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TACONITE TAILINGS IN-PIT DISPOSAL

FIELD TANK EXPERIMENTS

Data Summary
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Minnesota Department of Natural Resources
Division of Lands and Minerals

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Executive Summary

Supported by a grant from the Iron Ore Cooperative Research Program, the Minnesota Department of Natural Resources (MN DNR) and the University of Minnesota (U of MN) have been studying the potential water quality implications of disposal of taconite tailings in existing mine pits across the Mesabi Iron Range. In order to simulate a small-scale pit disposal environment, four experiments were performed in large in-ground tanks at the MN DNR field experimental facility in Hibbing, MN.

Results have been compiled from the onset of the first experiments in September, 1996 through January, 1999. Surface water chemistry remained relatively constant throughout the study period. Fluctuations in the concentrations of most elements were most likely the result of seasonal changes such as wet or dry periods and freezing temperatures during the winter. Manganese concentrations in surface waters appeared to be controlled by the formation of an oxidized solid phase, MnO_2. Arsenic was released into surface waters from Inland's tailings, presumably due to oxidation of minor sulfide minerals present in the tailings.

Prolonged contact between taconite tailings and process water tended to improve water quality, particularly with respect to arsenic, molybdenum, and boron. Manganese, and possibly, fluoride levels appeared to be controlled by mineral phases within the tailings. Manganese concentrations appeared to be controlled by the pH-dependent dissolution of carbonate minerals (e.g. rhodochrosite or ankerite) found in the tailings. The concentration of fluoride in tailings pore waters probably depended upon the solubility of the mineral fluorite. However, an adsorption mechanism may also be active in an in-pit disposal environment.

In general, tailings pore waters associated with LTV tailings tended to be higher in dissolved constituents, particularly fluoride and molybdenum, than the Inland tailings pore waters. Furthermore, the tailings pore water chemistry observed in the tank experiments agrees relatively well with the water chemistry observed in related laboratory experiments (i.e. process water columns). Some differences were noted between tailings pore waters in the tank experiments and those measured at the operations. However, these differences were related to acid production mechanisms that controlled the pH, and consequently, the geochemistry of tailings pore waters at the operations.

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1. INTRODUCTION

The Biwabik Iron Formation in northern Minnesota is a world class resource of iron and taconite ore which has been mined extensively for more than a century and could continue to be mined for another century or more (Ojakangas and Matsch 1982). In addition, the Biwabik Iron Formation serves a less well known but important role as a major regional aquifer (Cotter et al. 1965). Because of this dual function, regional water supply issues must be considered when addressing mining related decisions affecting ground water.

Currently, tailings generated by taconite plants are slurried with water used in ore processing and pumped into large above-ground tailings basins. Suspended tailings settle to the floor of the basin, and the majority of the process water is recycled back to the taconite plant. Largely to avoid the need to construct and maintain these tailings basins, mining companies are exploring the feasibility of using existing mine pits in the Biwabik Iron Formation for tailings deposition and process water recycling. As additional benefits, this approach eliminates the risk of dam failure and also reduces the area of land (including wetlands) disturbed by mining, the amount of energy used for pumping tailings, and the potential for dust generation. Although legal barriers have previously prevented such applications, laws have been modified recently to allow issuance of permits for in-pit disposal of tailings provided it can be shown that ground water in the surrounding Biwabik Iron Formation will not be adversely impacted.

Supported by a grant from the Iron Ore Cooperative Research Program, the Minnesota Department of Natural Resources (MN DNR) and the University of Minnesota (U of MN) have been studying the potential water quality implications of disposal of taconite tailings in existing mine pits across the Mesabi Iron Range (Berndt and Lapakko, 1997a, b; Berndt et al., 1998, 1999; Lapakko et al., 1998; Lapakko and Jakel, 1999). In order to simulate a small-scale pit disposal environment, four experiments were performed in large in-ground tanks at the field experimental facility at the MN-DNR, Hibbing, Minnesota. This document summarizes the methods, results and conclusions from these small-scale tank experiments over the period from September, 1996 through January, 1999.

2. METHODS

2.1. Field Tanks

The "pits" were simulated by four polyethylene plastic tanks filled with tailings and process waters. The tanks were 3.05 m (10 ft.) tall by 1.22 m (4 ft.) in diameter, and embedded 2.74 m (9 ft.) deep into an embankment (Figure 1). Since the experiment was designed to approximate field conditions, the top of each tank was open to the atmosphere. However, to address safety issues, the tanks were covered during the summer months. The covers were constructed of plastic, and had a one inch hole in the center to allow for air and precipitation transfer. During the winter months, the tanks were covered with a 5 cm Styrofoam cover to reduce ice buildup.

Tailings and process waters were obtained from the tailings basins, and transported to the MN DNR Hibbing field experimental facility as a slurry via cement truck. The rotating drum in the cement truck was cleaned and inspected for residual cement before being filled with tailings and associated process water. The rotating drum was thoroughly rinsed with fresh tailings before being used to collect tailings and process waters used in the experiments. Because tailings discharge contains a large fraction of process water, filling the tank in two stages was necessary. In the first stage, the tank was filled to the top and the tailings were allowed to settle out of solution for one week. Water above the tailings was then decanted before filling the tanks with a second batch of tailings and process waters. The entire process of filling the tanks took approximately one week to complete. A composite tailings sample was obtained from each of the tailings additions for each tank.

Four tanks were filled with tailings (Tanks 1- 4). Tanks 1 and 2 were filled with tailings from LTV Steel on September 13 and 16, 1996, while Tanks 3 and 4 were filled with tailings from Inland Steel on October 29 and November 8, 1996. The total depth of tailings in each tank depended on the amount of tailings present in the slurry used to fill the tanks. Total depth of tailings after settling was 152.4, 165.1, 144.8, and 137.2 cm for Tanks 1, 2, 3, and 4, respectively.

2.2. Sampling Methods

The initial sampling procedure for Tanks 1 and 2 consisted of opening a valve on the outside of the tank. The valve was connected to a horizontal tube, screened its entire length and positioned at the desired location within the tank (Figure 1). Two ports facilitated sampling of fluids at different levels within the settled tailings. The "bottom" port was placed 7.6 cm above the base of the tank at a depth of approximately 1.2 m below the tailings-water interface. The "middle" port was 1.0 m above the base of the tank, within 0.3 m of the tailings-water interface. Surface water samples were obtained approximately 15 to 20 cm below the water-atmosphere interface.

On October 10, 1996, the valve stems broke on both Tank 2 ports. Subsequent design modification involved constructing small sampling wells for both tanks, which were installed October 29, 1996. The wells were constructed of 2.54 cm (1 in.) inner diameter PVC pipe with a 7.6 cm section of slotted well screen (0.03 cm, or 0.012 in. slots) positioned at the sample points (Figure 2). On October 24, 1997, a flange was installed just below the surface of the tailings to prevent preferential flow down the well during pumping.

Tanks 3 and 4 were designed with an interior well sampling apparatus prior to tailings addition (October 23, 1996). Two 0.97 m long, 2.54 cm diameter horizontal PVC slotted well screens were attached to a 2.54 cm vertical PVC pipe that extended above the tailings

(Figure 3). The slotted well screens (0.03 cm slots) were slotted on the bottom side of the screen. This design greatly improved the rate at which water could be extracted from the tank experiments, and reduced the potential for sample contamination caused by preferential downward flow along the well casing.

Once the wells were installed in Tanks 1 and 2, the same sampling method was used for all four tanks. Each well was sealed with a tight end-cap to prevent oxygen transport down the wells between sampling periods. To extract a sample, the end cap was removed and the upper well section was screwed into a female fitting. A 0.1 cm (0.25 in.) PVC pipe equipped with a 0.1 cm hose adaptor and Tygon tubing was used as a feed line to a Model 107090-10 Delrin plastic Guzzler pump (Figure 4). Samples were taken periodically from all wells on all four tanks until July 31, 1997. After July 31, only the surface and tailings pore (bottom port) waters were sampled (Appendix 1).

In August 1999, a series of tailings pore water samples were collected from the bottom port of each tank to determine whether or not surface water was contaminating these samples (i.e. short-circuiting of surface waters). Three 250 ml pore water samples were taken from each tank. 1800 ml and 2000 ml of water was purged from the LTV and Inland tanks, respectively, between each sample. Each pore water sample was analyzed for elements that would be likely to adsorb to tailings surfaces (As, Mo, Li, Na, K, Rb) and redox-sensitive elements (Fe, Mn, As).

2.3. Analytical Methods

2.3.1. Composite Tailings Samples

As tailings and process water were transferred to the tanks, grab samples were collected in 4.7 L (5 quart) pails. Four pails were collected from each truckload of tailings used to fill the tanks. It was noted that the coarse material came out of the truck first. Consequently, samples were collected from the discharge stream at different points in time in order to obtain a somewhat representative sample of each truckload. In total, five tailings samples were collected to represent taconite tailings from each mine. Tailings samples from each mine were dried, composited, and split for analysis. Composite tailings samples were analyzed for particle size (Lerch Bros.), whole rock and trace elements (Act Labs).

2.3.2. Analysis of Water Chemistry

Water samples were analyzed at the MN DNR laboratory in Hibbing, MN for pH, Eh, specific conductance, and alkalinity. An Orion SA 720 pH meter equipped with a Ross combination pH electrode (model 8165) was used for pH analysis. A Beckman Eh meter equipped with an Orion combination redox electrode (model 9678BN) was used for Eh analysis. Specific conductance was measured using a Myron L model EP conductivity meter. Alkalinity was determined using standard titration technique (APHA et al., 1995).

Major and trace elements were analyzed at the University of Minnesota. Cations were filtered and acidified with 0.2 mL of Baker Instra-Analyzed nitric acid per 50 mL and analyzed using an inductively coupled plasma mass spectrometry (ICP-MS, Perkin Elmer mode-SCIEX-Elan 5000). Anions were filtered and measured using ion chromatography (IC, Dionex Ion Chromatograph fitted with GP40 gradient pump, CD20 conductivity detector, and two AS4A anion exchange columns).

3. RESULTS AND DISCUSSION

3.1. Taconite Tailings

Taconite tailings from LTV were significantly coarser than those from Inland. Approximately 50% of the tailings in the LTV sample did not pass through a 35 mesh sieve, whereas only 4-12% of the Inland tailings were that large (Table 1). At the other extreme, approximately 33% of the Inland tailings were finer than 500 mesh, compared to 15% of the LTV tailings.

The chemical composition of taconite tailings from both mines was very similar. Major elements present in the samples were silicon, iron, calcium, and magnesium (Table 2). Carbon dioxide, which reflects the carbonate mineral content of the tailings, was not analyzed. The amount of carbon dioxide in these tailings can be estimated assuming that carbon dioxide was the only component not analyzed. Estimated values indicate that these tailings contain a maximum of 6-8% carbon dioxide. While this range is somewhat higher than that found in taconite tailings used in laboratory column experiments (Berndt and Lapakko, 1997a), it is comparable to that of taconite tailings disposed of in the Snively Pit at US Steel-Minntac, Mountain Iron, MN (Jakel and Lapakko, 1999a).

Manganese was present in tailings from LTV and Inland at 0.5% and 0.8%, respectively (Table 3). Arsenic concentrations were similar for both types of tailings, averaging 21 mg/L. Molybdenum was not detected in any of the tailings samples. The range of concentrations observed for these three elements closely matched those of previous analyses (Berndt and Lapakko, 1997a; Jakel and Lapakko, 1999a). Fluoride and boron were not analyzed in these samples. However, previous analyses of taconite tailings suggest that these concentrations would be approximately 180 - 240 mg/L and less than 20 mg/L, respectively (Berndt and Lapakko, 1997a; Jakel and Lapakko, 1999a).

3.2. Water Chemistry: Elements of Concern

Tanks 1 and 2 represent duplicate experiments with tailings from LTV (Appendix 2). Likewise, Tanks 3 and 4 represent duplicate experiments with tailings from Inland (Appendix 3). Visual inspection of these figures shows that water chemistry in the tank experiments was reproducible for each tailings source.

3.2.1 Manganese

Manganese concentrations in surface waters

During the initial stages of the tank experiments, manganese concentrations in surface waters remained constant (Figure 5). Average manganese concentrations were 30 ug/L over 19 and 28 weeks for LTV Tanks 1 and 2, respectively, and averaged 79 ug/L over 8 and 16 weeks for Inland Tanks 3 and 4, respectively. After this initial period, manganese concentrations in all four tanks decreased to levels less than 10 ug/L.

The length of time required for manganese concentrations to decrease to these low levels was not precisely determined during this experiment. These data imply that the residence times for manganese in an oxygenated water in contact with taconite tailings were in the range of 19 to 45 weeks in Tank 1, 28 to 45 weeks in Tank 2, 8 to 38 weeks in Tank 3, and 16 to 38 weeks in Tank 4 (Figure 5). Assuming no additional manganese inputs (i.e. after tailings deposition ceases), these observations can be combined to estimate the residence time of dissolved manganese in a hypothetical in-pit disposal environment. The maximum span of time required for manganese to reach acceptable levels could vary from two to eleven months. The minimum residence time can be estimated at seven to nine and a half months. Subsequent manganese oxidation experiments have indicated that the residence time of dissolved manganese depends, in part, upon the initial concentration of manganese in solution (Jakel and Lapakko, 1999b). For initial manganese concentration less than 1.0 mg/L, residence times were approximately seven weeks. This residence time increased to fourteen weeks when the initial manganese concentration was 1.9 mg/L.

The mechanism controlling manganese levels in the tank surface waters is believed to be the oxidation of manganese and subsequent formation of MnO_2. Manganese is unstable in an oxidizing environment, such as the surface waters in these tank experiments. Dissolved manganese will readily react with dissolved oxygen to produce MnO_2. The kinetics for this reaction are slow in the pH range of the tank experiments (Stumm and Morgan, 1995). However, MnO_2 formation is an autocatalytic reaction. Thus, the rate of manganese oxidation should increase as MnO_2 forms. Biological activity may also increase the rate of manganese oxidation in surface waters (Ehrlich, 1990, 1996). Based on the manganese oxidation experiments, it is clear that manganese is removed as an oxide (Jakel and Lapakko, 1999b). However, it is unclear whether the mechanism is chemical or biological. The observed decrease in manganese concentrations in the surface waters of the tank experiments are consistent with this model.

Manganese concentrations in tailings pore waters

Manganese concentrations generally increased in the tailings pore waters at the base of the LTV tanks, but fluctuated in the Inland tanks (Figure 6). Initial concentrations in the LTV tanks averaged 50 ug/L. As of week 123, manganese had increased to approximately 140 ug/L. After an initial increase, manganese concentrations in tailings pore waters from the Inland tanks began to fluctuate. Over the 116 week time period of these experiments, manganese concentrations ranged from 50 ug/L to 117 ug/L, averaging 79 ug/L (standard deviation = 15).

Previous mineralogical analyses have identified manganese-containing carbonates such as rhodochrosite and ankerite in taconite tailings from mining operations in northern Minnesota (Mattson, 1996). Geochemical analyses have indicated that waters trapped in taconite tailings pore spaces in the absence of oxygen are generally saturated with respect to the mineral rhodochrosite (Berndt and Lapakko, 1997a; Berndt et al., 1998, 1999; Lapakko et al., 1998; Lapakko and Jakel, 1999). This implies that manganese concentrations in tailings pore waters will be controlled by the dissolution behavior of these minerals (equations 1 and 2, respectively).

$$H_2CO_3 + MnCO_3 \rightarrow Mn^{2+} + 2HCO_3^- \tag{1}$$

$$2H_2CO_3 + CaMn(CO_3)_2 \rightarrow Ca^{2+} + Mn^{2+} + 4HCO_3^- \tag{2}$$

Since the concentration of carbonic acid is determined by the solution pH, manganese concentrations will be determined by the pH and alkalinity of the tailings pore waters.

Alkalinity in tailings pore waters varied with respect to the tailings source during this experiment. Tailings pore water alkalinity in the LTV tanks ranged from 235 to 325 mg/L as $CaCO_3$ with an average value of 273 mg/L. The alkalinity of tailings pore waters from the Inland tanks were much lower, averaging 132 mg/L as $CaCO_3$ (95 - 197 mg/L as $CaCO_3$). Using an approximate alkalinity of tailings pore waters in the Inland tanks (130 mg/L $CaCO_3$), manganese concentrations appeared to be at saturation with respect to rhodochrosite (Figure 7). However, manganese concentrations in tailings pore waters of the LTV tanks were slightly higher than predicted by rhodochrosite solubility at an approximate alkalinity of 275 mg/L. This may be due, in part, to the wide range of alkalinity values measured during this experiment.

3.2.2. Fluoride

Fluoride concentrations in surface waters

Fluoride concentrations fluctuated within a fairly constant range throughout the tank experiments, averaging 8.2 mg/L in the LTV tanks and 4.2 mg/L in the Inland tanks (Figure 8). Since the volume of water above the tailings was continually exposed to the elements, concentration variations could have been the result of seasonal events. Precipitation and spring snow/ice melt could have diluted surface waters in the tanks. Evaporation during dry periods and ice formation during the winter could result in concentration of dissolved constituents of surface waters.

Seasonal effects on surface water chemistry were evaluated by comparing the concentration ratio of any parameter of interest ([PI]) to a conservative element (i.e. chloride) of a sample at a given point in time (equation 3) to the concentration ratio that existed at the onset of the experiment (equation 4).

$$R_{t=i} = [PI]_{t=i}/[Cl]_{t=i} \quad (3)$$

$$R_{t=0} = [PI]_{t=0}/[Cl]_{t=0} \quad (4)$$

If the concentration fluctuations for the parameter of interest are due solely to seasonal effects, then the difference between the two ratios should be zero. A positive deviation from zero indicates release of the parameter of interest due to chemical reaction. Similarly, removal is indicated when the difference between the ratios is negative.

For the most part, fluoride to chloride ratios indicated that fluctuations in fluoride concentrations in surface waters during the first sixty nine to seventy two weeks of the experiment were due to seasonal events (Figure 9). The apparent removal at week forty five in the LTV tanks was considered an aberration caused by the removal of wells from those tanks the day before those samples were taken (see Appendix 1). After seventy two weeks, fluoride removal from surface waters became apparent.

Throughout the wider, in-pit disposal study, the exact mechanism controlling fluoride levels in waters associated with taconite tailings has been difficult to quantify (Berndt and Lapakko, 1997a; Berndt et al., 1998, 1999; Lapakko and Jakel, 1999). Two mechanisms, adsorption to iron oxides and fluorite (CaF_2) solubility, appear to have some influence on fluoride levels. In this case, adsorption may be the controlling mechanism. However, it is unusual to have a seventy two week lag time before adsorption occurs. Fluorite solubility clearly is not the controlling mechanism in these waters. If fluoride levels were determined by fluorite solubility limits, the highest fluoride levels should correspond to the lowest calcium levels. However, the opposite trend is observed (Figure 10). Thus, it remains unclear as to the exact mechanism controlling fluoride levels in surface waters above taconite tailings.

Fluoride concentrations in tailings pore waters

Based on a cursory inspection of the data, it appeared as if fluoride levels in all four tanks increased during the first sixteen to twenty eight weeks of each experiment (Figure 11). After this initial increase, fluoride concentrations decreased to relatively constant levels. More detailed analysis later revealed that surface waters had infiltrated the tailings in the LTV tanks between weeks ten and nineteen. This determination was supported by the fact that concentrations of trace elements known to adsorb to iron oxides (e.g. As, and Mo) and those that readily undergo ion exchange (Na, K, Rb, and Cs) followed the same trend. A second period of possible surface contamination in tank #2 occurred at week 93. Eliminating the contaminated measurements, fluoride concentrations in pore waters of the LTV tailings averaged 7.0 mg/L, ranging from 6.3 to 8.4 mg/L.

Fluoride concentrations in pore waters in contact with Inland's tailings increased from 4.9 mg/L to 7.7 mg/L over the first 16 weeks of the experiment (Figure 11). In this case, there was no indication of surface contamination. Subsequently, these levels dropped to steady concentrations averaging 3.9 mg/L and 5.1 mg/L for Tanks 3 and 4, respectively.

Previous work has shown that fluoride concentrations in tailings pore waters were controlled by saturation with respect to fluorite,CaF_2 (Berndt and Lapakko, 1997a; Berndt et al., 1998, 1999; Lapakko et al., 1998; Lapakko and Jakel, 1999). However, quantification of fluorite solubility has been an issue. Two solubility constants reported in the literature appear to describe fluoride levels in active taconite tailings basins. The Geochemist's Workbench modeling software uses a $K_{sp} = 10^{-10.58}$, while Brown and Roberson (1977) determined a $K_{sp} = 10^{-10.98}$. In addition, Berndt et al. (1999) calculated an empirical solubility constant ($K_{sp} = 10^{-10.05}$) based on operational measurements of waters from the tailings basin at LTV.

The composition of tailings pore waters from the LTV tanks matched the empirical solubility constant (Berndt et al., 1999) reasonably well (Figure 12). This suggests that fluoride levels in waters contacting tailings from LTV are controlled by the solubility of fluorite. It further implies that waters in contact with tailings from Inland are generally undersaturated with respect to fluorite. In this case, it may be reasonable to expect that an adsorption mechanism controls fluoride levels. It is likely, however, that both mechanisms affect fluoride levels in tailings pore waters.

3.2.3. Arsenic

Arsenic concentrations in surface waters

Arsenic concentrations in surface waters from the LTV tanks ranged from 0.7 to 14 ug/L, averaging 5.6 ug/L (Figure 13). Much of the fluctuations in these concentrations was probably due to seasonal events (Figure 14). However, arsenic levels are controlled by adsorption to iron oxides present in taconite tailings (Berndt and Lapakko, 1997a; Berndt et al., 1998, 1999; Lapakko et al., 1998; Lapakko and Jakel, 1999). It is possible that dilutional inputs may have temporarily rinsed some arsenic from the tailings surface, only to readsorb later.

In contrast to waters in contact with LTV's tailings, arsenic concentrations increased in surface waters above Inland's tailings (Figure 13). During the first thirty eight weeks of the experiment, arsenic concentrations remained constant, averaging 2.0 ug/L. Subsequently, arsenic levels increased, reaching maximum concentrations of 12 ug/L to 14 ug/L. This apparent release of arsenic was confirmed by a large positive deviation in arsenic levels normalized to chloride (Figure 14). Similar release of arsenic was observed in tailings basin clear pools at Inland and LTV (Berndt et al., 1999; Jakel and Lapakko, 1999c). This release was believed to be the result of oxidation of minor amounts of sulfide material present in taconite tailings (Berndt and Lapakko, 1997a; Mattson, 1996).

Arsenic concentrations in tailings pore waters

Arsenic concentrations decreased over time in the LTV tailings pore waters, reaching 1.8 ug/L as early as week 12 (Figure 15). This decrease was most likely due to adsorption of dissolved arsenic by iron oxide minerals present in the tailings. Taconite tailings used in related experiments contained 5-19 wt% iron oxide minerals (Berndt and Lapakko, 1997a), providing an ample number of sorption sites.

The sharp increase in arsenic concentrations that occurred between weeks 12 and 19 and at week 93 was most likely caused by surface contamination of the tailings pore waters. Surface water may have percolated downward through channels created during the installation of new sampling wells on October 29, 1996 (week 8). However, arsenic concentrations in subsequent samples continued to decrease and appeared to be approaching a constant concentration of approximately 2.1 ug/L. This value is comparable to arsenic concentrations observed in tailings pore waters in the Inland tanks, which ranged from 0.6 to 4.2 ug/L and averaged 2.4 ug/L. These data suggest that, in general, arsenic concentrations in tailings pore waters will be on the order of 2 ug/L.

3.2.4. Molybdenum

Molybdenum concentrations fluctuated, but appeared to decrease slightly in the surface waters of all four tank experiments (Figure 16). The average molybdenum concentrations were 290 ug/L and 67 ug/L for the LTV and Inland experiments, respectively. A comparison of normalized molybdenum concentrations revealed that molybdenum was removed from surface waters above LTV's tailings (Figure 17). This removal was most likely the result of adsorption to iron oxides (Berndt and Lapakko, 1997a; Berndt et al., 1998, 1999; Lapakko et al., 1998; Lapakko and Jakel, 1999). However, normalized molybdenum concentrations in waters associated with tailings from Inland indicated that the fluctuations were the result of seasonal effects.

Molybdenum concentrations decreased over time in the LTV tailings pore waters (Figure 18). As with arsenic, molybdenum levels are believed to be controlled by adsorption to iron oxides. Initial concentrations averaged 285 ug/L, and rapidly decreased to approximately 68 ug/L by week 12. The surface contamination described in section 3.2.2 and 3.3.2 was also evident with molybdenum. However, it appears that molybdenum concentrations were decreasing to relatively low levels prior to contamination. Averaging these low values, it appears that molybdenum concentrations in LTV's tailings pore waters are approximately 58 and 24 ug/L in tanks 1 and 2, respectively. Molybdenum concentrations in the Inland tailings pore waters remained relatively constant at an average of 25 ug/L, ranging from 13 ug/L to 45 ug/L (Figure 18).

3.2.5. Boron

The average boron concentrations were 362 ug/L and 115 ug/L for the LTV and Inland experiments, respectively. While boron concentrations surface waters of the Inland tank experiments fluctuated with in a constant range, they appeared to decrease slightly in waters above LTV tailings (Figure 19). A comparison of normalized boron concentrations revealed that boron was removed from surface waters above LTV's tailings after fifty weeks of reaction time (Figure 20). Very little is known about geochemical controls on boron concentrations. The most likely explanation for the removal is adsorption to clay minerals (Berndt and Lapakko, 1997a; Berndt et al., 1999). Normalized boron concentrations in waters associated with tailings from Inland indicated that the fluctuations were the result of seasonal effects.

Boron concentrations in tailings pore waters varied widely throughout the experiment (Figure 21). Average boron concentrations in pore waters of LTV's tailings averaged 470 ug/L, but ranged from 254 ug/L to 608 ug/L. Inland's tailings pore waters contained lower boron concentrations than those observed in the LTV experiments, averaging 97 ug/L (range = 52 - 169 ug/L). A satisfactory explanation for this variation had not been determined at the time that this document was written.

3.3. Results of Short-Circuiting Tests

Based on observations during sample collection and the water chemistry results, short-circuiting of surface waters through the tailings pore sampling wells did not occur. As samples were collected from each of the four wells, the smell of hydrogen sulfide gas was noted (field notes, MN DNR, Hibbing, MN). The presence of hydrogen sulfide indicates sulfate reduction was occurring in a reducing environment within the tailings pores, which is consistent with the lower sulfate concentrations found in pore waters relative to surface waters (Figure 22). This could not occur if surface waters were reaching the wells because surface water is oxygenated and sulfate is stable in oxygenated waters.

The redox-sensitive element manganese provided additional evidence for reducing rather than oxidizing conditions with in the tailings pore spaces. Manganese concentrations remained elevated relative to surface waters, indicating no contamination of oxygenated waters into the tailings mass (Figure 22; see section 3.2.1).

Trace element chemistry also indicated that the wells sample water from tailings pore spaces rather than the surface. If surface water were short-circuited through the wells, the composition of water drawn through the well should reflect surface water. This will be increasingly so as the volume of water drawn through the well increases. However, this is not what we observed in the three consecutive samples taken in August, 1999.

Arsenic and molybdenum adsorb to iron oxides present in the tailings. Consequently, these elements are removed from tailings pore waters. In all four tanks, arsenic and molybdenum concentrations were low when compared to surface waters and decreased after each consecutive purge volume (Figure 23). This is the opposite trend that would be expected if surface water was rapidly streaming through the tailings along the well and contaminating sample collection. Similar results were observed for elements that readily exchange, such as lithium, sodium, and potassium (Figure 23).

3.4. Water Chemistry Associated with LTV Tailings Relative to Inland Tailings

The chemistry of water associated with the tailings varied somewhat with respect to the source of the tailings. In general, water in contact with tailings from LTV tended to be higher in dissolved constituents, particularly fluoride, molybdenum, and boron (Figure 24). Fluoride concentrations were approximately 7 mg/L in the LTV experiments compared to 5 mg/L in water from the Inland experiments. Molybdenum and boron concentrations in water in intimate contact with tailings from LTV were nearly five times higher than waters contacting Inland's tailings. Manganese and arsenic concentrations appeared to be independent of the tailings source.

3.5. Water Chemistry Relative to Laboratory Process Water Column Experiments

3.5.1. LTV experiments

Tailings pore waters from the wells at the base of each tank experiment were compared to laboratory column experiments using tailings and process water from the corresponding taconite operation. Overall, the chemistry of LTV tailings pore waters from the field tank experiments was similar to the laboratory column experiments (Figure 25). Manganese was the exception. Manganese concentrations in the tank waters were nearly one third the concentrations observed in column effluents. Lower manganese concentrations may have been due to the slightly higher pH of tailings pore waters in the tank experiments, resulting in less dissolution of manganese carbonate minerals.

3.5.2. Inland experiments

The chemistry of water that evolved due to contact with Inland tailings in the tank did not match that of the laboratory column experiments using Inland tailings (Figure 26). Manganese, arsenic, molybdenum, and boron concentrations were lower in the tank tailings pore waters than observed in column effluents. Manganese levels were approximately one fifth of those observed in column effluents. Once again, it is believed that the higher pH in the tank tailings pore waters inhibited manganese carbonate dissolution, resulting in lower manganese levels. Arsenic, molybdenum, and boron levels were nearly half that of the column experiments. Fluoride concentrations were nearly twice as high as observed in column effluents. This may be due, in part, to differences in plant discharges at the times when tailings and process waters were collected for these experiments.

