Flooding of Pre-Oxidized Mine Tailings:
Mattabi Case Study

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Mattabi Case Study

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EXECUTIVE SUMMARY

The study was initiated in 1992 to address uncertainties in the design of water covers for decommissioning oxidized tailings. Laboratory column experiments and field cell tests were carried out with tailings from the Mattabi Mine (Noranda Inc.) site near Ignace, Ontario. Some experiments involved placement of attenuation layers made of sand or peat at the tailings-water interface. In contrast to other studies, tailings were not amended with alkaline material, either prior or after flooding.

The benefits sought by implementing a water cover over oxidized tailings include: (1) limiting further oxidation of the tailings, (2) providing sufficient improvement of the water cover quality to permit discharge of runoff to the surrounding environment without the need for treatment after a transition period (i.e., the period during which previous oxidation products are flushed out of the water cover), and (3) reducing contaminant loads and treatment costs associated with seepage from the tailings over time.

Flooding oxidized tailings without prior installation of an attenuation layer resulted in the release of metals and sulphate from the pore water solution and soluble mineral phases to the water cover. In the columns, average total iron, sulphate and zinc concentrations in the water cover reached respectively 257 mg/L, 927 mg/L and 20.2 mg/L approximately one year after flooding. Corresponding concentrations in the field cell water cover one year after the flooding of July 1992 were 466 mg/L, 2850 mg/L and 3.8 mg/L, respectively. Differences between concentrations measured in the laboratory and in the field tests were likely due to differences in initial pore water compositions and soluble mineral contents between the columns and the test cell.

Because the pore water of Mattabi tailings was rich in ferrous iron, the establishment of a water cover was accompanied by the precipitation of a thin layer of hydrous ferric oxide precipitate on the surface of the tailings. This was due to the oxidation of ferrous iron by dissolved oxygen and subsequent hydrolysis of ferric iron.

Over time, contaminant concentrations in the water cover decreased as a result of 1) dilution of the water cover by addition of deionised water (laboratory columns) or rain and snowmelt (field test cell), 2) flushing of solutes by water infiltration from the cover to the tailings, and 3) removal of some metals by precipitation and sorption on a hydrous ferric oxide precipitate layer that formed at the water/tailings interface. In the field test cell, the water cover met regulatory discharge limits two years after flooding: As<0.5 mg/L, Cu<0.3 mg/L, Fe < 3 mg/L, Pb < 0.2 mg/L and Zn < 0.5 g/L. However, the water cover pH remained lower than the minimum of 6.0. It is

estimated that about 1855 mm of water infiltrated during this period. In the laboratory column water covers, the zinc concentration decreased much more slowly than in the field test cell and was still ~6 mg/L after 620 days of simulated infiltration, which translates into ~955 equivalent field days given average field infiltration rates.

The persistence of elevated zinc concentrations in the laboratory column water covers is likely explained by geochemical equilibrium of the overlying water with a Zn–containing solid phase in the hydrous ferric oxide layer at the tailings/water interface. Hence, the hydrous ferric oxide precipitate, although contributing to the decrease of zinc concentrations in the column water cover during the first year of testing, later acted as a source of soluble zinc as metal concentrations in the water cover and pore water decreased. In the field cell, the zinc content in the precipitate layer (0.22%) was less than in the laboratory columns (1.28%), presumably because of lower initial pore water concentrations. As a result, zinc did not leach as much, and discharge limits were met in the water cover two years after first flooding the cell, as pointed out above. Hence, the geochemical characteristics of the oxidized tailings (pore water composition, soluble minerals) have a large influence on the time required to achieve discharge limits in the water cover.

Attenuation layers made of sand or peat were only tested in the laboratory columns. Fluxes of metals from the tailings to the water cover were greatly reduced by placing an attenuation layer at the tailings-water interface. This was primarily because diffusion of metals from the oxidized tailings through the attenuation layer and to the water cover is a very slow process. Moreover, the attenuation layer also imposes a diffusion control on the availability of dissolved oxygen to the tailings, and therefore limits further tailings oxidation more effectively than a simple water cover.

When a sand layer was used, the water cover met discharge limits during the entire duration of the tests. The average total iron, sulphate, and zinc concentrations in the water cover were below 0.3mg/L, 50 mg/L, and 0.03 mg/L approximately half a year after flooding. The peat layer was less effective because of its own leachable zinc content: after 163 days of test, the zinc concentration was still 1.5 g/L in one of the columns. Hence, it is important to ensure that material used to build the attenuation layer has low contaminant levels so that it does not contribute to the contamination of the water cover. A careful and detailed characterization of this material is therefore very important. In general, peat obtained around the vicinity of mining sites does not appear to be a good candidate for building attenuation layers, as it is often a source of iron and other metals in water cover applications.

Seepage water quality was only measured in the laboratory column tests. Seepage concentrations were initially very high (similar to pore water concentrations) and remained stable for all columns until the displacement front reached the bottom of the columns (at about 0.7 pore volumes), after which they decreased over time as infiltrating water flushed the contaminated pore water. The presence of a water cover accelerated the decrease in seepage concentrations when compared with tailings left exposed to the atmosphere, probably as a result of reducing further tailings oxidation.

The time or pore volumes of infiltration water required to meet discharge limits in the seepage depends on the distribution of the contaminants in the tailings. When contaminants are mostly contained in the pore water, discharge limits may be achievable after flushing the tailings with ~ 3 pore volumes. However, when a significant portion of the contaminants is contained in soluble solid phases, concentrations in the seepage stabilized at elevated values and long-term seepage treatment will be required. The presence of an attenuation layer at the water/tailings interface seemed to have relatively little influence on the seepage water quality.

Long-term maintenance of water covers generally requires that seepage losses from the facility be minimal. In this case, the contaminated pore water will remain in place for many years, and seepage treatment, if part of the closure plan, can be expected to be long lasting.

