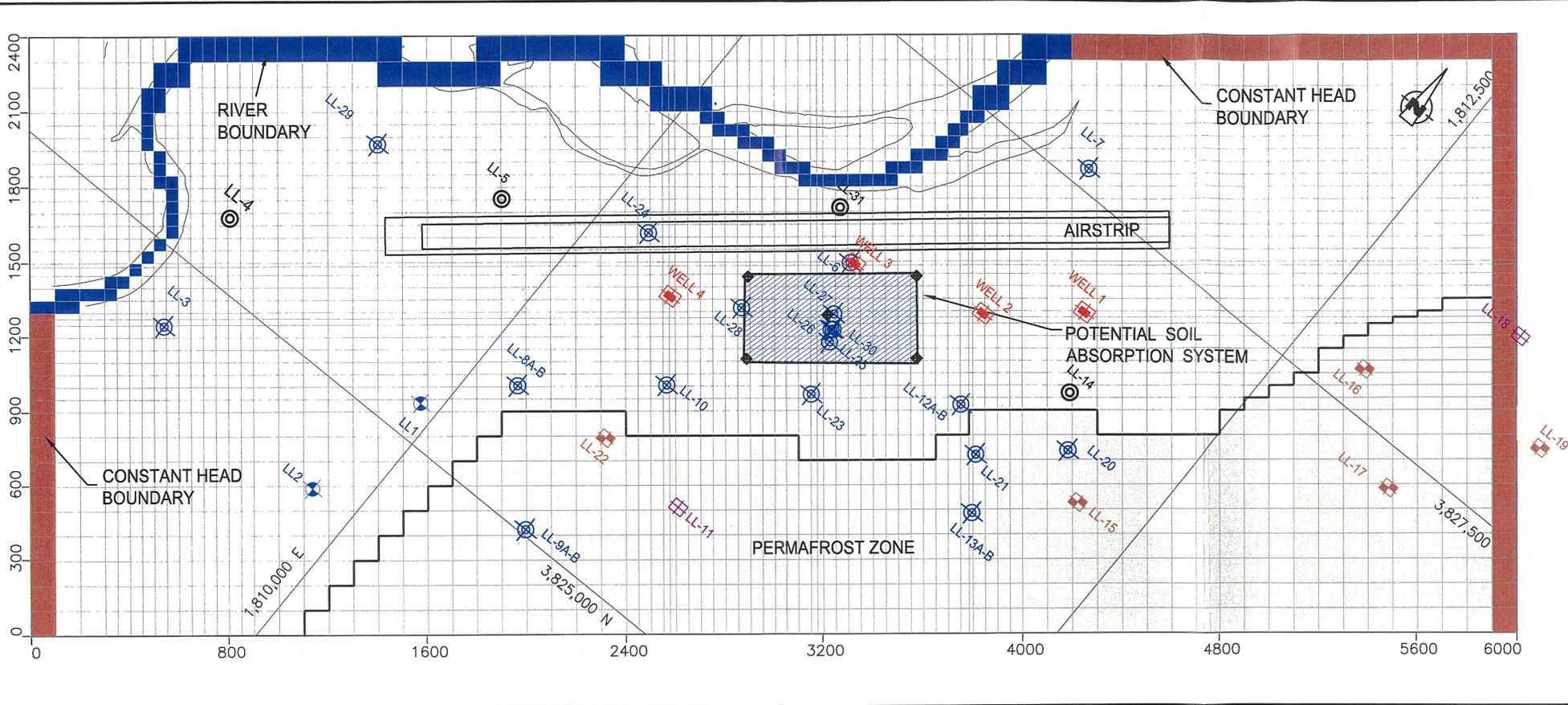

per Luquman Shaheen, P.E.
Project Engineer
Peter Lighthall, M.Eng., P.Eng.
Vice-President
Michael Davies, Ph.D., P.Eng., P.Geo.
Project Manager

References

AMEC Earth & Environmental (2001). "Pogo Soil Absorption System Subsurface Flow Modeling Memorandum", 30 May 2001, appendix to Pogo Water Management Plan, 8 pp. plus illustrations.

Waterloo Hydrogeologic Inc. (1999). Visual MODFLOW User's Manual.

REPORT: B0172-07-001.dwg Tue, Jan. 22 4:05pm 2002 Layout1 Steve.Milne
 PLOT 1:1=D F:\P020\0



- LEGEND**
- MODELED WELLS
 - 2000 ABANDONED PORTABLE ROTARY RIG BOREHOLE
 - 1999 EXISTING BOREHOLE (AGRA)
 - 2000 PORTABLE ROTARY RIG BOREHOLE
 - ⊗ 2000 PORTABLE ROTARY RIG BOREHOLE, WELL INSTALLED
 - POTENTIAL MONITORING WELL LOCATIONS
- NOTE: TOPOGRAPHY APPROXIMATE

	AMEC Earth & Environmental Limited 2227 Douglas Road Burnaby, B.C. V5C 5A9 Tel. 294-3811 Fax. 294-4664	DWN BY: SM CHK'D BY: LAS APP: MPD SCALE: AS SHOWN	POGO PROJECT SOIL ABSORPTION SYSTEM	DATE: JAN. 2002
	<i>Client</i>		FREEZE PROTECTION SYSTEM MODELED WELL LOCATIONS	PROJECT NO.: VM00172-V-III REV. NO.: - FIGURE No. B0172-07-001