3.6. Water Chemistry Relative to Operational Measurements

3.6.1. LTV

When tailings pore water chemistry in the tank experiments was compared to measurements of seep water chemistry at LTV's tailings basin, several differences were noted. Calcium, magnesium, and sulfate levels were higher and pH was lower in water seeping from the tailings basin relative to tailings pore waters of the tank experiments (Figure 27). These differences were likely the result of oxidation of waste rock containing high levels of sulfidic material that was buried in the tailings basin (LTV, 1996). Acid produced by the oxidation of these materials results in decreased pH and elevated sulfate in the effluent. Furthermore, acid production leads to carbonate dissolution and subsequent release of calcium and magnesium.

Acid production in the tailings basin may also explain why manganese levels were higher and fluoride levels were lower in waters seeping from the tailings basin relative to the tank experiments (Figure 28). Carbonate minerals present in taconite tailings are a complex solid solution containing calcium, magnesium, iron, and trace amounts of manganese (Mattson, 1996). Thus, carbonate dissolution will result in elevated levels of all four of these elements in the effluent.

Two geochemical mechanisms, fluorite precipitation and adsorption, have been identified as potentially controlling fluoride levels in tailings pore waters. Both of these mechanisms would be expected to result in decreased dissolved concentrations as the effluent pH decreased. As described previously, acid production and subsequent carbonate dissolution leads to the release of calcium from the tailings. If fluoride levels are controlled by fluorite solubility, increased calcium concentrations will lead to decreased fluoride concentrations in tailings pore waters. Similarly, low pH favors fluoride adsorption onto iron oxide minerals. As pH decreases, the number of surface adsorption sites capable of adsorbing anions such as fluoride increases. As a result, dissolved fluoride concentrations decrease in lower pH waters.

3.6.2. Inland

Tailings pore water chemistry in the tank experiments using tailings from Inland was fairly similar to that of operational measurements at Inland. The most noticeable difference was elevate pH and lower calcium concentrations in tailings pore waters from the tanks relative to that of the operation (Figure 29). Similar to the situation at LTV, tailings pore water chemistry in two wells and one seep located on the north side of the tailings basin at Inland has been influenced by local environmental factors (Berndt et al., 1998, 1999). The north side of the tailings basin was constructed on top of a wetland. Oxidation of organic matter in this substrate results in acid production, and subsequent dissolution of carbonates in the tailings. Oxidation of siderite in the tailings may also produce acid. Thus, elevated calcium levels are to be expected. It is puzzling that magnesium levels in waters seeping from the tailings basin are not higher. Apparently, the tailings used to build the dike at this location do not contain high levels of magnesium carbonate, or these carbonates have been rendered inactive.

Regardless of the acid source, elevated manganese concentrations and decreased fluoride concentrations would be expected in operation tailings pore waters relative to the tank experiments as described in the previous section (Figure 30). However, differences in molybdenum and boron levels were also observed for pore waters in contact with tailings from Inland. Both molybdenum and boron are believed to by controlled by adsorption mechanisms in taconite tailings pore waters. Dissolved molybdenum is present as an anion, MoO_4^-, and therefore, will adsorb more strongly to iron oxides at low pH. Thus, the lower molybdenum concentrations observed for operational measurements is consistent with lower pH measurements. Boron is believed to be controlled by adsorption to clay minerals, although this mechanism has not been confirmed. Since boron can form an anion, $B(OH)_4^-$, it is reasonable to expect adsorption to be favored at low pH.

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Table 1. Particle size distribution (in weight percent) of LTV and Inland taconite tailings used in the field tank experiments. Analysis by Lerch Brothers Inc., Hibbing, MN.

	LTV		Inland	
Screen	Tank 1	Tank 2	Tank 3	Tank 4
35M	47.2	53.5	11.8	3.9
48M	4.2	8.1	6.9	4.4
65M	4.0	7.0	8.2	7.9
100M	6.9	6.0	10.1	11.3
150M	7.0	3.6	8.8	9.7
200M	4.7	2.4	6.6	7.5
270M	3.6	2.5	6.7	7.8
325M	2.7	1.5	3.8	4.4
400M	1.3	1.0	2.4	2.7
500M	1.8	1.4	3.8	4.4
-500M	16.6	13.0	30.9	36.0
TOTAL	100	100	100	100

Table 2. Whole rock analysis (in weight percent) of taconite tailings used in the field tank experiments. Analysis conducted by ActLabs Enzyme Laboratories Inc., Wheat Ridge, CO.

Major Elements	LTV		Inland	
	Tank 1	Tank 2	Tank 3	Tank 4
SiO_2	66.08	65.85	66.01	65.51
Fe_2O_3	21.23	21.61	18.88	18.56
MnO	0.51	0.52	0.76	0.80
CaO	2.38	2.49	3.50	3.78
MgO	2.81	2.85	2.96	3.11
Na_2O	0.07	0.06	0.02	0.02
K_2O	0.12	0.08	0.04	0.04
Al_2O_3	0.58	0.57	0.16	0.15
Ti_2O	0.03	0.03	0.00	0.00
P_2O_5	0.09	0.08	0.04	0.03
CO_2[1]	6.1	5.9	7.6	8.0
TOTAL	100	100	100	100

[1] % CO_2 was calculated by subtraction.

Table 3. Trace parameter chemical composition of taconite tailings used in the field tank experiments. Concentrations are in mg/L. Analysis conducted by ActLabs Enzyme Laboratories Inc., Wheat Ridge, CO.

Trace Element	LTV		Inland	
	Tank 1	Tank 2	Tank 3	Tank 4
Ag	<0.4	<0.4	<0.4	<0.4
As	20	18	25	20
Ba	17	18	11	10
Be	1	<1	<1	<1
Bi	<5	<5	<5	<5
Br	<1	<1	<1	<1
Cd	<0.5	<0.5	<0.5	<0.5
Co	8	8	9	9
Cr	6	6	7	7
Cs	1.3	1.1	0.2	<0.5
Cu	4	4	10	6
Mo	<5	<5	<5	<5
Ni	3	4	9	2
Pb	<5	<5	<5	<5
Sb	0.2	<0.2	<0.2	<0.2
Se	<3	<3	<3	<3
Sr	39	39	30	32
V	19	20	11	13
W	<3	<3	<3	<3
Y	2	2	3	4
Zn	10	8	7	7
Zr	15	14	8	9

In-Pit Taconite Tailings Tank Experiments

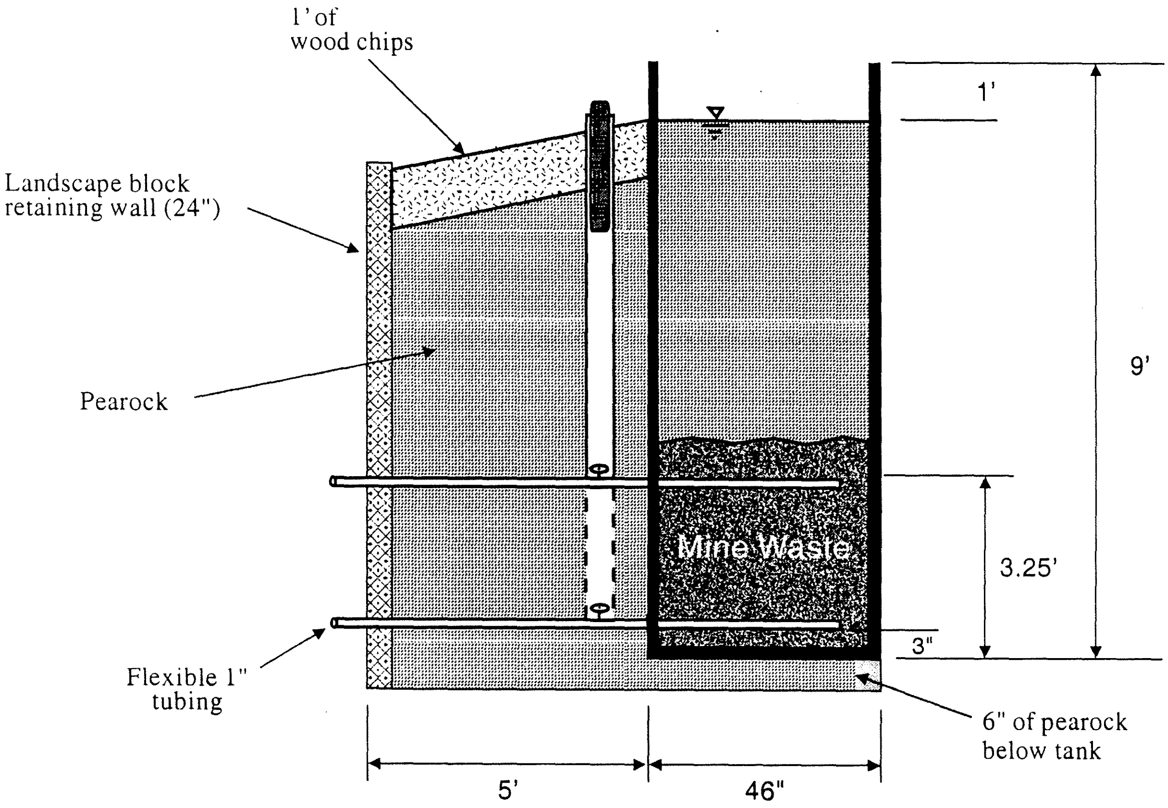


Figure 1. End view of underwater disposal facility at DNR-Minerals research site.

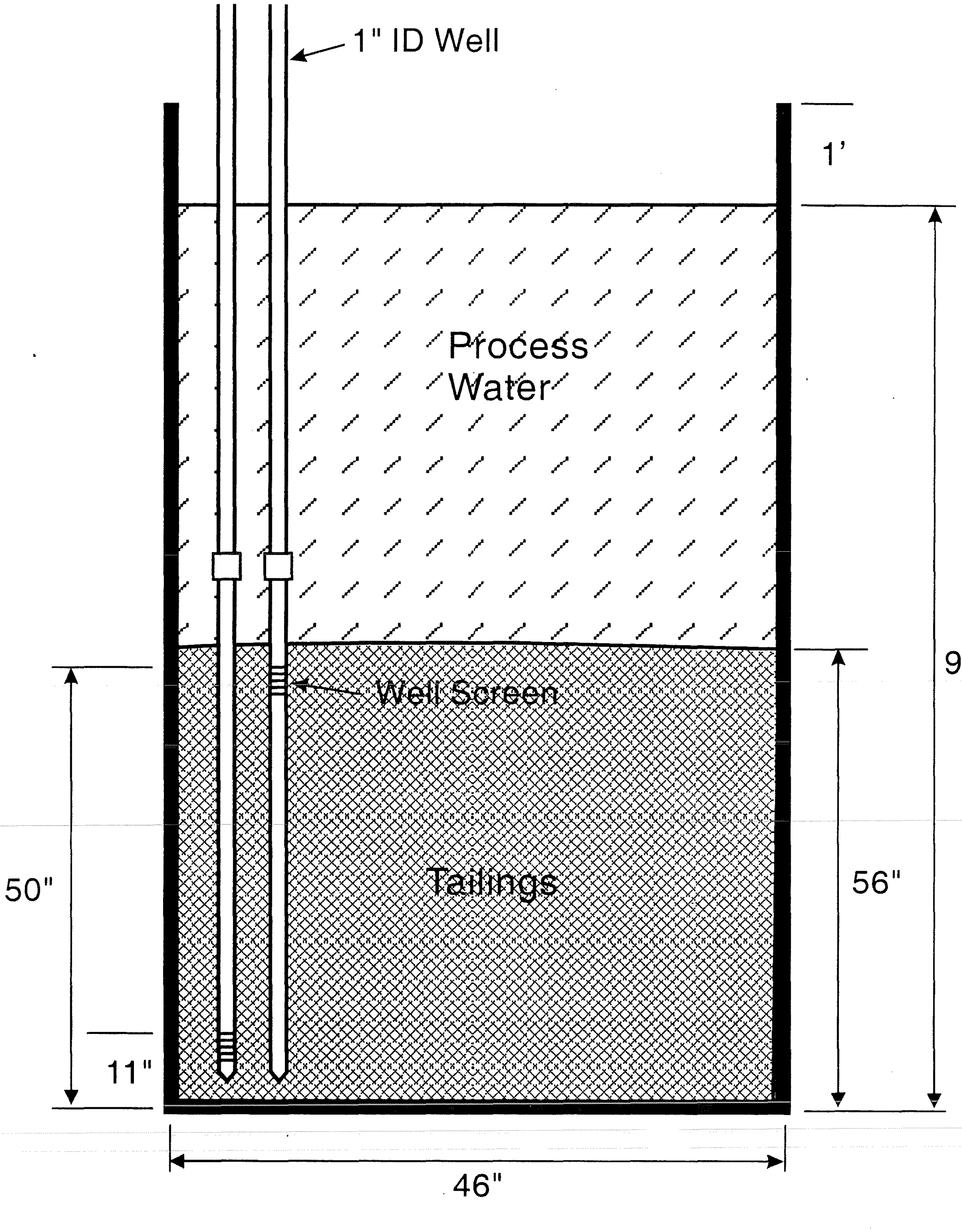


Figure 2. Interior sampling wells installed in LTV Tanks 1 and 2 on October 29, 1996.

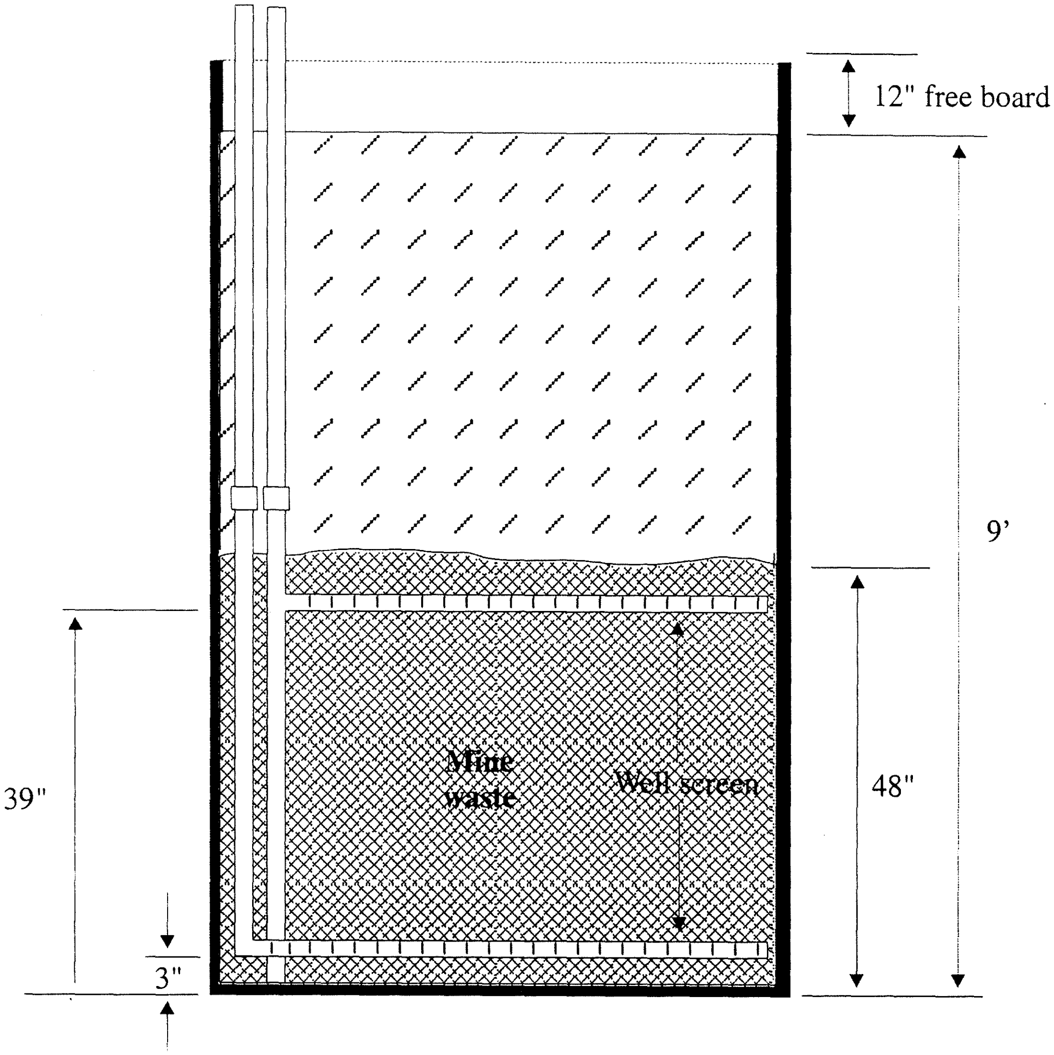


Figure 3. Interior well sampling apparatus designed for Inland Tanks 3 and 4. This apparatus was installed prior to filling the tanks with tailings.

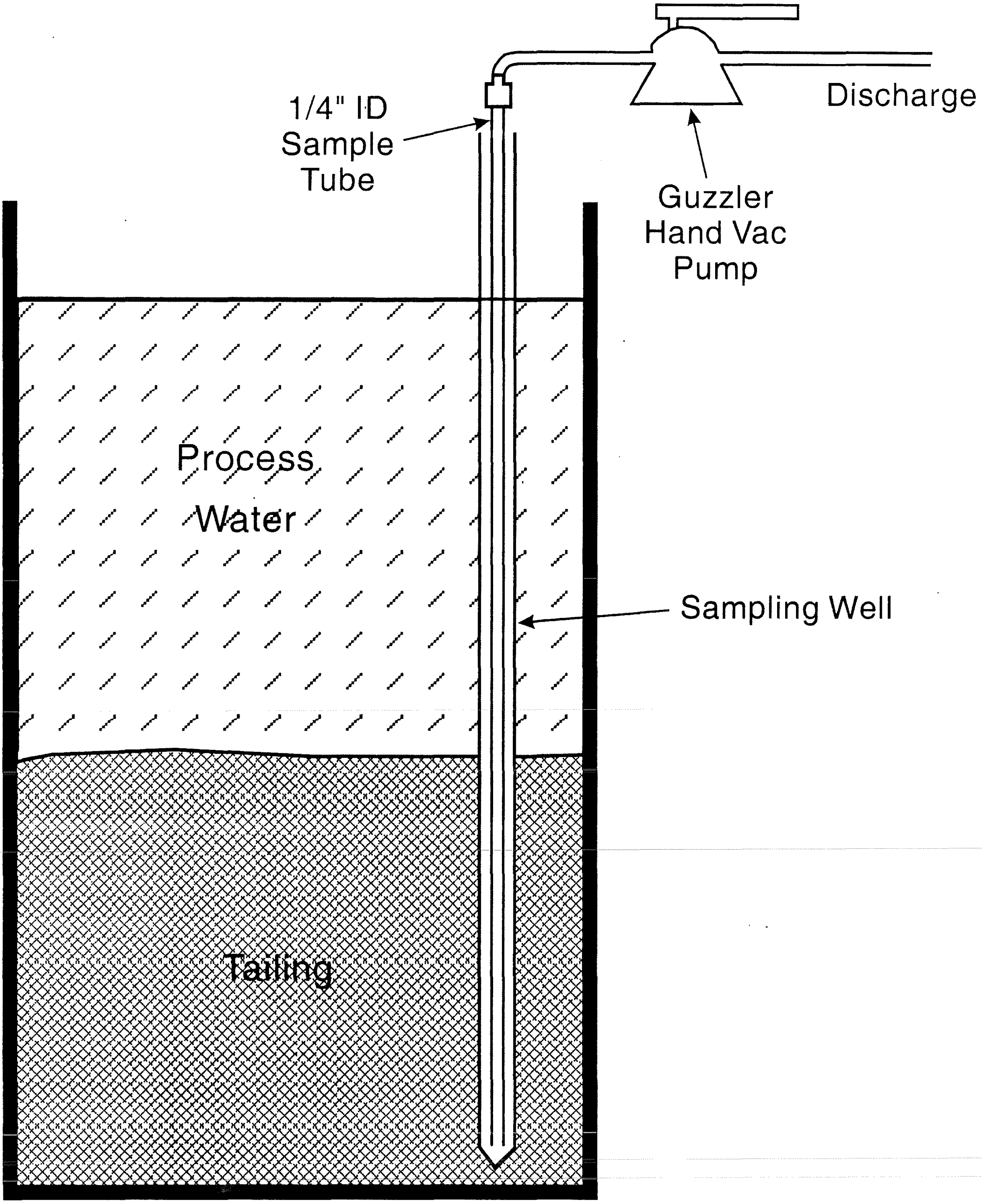


Figure 4. A Guzzler pump apparatus was used for extracting water samples from the wells.

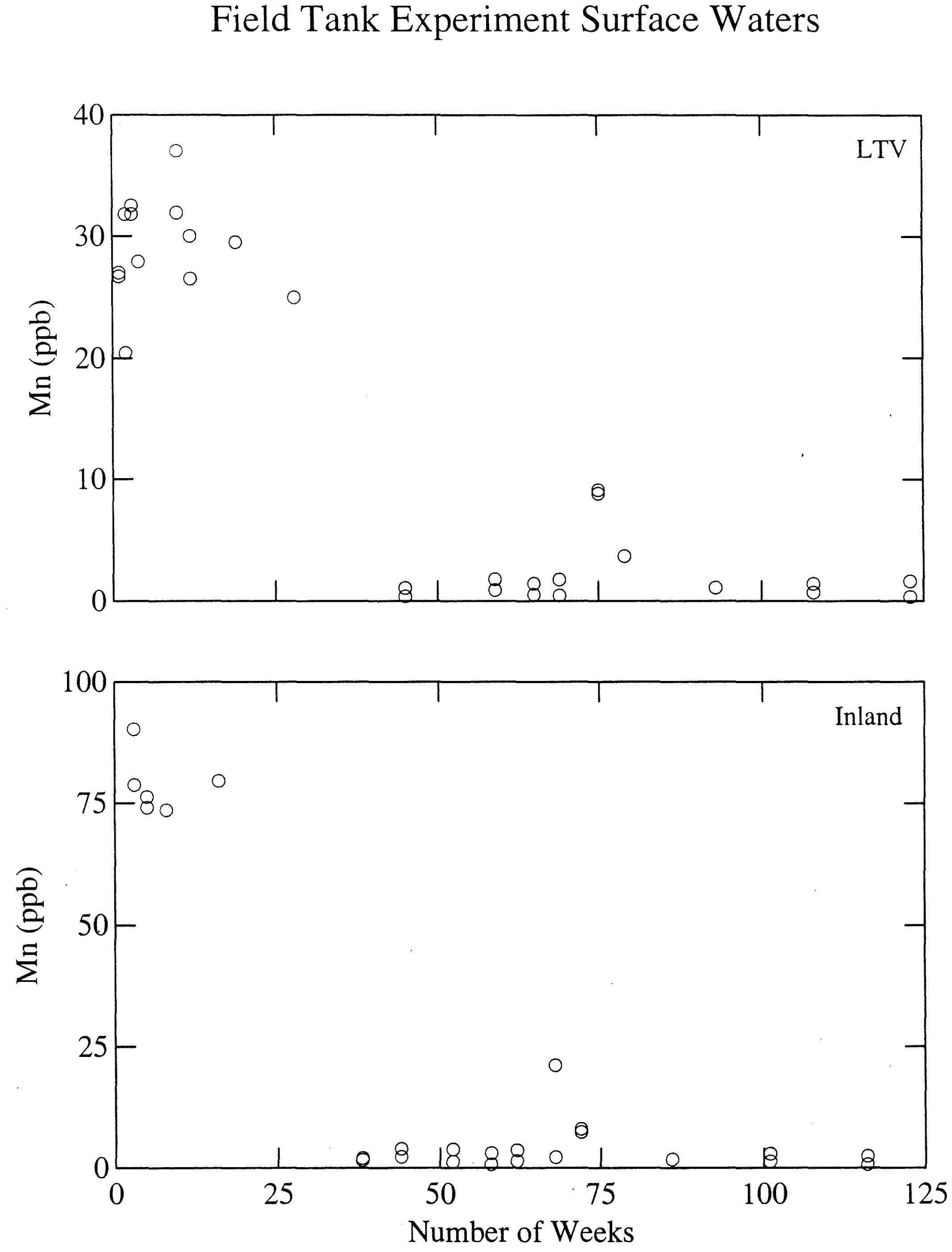


Figure 5. Manganese concentrations in surface waters of the LTV and Inland field tank experiments decreased rapidly after 28 and 16 weeks, respectively. The decrease was the result of manganese oxidation to MnO_2.

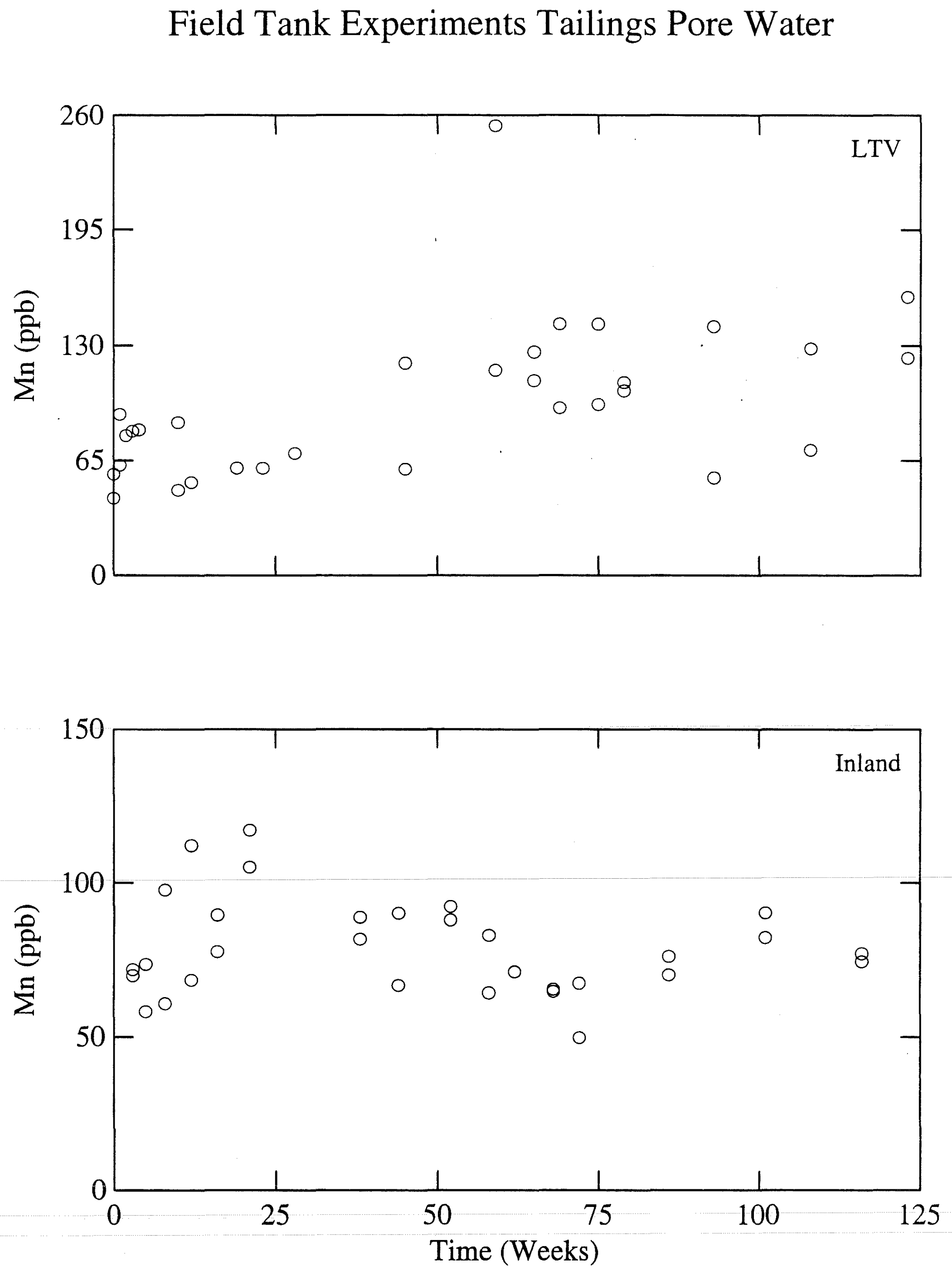


Figure 6. Manganese concentrations gradually increased over time in pore waters contacting LTV's tailings. While a similar trend was initially observed in Inland tailings pore waters, it was determined that manganese concentrations fluctuated within a relatively constant range for 116 weeks.

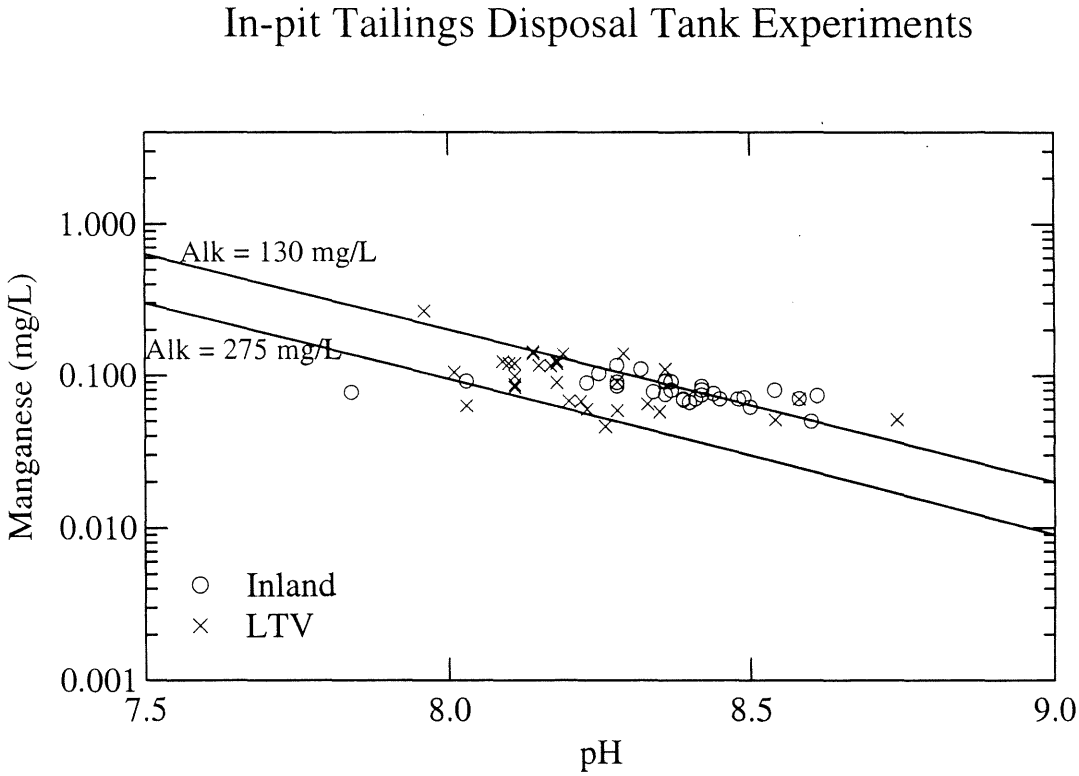


Figure 7. Manganese concentrations in taconite tailings pore waters are believed to be controlled by the solubility of rhodochrosite ($MnCO_3$). Using the average tailings pore water alkalinity measured in the LTV and Inland tank experiments (approximately 275 and 130 mg/L respectively), manganese concentrations appear to be consistent with a rhodochrosite control model.