If the seepage rate is high, as was the case in this study, large volumes of seepage will need to be intercepted and treated. Economic considerations suggest that at sites with high seepage rates, a water cover may be suitable only if it can be supplemented with gravity-fed fresh water from a nearby source to the cover, and thus compensate for seepage losses. In this situation, treatment costs for the seepage will increase after flooding due to higher infiltration rates. Although the quality of seepage will increase over time, treatment may still be required in the very long term since solute concentrations may reach near-asymptotic values that are still above discharge limits, as was the case in some of the tests. Hence, the establishment of a water cover over oxidized tailings is not recommended at sites with significant seepage losses.

SOMMAIRE

L’étude a débuté en 1992 dans le but de régler certaines questions liées à la conception des couvertures aqueuses utilisées pour la réhabilitation des résidus oxydés. Des expériences de colonne en laboratoire et des essais en cellules de terrain ont été réalisées pour des résidus provenant du site de la mine Mattabi (Noranda Inc.) près d’Ignace (Ontario). Certaines des expériences comportaient la mise en place de couches d’atténuation constituées de sable ou de tourbe à l’interface résidus-eau. Contrairement à ce qui a été fait pour d’autres études, les résidus n’ont pas été modifiés par l’ajout de matières alcalines, que ce soit avant ou après l’inondation.

Les avantages recherchés par la mise en place d’une couverture aqueuse sur des résidus oxydés sont notamment (1) de freiner l’oxydation des résidus, (2) d’améliorer suffisamment la qualité de la couverture aqueuse pour permettre une décharge des eaux de ruissellement dans l’environnement immédiat sans avoir besoin d’effectuer un traitement après la période de transition (période durant laquelle les produits de l’oxydation antérieure sont libérés de la couverture aqueuse), et (3) de réduire la charge de contaminants et les coûts du traitement associés aux eaux d’exfiltration provenant des résidus avec le temps.

L’inondation des résidus oxydés sans installation préalable d’une couche d’atténuation a donné lieu à la lixiviation de métaux et de sulfate provenant des eaux interstitielles et de la phase minérale soluble dans la couverture aqueuse. Dans les colonnes, les concentrations moyennes de fer total, de sulfate et de zinc dans la couverture aqueuse étaient respectivement de 257 mg/L, de 927 mg/L et de 20,2 mg/L environ un an après l’inondation. Les concentrations correspondantes dans la couverture aqueuse de la cellule de terrain un an après l’inondation de juillet 1992 étaient de 466 mg/L, 2850 mg/L et 3,8 mg/L respectivement. Les différences entre les concentrations mesurées en laboratoire et lors des essais sur le terrain sont probablement imputables aux différences de composition initiale de l'eau interstitielle et de la teneur en minéraux solubles entre les colonnes et la cellule d’essai.

Comme l’eau de porosité des résidus de Mattabi était riche en fer ferreux, la mise en place de la couverture aqueuse a été accompagnée de la précipitation d’une mince couche d’oxyde ferrique hydraté précipité à la surface des résidus. Ce phénomène est causé par l’oxydation du fer ferreux par l’oxygène dissous et par l’hydrolyse subséquente du fer ferrique.

Au fil du temps, les concentrations de contaminants dans la couverture aqueuse ont diminué par suite 1) de la dilution de la couverture aqueuse causée par l'ajout d'eau déionisée (colonnes de laboratoire) ou à cause de la précipitation et de l'eau provenant de la fonte des neiges (cellule d'essai sur le terain), 2) du lessivage des solutés par infiltration d'eau provenant de la couverture vers les résidus, et 3) de l'élimination de certains métaux par précipitation et sorption sur une couche d'oxyde ferrique hydraté précipité qui s'était formée à l'interface eau-résidus. Dans la cellule de terrain, la couverture aqueuse a atteint régulièrement les limites de décharge réglementaires deux ans après l'inondation : As < 0,5 mg/L, Cu < 0,3 mg/L, Fe < 3 mg/L, Pb < 0,2 mg/L et Zn < 0,5 g/L. Cependant, le pH de la couverture aqueuse est demeuré sous la valeur minimale de 6,0. On a estimé à environ 1 855 mm la quantité d'eau qui s'est infiltrée durant cette période. Dans les couvertures aqueuses de la colonne de laboratoire, la concentration de zinc a diminué beaucoup plus lentement que dans la cellule d'essai sur le terrain et était encore à ~6 mg/L après 620 jours d'infiltration simulée, ce qui se traduit par ~955 de jours équivalents pour des vitesses d'infiltration moyennes.

On peut expliquer le fait que les concentrations de zinc étaient encore élevées dans les couvertures aqueuses de la colonne de laboratoire par la recherche d'un équilibre géochimique entre la couche d'eau superficielle et la phase solide renfermant du zinc et contenue dans la couche d'oxyde ferrique hydraté à l'interface eau-résidus. Ainsi, l'oxyde ferrique précipité, bien qu'il ait contribué à diminuer la concentration de zinc dans la colonne d'eau durant la première année des essais, a par la suite servi de source de zinc soluble à mesure que les concentrations de métaux dans la couverture aqueuse et dans l'eau interstitielle diminuaient. Dans la cellule de terrain, la teneur en zinc de la couche de précipitat (0,22 %) était inférieure à celle des colonnes en laboratoire (1,28 %), probablement à cause du fait que les concentrations initiales de l'eau interstitielle étaient inférieures. Par conséquent, la lixiviation du zinc n'a pas été aussi importante, et les limites de décharge ont été atteintes dans la couverture aqueuse deux ans après la première inondation de la cellule, comme nous l'avons vu précédemment. Ainsi, les caractéristiques géochimiques des résidus oxydés (composition de l'eau interstitielle, minéraux solubles) ont une incidence importante sur le temps requis pour atteindre les limites de décharge dans la couverture aqueuse.