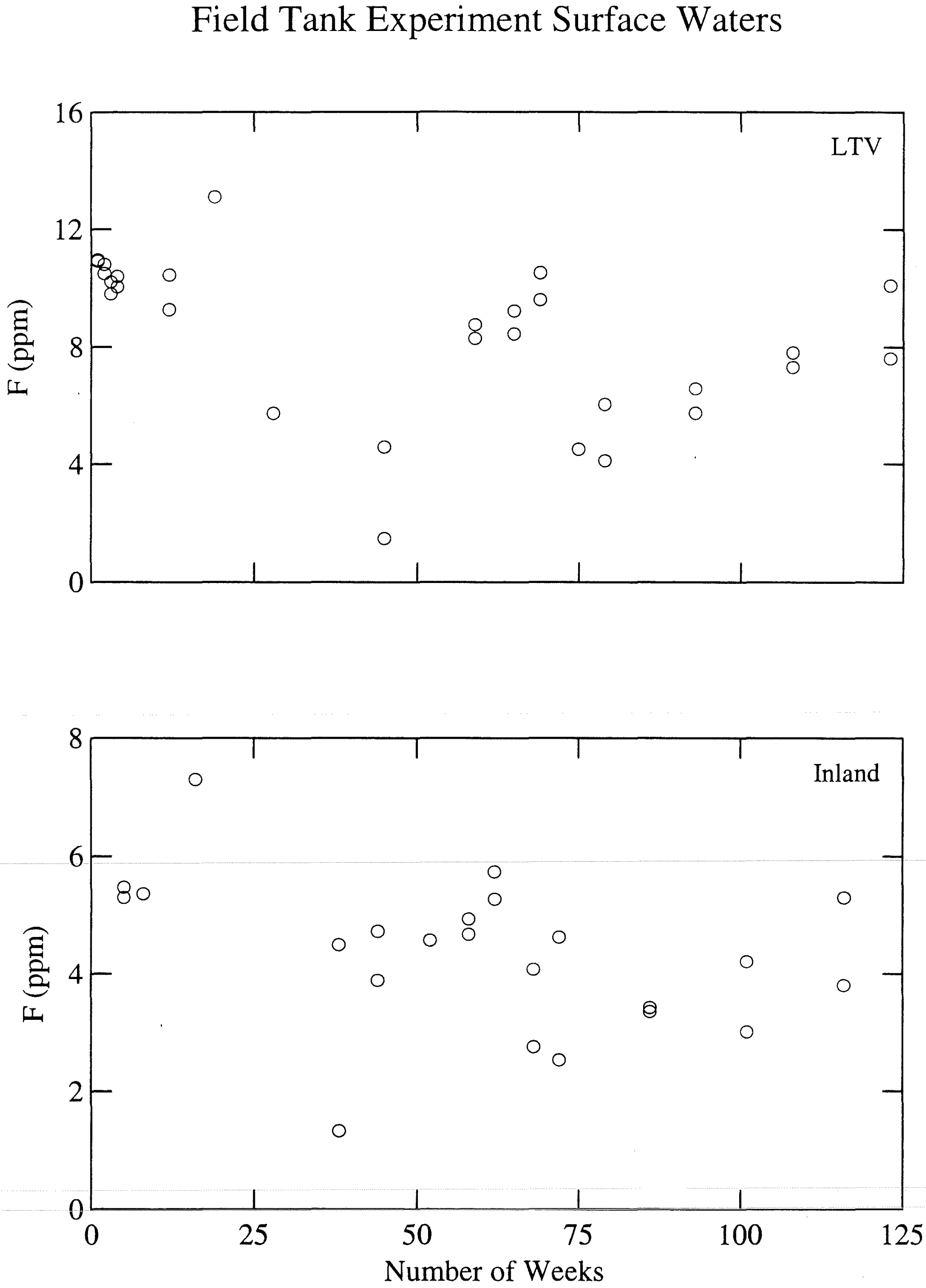


Figure 8. Fluoride concentrations in the surface waters of the field tanks fluctuated within a fairly constant range throughout the experiment, possible due to seasonal fluctuations in the volume of water above the tailings.

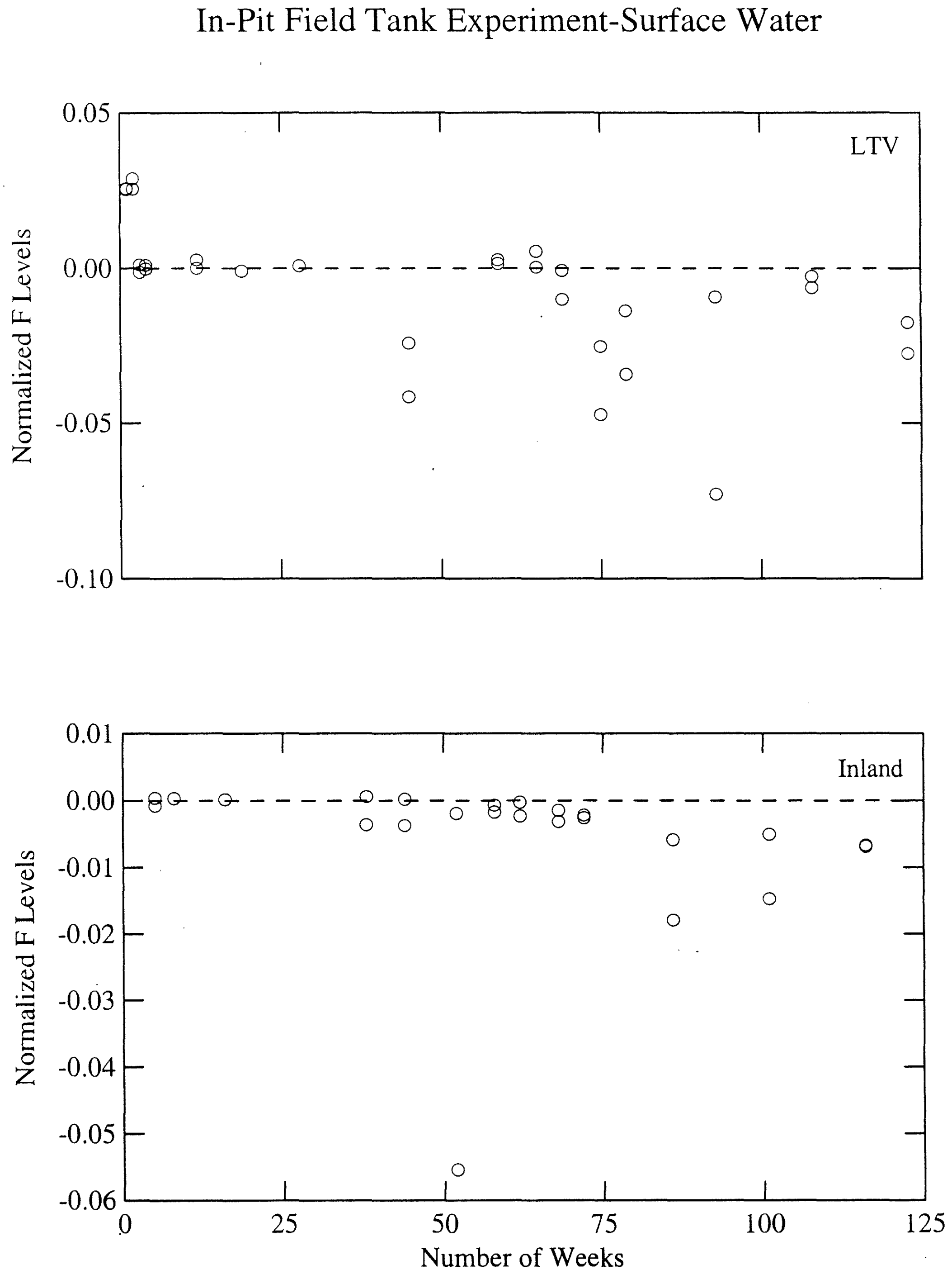


Figure 9. Fluoride removal from surface waters of the tank experiments occurred after approximately seventy weeks had passed. The dashed line represents the fluoride to chloride ratio that should be maintained despite seasonal variations in water levels ($R_{t=i}$ - $R_{t=0\text{-}4,avg}$).

In-Pit Tank Experiments - Surface Water

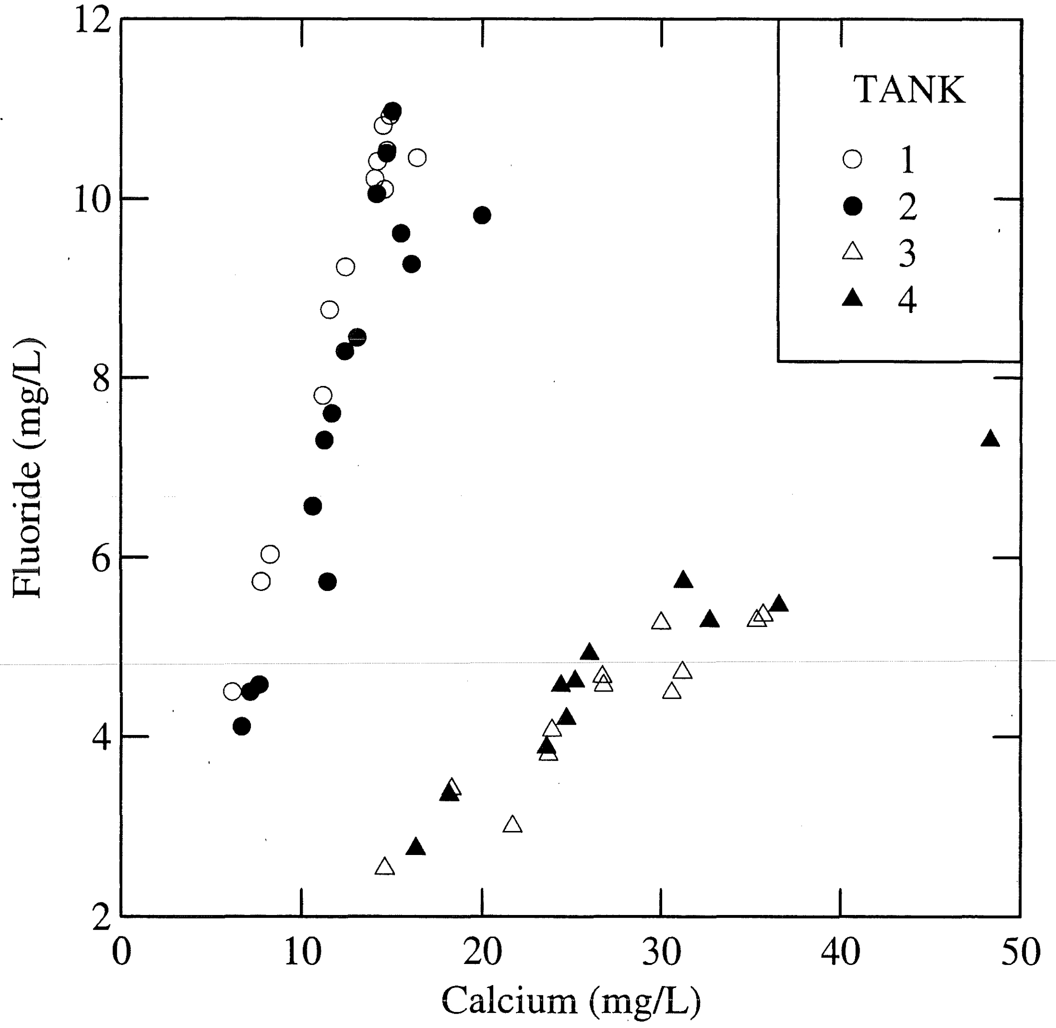
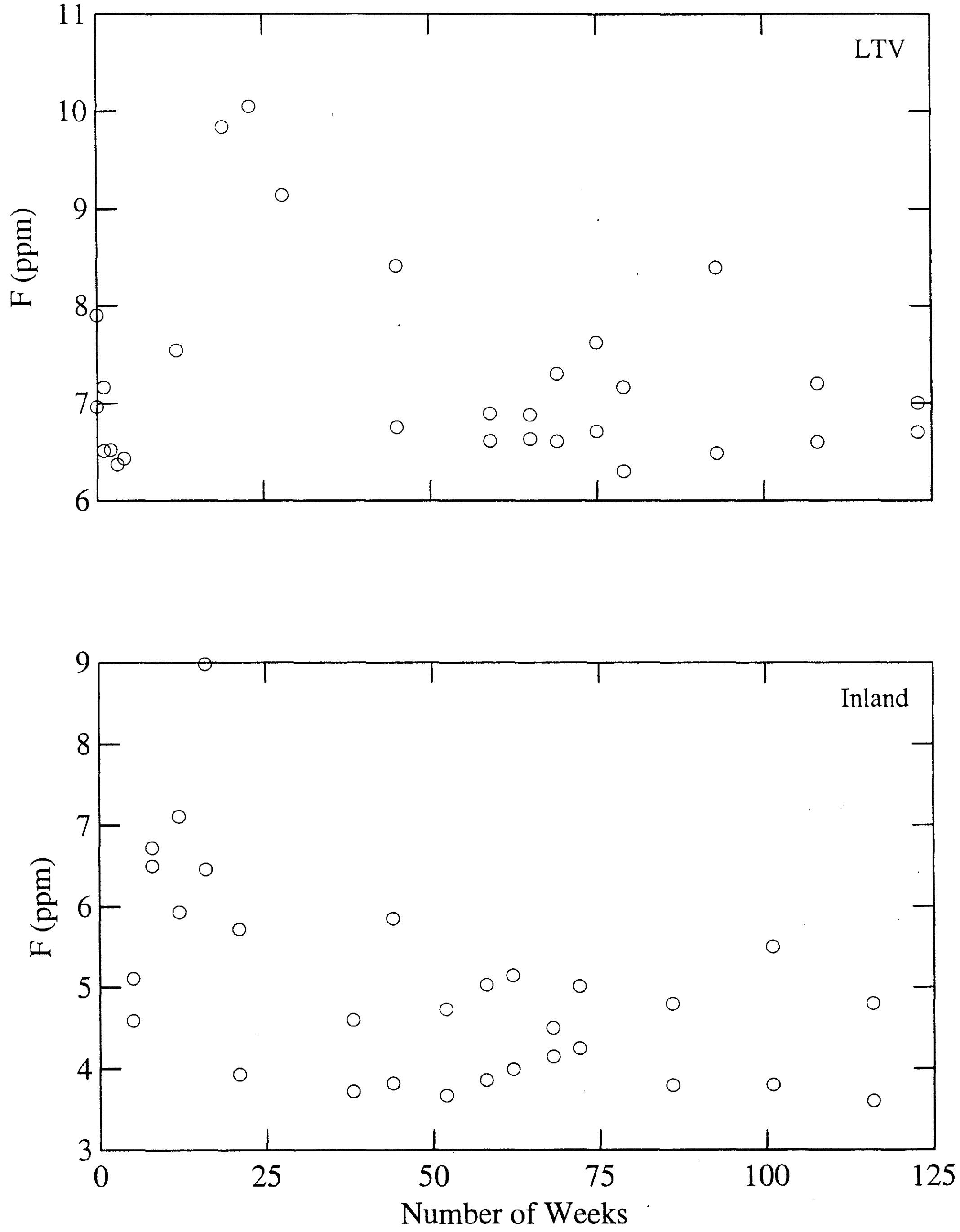


Figure 10. High fluoride concentrations in surface waters above taconite tailings corresponded with high calcium concentrations. Thus, fluoride levels in these waters do not appear to be controlled by the solubility of fluorite, CaF_2.



Field Tank Experiments-Tailings Pore Water

Figure 11. After an initial increase, fluoride levels in tailings pore waters decreased to a fairly constant concentration for the duration of the experiment.

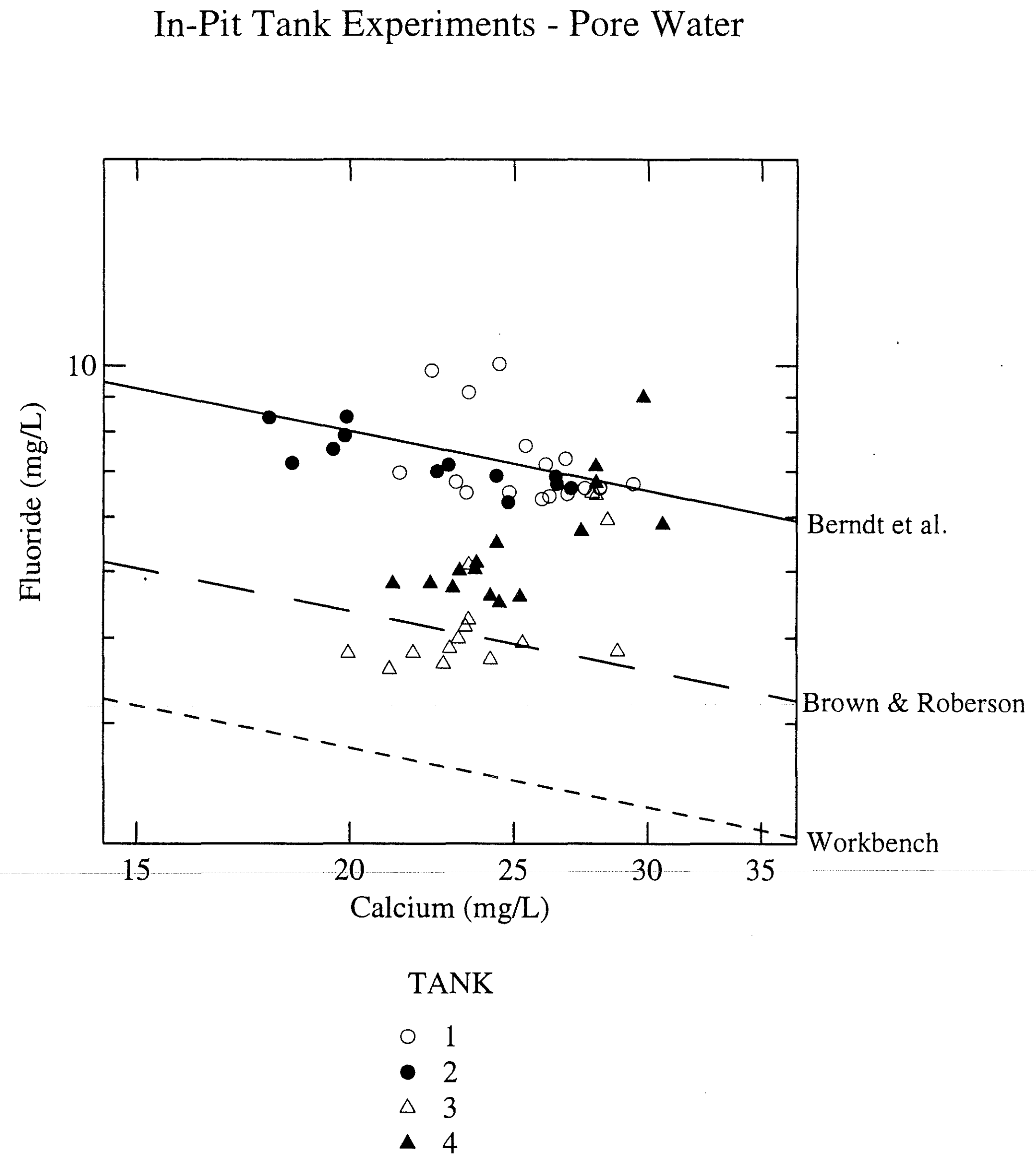


Figure 12. Tailings pore waters in contact with LTV's tailings closely matched the empirical K_{sp} calculated by Berndt et al. (1999), indicating that fluoride levels in these waters may be controlled by the solubility of fluorite. This implies that Inland's tailings pore waters are undersaturated with respect to fluorite solubility.

Field Tank Experiment-Surface Waters

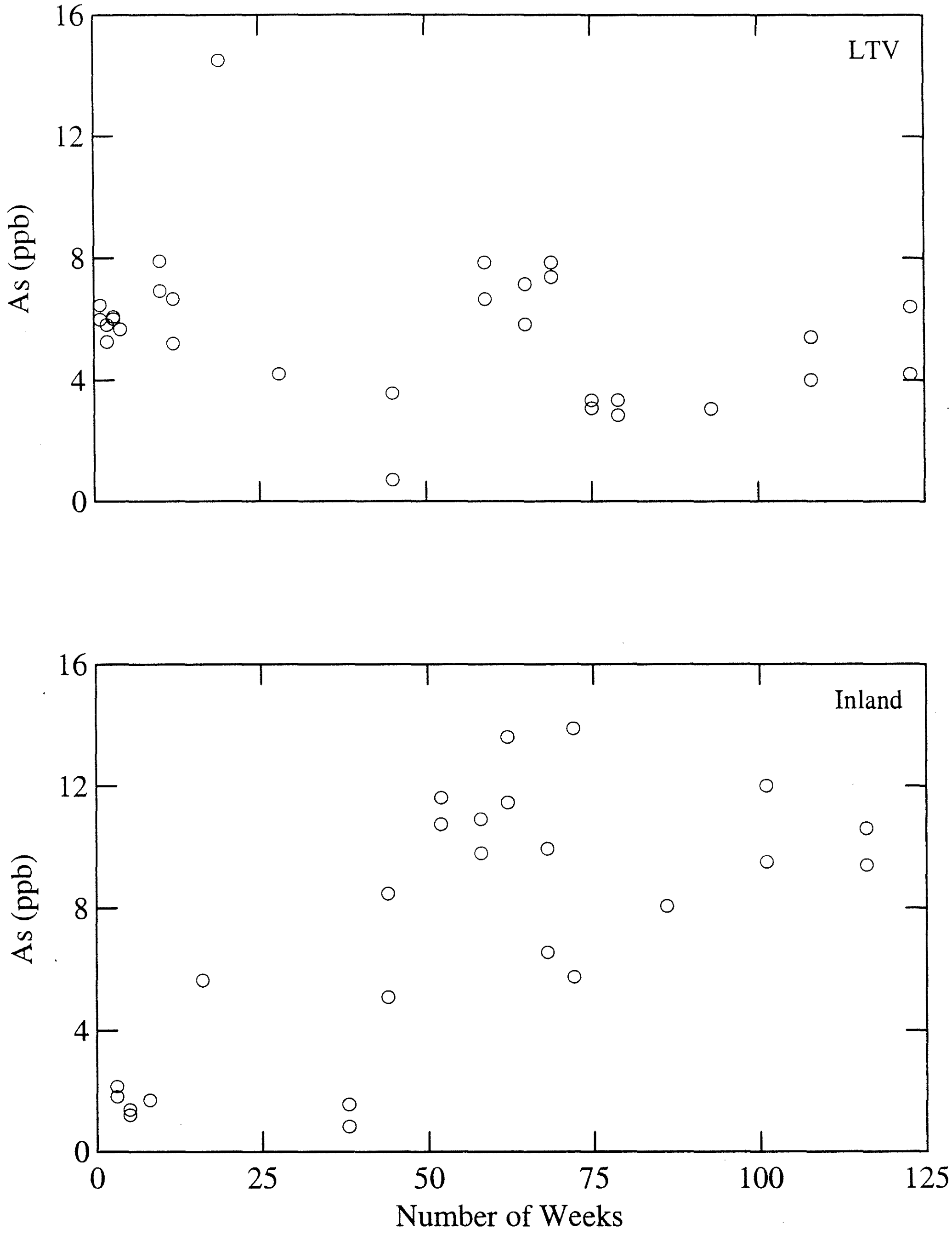


Figure 13. Arsenic levels in the surface waters above LTV's tailings fluctuated within a fairly constant range, averaging 5.6 ug/L. There appeared to be a substantial increase in surface waters in contact with Inland's tailings.

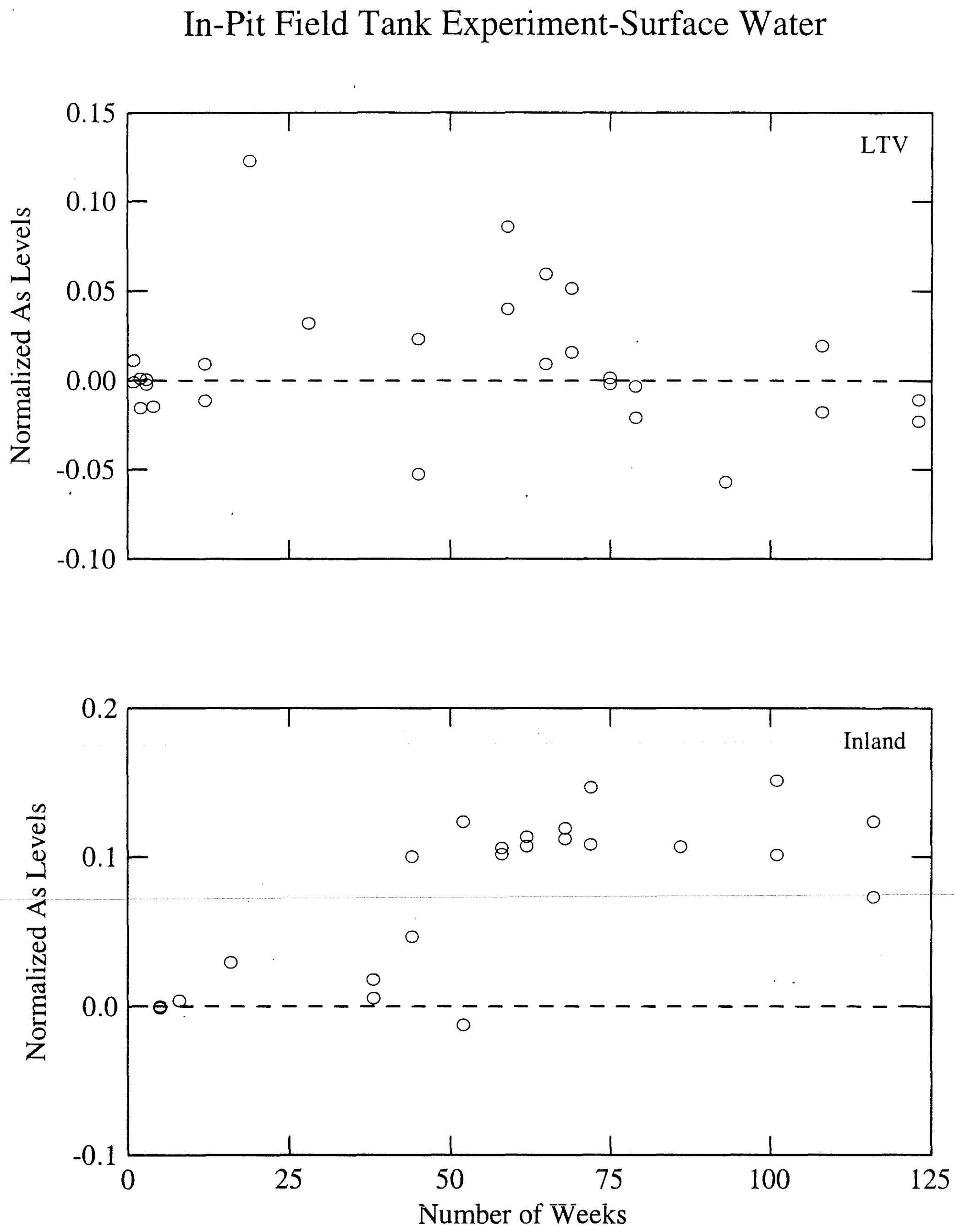


Figure 14. After normalizing arsenic concentrations to chloride, it is clear that increasing arsenic concentrations in surface waters above Inland's tailings were due to chemical reaction rather than seasonal events. The most likely explanation is that arsenic was released during the oxidation of sulfide minerals present in the tailings. The variation observed in the LTV tanks were probably controlled by an adsorption mechanism.

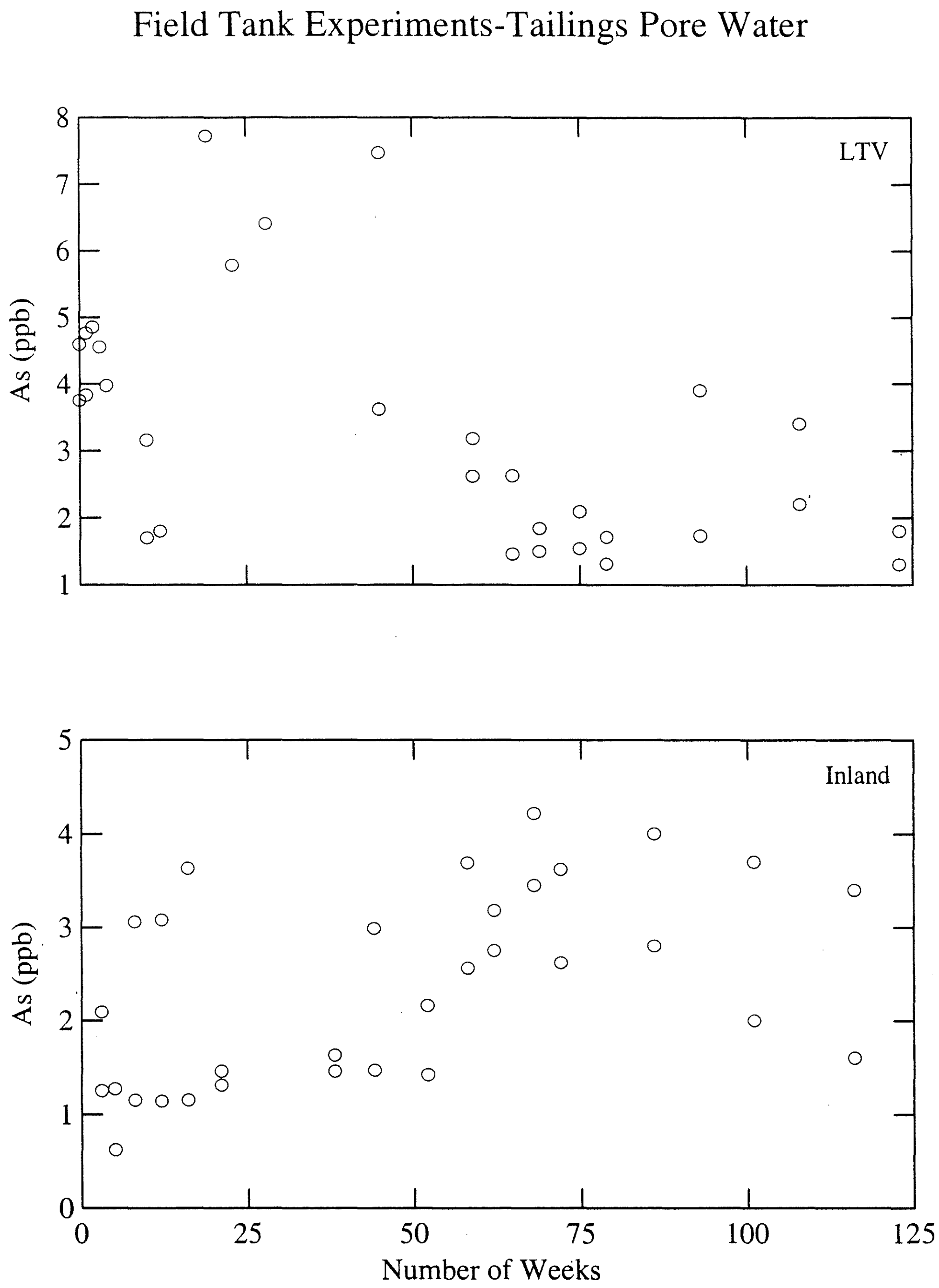


Figure 15. Arsenic concentrations in taconite tailings pore waters were relatively stable, averaging 2.3 ug/L. Even after surface waters infiltrated tailings pore spaces in the LTV tanks (week 19), arsenic concentrations rapidly returned to approximately 2 ug/L. The controlling mechanism is believed to be adsorption to iron oxides present in the tailings.

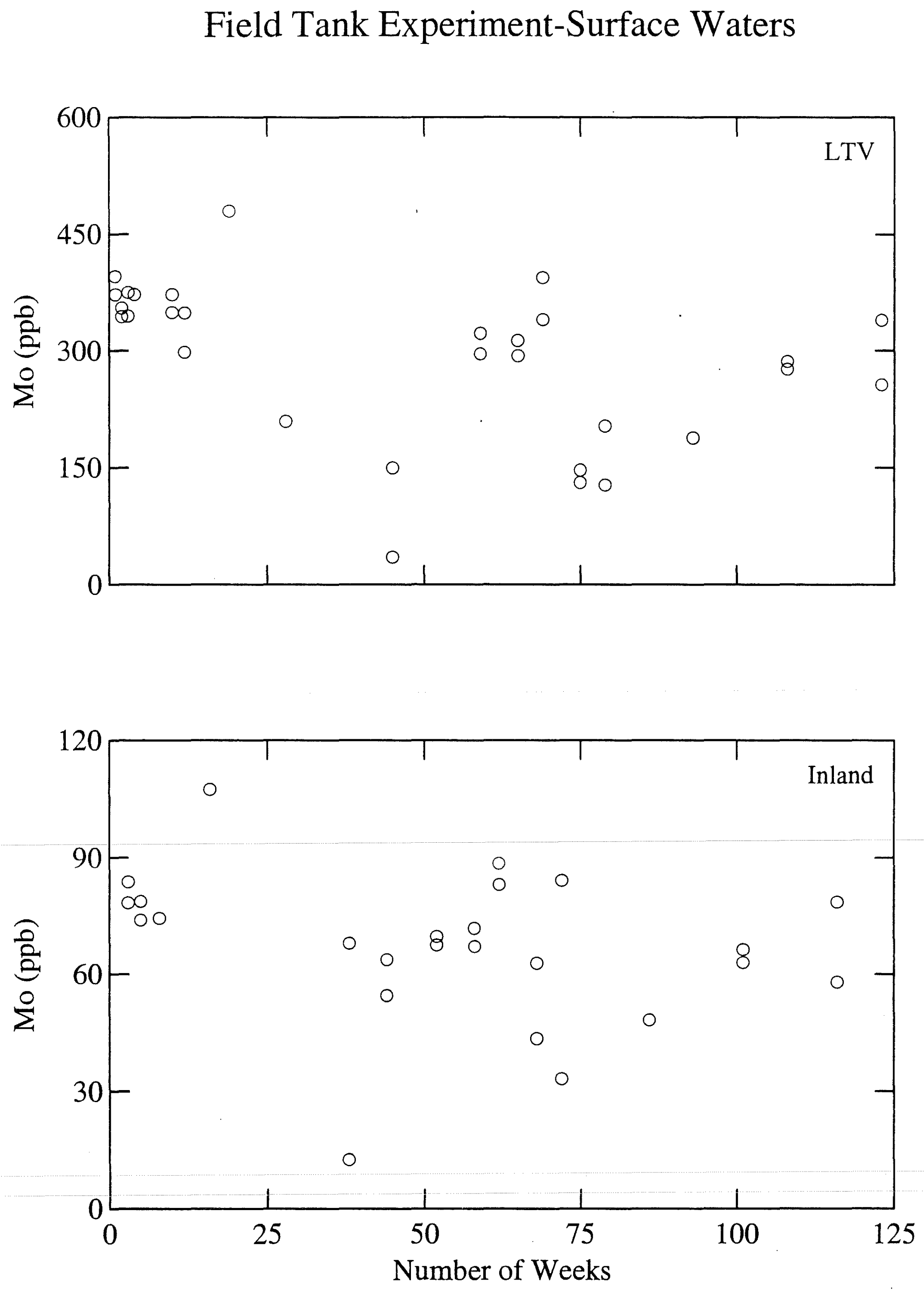


Figure 16. Molybdenum concentrations in surface waters above taconite tailings were elevated. However, they appeared to gradually decrease over time.

In-Pit Field Tank Experiment-Surface Water

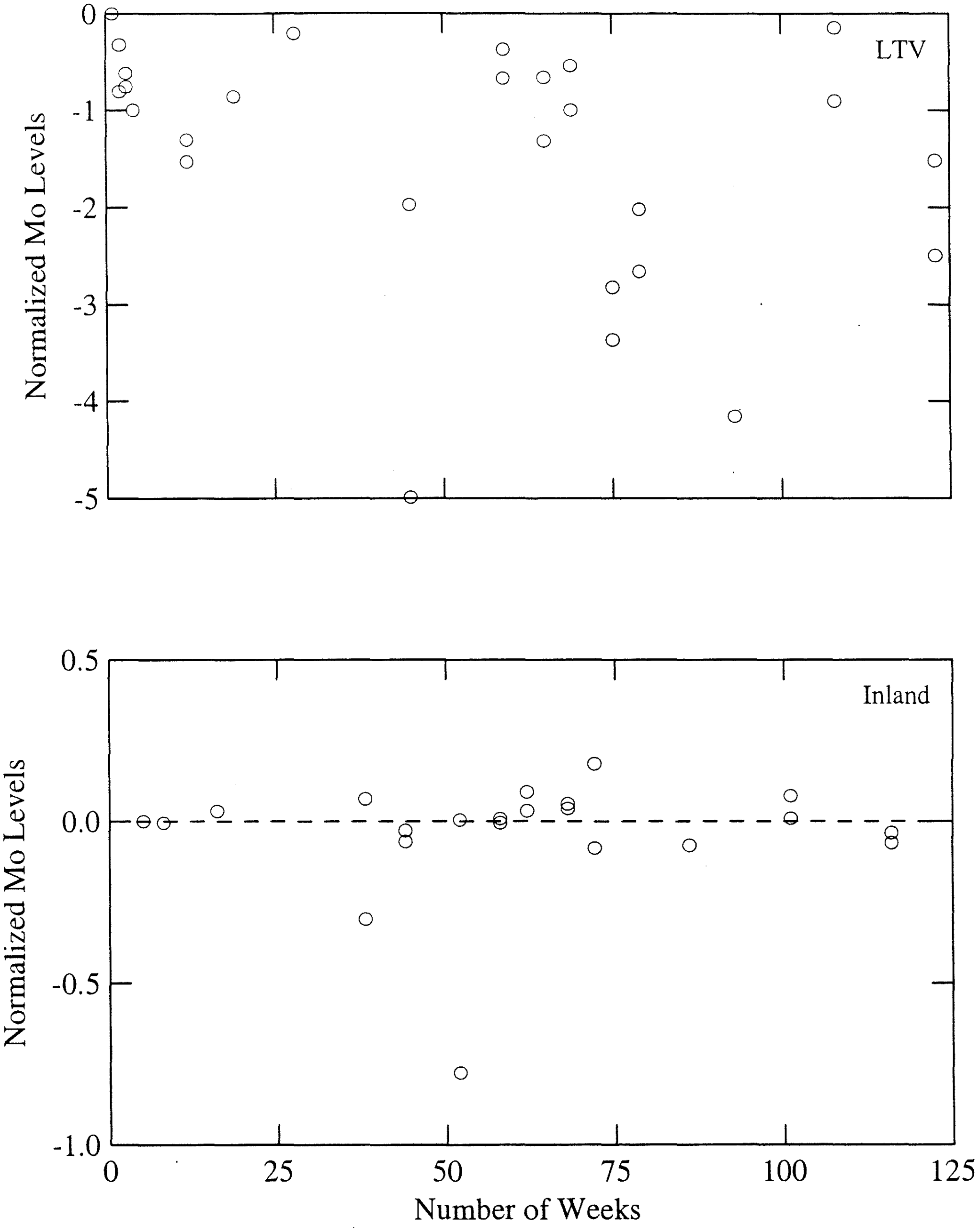


Figure 17. Normalization of molybdenum concentrations suggested significant removal from surface waters above LTV's tailings. However, fluctuations in molybdenum levels in waters associated with tailings from Inland were probably due to seasonal effects.

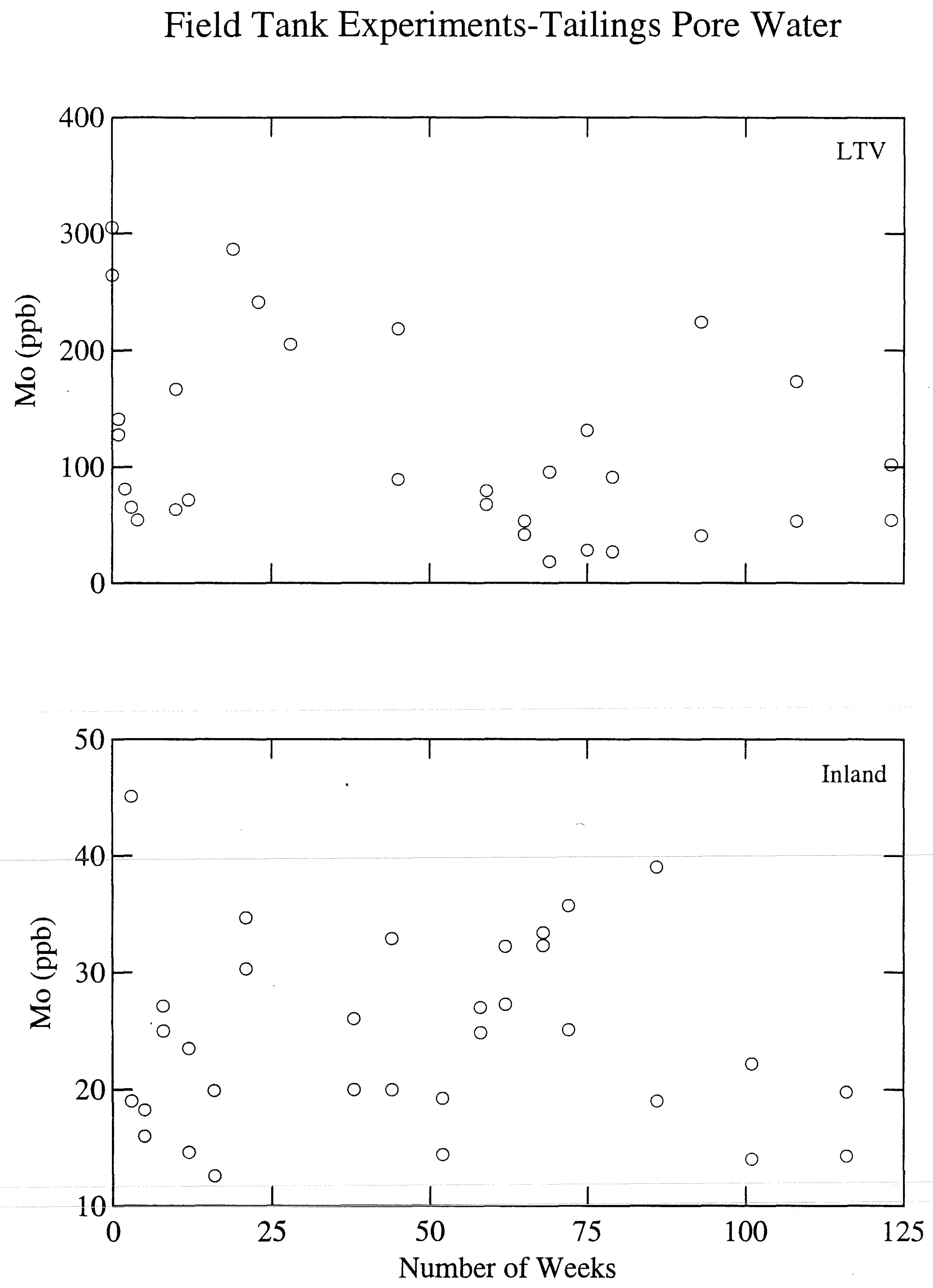


Figure 18. Molybdenum removal due to adsorption to iron oxides was apparent in LTV tailings pore waters. However, molybdenum levels in Inland's tailings pore waters remained fairly constant, averaging 25 ug/L.

Field Tank Experiment-Surface Waters

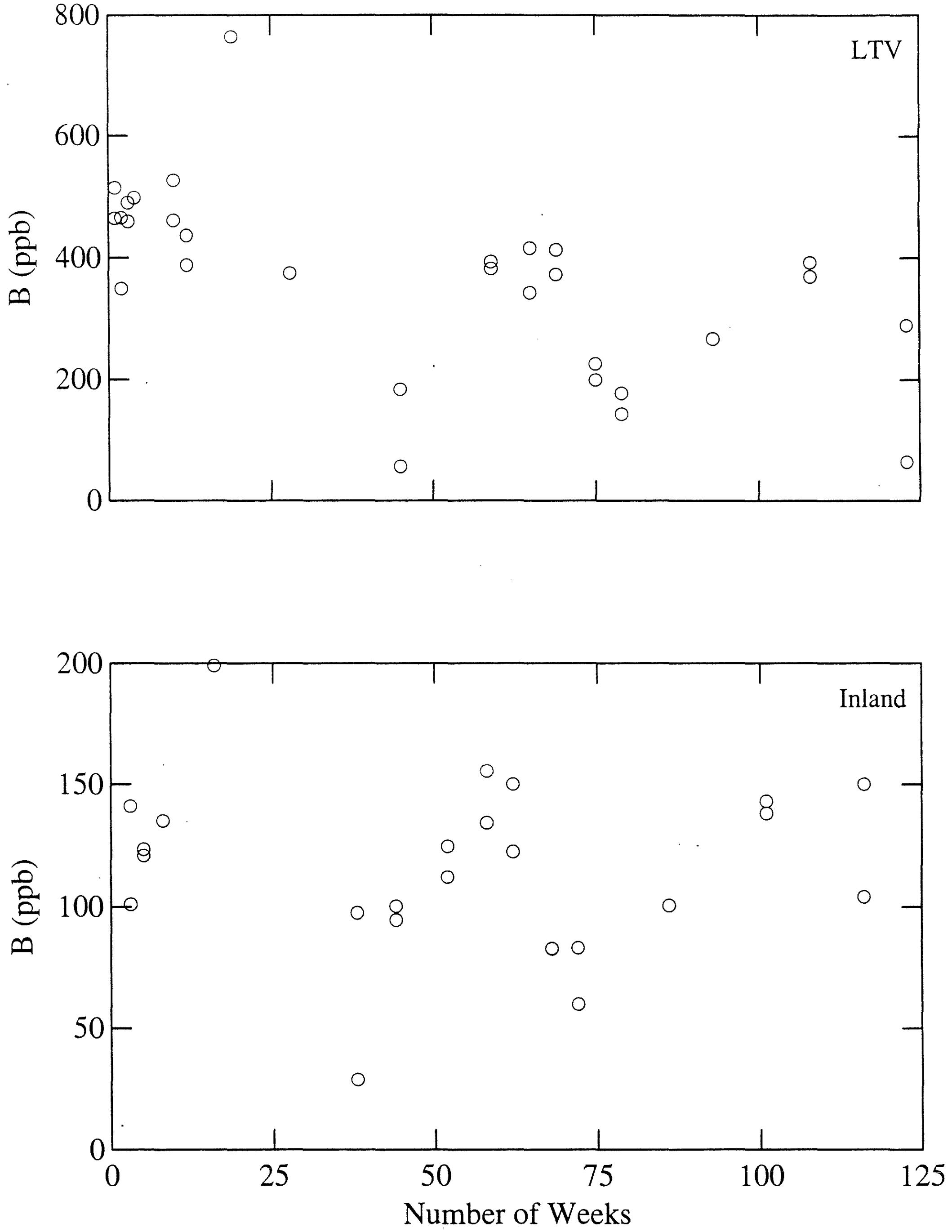


Figure 19. Boron concentrations fluctuated in surface waters above the tailings. However they appeared to decrease slightly over time in the LTV tanks.

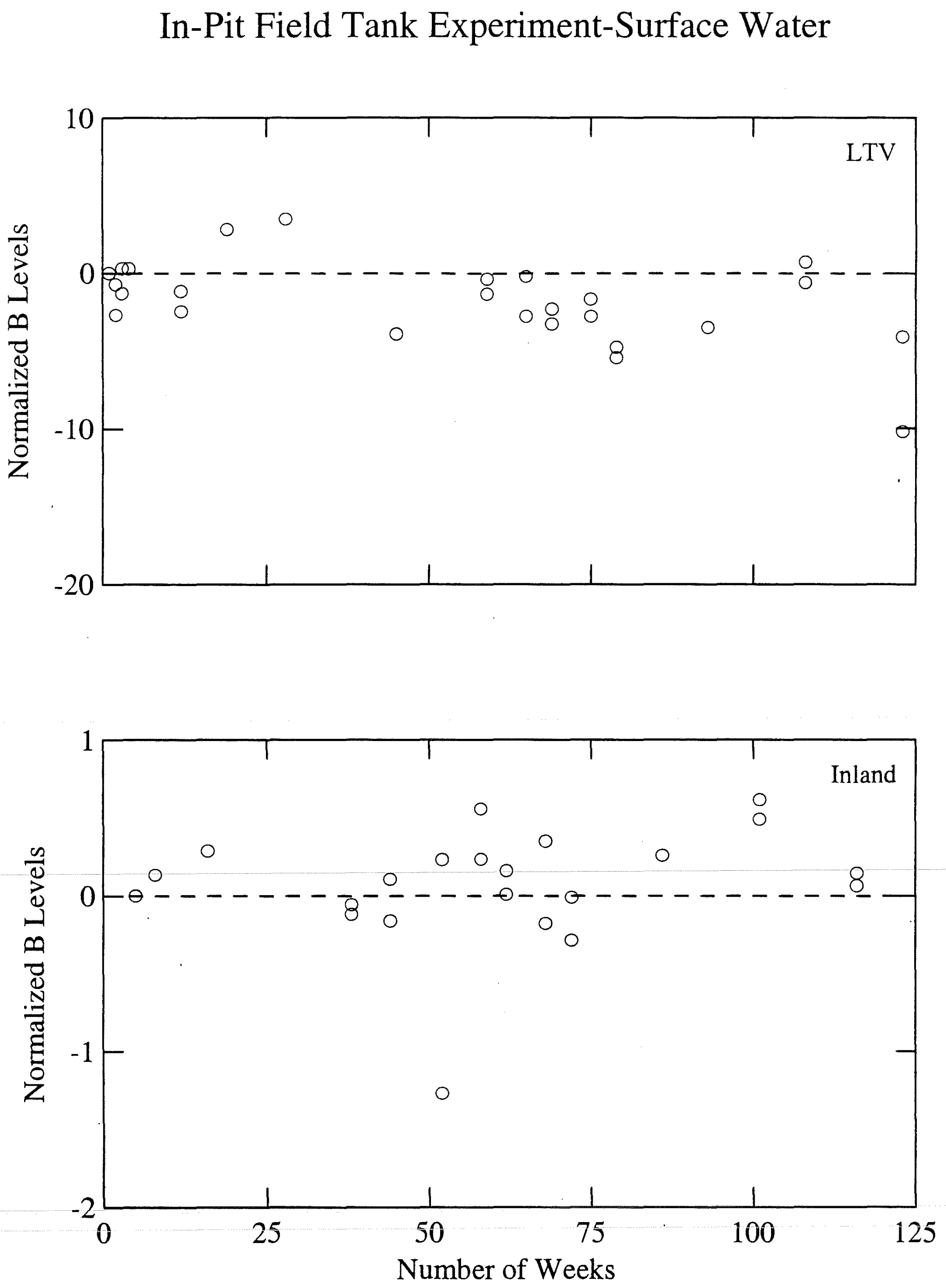


Figure 20. After approximately 50 weeks, boron appeared to be removed from surface waters above LTV's tailings. The most likely mechanism for this is adsorption to clay minerals. Fluctuations in boron levels associated with Inland's tailings were probably due to seasonal events.

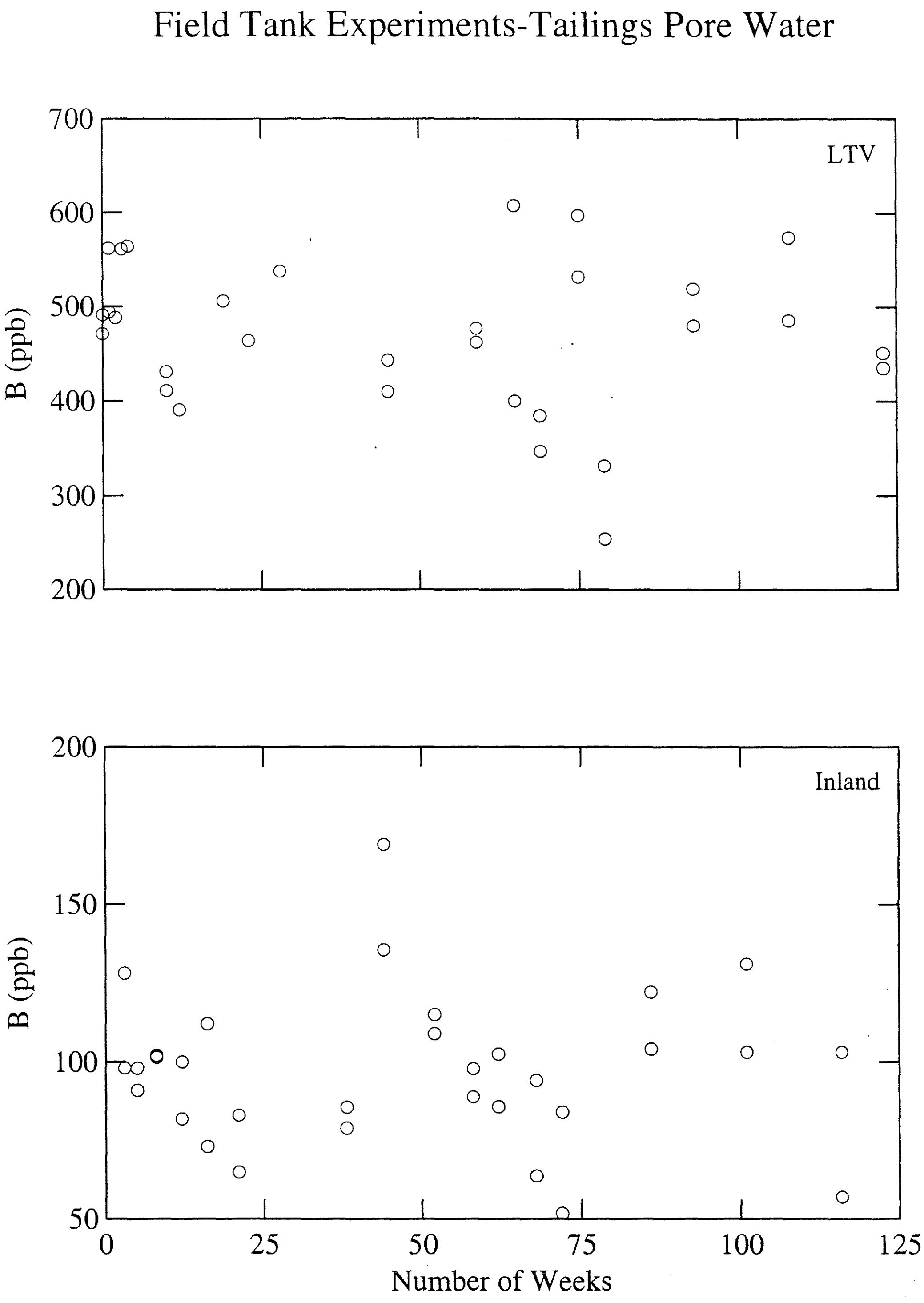


Figure 21. Boron concentrations varied widely in taconite tailings pore waters. Overall, however, they remained fairly constant, averaging 470 ug/L and 97 ug/L for LTV and Inland, respectively.

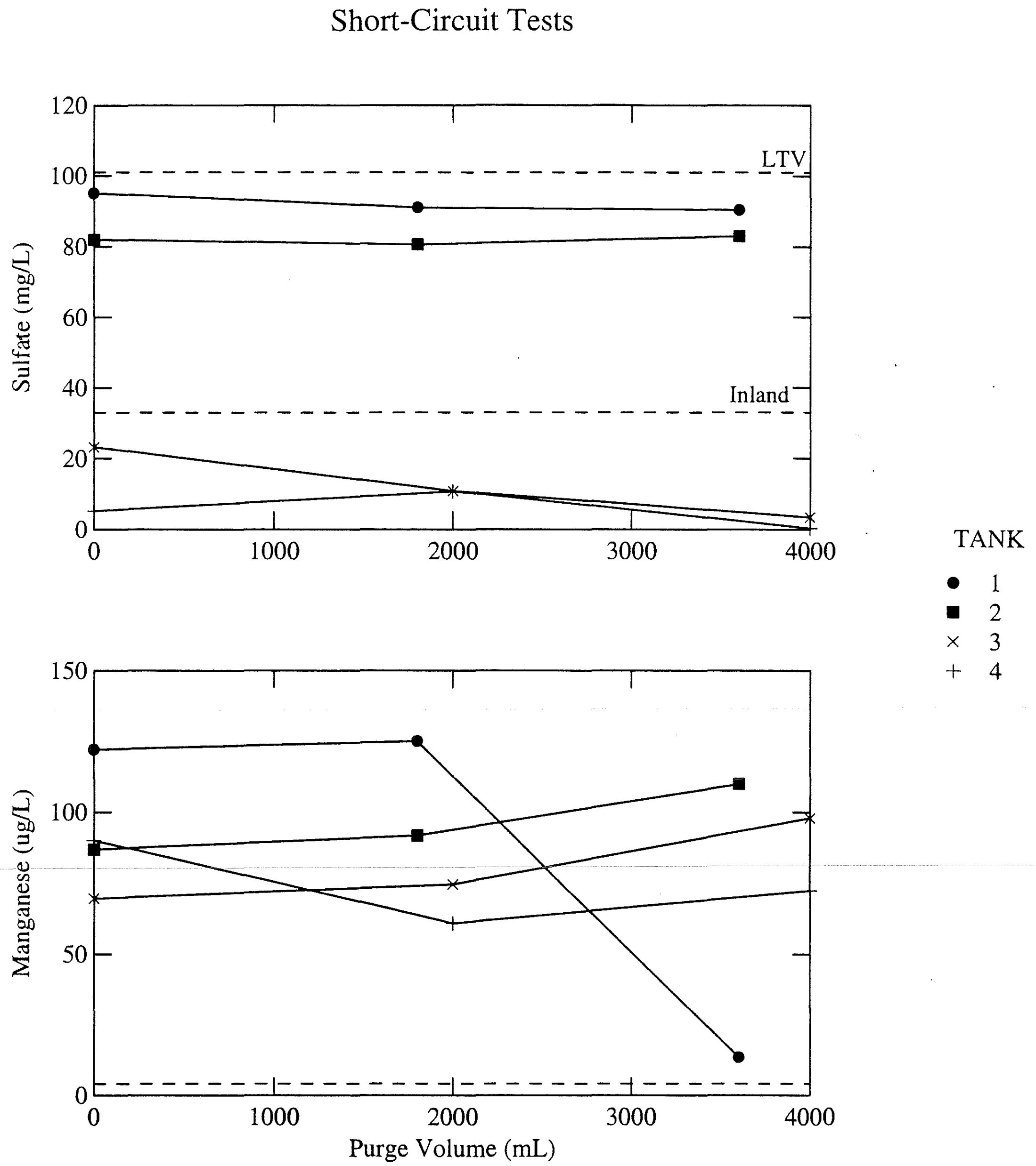


Figure 22. Low sulfate and elevated manganese concentrations in tailing pore waters relative to average concentrations in surface waters (dashed lines) suggested that reducing conditions existed in the tailings mass. These results indicate that short-circuiting of surface waters did not occur in the tank experiments. Tanks 1 and 2 contained tailings from LTV. Tanks 3 and 4 contained tailings from Inland.