Les couches d'atténuation constituées de sable ou de tourbe ont été mises à l'essai seulement dans les colonnes en laboratoire. Les flux de métaux provenant des résidus vers la couverture aqueuse ont été considérablement réduits par la mise en place d'une couche d'atténuation à l'interface eau-résidus. Cela s'explique par le fait que la diffusion des métaux provenant des résidus oxydés à travers la couche d'atténuation et vers la couverture aqueuse est un processus très lent. En outre, la couche d'atténuation exerce un contrôle sur la diffusion pour ce qui est de la disponibilité de l'oxygène dissous vers les résidus et par conséquent, elle restreint l'oxydation ultérieure des résidus plus efficacement qu'une simple couverture aqueuse.

Dans le cas où on a utilisé une couche de sable, la couverture aqueuse a atteint les limites de décharge durant toute la durée des essais. Les concentrations moyennes de fer, de sulfate et de zinc dans la couverture aqueuse étaient inférieures à 0,3 mg/L, 50 mg/L et 0,03 mg/L environ six mois après l'inondation. La couche de tourbe était moins efficace à cause de sa propre teneur en zinc lixiviable : après les 163 premiers jours de l'essai, la concentration de zinc était encore de 1,5 g/L dans une des colonnes. Par conséquent, il est important de s'assurer que les matériaux employés pour aménager la couche d'atténuation possèdent de faibles niveaux de contaminants, de sorte que la couche ne contribue pas à contaminer la couverture aqueuse. Une caractérisation attentive et détaillée de ces matériaux est donc très importante. De façon générale, la tourbe obtenue à proximité de sites miniers ne semble pas être un matériau qui convienne à l'aménagement des couches d'atténuation, car elle est souvent une source de fer et d'autres métaux dans les applications de couverture aqueuse.

La qualité de l'eau d'exfiltration a été mesurée seulement dans les essais de colonne en laboratoire. Les concentrations dans l'eau d'exfiltration étaient à l'origine très élevées (semblables aux concentrations de l'eau interstitielle) et sont demeurées stables dans toutes les colonnes d'eau jusqu'à ce que le front de déplacement ait atteint le fond des colonnes (taux de renouvellement de l'eau du volume poreux d'environ 0,7), après quoi elles ont diminué en fonction du temps à mesure que l'eau qui s'infiltrait évacuait l'eau interstitielle contaminée. La présence d'une couverture aqueuse a accéléré la diminution des concentrations dans l'eau d'exfiltration lorsqu'on compare la présence de cette couche à des résidus exposés à l'atmosphère, probablement par suite de la réduction subséquente de l'oxydation des résidus.

Le temps ou le taux de renouvellement de l'eau du volume poreux requis pour atteindre les limites de décharge dans les eaux d'infiltration dépendent de la répartition des contaminants dans les résidus. Lorsque les contaminants sont principalement contenus dans l'eau interstitielle, les limites de décharge peuvent être atteintes après l'évacuation des résidus avec ~ 3 volumes poreux. Cependant, lorsqu'une proportion importante des contaminants est contenue dans les phases solides, les concentrations dans les eaux d'exfiltration se sont stabilisées à des valeurs élevées et un traitement à long terme des eaux d'exfiltration sera requis. La présence d'une couche d'atténuation à l'interface eau-résidus semble avoir relativement peu d'incidence sur la qualité des eaux d'exfiltration.

L'entretien à long terme des couvertures aqueuses exige généralement que les pertes d'eaux d'exfiltration soient réduites au minimum. Dans ce cas, l'eau interstitielle contaminée demeurera en place pendant de nombreuses années, et l'on peut s'attendre à ce que le traitement des eaux d'exfiltration, s'il fait partie du plan de fermeture, soit durable.

Si la vitesse d'écoulement des eaux d'exfiltration est élevée, comme c'était le cas dans la présente étude, de grands volumes d'eaux devront être interceptés et traités. Les considérations économiques laissent supposer qu'aux sites où les vitesses d’écoulement des eaux d’exfiltration sont élevées, une couverture aqueuse ne pourrait convenir que si elle est additionnée d’eau douce alimentée par gravité provenant d’une source à proximité, et ainsi elle pourra compenser pour les pertes d’eaux d’exfiltration. Dans ce cas, les coûts du traitement des eaux d’exfiltration augmenteront après l’inondation à cause des vitesses d’infiltration élevées. Même si la qualité des eaux d’exfiltration augmente avec le temps, le traitement pourrait être nécessaire à très long terme parce que les concentrations d’éléments en solution peuvent atteindre des valeurs près de l’asymptote qui se trouveraient encore au-dessus des limites de décharge, comme ce fut le cas lors de certains essais. Ainsi, l’établissement d’une couverture aqueuse sur les résidus oxydés n’est pas recommandé pour des sites où les eaux d’exfiltration sont importantes.

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1 INTRODUCTION

1.1 GENERAL

Covering of old, oxidized sulphidic mine tailings with water has been proposed for several years as a method for reducing sulphide oxidation and generation of acid mine drainage. The method usually involves the construction of containment structures around the tailings deposit to hold water. Since the oxygen diffusion coefficient and solubility in water are very low compared to their values in air (Davé et al., 1997), oxygen influx to the tailings is effectively reduced. However, metals present in pore water solutions and in soluble mineral phases have the potential to be released from the tailings. As a result, treatment of runoff and seepage water leaving the tailings may be required for a long time after the placement of the cover if the concentrations and loads of released metals are important enough.

The benefits sought by implementing a water cover over oxidized tailings include:

(1) reduction in further tailings oxidation
(2) sufficient improvement of the water cover quality to permit discharge of runoff to the surrounding environment without the need for treatment after the transition period, i.e., the period when previous oxidation products are being flushed out of the water cover, and
(3) reduction over time of contaminant loads and treatment costs associated with seepage from the tailings.

1.2 BACKGROUND ON MATTABI TAILINGS AREA

1.2.1 Site Description

The Mattabi site is located 73 km Northeast of the Town of Ignace, Ontario, on the south shore of Sturgeon Lake. The Mattabi tailings impoundment was active from 1972 to April 1991. During this period, approximately 15.5 million tonnes of tailings from three different ore bodies were end-spilled over an area of 125 hectares. The general condition of the tailings basin at end of operations is shown on Figure 1-1.

The aerial photograph on Figure 1-2 illustrates the tailings basin in October 1987. Tailings were deposited to a maximum depth of approximately 10 m in an oblong bowl-shaped depression that previously contained a shallow lake. Additional tailings containment was provided by dams constructed of cycloned tailings spilled over waste rock "starter dams" - a construction technique typically used at most tailings impoundments prior to the mid-seventies. These dams offered only physical support to the tailings mass, allowing the tailings to drain freely and to develop an unsaturated zone.

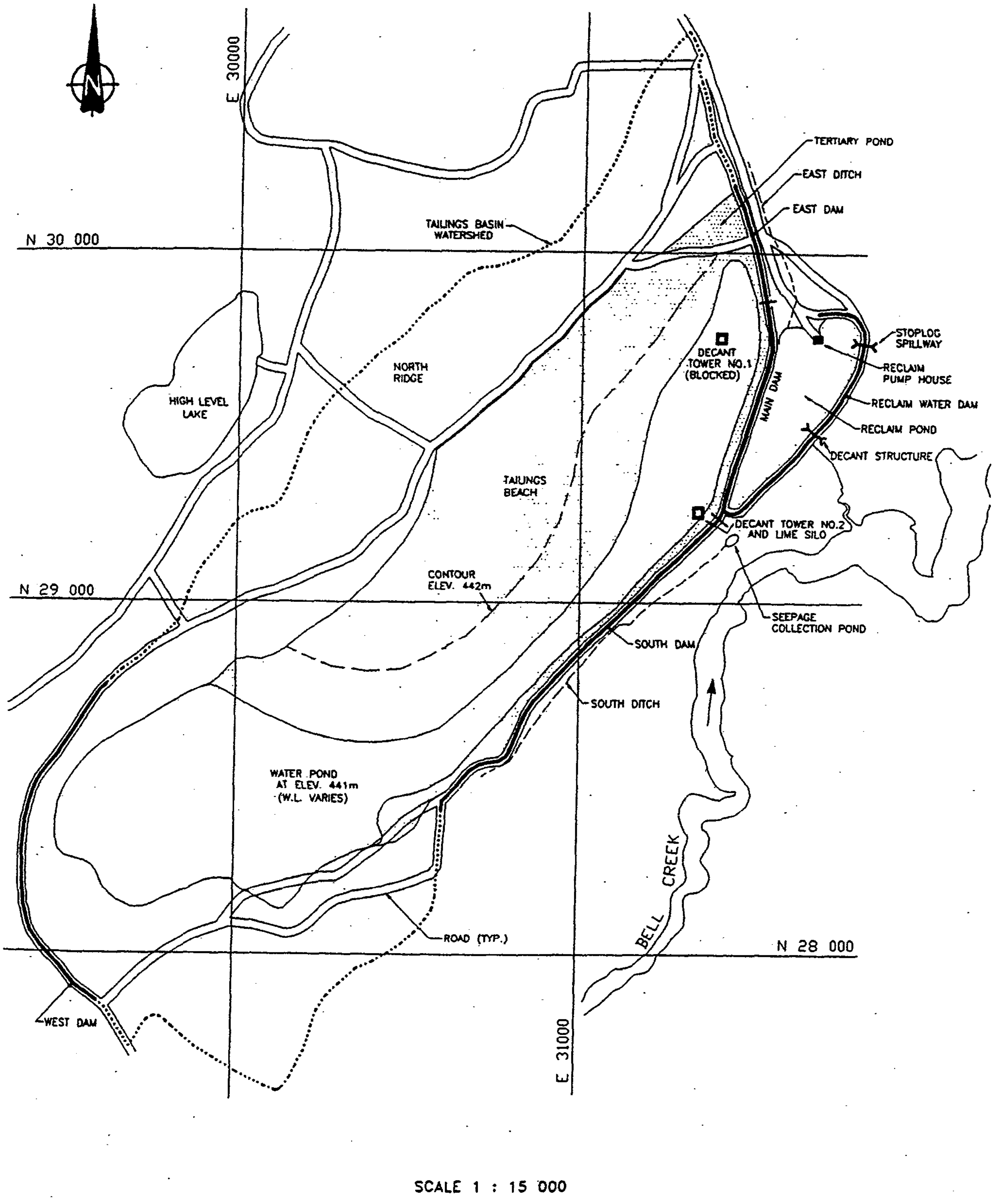

Figure 1-1: Plan of tailings basin at end of operations

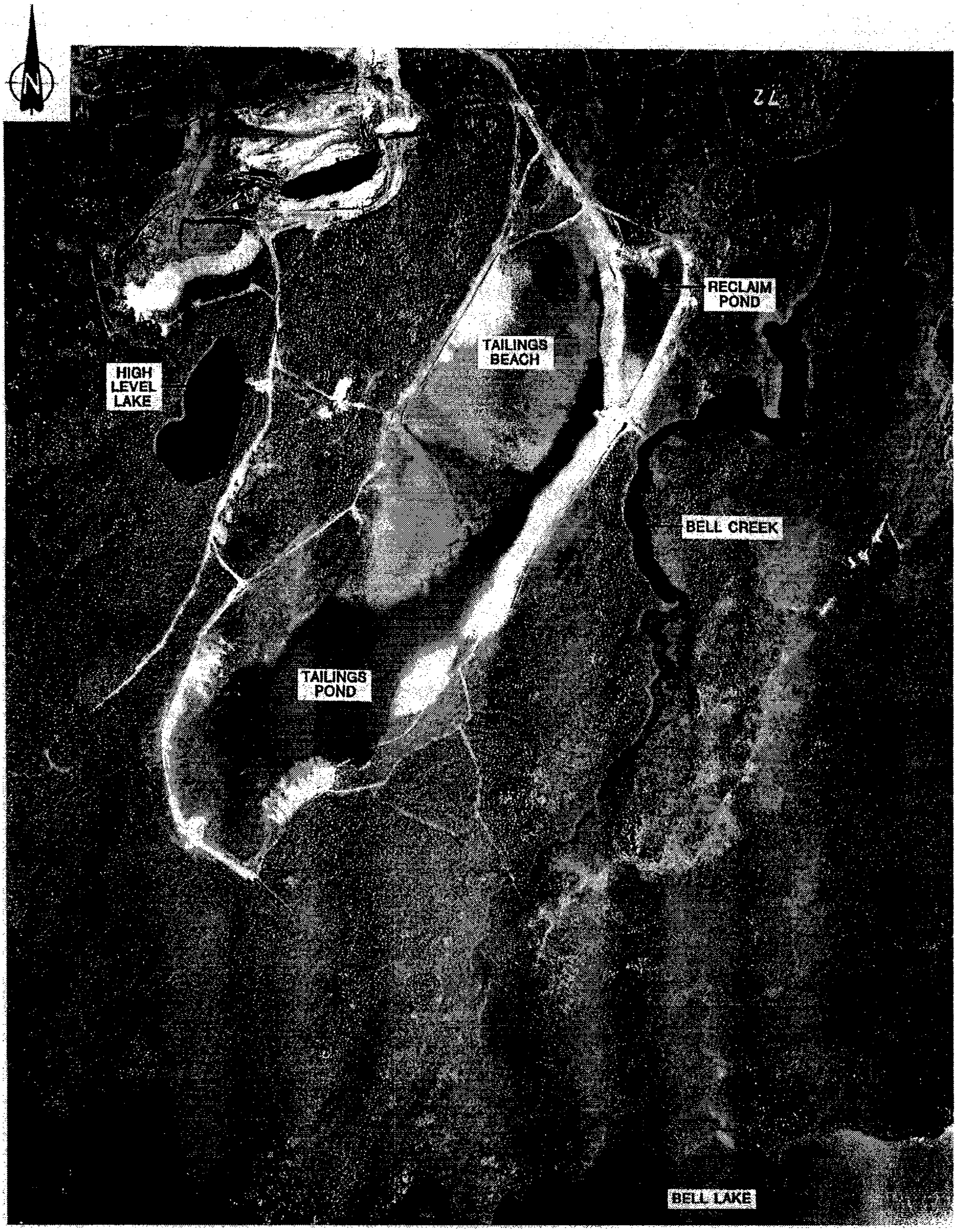

Figure 1-2: Aerial photo of tailings basin – October 1987

1.2.2 Environmental Concerns

The tailings contain approximately 37% pyrite and 12% pyrrhotite by mass but few alkaline minerals, thus indicating strong AMD potential if exposed to oxygen and water. Oxidation and geochemical evolution of the tailings occurred during a period of approximately twenty years. As a consequence of tailings oxidation, surface runoff and seepage from the tailings have exhibited high levels of dissolved metals (especially zinc) and sulphate and low pH typical of acid mine drainage. The principal downstream receiver is the Bell Creek that flows eventually into Sturgeon Lake. Contamination of the Bell Creek in the past resulted primarily from contaminated surface runoff and shallow seepage in the south dam area. A relatively small contribution to the metal loadings reporting to Bell Creek resulted from the discharge of lime-treated effluent from the reclaim pond (Geocon, 1993a).