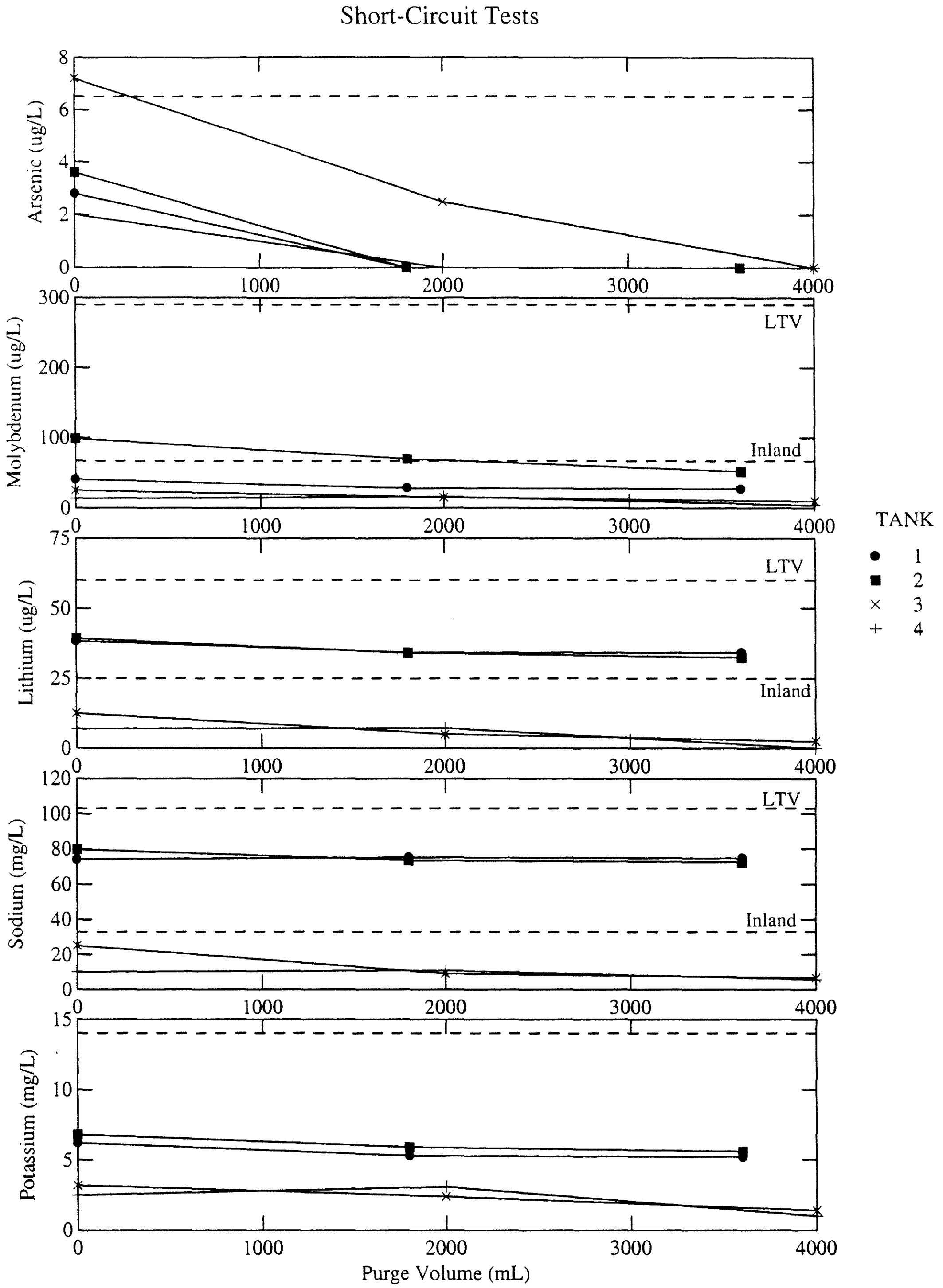


Figure 23. Concentrations of elements that adsorb to iron oxides in tailings generally decreased with each purge volume rather than approaching the average surface water composition (dashed lines). Thus, short-circuiting of surface waters was not apparent. Tanks 1 and 2 contained tailings from LTV. Tanks 3 and 4 contained tailings from Inland.

Comparison of LTV and Inland Tailings Pore Water Chemistry
Trace Elements

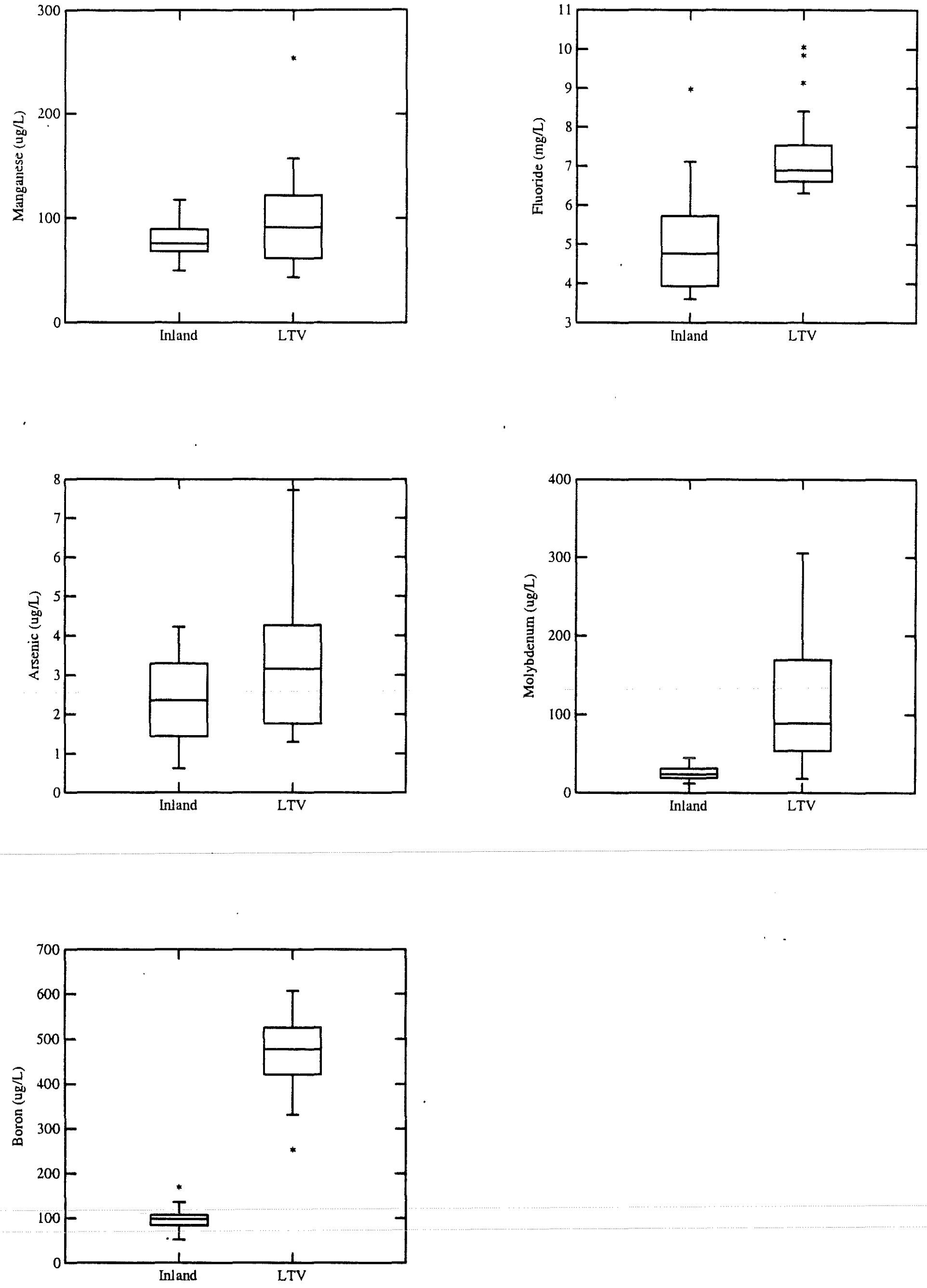
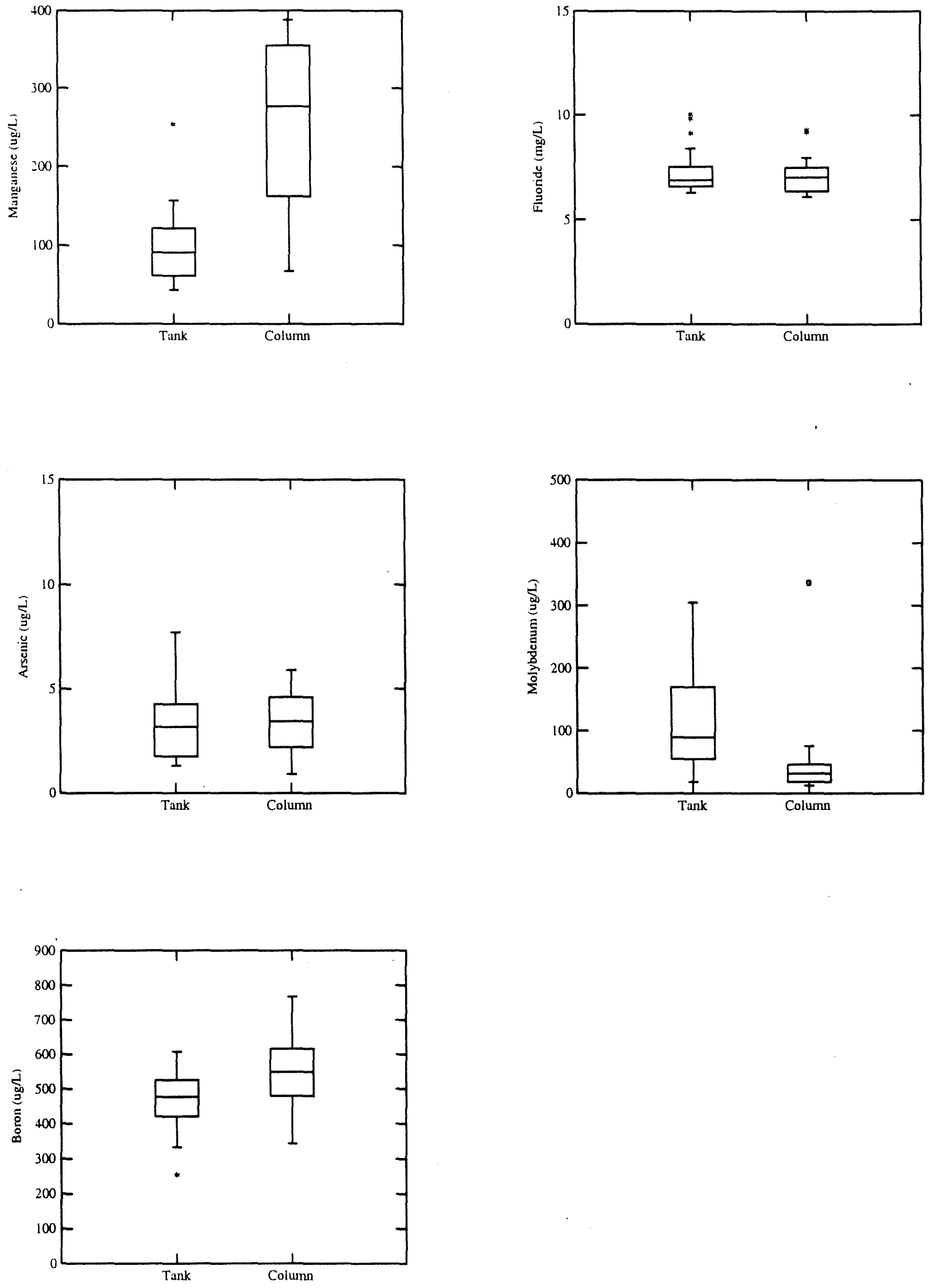
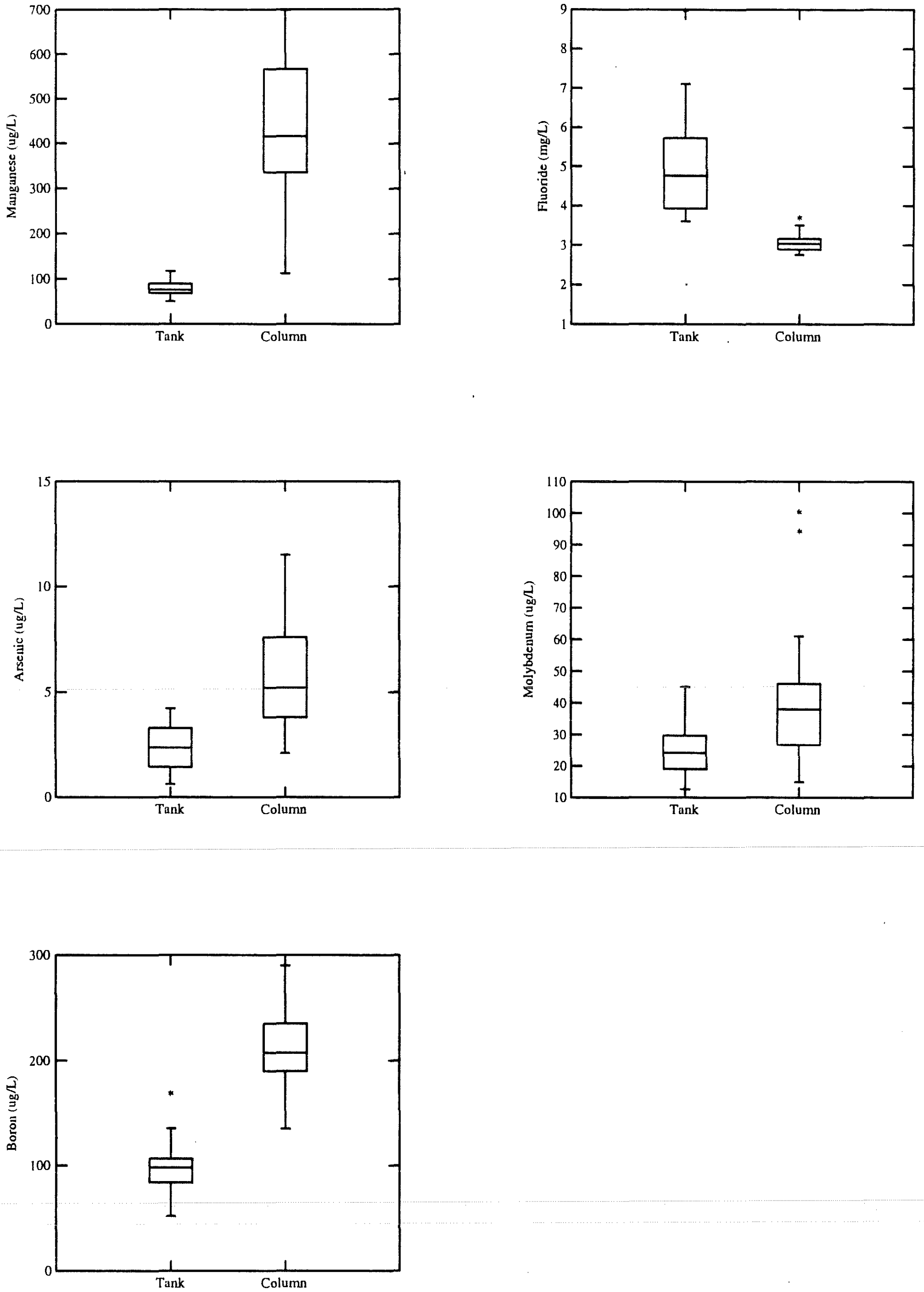


Figure 24. Manganese and arsenic appeared to be independent of the taconite tailings source. However, pore waters in contact with tailings from LTV contained higher levels of fluoride, molybdenum, and boron than Inland's tailings pore waters.



Comparison of LTV Tank and Column Experiments
Trace Elements

Figure 25. Trace element chemistry between field tank and laboratory column experiments using tailings from LTV was similar. Slightly lower manganese levels in the tank experiments were believed to be caused by a slightly higher pH in tank pore fluids.



Comparison of Inland Tank and Column Experiments
Trace Elements

Figure 26. In general, tailings pore waters from tank experiments using tailings from Inland contained lower concentrations of most dissolved constituents than in the process water column experiments.

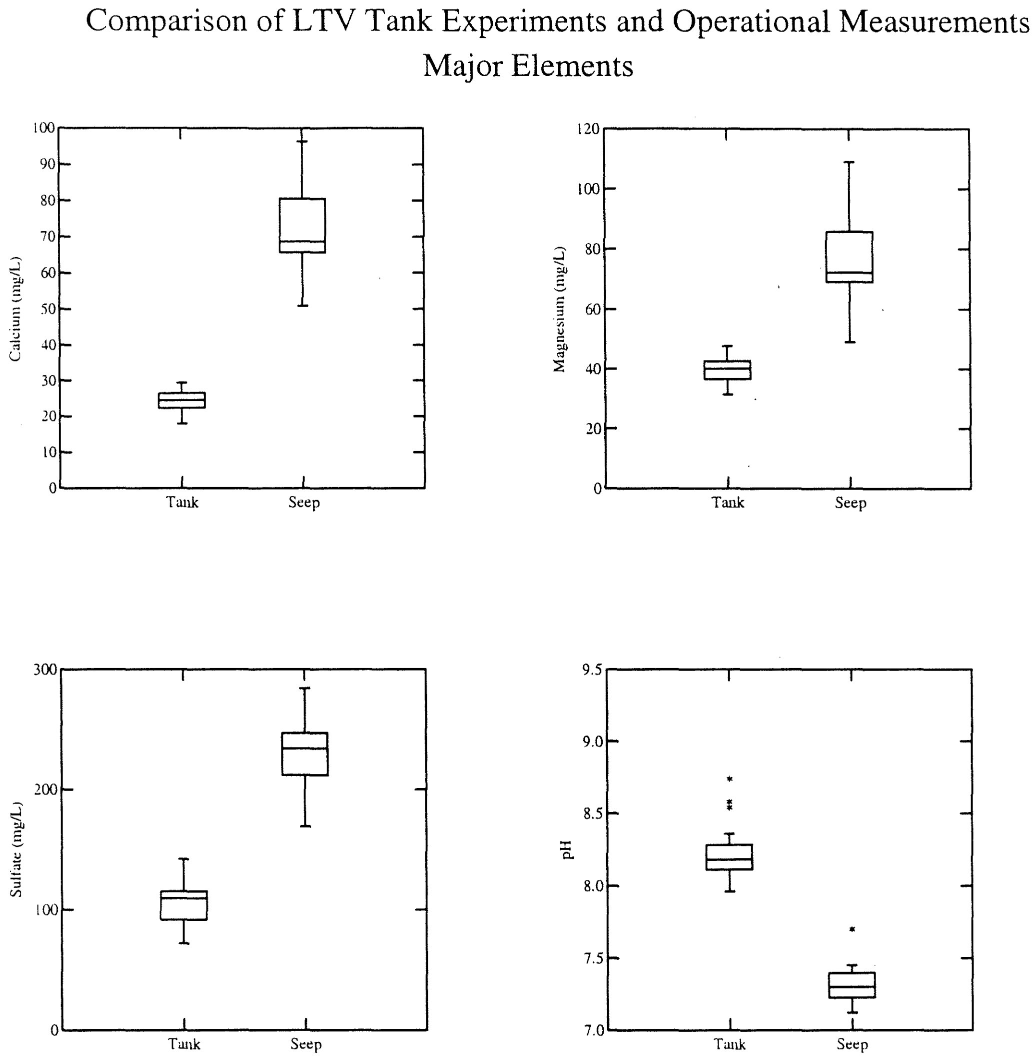

Comparison of LTV Tank Experiments and Operational Measurements
Major Elements

Figure 27. Differences in major element water chemistry between the tank experiments and operational measurements at LTV resulted from differences in reaction environment. Oxidation of sulfidic material buried in the tailings basin resulted in lower pH and elevated calcium, magnesium, and sulfate in waters seeping from the basin relative to the tank experiments.

Comparison of LTV Tank Experiments and Operational Measurements
Trace Elements

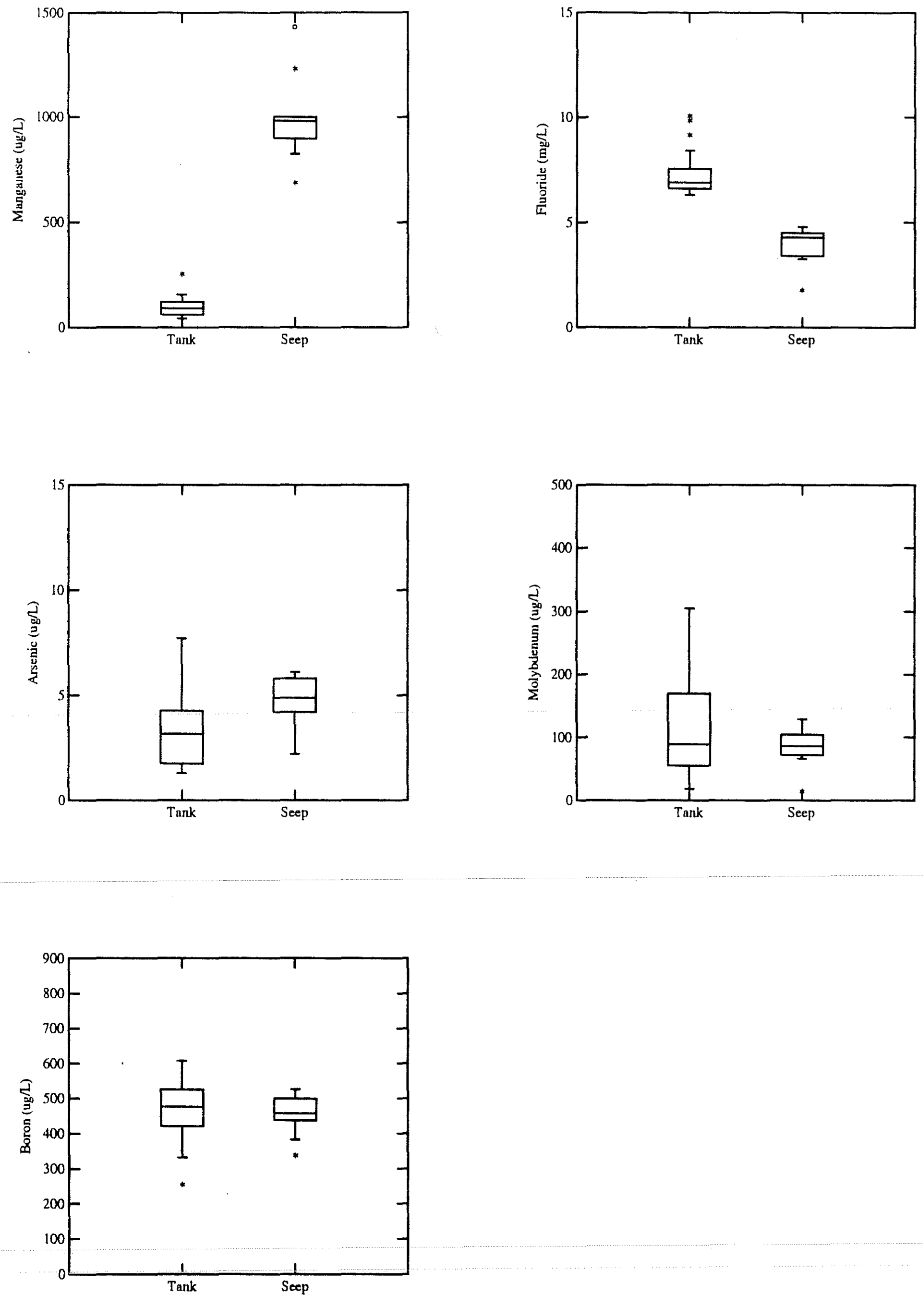


Figure 28. Manganese and fluoride levels in tailings pores of the tank experiments differed from those observed at LTV's tailings basin due to differences in reaction environment (i.e. sulfide oxidation). Arsenic, molybdenum, and boron were unaffected by these differences.

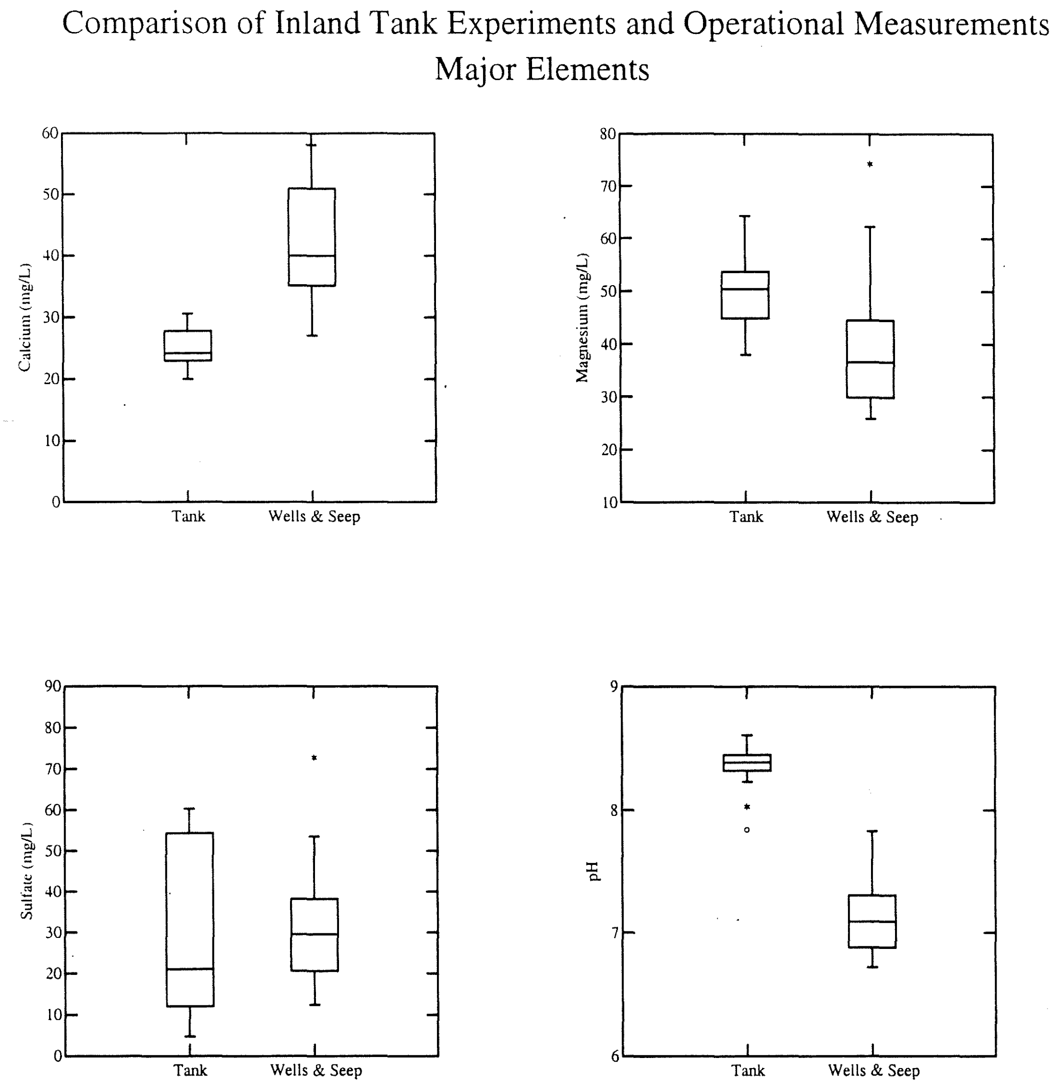

Comparison of Inland Tank Experiments and Operational Measurements
Major Elements

Figure 29. Differences in major element water chemistry between the tank experiments and operational measurements at Inland resulted from differences in reaction environment. Oxidation of organic material in the substrate beneath the tailings and siderite present in the tailings probably resulted in lower pH in waters seeping from the basin relative to the tank experiments.