The unsaturated zone within the tailings is very shallow (0 to 0.6 m), and a large portion of the tailings is already flooded. The largest sources of potential oxidation products are the south and west dams bounding the tailings from the south-east to the south-west (Figure 1-1). The dam core is made of waste rock onto which tailings were spigotted. The unsaturated zone in the dam is approximately 3.5 m, and its surface area is approximately 10 hectares. This constitutes a significant volume of material that has been oxidizing over the life of the impoundment.

1.2.3 Current Closure Plan

The conceptual design for the selected tailings basin closure scheme is illustrated in Figure 1-3 and described in detail in Geocon (1993a). Under this scheme, the tailings basin will be divided into the West Cell and East Cell by construction of an internal dyke across the basin. The majority of the tailings deposit will be located within the East Cell where the generation of acid mine drainage will continue. The runoff will be routed to the new Pump Pond for transfer to Mattabi Pit for temporary storage before treatment in a wastewater treatment plant. Only a very small amount of tailings will be left in the West Cell, which will be permanently flooded with a minimum 1.0-m deep water cover over the tailings. After a transition period during which the water quality in the West Cell is expected to improve as a result of implementing the water cover, the runoff from this cell will be routed directly to Bell Creek. During the transition period, the West Cell runoff will be routed through the East Cell to the Pump Pond for transfer to Mattabi Pit. A portion of the tailings beach (upper portion of East Cell) would be utilized for sludge disposal under this scheme (Geocon, 1993a).

At this time, progressive rehabilitation works have already been carried out. They include the construction of interceptor ditches (East Ditch and South Ditch) to collect contaminated surface runoff and shallow groundwater seepage originally reporting to the Cedarclump Lake watershed and to Bell Creek. However, the construction of the internal dyke and flooding of the West Cell have not yet been completed. An important objective provide information needed to assess the environmental benefits of implementing a water cover over the tailings in the West Cell.

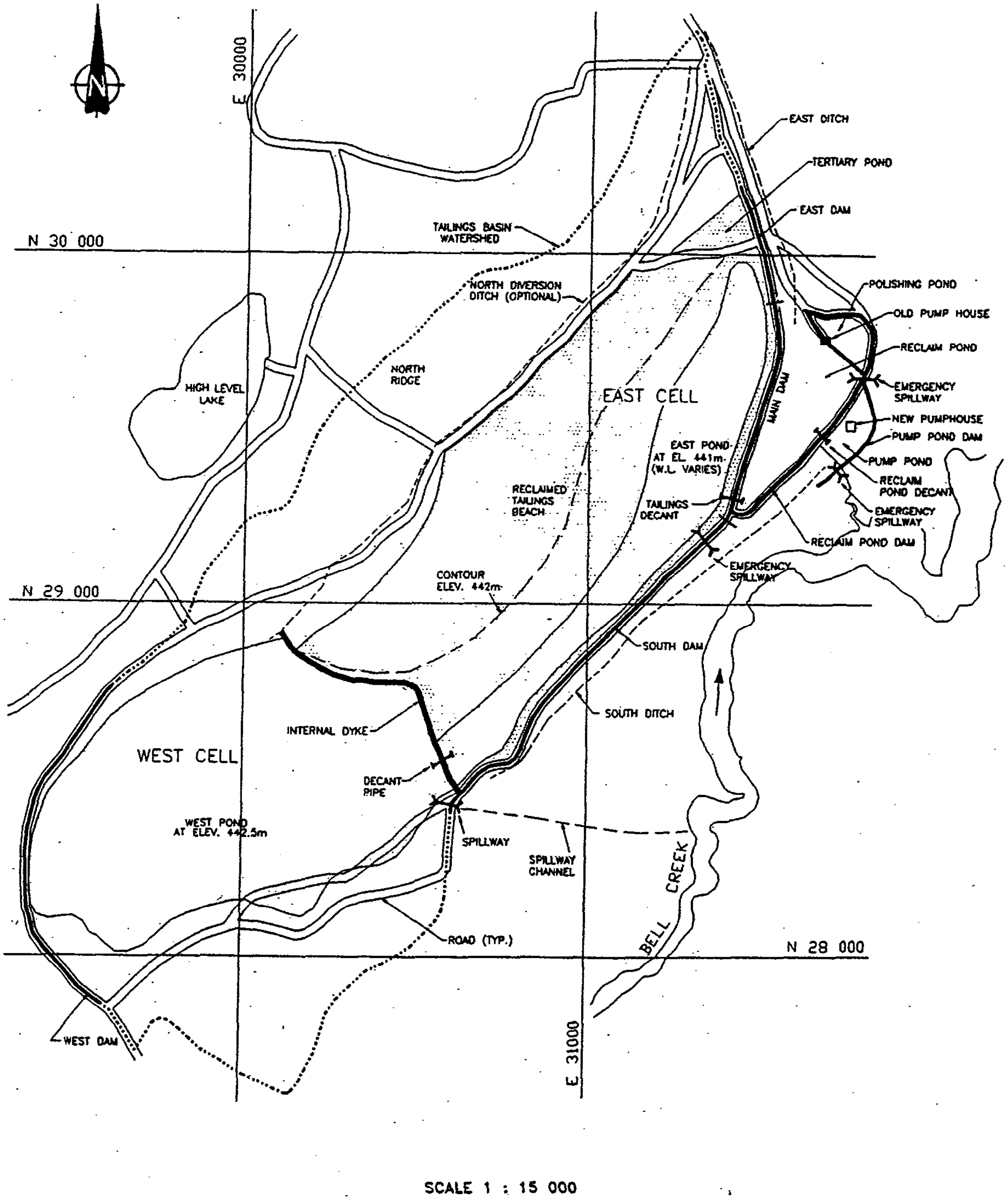

Figure 1-3: Current plan for tailings basin closure

1.3 REVIEW OF OTHER PROPERTIES

According to a recent review of water cover sites and research projects (MEND 2.18.1, 1997), flooding of oxidized tailings has already been implemented at a number of sites including three closed operations: the Solbec tailings site near Stratford, Québec, the Quirke Lake tailings site in Elliot Lake, Ontario, and the Stekenjokk site in northern Sweden.

Prior to flooding at the Solbec site, hydrated lime ($Ca(OH)_2$) was dumped in the tailings pond water, and calcite dust and granules ($CaCO_3$) were incorporated into the tailings by ploughing to a depth of up to 30 cm in the area that was exposed to atmosphere. On average, 230 tonnes of alkaline material per hectare were applied to limit the solubility of metals (Amyot and Vézina, 1997). The water cover was implemented in 1994. All water quality parameters in the water cover conformed to the applicable Quebec regulation as early as in the summer of 1995. However, in the fall of 1996 the oxidized tailings pore water still contained iron and zinc concentrations of 150 mg/L and 9.3 mg/L, respectively. Further details on studies pertaining to the Solbec site are available in MEND 2.13.2a (1994) and MEND 2.13.2c (1994).

The Quirke Lake tailings site was flooded between 1992 and 1995. The water cover was designed as a series of five terraced cells separated by internal dykes. To neutralize the acidity generated from previously oxidized uranium tailings, lime is added to all cells, except to Cell 14 which is located upstream of the other cells. Within two years after flooding, the iron and zinc concentrations in the water cover of Cell 14 stabilized below 0.6 mg/L and 0.01 mg/L, respectively. The water cover pH varied between 6.5 and 7.1 during the same time period, and sulphate levels show a continuous decline since flooding was initiated. The mean water retention time in Cell 14 is estimated at about three months. Significant downward seepage in this cell and the consequent flushing of oxidation products down into the pore water are important in explaining the rapid attainment of discharge compliance standards in the water cover without lime addition. The high seepage loss is offset by diverting fresh water from a nearby lake and can be maintained in the long term. The quality of shallow pore water in the upper tailings also improved significantly after flooding. The acidity declined from peak levels of 12,500 mg/L $CaCO_3$ prior to flooding to a maximum of 240 mg/L in 1996. Treatment requirements have increased in the short term due to increased seepage caused by flooding (Kam et al. 1997).