Comparison of Inland Tank and Column Experiments
Trace Elements

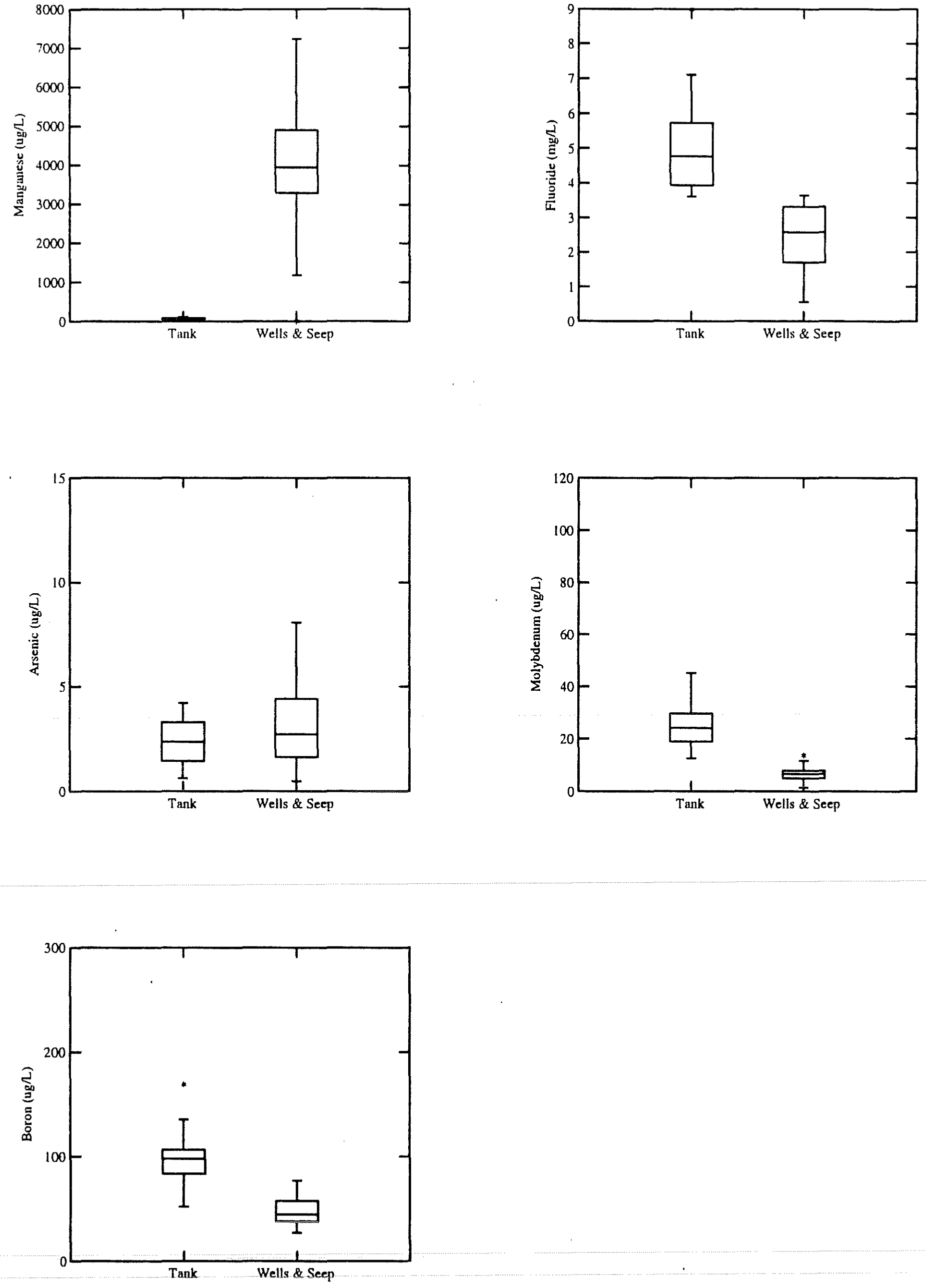


Figure 30. Manganese, fluoride, molybdenum, and boron levels in tailings pores of the tank experiments differed from those observed at Inland's tailings basin due to differences in reaction environment (i.e. organic matter and/or siderite oxidation). Arsenic was unaffected by these differences.

Appendix 1

Tank Experiment Time Lines

A1.1. Time line for the LTV tank experiments
A1.2. Time line for the Inland tank experiments

A1.1. LTV TAILINGS

09/13/96 - Filled cement truck with tailings from LTV's spigot line to the tailings basin. The truck was initially filled half full, rinsed for five minutes, and then emptied. There was no noticeable traces of cement from the truck. A five gallon pail of tailings from Area 2 West was added to the fresh tailings for seed. Filled Tank 1 and then Tank 2 with 29" of slurry, . There was approximately 10-12" of water above the coarse tails. Waited 45 minutes and filled Tank 2 to a depth of 53", there were still coarse tailings present. Filled Tank 1 to a depth of 53", the majority of which was water and fine tailings. Measurements of the depth of coarse tailings at this time were 21" in Tank 1 and 35" in Tank 2. The tanks were allowed to sit for 45 minutes and then filled to a depth of approximately 85" with mostly water and fine tailings. Since the slurry was relatively uniform the remainder of the tanks were filled after 15 minutes. The depth of coarse tailings in Tank 1 was 25" and Tank 2 was 39". A composite sample was taken from each of the four tailings additions for both tanks. At this time there was no way to determine how much the fine tailings would add to the overall bed depth. It was decided that to achieve the desired bed depth that we would need more tailings.

09/16 - Pumped approximately 72" of water out of each tank to make room for more tailings. The cement truck was not rinsed before the tailings addition due to problems encountered with the piping plugging during the first sample. There was still no noticeable cement when the tailings were emptied into the tanks. To ensure that we had plenty of tailings this time around, Geno did us the favor of overloading the truck and thus giving us a higher coarse tailing to fine tailing ratio than the first load. Started filling Tank 1 with the hopes of obtaining a similar bed depth of coarse tailings in both tanks. Added approximately three feet to both tanks and then filled them to within a foot of the top of the tank. The coarse tailings depths were 60" in Tank 1 and 65" in Tank 2. A composite sample was taken from both tanks.

09/18 - Week 0 sampling: Sampled tanks 1 and 2 using the value sampling apparatus (Figure 1). The initial purge volume was measured in a graduate, the sample was taken, and then the remaining water in the line was measured and added to the purge volume. The flow rate was based on the time the valve was opened to the end of the sample when the valve was closed. Surface samples were taken approximately 6 - 8" below the surface. The tailings measurements were to the top of the coarse tailings. It was difficult to determine the depth of fine fluffy tailings above the coarse due top cloudy water conditions, a reasonable estimate was 6" based on the amount of tailings on the sample rod.

09/25 - Tank 1: Middle Port - Flow started fast then decreased, sample was very cloudy with tailings present. Bottom Port - Flow started fast then decreased, sample was very cloudy with tailings present. Tank 2: Middle Port - No flow surge, flow was constant and clear. Bottom Port - Very fast flow, cloudy with some tailings present.

10/02 - Tank 1: Middle Port - Slow flow, cloudy with tailings present. Bottom Port - Flow started fast then decreased, sample was very cloudy with tailings present. Tank 2 : Middle Port - Flow was slow, constant, and clear. Bottom Port - Flow was slow, constant, and clear.

10/03 - Since the depth of tailings in tanks 1 and 2 would not leave much room for water above the tailings if the tanks froze to a depth of four feet, it was decided to remove a portion of the bed depth. The fine tailings were stirred until the majority of the tailings were suspended and then pumped to a holding tank using a submersible pump. The tanks were pumped down to the top of the coarse tailing leaving only traces of fine tailings on the surface. 14" of coarse tailings were removed from Tank 1 and 24" from Tank 2, which left 48" of coarse tailing in each tank. There was very little sign of fine tailings mixed in with the coarse. The coarse tailing was very compact when stood on. The water and fine tailings were then pumped back into the tanks.
Both tanks were about 100 gallons shy of the desired water depth so additional water was obtained from LTV's Area 2 West tailings pond and added to the tanks.

10/10 - Tank 1: Middle Port - Slow flow with some cloudiness. Bottom Port - Slow flow and clear. Tank 2: Both valve stems were broken so only a surface sample was collected.

10/16 - Tank 1: Middle Port - Slow flow and clear. Bottom Port - Flow started fast and then decreased, medium cloudiness present.

10/29 - Due to the valve failure on 10/10, new sampling wells were installed in tanks 1 and 2 (Figure 2). The wells are constructed of 1" ID PVC pipe with a 3" section of slotted well screen (.012" slots) positioned at the sample points. The wells consist of two sections, the bottom permanent section containing the well screen is 63" in height and is equipped with a female PVC fitting for securing the upper section during sampling and an end cap between sampling periods. The purpose of the end cap is to stop oxygen transport down the wells between sample periods. These wells will be used at least throughout the winter months.

11/27 - Sampled both tanks using the new sampling method. SAMPLING METHOD (winter months): A hole was drilled in the ice directly above the sample ports. The end cap was removed and the upper well section was screwed into the female fitting. A 1/4" PVC pipe equipped with a 1/4" hose adaptor to which Tygon tubing was attached and used as a feed line to a Model 107090-10 Delrin plastic Guzzler pump was inserted down the well to remove the sample (Figure 3). A predetermined purge volume was removed and the appropriate samples taken. The sampling device was rinsed with distilled water between samples. Depth of the tailings bed was determined and the end cap was reinstalled. When placing the PVC pipe down the wells to remove the bottom samples in both tanks it felt like there was about 4 - 5" of tailings in the well screens. The bottom samples from both tanks were cloudy and contained tailings, the middle samples from both tanks were slightly cloudy with very little tailings.

12/12 - Tank 1: Middle Port - Purge volume was very cloudy and well was pumped dry after removing 780 mLs. Bottom Port - The upper sampling section was cross-threaded and didn't seal to allow for removal of the purge volume or sample. When attempting to remove the upper section the entire well began moving so the well was left in place until 12/13 at which time the tailings had resettled around the well and stabilized it to allow removal of the upper section. No sample was taken from this port. Tank 2: Middle Port - Purge volume was very cloudy and well was pumped dry. Bottom Port - Purge volume was slightly cloudy and was pumped dry.

01/30/97 - Tank 1: Ice thickness = 19". Water depth = 101". Bottom Port - Started very cloudy then began to clear up. Tank 2: Ice thickness = 7". Water depth = 103". Started very cloudy then began to clear up.

02/26 - Purge volume of 1500 mLs for both tanks. Tank 1: Ice thickness = 18". Water depth =100". Tank 2: Ice thickness = 9". Water depth = 103" Used a new Eh electrode, check BLM notebook for reference check results.

04/02 - Purge volume of 1500 mLs for both tanks.

07/31 - The data from both tanks is confusing. One explanation for this could be that the sample water was being pulled from the surface down the well to the sampling port. In order to address this problem both wells were removed from both tanks for redesign. When removing the wells from tank 2 it was discovered that there was a mixup in the well identification. The bottom port was being sampled as the middle port and vice versa.

10/24 - Installed the bottom sampling wells in both tanks. A flange was added to the sampling wells just below the surface of the tailings to prevent preferential flow down the well during pumping. The flanges were installed 16.5" below the top of the stand pipes.

11/05 - Tank 1: The purge and sample volumes were very cloudy with fine tailings present. Tank 2: The purge and sample volumes were slightly cloudy.

12/17 - Tank 1: Ice thickness = 2". Purge and sample volumes were clear. Tank 2: Ice thickness = ½". Purge volume was slightly cloudy.

01/15/98 - Tank 2: Purged 1200 mLs and port went dry, waited for port to recharge and took remaining purge volume before sampling. Samples from both tanks were cloudy. Ice thickness on both tanks was 10 - 12".

02/26 - Both purge volumes were slightly cloudy. Ice thickness on both tanks was 12".

03/26 - Ice thickness on both tanks was about 10" and free floating.

7/1/98-Tank 1; Initial purge volume of approx. 400 mL was slightly cloudy then clear. Water level was 10 ½" from the top of the tank. Tank 2; the first 100 mL was slightly cloudy then cleared. Water level was 7 3/4" from the top of the tank.

7/6/98- Water removal from tanks 1 & 2. Initial and final measurements were taken from the top of the tank to the level of the water.

	Initial	Final	Vol(L)
Tank 1	9 1/4"	12"	74.9
Tank 2	7"	12 1/8"	139.5

10/14/98- Water level measurements. Tank 1 has 9 ½" of freeboard and tank 2 has 9 1/4" of freeboard

1/28/99- Ice thickness; tank 1 has 20" and tank 2 has 8".

A1.2. INLAND TAILINGS

10/23/96 - Installed interior well sampling apparatus. A different design was used for these tanks since they were able to be installed before the tailings addition (Figure 4). The slotted well screens (.012" slots) are only slotted on the bottom side of the screen and no geotextile sleeve was used. The same sampling apparatus and procedure was used for the Inland tanks (tanks 3 and 4) as was used for the LTV tanks.

10/29 - Filled cement truck with tailings from Inland's spigot line to the basin. The truck was filled approximately half full, rinsed, and discharged. The truck was then filled with tailings and five gallons of tailings from the old portion of the basin was added for seed. Filled Tank 3 with 25" of tailings and Tank 4 with 31". There was about 4 - 5" of coarse tailing in the bottom of Tank 3 and 1 - 2" in the bottom of Tank 4. It appeared at this time that the majority of the coarse tailings was in this addition. Switched to Tank 3 and filled to a depth of 49" then to Tank 4 to a depth of 56", both tanks were then filled to the top starting with Tank 3. After the tanks were filled there was about 19" of tailing in each tank, this was extremely hard to judge because of the fine fluffy nature of the tailing. A composite sample was taken from each tank for the first addition and the second and third additions combined.

10/31 - Measured about 34" of tailing in each tank.

11/01 - Measured about 39" of tailing in each tank.

11/08 - A second truck was needed to provide a sufficient bed depth in both tanks. The truck was rinsed once with tailing. Emptied 52" of water out of each tank and added 2 feet of tailing to each tank starting with Tank 4. Both tanks were then filled to within one foot of the top of the tank. One composite sample was taken for each tank.

11/27 - Sampled tanks (week 3), Tank 3: Middle Port - sample was slightly cloudy. Bottom Port - when inserting the 1/4" sample tube it felt like about one foot of tailing in the bottom on the well. The sample was very cloudy and contained a high percentage of tailings, (maybe as high as 50 - 60%). No nutrient sample was taken from this port due to the high percentage of tailings present. Tank 4: Middle Port - sample was slightly cloudy. Bottom Port - there was also about one foot of tailing in the bottom of the well. The sample was cloudy but didn't contain as much tailing as Tank 3. The depth of tailings was 56" in both tanks. The sample procedure was to purge all ports, wait one hour for recharge, and then sample.

12/12 - Tank 3: Middle Port - sample was clear, unable to purge dry. Bottom Port - very cloudy with lots of tailing in sample, unable to purge dry. Estimated about one foot of tailing in the bottom of the well. Tank 4: Middle Port - sample was cloudy, unable to purge dry. Bottom Port - Started clear then turned cloudy, unable to purge dry. Waited one hour between purge and samples.

01/02/97 - Tank 3: Ice thickness = 6". Middle Port - Slightly cloudy, unable to purge dry. Bottom Port - Very cloudy with tailings present, unable to purge dry. Tank 4: Ice thickness

= 9". Middle Port - Clear, unable to purge dry. Bottom Port - Slightly cloudy, unable to purge dry. All ports were sampled immediately after purging. Placed end caps on the middle and bottom wells of Tank 4 and the bottom of Tank 3, was unable to cap the middle port on Tank 3 due to cloudiness from tailings disturbance while measuring tailings depth, the ports were previously left open. Tailings depth: Tank 3 = 56.5" Tank 4 = 53.5".

01/30 - Tank 3: Ice thickness = 7". Water depth = 103". Bottom Port - Very cloudy purge volume and sample, when inserting the sample tube you can at least a foot of tailing in the well. Tank 4: Ice thickness = 12". Water depth = 96". Bottom Port - Purge volume was slightly cloudy.

02/26 - Tank 3: Ice thickness = 9". Water depth = 104". Purge volume was very cloudy, pumped sample port dry while purging, sampled after port recharged. Tank 4: Ice thickness = 16". Water depth = 99". A new Eh probe was used, see BLM notebook for reference check results.

04/02 - Purge volume for both tanks was 2000 mLs. Tank 3: After chopping through the ice the surface water appeared cloudy. Tank 4: The surface water under the ice was cloudier than tank 3.

07/31 - Tank 3: The well cap for the bottom sampling port was off. Replaced the cap after sampling.

11/05 - The purge and sample volumes were clear for both tanks.

12/17 - Both tanks had about ½" of ice on the surface. The purge volume for tank 4 started out cloudy and cleared up after about 1000 mLs.

01/15/98 - Ice thickness was about 10 - 12" in both tanks.

02/26 - Ice thickness was 12" in both tanks.

03/26 - Ice thickness was about 10" in both tanks and free floating.

7/1/98-Tank 3 the water level was 6 ½" from the top of the tank. Tank 2 water level was 10 ½" from the top of the tank.

7/6/98- Water removal from tanks 3 & 4. Initial and final measurements were taken from the top of the tank to the level of the water.

	Initial	Final	Vol(L)
Tank 3	5 1/4"	12 1/8"	139.9
Tank 4	10 3/4"	12 1/4"	40.8

10/14/98- Water level measurements. Tank 3 has 9 " of freeboard and tank 4 has 12" of freeboard

1/28/99- Ice thickness; tank 3 has 8" and tank 4 has 14".

Appendix 2

Water Chemistry of the LTV Tank Experiments

Table A2.1. Surface water chemistry data for Tank 1
Table A2.2. Surface water chemistry data for Tank 2
Table A2.3. Tailings pore water chemistry data for Tank 1
Table A2.4. Tailings pore water chemistry data for Tank 2
Figure A2.1. Surface water chemistry was reproducible for Tanks 1 and 2
Figure A2.2. Tailings pore water chemistry was reproducible for Tanks 1 and 2

Table A2.1. Surface water chemistry data for Tank 1

Tank 1: Surface Water

Date	09/18/96	09/25/96	10/02/96	10/08/96	10/16/96	11/27/96	12/12/96	01/30/97	08/01/97	11/05/97	12/17/97	01/15/98	02/26/98	03/26/98	07/01/98	10/14/98	01/28/99
weeks	0	1	2	3	4	10	12	19	45	59	65	69	75	79	93	108	123
pH	8.26	8.66	8.68	8.58	8.79	8.68	8.68	8.36	7.94	8.69	8.74	8.79	8.54	8.53	8.72	9.06	9.05
Alk	271	258	251	256	256	265	289	355	340	235	235	255	130	165	150	210	270
Eh	195	170	193	194	232	144	-		264		185	140	171	145	100	121	222
majors (mg/L)																	
Al		0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	-0.00	0.00	-0.00	0.01	0.01
Si		9.63	9.24	9.68	9.44	9.55	9.65	10.62	0.32	1.44	1.41	1.42	0.69	1.17	0.09	1.04	0.90
P		0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	-0.02	-0.01	-0.01	-0.01	-0.01	-0.03	0.00
Fe		0.03	0.00	0.01	0.00	0.04	0.01	0.02	0.00	0.00	-0.02	-0.01	-0.02	0.27	-0.02	-0.02	0.00
Mn		0.03	0.02	0.03	0.03	0.03	0.03	0.03	0.00	0.00	0.00	0.00	0.01	0.05	0.00	0.00	0.00
Sr		0.11	0.10	0.11	0.11	0.13	0.12	0.15	0.01	0.09	0.09	0.11	0.05	0.06	0.06	0.08	0.11
Ba		0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca		14.9	14.5	14.1	14.2	17.4	16.4	21.1	2.2	11.6	12.4	14.7	6.2	8.3	7.8	11.2	14.6
Mg		31.7	30.4	33.0	33.3	38.0	36.9	46.8	3.3	31.3	33.1	37.8	14.9	21.2	20.7	30.3	40.1
Na		127.5	121.3	124.3	124.4	136.4	131.9	165.7	18.4	107.8	111.1	125.4	58.1	75.1	73.5	100.2	125.0
K		18.9	17.9	16.2	16.2	17.5	16.7	20.5	3.1	13.4	14.4	18.3	11.5	10.3	18.1	11.7	19.3
F		10.92	10.81	10.22	10.41	-	10.45	13.10	1.48	8.76	9.24	10.54	4.50	6.03	5.73	7.81	10.07
Cl		40.1	39.2	41.2	42.0	-	41.8	53.2	7.2	35.1	36.6	44.4	22.5	25.8	32.9	31.9	46.0
NO2-N		0.13	0.15	0.16	0.15	-	0.07	0.04				-0.01	-0.01	-0.01	-0.01	0.00	-0.01
Br		0.17	0.17	0.18	0.18	-	0.19	0.22	0.03	0.15	0.14	0.18	0.08	0.10	0.10	0.12	0.15
NO3-N		1.29	0.13	1.12	1.17	-	3.80	1.65	0.10	0.72	0.23	0.54	0.05	0.49	0.17	0.41	0.25
SO4		118.8	116.4	122.5	124.5	117.0	126.5	162.4	12.0	111.0	114.5	132.4	52.7	73.1	70.3	99.5	129.2
trace (ug/L)																	
Li		80	78	93	86	84	63	112	8	54	62	76	28	36	36	51	63
B		464	349	490	498	527	436	764	56	393	416	413	199	177	267	392	424
Sc		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.4	0.6	0.4	0.2	0.2			
Ti		0.1	0.1	0.2	0.2	0.1	0.1	0.0	1.0	1.7	2.0	2.4	1.0	1.2			
V		0.4	0.3	0.7	0.8	0.8	0.7	0.8	0.0	0.2	0.3	0.4	0.2	0.1			
Cr		3.7	1.4	3.3	1.7	2.5	0.9	8.6	0.0	1.4	0.7	1.5	0.8	0.4	0.9	3.0	3.0
Mn		26.7	20.4	32.5	27.9	31.9	26.5	29.5	1.0	1.8	1.4	1.7	8.8	49.0	1.1	1.4	1.6
Fe		32.6	0.0	0.0	0.0	37.5	5.4	7.2	7.7	27.8	32.0	26.2	30.7	580.6	1.7	1.4	0.0
Co		0.2	0.6	0.7	0.5	0.3	0.2	0.4	0.4	0.2	0.6	0.3	0.5	5.5	0.3	0.2	0.6

Tank 1: Surface Water

Date	09/18/96	09/25/96	10/02/96	10/08/96	10/16/96	11/27/96	12/12/96	01/30/97	08/01/97	11/05/97	12/17/97	01/15/98	02/26/98	03/26/98	07/01/98	10/14/98	01/28/99
weeks	0	1	2	3	4	10	12	19	45	59	65	69	75	79	93	108	123
Ni		0.8	1.3	0.6	0.6	1.0	1.1	0.0	0.2	0.6	1.0	1.0	2.1	2.5	1.7	0.8	1.4
Cu		2.8	2.4	1.8	1.4	2.2	1.2	1.0	1.1	2.9	4.1	3.7	3.4	5.8	3.6	4.0	9.4
Zn		1.7	1.7	28.1	54.2	48.7	45.3	28.8	1.5	20.0	45.0	16.5	16.2	95.6	30.3	17.3	30.6
As		6.5	5.3	6.1	5.7	7.9	6.7	14.5	0.7	6.7	5.8	7.4	2.4	3.3	3.0	5.4	6.4
Br									36	156	154	173	76	90	117	154	2
Se		1.1	1.7	0.1	0.0	0.9	0.0	0.0	0.0	1.2	0.0	1.0	0.4	0.0	0.3	2.3	208.0
Rb		22.2	20.1	17.3	17.5	19.1	15.8	21.8	3.6	15.2	16.4	17.2	8.9	10.3	9.8	13.4	17.2
Sr		108	104	113	109	130	114	159	16	94	99	116	50	63	58	86	116
Mo		395	355	375	372	372	349	479	35	322	313	394	146	203	188	286	339
Ag		0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.58	0.58	0.08			
Cd		0.35	0.42	0.34	0.36	0.52	0.42	0.37	0.06	0.15	0.27	0.43	0.16	0.30	0.29	0.40	0.40
Sn		0.05	0.35	0.18	0.09	0.18	0.12	0.30	0.00	0.33	0.32	0.40	0.23	0.85			
Sb		0.63	0.30	0.26	0.28	0.13	0.18	0.06	0.01	0.09	0.08	0.09	0.04	0.05			
Cs		3.23	2.97	2.29	2.16	2.29	1.72	2.11	0.37	1.48	1.35	1.53	0.72	0.74	0.73	1.02	1.25
Ba		6.56	5.94	6.50	6.76	6.75	6.73	8.32	0.90	3.60	3.50	4.25	1.96	2.38	2.54	3.17	3.76
W		4.87	4.84	5.54	5.38	5.50	5.76	6.59	0.39	3.86	3.28	4.57	1.73	2.10	3.20	3.49	5.19
Pb		0.06	0.00	0.18	2.62	0.34	0.14	0.00	0.05	0.01	0.02	0.06	0.34	0.45	0.41	0.13	0.29
U		0.53	0.26	0.33	0.32	0.28	0.15	1.80	0.02	0.25	0.27	0.30	0.28	0.45	0.59	0.92	1.19
TKN			0.20	<0.20	0.31	0.53	<0.20			0.54							
NH3-N			0.10	0.12	0.05	0.03	0.05			0.03							
TP			0.02	0.01	<0.01	<0.01	0.05										
TOC																	

Table A2.2. Surface water chemistry data for Tank 2

Tank 2: Surface Water																	
Date	09/18/96	09/25/96	10/02/96	10/10/96	10/16/96	11/27/96	12/12/96	04/02/97	08/01/97	11/05/97	12/17/97	01/15/98	02/26/98	03/26/98	07/01/98	10/14/98	01/28/99
weeks	0	1	2	3	4	10	12	28	45	59	65	69	75	79	93	108	123
pH	8.63	8.66	8.66	8.73	8.80	8.86	8.56	8.49	8.70	8.75	8.73	8.74	8.65	8.59	8.82	9.03	8.95
Alk	278	258	243	249	252	270	271	170	125	210	225	240	122	120	160	195	215
Eh	188	171	191	191	230	150	-	160	205		171	142	163	133	102	79	201
majors (mg/L)																	
Al		0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	-0.00	0.00	0.00	0.00	0.00	0.01	0.00
Si		9.83	9.35	9.01	9.00	8.30	7.90	5.35	1.44	1.57	1.67	1.88	0.79	0.61	0.27	0.61	0.00
P		0.01	0.01	0.00	0.00	0.01	0.00	0.01	0.00	0.00	-0.01	-0.01	-0.01	-0.01	-0.01	-0.02	0.00
Fe		0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	-0.02	-0.01	-0.02	-0.02	-0.02	-0.02	0.00
Mn		0.03	0.02	0.03	0.03	0.04	0.03	0.02	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00
Sr		0.11	0.10	0.11	0.11	0.13	0.12	0.08	0.05	0.10	0.10	0.12	0.05	0.05	0.08	0.09	0.09
Ba		0.01	0.01	0.01	0.07	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca		15.0	14.7	20.0	14.2	17.5	16.1	11.4	7.7	12.4	13.1	15.5	7.2	6.7	10.6	11.3	11.7
Mg		32.3	31.4	33.6	34.0	37.2	35.0	21.7	15.7	32.8	33.7	37.8	17.5	15.6	26.8	30.3	33.6
Na		124.2	119.2	116.1	117.6	123.4	114.0	69.7	59.3	101.7	103.9	116.4	58.7	54.0	82.3	92.0	98.7
K		18.3	17.5	14.8	15.2	15.6	14.5	8.6	8.1	12.6	13.0	14.7	8.0	7.9	10.0	10.7	12.1
F		10.97	10.50	9.81	10.05	-	9.27	5.73	4.58	8.29	8.45	9.61	4.50	4.17	6.57	7.25	7.64
Cl		40.2	38.5	39.9	40.7	-	37.5	23.1	20.5	33.3	34.1	39.0	20.3	19.3	27.6	30.3	33.1
NO2-N		0.14	0.17	0.16	0.15	-	0.07	0.01	0.11			-0.01	-0.01	-0.01	-0.01	0.00	-0.01
Br		0.18	0.17	0.17	0.18	-	0.16	0.11	0.11	0.15	0.14	0.17	0.09	0.82	0.12	0.13	0.13
NO3-N		2.72	1.46	0.99	1.02	-	4.68	1.22	0.13	0.24	1.35	0.05	0.20	0.56	0.12	0.33	0.19
SO4		120.0	115.0	119.0	120.7	-	116.3	72.2	53.1	107.6	110.1	124.8	55.0	51.5	86.0	95.6	102.9
trace (ug/L)																	
Li		81	84	86		72	61	39	32	63	58	72	28	34	43	50	51
B		514	465	459		461	388	375	183	382	343	373	226	142	303	369	289
Sc		0.1	0.1	0.1		0.1	0.1	0.1	0.4	0.5	0.6	0.5	0.2	0.1			
Ti		0.8	0.1	0.2		0.1	0.1	0.8	0.1	1.8	0.1	2.7	1.2	0.1			
V		0.3	0.7	0.7		0.7	0.6	0.2	0.4	0.4	0.4	0.4	0.2	0.1			
Cr		3.2	2.2	1.9		0.8	0.4	4.3	1.0	0.5	1.0	2.2	2.6	0.0	0.9	3.0	1.0
Mn		27.0	31.8	31.8		37.0	30.0	25.0	0.4	0.9	0.5	0.4	9.1	3.7	0.7	0.7	0.3
Fe		0.0	0.0	0.0		7.7	0.0	2.3	21.1	17.3	9.1	20.3	14.6	0.0	0.0	0.0	0.0
Co		0.1	0.7	4.0		0.5	0.2	0.3	1.3	0.4	0.3	0.3	0.3	0.4	0.2	0.2	0.2

Tank 2: Surface Water

Date	09/18/96	09/25/96	10/02/96	10/10/96	10/16/96	11/27/96	12/12/96	04/02/97	08/01/97	11/05/97	12/17/97	01/15/98	02/26/98	03/26/98	07/01/98	10/14/98	01/28/99
weeks	0	1	2	3	4	10	12	28	45	59	65	69	75	79	93	108	123
Ni		0.9	0.6	1.2		1.1	1.6	1.2	0.4	1.7	0.5	0.7	2.5	0.5	0.8	0.9	0.7
Cu		1.9	1.7	3.4		2.3	0.9	0.7	2.0	3.2	3.0	2.2	2.5	1.3	2.4	3.6	3.2
Zn		2.3	26.8	51.4		42.5	52.1	25.0	3.2	32.5	22.0	16.6	26.1	36.6	14.9	18.6	14.1
As		6.0	5.8	6.0		6.9	5.2	4.2	3.6	7.9	7.1	7.9	3.1	2.8	4.2	4.0	4.2
Br		1	1	0		2	0	1	0	0	1	1	0	0	1	2	4
Se									98.4	151.5	144.8	155.2	79.8	72.9	136.2	148.0	148.0
Rb		21.6	15.6	15.8		15.9	13.3	9.9	9.1	13.7	13.4	15.4	9.0	7.2	10.7	12.3	12.1
Sr		110	111	112		132	109	92	60	110	107	118	56	54	82	91	88
Mo		372	344	344		349	298	209	150	296	293	340	130	127	226	276	256
Ag		0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.05			
Cd		0.34	0.33	0.34		0.31	0.32	1.60	0.19	0.23	0.32	0.23	0.16	0.16	0.31	0.40	0.40
Sn		0.15	0.16	0.11		0.04	0.05	0.21	0.30	0.19	0.19	0.14	0.16	0.00			
Sb		0.24	0.25	0.27		0.12	0.17	0.02	0.06	0.07	0.08	0.07	0.04	0.04			
Cs		3.22	2.08	2.18		1.80	1.48	1.03	0.92	1.39	1.31	1.39	0.70	0.60	0.75	0.93	0.91
Ba		6.74	6.88	7.12		7.74	6.50	5.08	3.51	4.05	3.69	4.69	2.50	1.93	2.78	3.29	2.91
W		4.65	5.50	5.39		5.16	4.57	2.18	1.83	3.69	2.92	4.13	1.49	1.51	3.38	3.00	8.48
Pb		0.08	0.05	0.33		0.20	8.34	0.04	4.70	0.00	0.03	0.00	0.11	0.06	0.14	0.09	0.08
U		0.46	0.32	0.31		0.20	0.10	0.24	0.15	0.24	0.22	0.24	0.29	0.29	0.70	0.78	0.81
TKN																	
NH3-N						0.30	<0.20			0.35							
TP						0.05	0.07			0.02							
TOC						<0.01	0.04										

Table A2.3. Tailings pore water chemistry data for Tank 1

Tank 1: Tailings Pore Water

Date	09/18/96	09/25/96	10/02/96	10/10/96	10/16/96	11/27/96	01/30/97	02/26/97	04/02/97	08/01/97	11/05/97	12/17/97	01/15/98	02/26/98	03/26/98	07/01/98	10/14/98	01/28/99
weeks	0	1	2	3	4	10	19	23	28	45	59	65	69	75	79	93	108	123
pH	8.26	8.22	8.11	8.11	8.11	8.28	8.03	8.33	8.20	8.18	7.96	8.15	8.01	8.18	8.11	8.09	8.18	8.29
Alk	271	270	282	290	288	260	310	325	300	260	285	265	298	268	270	268	255	270
Eh	195	173	197	199	237	151	nd	198	231	178	nd	188	144	185	151	119	-12	211
majors (mg/L)																		
Al	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.02	0.00	0.00	0.33	-0.00	0.02	0.00	0.00	-0.00	0.00	0.00
Si	9.39	9.04	8.96	9.01	8.51	7.86	8.29	8.36	8.85	7.68	11.90	6.34	5.85	5.31	5.48	6.82	7.46	5.40
P	0.01	0.01	0.00	0.01	0.02	0.01	0.01	0.01	0.00	0.00	0.03	-0.02	-0.02	0.01	0.01	-0.01	-0.03	0.00
Fe	0.03	0.06	0.01	0.03	0.01	0.06	0.04	0.01	0.01	0.00	5.21	-0.01	0.11	-0.01	-0.02	-0.02	0.09	0.10
Mn	0.05	0.07	0.09	0.08	0.09	0.09	0.06	0.07	0.07	0.13	0.27	0.12	0.10	0.09	0.12	0.12	0.12	0.14
Sr	0.26	0.31	0.34	0.35	0.37	0.34	0.24	0.28	0.27	0.31	0.39	0.40	0.36	0.34	0.36	0.40	0.41	0.41
Ba	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Ca	21.4	23.4	24.8	26.0	26.2	24.9	22.4	24.5	23.5	23.1	27.5	28.1	26.8	25.4	26.1	26.9	28.1	29.4
Mg	32.7	35.1	36.4	38.3	38.3	38.0	42.6	47.6	43.1	36.6	41.4	43.4	43.2	43.3	42.5	40.1	40.0	33.6
Na	119.1	114.9	109.2	109.6	108.7	97.9	134.6	135.6	120.7	93.1	88.7	89.4	94.5	98.1	90.3	81.2	83.4	98.7
K	11.2	9.9	8.9	8.5	8.0	6.3	12.6	12.8	11.0	7.8	6.8	5.9	7.8	7.8	6.9	8.4	5.9	12.1
F	6.96	6.51	6.52	6.37	6.43	nd	9.84	10.05	9.14	6.75	6.61	6.63	7.30	7.62	7.16	6.48	6.58	6.73
Cl	34.1	34.1	34.9	36.4	37.0	nd	45.2	45.7	42.7	34.9	36.1	36.8	38.8	38.6	38.3	39.3	37.2	41.4
NO2-N	0.16	0.04	0.02	-0.01	-0.01	nd	0.02	0.01	0.04				-0.01	-0.01	-0.01	-0.01	0.00	-0.01
Br	0.14	0.14	0.14	0.14	0.15	nd	0.19	0.22	0.19	0.16	0.16	0.16	0.17	0.17	0.17	0.17	0.16	0.18
NO3-N	4.28	0.83	0.14	0.12	0.02	nd	0.89	3.90	0.65	0.23	0.31	1.46	0.03	0.38	0.15	0.23	0.40	0.35
SO4	113.0	113.3	115.1	118.9	120.2	112.0	136.5	142.0	131.0	102.2	104.0	104.2	109.8	111.1	105.9	95.5	91.1	95.0
trace (ug/L)																		
Li	58	55	56	58	67	45	88	43	59	41	40	40	41	45	39	35	36	35
B	491	562	488	561	564	411	506	464	538	410	462	608	385	598	332	519	574	451
Sc	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	2.2	3.5	2.5	1.5	1.4	1.2			
Ti	0.1	0.1	0.1	0.1	0.1	0.1	0.0	1.7	1.6	3.1	4.1	3.7	4.1	3.8	3.4			
V	0.2	0.1	0.0	0.3	0.3	0.3	0.5	0.3	0.3	0.2	0.9	0.2	0.3	0.2	0.2			
Cr	3.6	4.0	1.7	5.4	1.5	1.6	9.6	1.2	9.3	0.4	2.1	2.0	3.1	4.3	1.4	1.6	3.0	3.0
Mn	43.4	62.1	79.0	81.5	82.2	86.4	60.6	60.5	69.0	120.0	254.0	110.3	94.7	96.7	109.0	140.5	128.1	157.1
Fe	29.6	29.7	14.6	20.2	10.3	19.7	11.0	0.0	10.1	16.0	5300.0	24.0	135.1	35.0	17.8	17.2	90.0	73.0

Table A2.4. Tailings pore water chemistry data for Tank 2

Tank 2: Tailings Pore Water

Date	09/18/96	09/25/96	11/27/96	12/12/96	08/01/97	11/05/97	12/17/97	01/15/98	02/26/98	03/26/98	07/01/98	10/14/98	01/28/99
weeks	0	1	10	12	45	59	65	69	75	79	93	108	123
pH	8.23	8.11	8.54	8.35	8.28	8.17	8.19	8.14	8.14	8.10	8.74	8.58	8.36
Alk	281	270	245	273	280	293	270	280	260	250	260	235	240
Eh	190	172	151	-	132		173	132	179	130	102	NA	207
majors (mg/L)													
Al	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00
Si	9.26	9.17	7.79	9.26	10.51	7.00	6.78	6.41	6.16	5.29	2.71	4.25	4.10
P	0.00	0.06	0.01	0.04	0.00	0.00	-0.01	-0.02	-0.01	0.01	-0.01	-0.03	0.00
Fe	0.01	0.02	0.02	0.05	0.00	0.00	-0.02	-0.01	0.02	-0.02	0.05	0.06	0.00
Mn	0.06	0.10	0.05	0.06	0.06	0.12	0.14	0.14	0.14	0.12	0.05	0.07	0.11
Sr	0.22	0.29	0.18	0.21	0.21	0.35	0.39	0.36	0.36	0.30	0.20	0.24	0.31
Ba	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Ca	19.9	22.9	18.4	19.6	19.9	24.4	26.5	27.0	26.5	24.8	17.9	18.5	22.5
Mg	31.4	34.4	38.7	41.4	40.7	40.5	43.2	44.9	45.1	45.5	38.8	35.5	40.7
Na	126.0	117.4	106.9	102.1	106.6	87.7	84.8	73.6	77.7	66.5	101.1	89.9	85.4
K	12.0	9.3	9.3	7.4	10.3	6.5	5.3	4.9	5.0	4.9	14.3	9.7	10.5
F	7.90	7.16	-	7.54	8.41	6.89	6.88	6.61	6.71	6.34	8.39	7.24	6.98
Cl	36.2	35.5	-	38.0	38.4	36.2	37.9	44.6	42.8	49.5	40.0	35.7	40.5
NO2-N	0.03	-0.01	-	0.00				-0.01	-0.01	-0.01	-0.01	0.00	-0.01
Br	0.15	0.15	-	0.16	0.18	0.17	0.17	0.24	0.22	0.29	0.16	0.15	0.16
NO3-N	0.76	0.08	-	2.44	0.22	0.98	0.51	0.04	0.46	0.17	0.59	0.25	0.38
SO4	116.0	113.3	-	111.3	116.0	91.6	91.1	78.2	84.4	72.4	108.7	90.4	89.3
trace (ug/L)													
Li	62	55	56	46	58	39	32	28	26	27	50	41	35
B	471	494	431	391	443	477	400	347	532	254	480	486	435
Sc	0.1	0.1	0.1	0.1	2.8	2.1	2.3	1.5	1.5	1.2			
Ti	0.1	0.1	0.1	0.1	2.5	0.1	3.1	3.4	3.9	0.1			
V	0.1	0.0	0.4	0.4	0.7	0.2	0.3	0.2	0.2	0.3			
Cr	4.9	3.6	0.5	0.4	6.8	2.2	1.3	2.0	4.9	1.4	1.7	3.0	3.0
Mn	57.0	91.0	48.0	52.4	60.0	116.0	126.2	141.9	141.8	104.4	55.0	70.8	122.9
Fe	197.0	16.4	15.0	15.0	6.8	12.6	10.7	27.3	13.1	7.5	47.2	53.8	15.0
Co	0.1	0.3	0.2	0.2	0.2	0.4	0.3	0.7	0.3	0.4	0.3	0.3	0.3

Tank 1: Tailings Pore Water

Date	09/18/96	09/25/96	10/02/96	10/10/96	10/16/96	11/27/96	01/30/97	02/26/97	04/02/97	08/01/97	11/05/97	12/17/97	01/15/98	02/26/98	03/26/98	07/01/98	10/14/98	01/28/99
weeks	0	1	2	3	4	10	19	23	28	45	59	65	69	75	79	93	108	123
Co	0.1	0.3	0.5	0.5	0.7	0.4	1.2	0.5	0.4	0.4	0.8	0.2	0.3	33.0	1.5	0.3	0.3	1.0
Ni	0.6	1.3	0.8	0.6	0.6	1.8	1.5	1.8	2.8	2.7	4.4	2.2	1.7	6.3	2.4	3.6	2.7	2.4
Cu	1.6	1.3	2.9	0.8	0.8	1.7	0.0	0.0	0.0	0.7	0.6	0.4	0.7	1.3	2.2	1.1	1.1	1.3
Zn	1.2	1.2	1.0	0.4	48.4	42.9	33.7	76.0	54.5	6.8	28.7	25.5	18.2	21.9	33.4	17.3	16.1	19.4
As	3.8	4.8	4.9	4.6	4.0	1.7	7.7	5.8	6.4	3.6	3.2	1.5	1.8	2.1	1.3	1.7	2.2	1.3
Br										159	167	151	153	149	141	182	175	1
Se	0.5	0.0	0.1	0.7	0.0	0.0	0.0	1.1	1.2	0.0	0.4	0.0	0.6	1.3	0.0	1.3	2.3	201.0
Rb	12.6	11.3	10.1	9.7	8.9	6.2	12.9	12.3	11.5	8.8	7.7	6.2	8.4	8.5	6.5	6.0	6.2	5.4
Sr	237	275	300	347	343	306	269	282	300	328	390	378	346	331	317	436	422	424
Mo	264	141	81	65	54	63	286	241	205	89	67	53	95	131	91	41	53	54
Ag	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00			
Cd	0.23	0.14	0.10	0.01	0.04	0.04	0.18	0.16	0.15	0.10	0.03	0.05	0.08	0.04	0.10	0.08	0.10	0.10
Sn	11.53	16.70	6.53	2.28	0.00	0.04	0.31	0.66	0.01	2.97	1.59	1.78	0.80	1.23	1.23			
Sb	0.19	0.18	0.14	0.11	13.30	0.03	0.04	0.02	1.87	0.03	0.02	0.01	0.03	0.03	0.02			
Cs	2.26	1.89	1.74	1.70	1.50	1.04	1.39	1.67	1.47	1.46	1.49	1.08	1.54	1.60	1.14	0.80	0.62	0.46
Ba	11.41	12.43	13.28	13.30	12.93	9.76	10.19	10.62	9.94	9.49	10.66	7.46	7.06	8.15	8.24	8.23	6.95	6.71
W	4.67	3.64	3.08	2.71	2.50	2.12	4.71	3.25	2.80	1.87	2.14	1.44	2.12	2.15	1.92	1.62	5.37	1.48
Pb	0.04	0.02	0.03	0.02	0.05	0.06	0.01	0.10	0.01	0.00	0.10	0.03	0.01	0.10	0.01	0.06	0.07	0.05
U	0.18	0.11	0.05	0.06	0.05	0.03	0.81	0.65	0.27	0.16	0.07	0.04	0.06	0.27	0.21	0.12	0.20	0.16
TKN			0.21	<0.2	0.34	0.23					0.28							
NH3-N			0.12	0.10	0.06	0.05					0.08							
TP			0.20	0.02	0.01	<0.01												
TOC																		

Tank 2: Tailings Pore Water

Date	09/18/96	09/25/96	11/27/96	12/12/96	08/01/97	11/05/97	12/17/97	01/15/98	02/26/98	03/26/98	07/01/98	10/14/98	01/28/99
weeks	0	1	10	12	45	59	65	69	75	79	93	108	123
Ni	0.6	0.6	1.0	1.5	1.5	1.2	0.9	1.9	2.4	0.8	4.8	1.9	2.0
Cu	1.6	0.5	1.5	0.4	0.7	0.6	0.5	0.7	0.5	0.5	4.4	1.6	1.3
Zn	1.5	0.3	44.9	45.0	1.3	29.4	25.8	24.5	22.9	24.9	17.9	14.7	17.8
As	4.6	3.8	3.2	1.8	7.5	2.6	2.6	1.5	1.5	1.7	3.9	3.4	1.8
Br	0	1	1	0	3	0	0	0	0	0	1	2	1
Se					192.0	167.0	161.0	208.8	182.5	240.5	174.9	165.0	187.0
Rb	13.2	9.5	8.9	6.9	11.8	6.2	5.4	4.8	5.0	4.9	11.2	9.2	7.1
Sr	214	268	175	193	225	343	380	335	317	293	209	248	318
Mo	305	128	167	72	218	79	41	18	28	27	224	173	102
Ag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00			
Cd	0.23	0.17	0.18	0.04	0.31	0.06	0.06	0.03	0.04	0.03	0.30	0.30	0.10
Sn	19.20	66.09	0.19	0.00	2.73	0.67	1.00	0.57	0.65	0.68			
Sb	0.19	0.13	0.06	0.04	0.06	0.02	0.01	0.01	0.01	0.01			
Cs	2.54	1.67	1.22	1.16	2.21	1.06	1.13	1.00	1.04	1.01	1.09	0.80	0.77
Ba	10.90	12.10	9.31	9.60	14.00	7.95	7.26	6.77	8.71	7.56	6.28	5.93	6.00
W	4.51	3.15	4.52	4.19	4.48	1.75	1.35	1.10	1.21	1.27	2.37	2.03	2.33
Pb	0.03	0.06	0.22	0.29	0.00	0.03	0.02	0.00	0.06	0.01	0.14	0.10	0.04
U	0.17	0.04	0.08	0.00	0.18	0.08	0.06	0.03	0.07	0.12	0.72	0.49	0.27
TKN													
NH3-N			<0.20	<0.20		0.35							
TP			0.06	0.12		0.07							
TOC			<0.01	0.23									

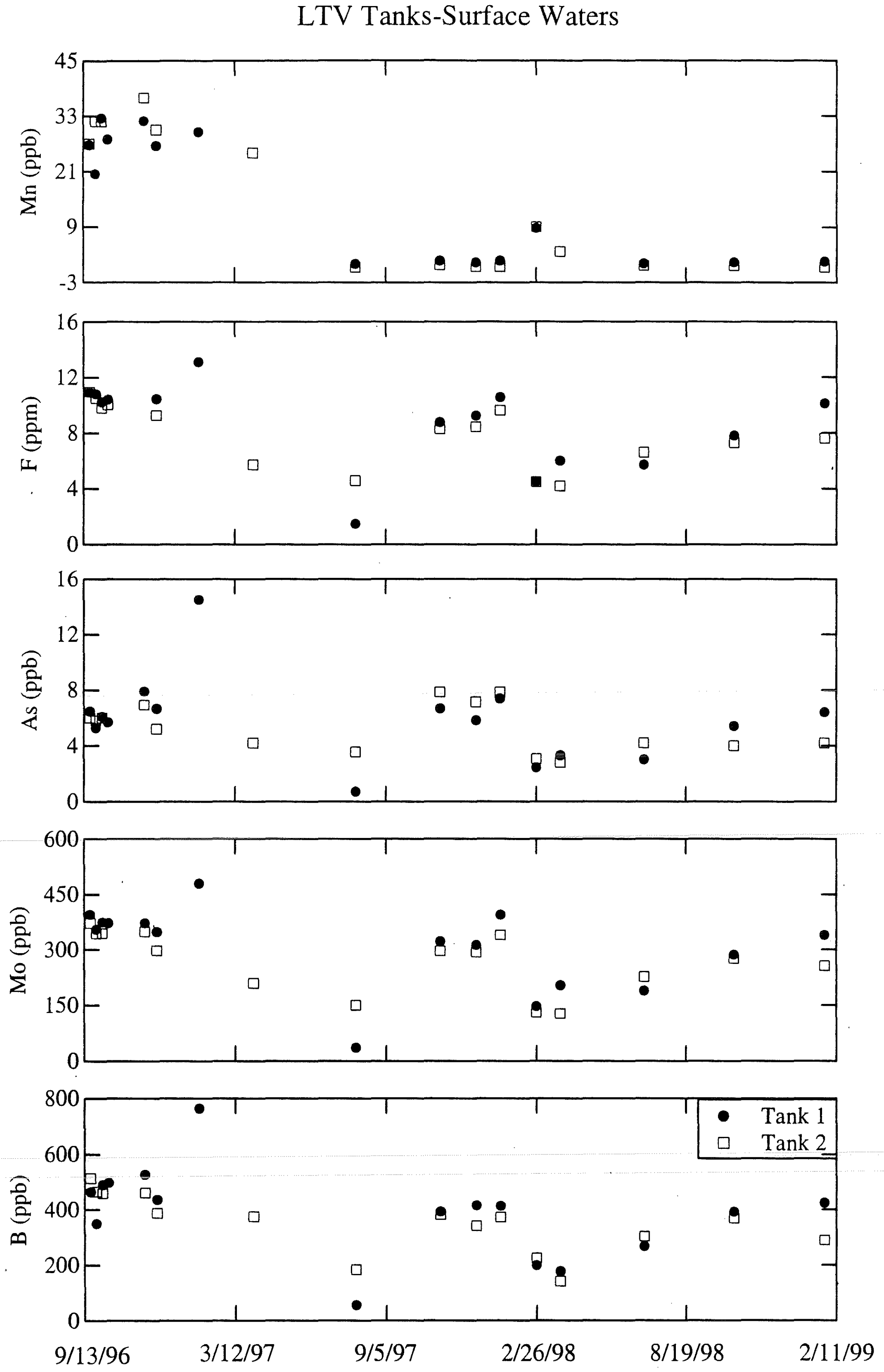


Figure A2.1. Surface water chemistry was reproducible for Tanks 1 and 2 (LTV).

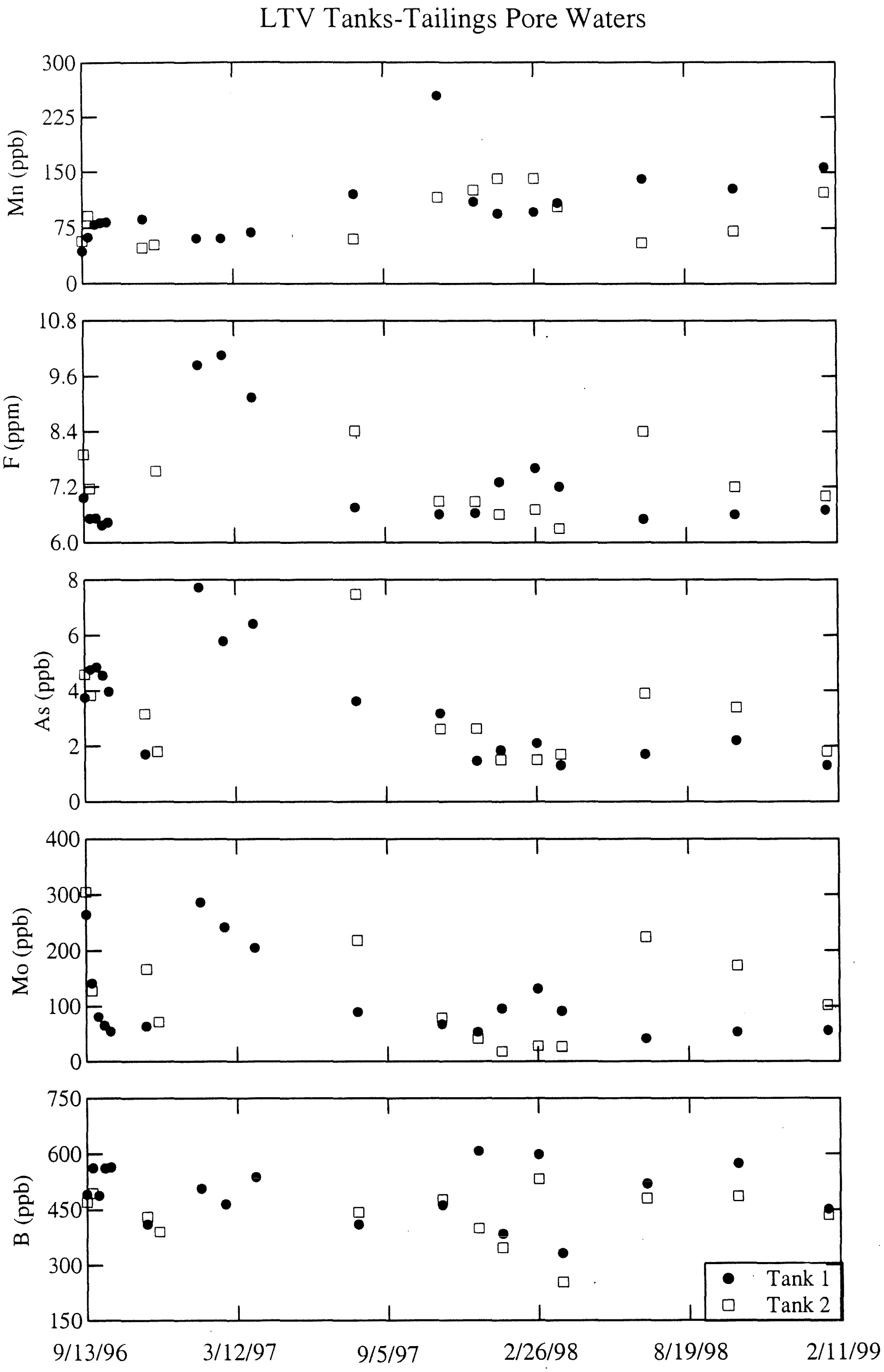


Figure A2.2. Tailings pore water chemistry was reproducible for Tanks 1 and 2 (LTV).

Table A3.1. Composition of the Tank 3 (Inland) surface waters. Alkalinity in units of mg/L $CaCO_3$. "na" = not available

Tank 3: Surface Water

Date	11/27/96	12/12/96	01/02/97	08/01/97	09/10/97	11/05/97	12/17/97	01/15/98	02/26/98	03/26/98	07/01/98	10/14/98	01/28/99
weeks	3	5	8	38	44	52	58	62	68	72	86	101	116
pH	8.58	8.42	8.38	8.58	8.56	8.63	8.79	8.85	8.77	8.84	8.42	8.24	8.35
Alk	218	201	195	170	170	160	158	170	142	90	105	135	150
Eh	143	-		154	226		157	117	161	112	96	81	201
majors (mg/L)													
Al	0.01	0.01	0.00	0.00	0.00	0.00	-0.00	0.04	-0.00	0.00	0.00	0.01	0.03
Si	9.50	9.20	8.86	6.70	6.45	3.47	3.02	2.42	1.94	1.30	0.13	3.72	3.60
P	0.01	0.01	0.01	0.00	0.00	0.00	-0.02	-0.02	-0.01	-0.01	-0.01	-0.02	0.00
Fe	0.01	0.01	0.00	0.00	0.00	0.01	-0.01	-0.01	-0.02	-0.02	-0.02	-0.03	0.10
Mn	0.10	0.08	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	-0.00	0.00
Sr	0.16	0.14	0.14	0.12	0.13	0.13	0.12	0.14	0.11	0.07	0.10	0.11	0.12
Ba	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca	40.3	35.3	35.7	30.6	31.2	26.8	26.7	30.0	23.9	14.6	18.3	21.7	23.7
Mg	57.5	51.2	50.4	44.8	47.5	48.8	49.0	54.5	43.1	26.1	42.1	44.1	46.4
Na	41.3	36.8	36.4	32.4	33.3	32.8	33.1	36.8	29.3	18.2	28.4	28.1	29.2
K	15.8	14.5	14.4	12.5	12.9	12.4	12.5	14.2	11.5	8.0	28.8	10.4	13.4
F	-	5.30	5.36	4.49	4.72	4.57	4.67	5.27	4.07	2.53	3.42	3.03	3.85
Cl	-	94.0	95.2	79.4	84.0	8139.0	84.5	94.6	74.7	47.0	89.8	72.7	77.1
NO2-N	-	0.09	0.09	0.02	0.03			-0.01	-0.01	-0.01	-0.01	0.00	-0.01
Br	-	0.63	0.64	0.60	0.63	0.62	0.60	0.69	0.55	0.35	0.54	0.54	0.57
NO3-N	-	4.21	1.35	1.09	2.35	0.63	1.69	0.46	1.27	0.38	0.38	0.52	0.33
SO4	66.8	58.3	59.2	50.6	53.7	53.3	54.8	61.3	47.9	28.1	47.3	47.4	48.7
trace (ug/L)													
Li	33	28	28	24	25	29	25	30	22	13	21	23	22
B	141	121	135	97	95	112	155	122	83	60	117	138	104
Sc	0.1	0.1	0.1	2.1	2.2	1.0	1.2	0.7	0.5	0.3			
Ti	0.1	0.1	0.1	3.0	3.0	2.7	3.8	4.0	3.5	2.0			
V	0.7	0.6	0.7	0.6	0.4	0.4	0.6	0.6	0.4	0.2			
Cr	0.7	0.9	2.3	1.2	0.6	1.1	0.8	2.2	2.8	0.7	0.7	2.0	2.0

Appendix 3

Water Chemistry of the Inland Tank Experiment

Table A3.1. Surface water chemistry data for Tank 3
Table A3.2. Surface water chemistry data for Tank 4
Table A3.3. Tailings pore water chemistry data for Tank 3
Table A3.4. Tailings pore water chemistry data for Tank 4
Figure A3.1. Surface water chemistry was reproducible for Tanks 3 and 4
Figure A3.2. Tailings pore water chemistry was reproducible for Tanks 3 and 4

Table A3.2. Composition of the Tank 4 (Inland) surface waters. Alkalinity in units of mg/L $CaCO_3$. “na” = not available