At the Stekenjokk site, Zn-Cu tailings rich in pyrite and other sulphides were flooded in 1991. A small area of the tailings deposit (about 5% of the bottom of the pond) consists of material that has oxidized and weathered before the flooding. In the summer of 1995, average concentrations of Ca (20.0 mg/L), S (11.1 mg/L), Cd (0.69 mg/L), Zn (139 mg/L), and Ni (1.3 mg/L) in the water cover were higher than local background concentrations in surface water (Ljungberg et al., 1997). According to these authors, the most important source of Zn in the water cover is probably diffusion from the oxidized tailings pore water where Zn concentrations are much higher than in the water cover. In addition, dissolution of gypsum in the oxidized tailings most likely accounts for the elevated concentrations of Ca and sulphate both in the pore water and in the water cover. There are some indications that sulphide oxidation continues under the water cover (although at a much lower rate than in tailings exposed to the atmosphere), and also contributes to the pore water composition.

1.4 PROJECT HISTORY

In May 1992, MEND approved a Noranda Technology Centre (NTC) and CANMET joint research plan aimed at using laboratory, computational, and field methods for reducing the uncertainties inherent to the design of water cover decommissioning schemes (St-Arnaud and Davé, 1992). Within that plan, NTC received the mandate to 1) measure and analyze the effective diffusion coefficients and fluxes of selected metals and major ions from oxidized tailings, 2) evaluate mineral dissolution from oxidized and unoxidized tailings, and 3) obtain site-specific geotechnical and hydrogeochemical parameters. The present report is an account of the work carried out by NTC to fulfil its mandate.

1.5 OBJECTIVES OF PRESENT STUDY

The NTC study involved laboratory column experiments and field pilot tests in which oxidized tailings from the Mattabi Mine site near Ignace, Ontario were placed under water covers. At that site, oxidation and geochemical evolution of the tailings had occurred for about 20 years. As a result, surface runoff and seepage from the tailings have exhibited low pH and high concentrations of metals (especially zinc) and sulphate. The following questions were addressed:

- What will be the evolution of water chemistry over flooded oxidized tailings?
- How will flooding affect the quality of seepage originating from the flooded tailings?
- For how long will water cover runoff and the seepage require treatment after flooding?
- What are the effects of placing an attenuation layer of sand or peat between the tailings and the water cover?
- What are the important economic considerations in the use of water covers for decommissioning oxidized tailings?

These questions are relevant for all the sites where a water cover over oxidized tailings is considered a decommissioning option.

This report is organized into six chapters. Chapter 1 reviews background information and states the objectives of the study. Chapter 2 and 3 present the results of laboratory column and field cell tests, respectively. Summary and recommendations are provided in Chapter 4. The research team is presented in Chapter 5, and references are listed in Chapter 6.

2 LABORATORY COLUMN EXPERIMENTS

2.1 MATERIALS

Samples of oxidized and unoxidized tailings were collected in the summers of 1992 and 1993 from two trenches on the north portion of the Mattabi tailings basin. Representative sub-samples were used to characterize the tailings whole rock composition, mineralogy, grain size distribution, acid generation potential, and pore water chemistry. The rest of the samples were used to pack eight laboratory columns for flooding experiments.

2.1.1 Elemental Composition

Elemental compositions of oxidized and unoxidized tailings were determined by inductively-coupled plasma spectrophotometry (ICP), after total digestion in a mixture of hydrochloric/hydrofluoric/nitric acids. The results are reported in Appendix I. Figure 2-1 compares the compositions of the various tailings for elements detected at concentrations higher than 0.1%. Iron, sulphur, silicon, and aluminium were the most abundant elements in all samples, in decreasing order. Oxygen accounted for the majority of the mass in the "other" category. Unoxidized tailings collected in 1993 had higher iron and sulphur content (26.52% and 26.38%, respectively) than the other samples. The zinc content of 1992 samples (0.60% and 0.54% in oxidized and unoxidized tailings, respectively) was about twice that of 1993 samples (0.33% and 0.18% in oxidized and unoxidized tailings, respectively).

2.1.2 Mineralogy

The mineralogy of the oxidized and non-oxidized tailings was determined by a combination of X-ray diffraction (XRD) and whole-rock geochemistry data. A normative mineralogy was calculated on the basis of the minerals identified by XRD. For these calculations, pyrrhotite was lumped in the calculated pyrite content. It was assumed that all the K was in muscovite; however, it is possible that some orthoclase was also present. The excess Fe in minerals other than sulphides was used to form magnetite in the fresh tailings, and both magnetite and goethite in the oxidized tailings. Minor amounts of ankerite were detected by XRD in the non-oxidized tailings, but not calculated because inorganic carbon was not analyzed.

The calculated normative mineralogy is given in Table 2-1. Other minerals possibly present in minor amounts were illite, diopside and allophane. Because their identification is uncertain, they were not considered in the normative mineralogy calculation.

The dominant silicate minerals were quartz, muscovite, chlorite, and albite. The sulphides were dominated by pyrite (33-52 wt%). Trace amounts of chalcopyrite, sphalerite,

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galena, and arsenopyrite were also present. Gypsum was more abundant in the oxidized tailings, and ranged between 0.18 and 1.03 wt%. Goethite (FeO(OH)) was present in the oxidized tailings and was responsible for the observed rusty colour.