Tank 4: Surface Water

Date	11/27/96	12/12/96	02/26/97	08/01/97	09/10/97	11/05/97	12/17/97	01/15/98	02/26/98	03/26/98	07/01/98	10/14/98	01/28/99
weeks	3	5	16	38	44	52	58	62	68	72	86	101	116
pH	8.55	8.32		8.23	8.60	8.76	8.77	8.81	8.68	8.70	8.67	8.65	8.58
Alk	198	207		50	140	160	160	190	95	160	120	150	200
Eh	135	-		156	145		101	122	159	117	94	96	189
majors (mg/L)													
Al	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	-0.00	0.01	0.00
Si	9.18	9.69	12.02	0.23	2.48	0.87	0.25	0.51	0.46	1.50	0.74	1.37	1.00
P	0.01	0.02	0.01	0.00	0.00	0.00	-0.02	-0.02	-0.01	-0.01	-0.01	-0.02	0.00
Fe	0.00	0.03	0.00	0.00	0.00	0.00	0.02	0.02	0.02	-0.02	-0.03	-0.02	0.00
Mn	0.08	0.08	0.08	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.00	0.00
Sr	0.15	0.15	0.20	0.03	0.11	0.12	0.13	0.16	0.08	0.12	0.09	0.12	0.16
Ba	0.00	0.00	0.01	0.00	2.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca	37.7	36.6	48.3	9.8	23.6	24.4	26.0	31.2	16.3	25.2	18.2	24.7	32.7
Mg	53.7	54.4	70.7	11.6	40.5	49.0	52.4	61.0	29.6	49.5	37.7	49.7	61.9
Na	39.7	39.2	51.9	10.4	29.4	33.6	35.9	41.2	20.8	33.6	26.0	31.8	40.1
K	15.5	15.3	20.6	5.2	12.1	12.8	13.6	16.1	8.9	13.5	10.2	11.6	18.9
F		5.47	7.30	1.33	3.88	4.57	4.93	5.74	2.75	4.62	3.35	4.22	5.27
Cl		99.1	130.0	25.4	74.3	84.5	90.9	107.0	52.1	86.6	66.9	82.5	108.0
NO2-N		0.10	0.04	0.01	0.02	0.01		-0.01	-0.01	-0.01	-0.01	0.00	-0.01
Br		0.66	1.00	0.20	0.56	0.64	0.65	0.80	0.39	0.64	0.50	0.59	0.75
NO3-N		4.11	2.06	1.17	1.67	1.89	1.35	0.25	0.31	0.94	0.25	0.38	0.15
SO4	61.9	61.0	82.9	10.5	44.5	55.0	58.7	68.7	33.5	54.9	40.6	53.0	65.9
trace (ug/L)													
Li	32	29	31	7	21	28	28	32	14	29	19	24	29
B	101	123	199	29	100	125	134	150	83	83	100	143	150
Sc	0.1	0.1	0.1	0.1	0.7	0.3	0.1	0.2	0.2	0.4			
Ti	0.1	0.1	3.2	0.0	0.1	2.7	3.4	4.4	0.1	0.1			
V	0.6	0.7	0.5	0.2	0.2	0.3	0.6	0.6	0.2	0.4			
Cr	1.3	0.8	1.7	0.8	0.7	1.0	0.8	2.0	0.9	7.9	0.7	2.0	2.0

Tank 3: Surface Water

Date	11/27/96	12/12/96	01/02/97	08/01/97	09/10/97	11/05/97	12/17/97	01/15/98	02/26/98	03/26/98	07/01/98	10/14/98	01/28/99
weeks	3	5	8	38	44	52	58	62	68	72	86	101	116
Mn	90.2	76.2	73.5	1.6	2.3	1.2	0.7	1.4	2.2	7.3	1.2	1.3	0.7
Fe	24.7	15.5	7.4	0.0	11.6	22.9	19.5	38.4	24.6	0.0	0.0	2.3	0.0
Co	0.2	0.2	0.2	1.8	0.2	0.2	0.2	0.2	0.4	2.0	0.2	0.1	0.3
Ni	1.5	2.2	1.8	1.1	1.5	0.9	0.6	1.3	1.5	1.2	1.2	1.6	1.2
Cu	2.3	2.6	3.1	5.5	5.9	6.1	5.8	7.5	7.2	4.8	8.3	8.0	7.9
Zn	44.7	43.6	25.2	4.9	2.9	27.3	33.6	18.5	21.1	53.4	22.5	17.7	18.0
As	1.8	1.2	1.7	1.5	5.1	10.7	9.8	11.5	9.9	5.7	9.8	12.0	10.6
Se	1	0	2	1	0	3	1	3	1	0	1	3	2
Br				624.0	657.0	595.0	539.1	625.3	458.9	282.5	544.5	587.0	568.0
Rb	12.4	10.6	11.3	9.8	10.5	10.5	10.1	11.5	9.0	5.7	9.0	9.0	9.1
Sr	158	151	146	135	131	143	131	146	116	79	99	119	119
Mo	78	74	74	68	64	70	67	83	63	33	58	63	58
Ag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.13			
Cd	0.07	0.11	0.09	0.14	0.12	0.07	0.09	0.08	0.09	0.10	0.13	0.10	0.10
Sn	0.00	0.00	0.06	0.13	0.04	0.09	0.06	0.06	0.15	0.11			
Sb	0.06	0.08	0.07	0.07	0.07	0.05	0.05	0.05	0.05	0.02			
Cs	1.49	1.30	1.36	1.12	1.20	1.04	0.97	1.06	0.78	0.49	0.60	0.73	0.64
Ba	4.00	3.90	3.81	3.30	3.44	2.46	2.36	2.46	2.21	1.21	1.69	2.28	1.85
W	1.59	1.57	0.02	1.09	1.58	1.44	1.06	1.44	1.13	0.64	2.33	1.08	4.27
Pb	0.12	0.13	0.03	0.00	0.00	0.02	0.02	0.05	0.07	0.06	0.09	0.06	0.11
U	0.05	0.05	0.06	0.11	0.13	0.11	0.08	0.08	0.20	0.13	0.30	0.31	0.31
TKN	0.35	0.60				0.37							
NH3-N	0.30	0.57				0.02							
TP	<0.01	0.05											
TOC													

Table A3.3. Composition of the Tank 3 (Inland) tailings pore waters. Alkalinity in units of mg/L $CaCO_3$. “na” = not available

Tank 3: Tailings Pore Water

Date	11/27/96	12/12/96	01/02/97	01/30/97	02/26/97	04/02/97	08/01/97	09/10/97	11/05/97	12/17/97	01/15/98	02/26/98	03/26/98	07/01/98	10/14/98	01/28/99
weeks	3	5	8	12	16	21	38	44	52	58	62	68	72	86	101	116
pH	8.42	8.50	8.25	8.32	8.03	8.28	8.37	8.36	8.36	8.42	8.58	8.48	8.60	8.61	8.37	8.54
Alk	198	133	135	145	155	139	125	130	115	115	120	120	135	105	95	95
Eh	138	-	-	-		168	130	208		156	117	162	118	94	81	172
majors (mg/L)																
Al	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.00	-0.00	0.00	-0.00	0.00	0.02
Si	8.86	4.03	7.60	5.60	4.75	4.94	5.15	11.37	4.20	3.57	3.08	2.99	3.15	1.99	3.42	2.60
P	0.01	0.02	0.02	0.02	0.01	0.01	0.00	0.01	0.00	-0.02	-0.02	-0.01	0.02	-0.01	-0.02	0.00
Fe	0.03	0.05	0.11	0.01	0.00	0.01	0.00	0.04	0.03	-0.01	-0.01	-0.02	-0.02	0.03	0.11	0.10
Mn	0.07	0.06	0.10	0.11	0.09	0.12	0.09	0.09	0.09	0.08	0.07	0.07	0.05	0.07	0.08	0.08
Sr	0.14	0.16	0.16	0.15	0.17	0.10	0.09	0.20	0.08	0.08	0.09	0.10	0.10	0.08	0.08	0.08
Ba	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca	27.0	23.5	27.8	28.4	28.0	25.3	24.2	28.8	22.7	22.9	23.2	23.4	23.5	20.0	21.8	21.1
Mg	59.0	54.6	57.9	58.7	60.0	47.1	42.7	64.3	41.1	42.4	43.3	43.7	44.9	39.9	38.0	39.0
Na	29.8	23.6	22.6	21.1	18.8	12.4	11.4	14.6	9.4	12.6	14.9	16.2	18.3	15.0	11.1	11.5
K	9.7	6.2	7.7	5.6	4.4	3.0	3.1	4.6	2.3	3.5	4.8	5.2	7.1	6.8	3.0	10.5
F	-	5.11	6.50	5.93	6.46	3.93	3.72	3.82	3.67	3.86	3.99	4.15	4.25	3.80	3.78	3.63
Cl	-	95.0	63.6	92.1	95.5	77.8	75.5	95.1	75.9	78.4	81.4	82.7	84.9	79.9	78.5	85.8
NO2-N	-	0.20	-0.01	0.02	-0.01	-0.01					-0.01	-0.01	-0.01	-0.01	0.00	-0.01
Br	-	0.65	0.63	0.62	0.76	0.56	0.56	0.72	0.57	0.55	0.60	0.60	0.62	0.58	0.57	0.61
NO3-N	-	1.26	1.17	0.12	1.55	0.49	0.23	1.68	1.60	0.93	0.14	0.17	1.13	0.13	0.41	0.20
SO4	60.0	57.3	55.8	52.8	52.0	34.1	18.5	38.9	7.3	13.0	18.3	21.6	25.8	18.4	10.4	10.7
trace (ug/L)																
Li	16	10	11	7	9	8	6	9	6	8	11	11	13	10	6	6
B	128	98	101	100	112	65	79	169	109	89	86	64	84	104	103	57
Sc	0.1	0.1	0.1	0.1	0.1	0.1	1.6	3.4	1.2	1.4	0.8	0.8	0.7			
Ti	0.1	0.1	0.1	0.0	2.0	1.2	2.6	2.3	2.2	2.8	3.3	3.2	2.8			
V	0.8	0.6	0.9	0.2	0.3	0.2	0.7	0.7	0.3	0.4	0.4	0.5	0.4			
Cr	1.4	0.5	1.6	2.2	2.1	4.0	1.6	1.4	1.3	1.4	1.4	2.0	1.0	0.9	1.0	1.0

Tank 4: Surface Water

Date	11/27/96	12/12/96	02/26/97	08/01/97	09/10/97	11/05/97	12/17/97	01/15/98	02/26/98	03/26/98	07/01/98	10/14/98	01/28/99
weeks	3	5	16	38	44	52	58	62	68	72	86	101	116
Mn	78.7	74.0	79.5	2.0	3.9	3.8	3.0	3.6	21.1	8.0	1.7	2.9	2.4
Fe	5.0	364.0	2.8	11.2	16.8	54.2	39.3	38.9	27.7	18.8	2.5	5.4	1.0
Co	0.3	0.2	0.5	1.7	0.8	0.2	0.4	0.3	0.6	1.6	0.2	0.2	0.3
Ni	1.8	1.8	2.4	0.8	1.8	0.9	1.1	1.0	1.2	1.2	1.1	1.3	1.6
Cu	2.0	1.4	1.4	3.4	4.7	5.0	5.5	5.7	3.9	4.6	4.3	5.7	7.6
Zn	49.8	51.5	49.3	8.8	9.8	26.1	34.2	17.1	21.5	13.6	15.6	13.7	16.3
As	2.1	1.4	5.6	0.8	8.5	11.6	10.9	13.6	6.6	13.9	8.1	9.5	9.4
Se	3	0	3	1	0	2	1	1	1	3	1	1	2
Br	673.0	777.0	869.0	207.0	536.0	651.0	619.6	718.9	317.7	577.1	488.7	619.0	808.0
Rb	11.8	11.7	16.3	4.7	9.8	11.1	11.5	14.4	7.0	11.4	7.8	9.6	11.7
Sr	150	162	208	41	98	133	143	167	83	137	88	125	158
Mo	84	79	107	13	54	68	72	89	43	84	48	66	79
Ag	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.02	0.06	0.06			
Cd	0.10	0.15	0.09	0.04	0.17	0.05	0.11	0.10	0.06	0.05	0.11	0.10	0.10
Sn	0.00	0.03	0.00	0.07	0.00	0.10	0.28	0.00	0.17	0.17			
Sb	0.05	0.09	0.02	0.01	0.04	0.04	0.04	0.05	0.02	0.04			
Cs	1.42	1.33	1.94	0.47	1.11	0.99	0.98	1.12	0.53	0.89	0.55	0.74	0.74
Ba	3.94	4.02	4.53	0.95	2.02	2.35	2.00	2.39	2.32	2.07	1.82	2.71	2.34
W													
Pb													
U	0.06	0.04	0.47	0.03	0.07	0.09	0.16	0.10	0.13	0.23	0.24	0.33	0.41
TKN	0.35	0.63				0.39							
NH3-N	0.32	0.46				0.02							
TP													
TOC													

Table A3.4. Composition of the Tank 4 (Inland) tailings pore waters. Alkalinity in units of mg/L $CaCO_3$. “na” = not available

Tank 4: Tailings Pore Water

Date	11/27/96	12/12/96	01/02/97	01/30/97	02/26/97	04/02/97	08/01/97	09/10/97	11/05/97	12/17/97	01/15/98	02/26/98	03/26/98	07/01/98	10/14/98	01/28/99
weeks	3	5	8	12	16	21	38	44	52	58	62	68	72	86	101	116
pH	8.44	8.34		8.40	7.84		8.28	8.36	8.23	8.45	8.49	8.39	8.41	8.39	8.28	8.45
Alk	135	128			11		140	135	130	140	138	140	150	135	140	115
Eh	125	-			-2		144	111		79	24	127	46	89	90	132
majors (mg/L)																
Al	0.02	0.01	0.00	0.00	0.01	0.00	0.00	0.02	0.01	0.00	0.02	-0.00	0.01	-0.00	0.00	0.00
Si	5.68	3.65	3.16	2.69	2.36	5.84	5.30	4.31	4.51	2.82	2.49	2.67	2.61	3.00	3.67	2.60
P	0.02	0.02	0.01	0.02	0.02	0.01	0.00	0.02	0.00	-0.01	-0.01	-0.01	0.01	-0.02	-0.02	0.00
Fe	0.09	0.00	0.00	0.00	0.01	0.01	0.03	0.02	0.16	0.19	0.17	0.16	0.13	0.18	0.22	0.20
Mn	0.08	0.08	0.06	0.07	0.08	0.11	0.09	0.07	0.09	0.07	0.07	0.07	0.07	0.07	0.09	0.08
Sr	0.15	0.16	0.17	0.19	0.21	0.12	0.11	0.21	0.10	0.10	0.10	0.11	0.09	0.09	0.10	0.09
Ba	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca	26.0	25.2	28.0	27.9	29.8	27.4	24.2	30.6	23.0	23.7	23.7	24.5	23.2	21.2	24.4	22.3
Mg	53.7	53.7	53.5	50.6	51.6	52.2	46.8	48.8	48.2	50.3	50.6	52.4	51.4	47.5	50.0	51.0
Na	26.8	25.1	33.6	25.6	23.3	14.2	10.8	14.6	9.1	15.9	15.1	17.6	14.2	12.3	11.1	11.0
K	6.6	5.3	7.8	5.0	4.2	3.5	3.0	3.3	2.3	5.1	5.2	6.2	4.8	3.7	3.1	7.3
F	acidified	4.59	6.72	7.11	8.98	5.72	4.60	5.85	4.73	5.03	5.14	4.50	5.01	4.80	5.49	4.80
Cl		97.3	99.0	97.6	98.0	83.5	77.5	92.7	80.6	84.8	88.2	92.0	89.1	83.3	86.0	91.9
NO2-N		0.03	0.03	-0.01	-0.01	-0.01					-0.01	-0.01	-0.01	-0.01	0.00	-0.01
Br		0.66	0.67	0.67	0.77	0.62	0.58	0.70	0.62	0.72	0.67	0.68	0.67	0.62	0.63	0.66
NO3-N		2.06	1.85	0.12	1.89	0.30	0.31	1.28	1.50	2.62	0.11	0.96	0.82	0.26	0.15	0.15
SO4	59.2	58.2	60.3	56.9	57.2	22.6	8.5	29.9	4.7	18.0	16.0	20.5	13.7	10.6	7.6	6.8
trace (ug/L)																
Li	13	11	18	6	8	10	5	7	5	10	10	11	10	7	6	6
B	98	91	102	82	73	83	86	135	115	98	102	94	52	122	131	103
Sc	0.1	0.1	0.1	0.0	0.0	0.1	1.7	1.5	1.4	1.3	0.7	0.6	0.6			
Ti	0.1	0.1	0.1	0.0	2.0	1.6	2.5	2.6	0.2	0.1	0.0	0.0	0.1			
V	0.7	0.6	0.7	0.2	0.2	0.2	0.6	0.3	0.3	0.4	0.3	0.3	0.4			

Tank 3: Tailings Pore Water

Date	11/27/96	12/12/96	01/02/97	01/30/97	02/26/97	04/02/97	08/01/97	09/10/97	11/05/97	12/17/97	01/15/98	02/26/98	03/26/98	07/01/98	10/14/98	01/28/99
weeks	3	5	8	12	16	21	38	44	52	58	62	68	72	86	101	116
Mn	69.8	58.1	97.6	112.0	89.4	117.0	88.7	90.0	92.2	82.8	71.1	65.4	49.7	75.8	82.1	74.4
Fe	44.7	418.0	445.0	2.0	2.9	5.5	0.0	38.0	37.7	15.8	31.5	2.8	0.0	34.4	104.3	104.0
Co	0.2	0.2	0.2	0.3	0.3	0.3	0.1	0.1	0.3	0.3	0.3	0.4	0.4	0.3	0.2	0.3
Ni	1.1	1.6	1.2	0.9	1.9	2.3	1.1	2.8	1.2	0.8	1.6	1.5	1.4	1.8	1.7	1.5
Cu	0.8	0.8	0.7	0.0	0.0	0.0	0.4	10.3	0.2	0.6	0.8	1.9	1.7	1.4	0.9	1.6
Zn	45.7	50.9	31.0	43.7	44.8	33.1	1.9	2.0	33.6	24.8	22.9	32.1	38.5	17.6	14.9	19.5
As	2.1	1.3	3.1	3.1	3.6	1.3	1.5	3.0	2.2	2.6	2.8	3.5	3.6	4.0	3.7	3.4
Se	0	0	1	0	1	1	1	0	1	0	0	0	0	1	1	0
Br							547.0	759.0	528.0	508.1	543.3	517.4	540.1	558.1	574.0	598.0
Rb	8.2	5.0	7.0	4.4	3.6	2.4	2.6	4.3	2.1	2.8	3.9	3.8	4.7	3.9	2.4	2.6
Sr	142	163	168	165	183	117	104	209	98	91	98	101	113	86	87	79
Mo	45	18	25	24	20	35	26	33	19	25	32	32	36	29	22	20
Ag	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01			
Cd	0.03	0.03	0.03	0.00	0.00	0.00	0.05	0.01	0.00	0.04	0.03	0.07	0.04	0.07	0.10	0.10
Sn	0.00	0.12	0.26	0.00	0.09	0.55	0.77	0.94	0.74	0.99	0.65	0.73	0.90			
Sb	0.04	0.03	0.04	0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.02	0.02	0.02			
Cs	1.11	0.72	1.05	0.61	0.52	0.31	0.37	0.84	0.28	0.29	0.40	0.35	0.38	0.31	0.20	0.18
Ba	2.36	2.70	3.06	2.47	2.55	2.34	1.61	4.05	1.68	1.86	1.70	2.91	2.40	1.92	1.81	1.58
W	1.58	1.23	1.90	1.27	1.03	0.58	0.87	2.08	1.04	0.82	0.86	0.94	1.00	1.00	3.88	1.48
Pb	0.20	2.54	0.03	0.00	0.07	0.11	0.03	0.90	0.00	0.02	0.01		0.01	0.03	0.07	0.14
U	0.07	0.03	0.03	0.18	0.10	0.03	0.03	0.09	0.03	0.03	0.01	0.12	0.10	0.12	0.07	0.07
TKN		0.62							0.46							
NH3-N		0.47							0.03							
TP		2.31														
TOC																

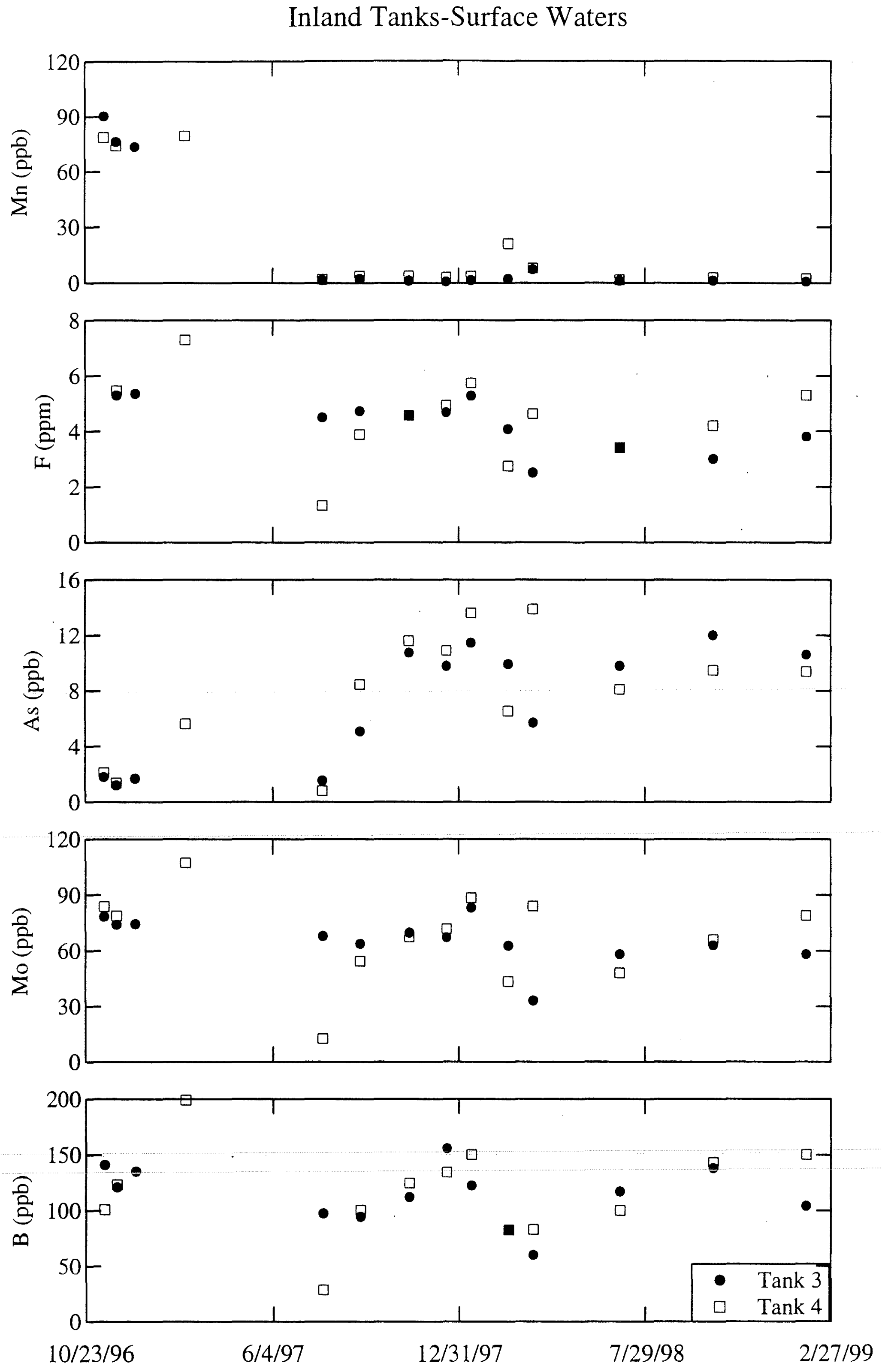


Figure A3.1. Surface water chemistry was reproducible for Tanks 3 and 4 (Inland).

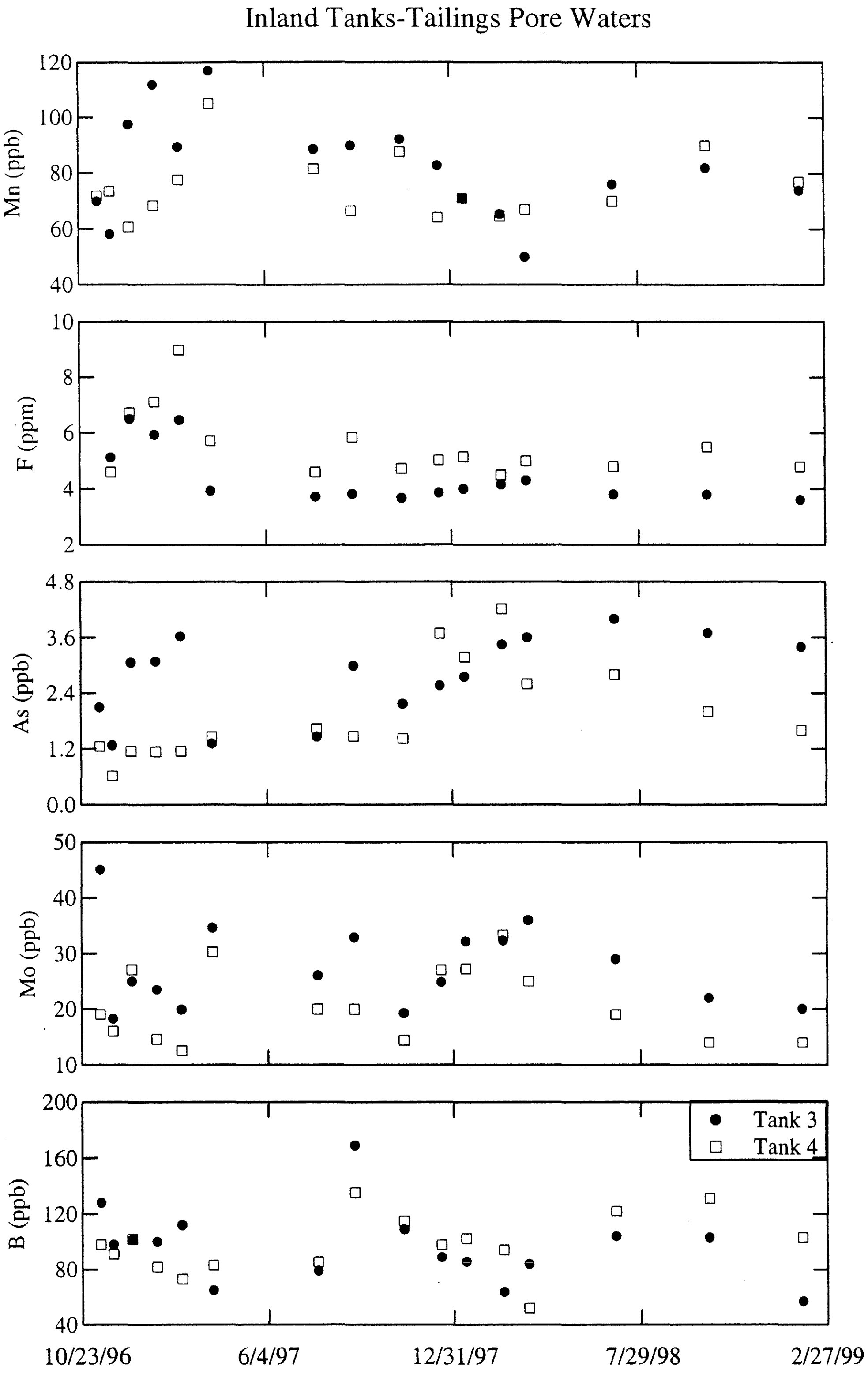


Figure A3.2. Tailings pore water chemistry was reproducible for Tanks 3 and 4 (Inland).

Tank 4: Tailings Pore Water

Date	11/27/96	12/12/96	01/02/97	01/30/97	02/26/97	04/02/97	08/01/97	09/10/97	11/05/97	12/17/97	01/15/98	02/26/98	03/26/98	07/01/98	10/14/98	01/28/99
weeks	3	5	8	12	16	21	38	44	52	58	62	68	72	86	101	116
Cr	2.7	0.4	2.3	2.5	1.4	4.8	1.6	0.5	0.9	0.9	1.9	2.3	1.2	0.9	1.0	2.0
Mn	71.7	73.4	60.7	68.3	77.5	105.0	81.6	66.6	87.8	64.2	71.0	64.6	67.4	70.0	90.1	77.0
Fe	103.0	16.0	17.0	5.8	15.6	10.7	46.1	22.5	209.0	209.7	187.1	262.6	133.4	186.4	218.5	178.0
Co	0.2	0.2	0.1	0.2	0.4	0.3	0.1	0.2	0.3	0.2	0.4	0.3	0.3	0.2	0.2	2.3
Ni	1.4	2.3	1.5	1.0	1.4	1.1	0.9	1.4	1.3	2.6	3.2	1.1	1.6	1.8	1.8	1.3
Cu	1.0	0.7	0.8	0.0	0.0	0.0	0.3	0.3	0.5	1.2	1.3	0.9	1.6	0.9	0.6	0.6
Zn	59.4	44.0	22.9	29.0	43.1	29.2	2.4	1.7	24.9	27.4	25.8	22.2	29.1	17.3	16.1	15.6
As	1.3	0.6	1.2	1.1	1.2	1.5	1.6	1.5	1.4	3.7	3.2	4.2	2.6	2.8	2.0	1.6
Se	0	0	1	0	1	1	1	0	1	0	1	1	1	0	2	1
Br	631.0	770.0	792.0	809.0	662.0	575.0	611.0	718.0	629.0	561.1	569.2	587.8	557.4	620.7	662.0	701.0
Rb	5.3	4.1	5.8	3.7	3.1	2.9	2.4	2.9	1.9	3.9	3.9	4.2	3.1	2.9	2.5	2.3
Sr	147	181	180	201	214	141	122	222	112	106	104	122	96	95	108	89
Mo	19	16	27	15	13	30	20	20	14	27	27	33	25	19	14	14
Ag	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00			
Cd	0.01	0.05	0.02	0.00	0.00	0.00	0.03	0.00	0.00	0.02	0.12	0.08	0.01	0.06	0.10	0.00
Sn	0.00	0.14	0.26	1.60	0.15	0.32	0.71	0.37	0.67	0.75	0.57	0.84	0.77			
Sb	0.03	0.04	0.03	0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.02	0.01	0.01			
Cs	0.78	0.64	0.86	0.39	0.38	0.30	0.29	0.39	0.21	0.33	0.35	0.33	0.27	0.25	0.21	0.16
Ba	2.76	4.02	4.48	4.60	5.04	2.70	1.83	3.18	1.84	1.66	1.97	3.04	2.38	2.03	1.84	1.49
W																
Pb																
U	0.02	0.00	0.00	0.05	0.04	0.06	0.03	0.06	0.02	0.03	0.03	0.06	0.06	0.07	0.06	0.05
TKN	<0.20	0.36							0.33							
NH3-N	0.00	0.22							0.04							
TP																
TOC																