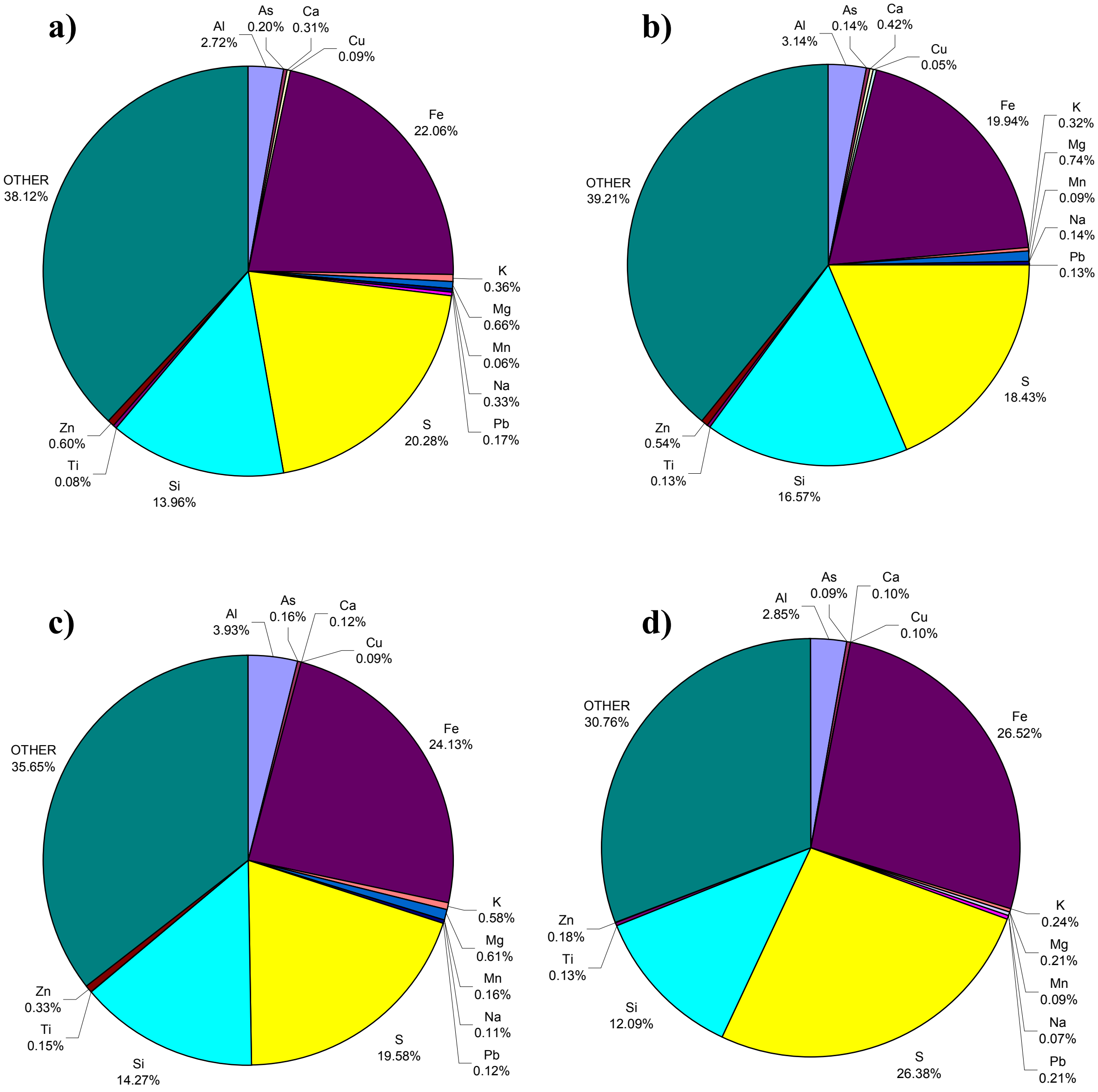

Figure 2-1: Elemental composition of Mattabi tailings: a) oxidized tailings collected in 1992, b) unoxidized tailings collected in 1992, c) oxidized tailings collected in 1993, and d) unoxidized tailings collected in 1993

TABLE 2-1: NORMATIVE MINERALOGY OF MATTABI TAILINGS (mass %)

	Unoxidized (1992)	*Oxidized (1992)*	*Unoxidized (1993)*	*Oxidized (1993)*
Quartz	29.00	22.11	19.85	19.76
Albite	1.58	3.75	0.67	1.25
Muscovite	4.26	4.69	2.18	14.54
Chlorite	12.30	11.00	3.30	10.60
Ankerite	traces		traces	
Pyrite	33.04	36.20	51.68	34.64
Chalcopyrite	0.14	0.26	0.32	0.26
Sphalerite	0.81	0.90	0.30	0.90
Galena	0.15	0.20	0.24	0.23
Arsenopyrite	0.42	0.39	0.21	0.60
Magnetite	2.81	2.81	4.53	4.53
Rutile	0.13	0.13	0.20	0.25
Goethite	0.00	1.80	0.00	3.56
Gypsum	0.59	1.03	0.18	0.23

2.1.3 Grain Size Distribution

Grain size distributions of tailings samples are shown in Figure 2-1. The majority of the particles were classified as fine sand (75 to 200 µm). The median size (D_{50}) ranged between 120 and 200 µm. No significant difference in size distribution was found between 1992 and 1993 samples, or between oxidized and unoxidized tailings.

2.1.4 Acid Generation Potential

Acid-base accounting (ABA) tests were conducted on Mattabi tailings samples using the Sobek procedure (Sobek et al., 1978). These tests measure the overall balance between acidity potential (AP) and the neutralisation potential (NP). In a standard ABA test, the total S is measured, and the AP is calculated based on the assumption that all the S exists as pyrite and that all pyrite will weather completely to produce sulphuric acid. The NP is determined from the amount of acid that the sample material neutralizes in a standardized digestion-back titration procedure.

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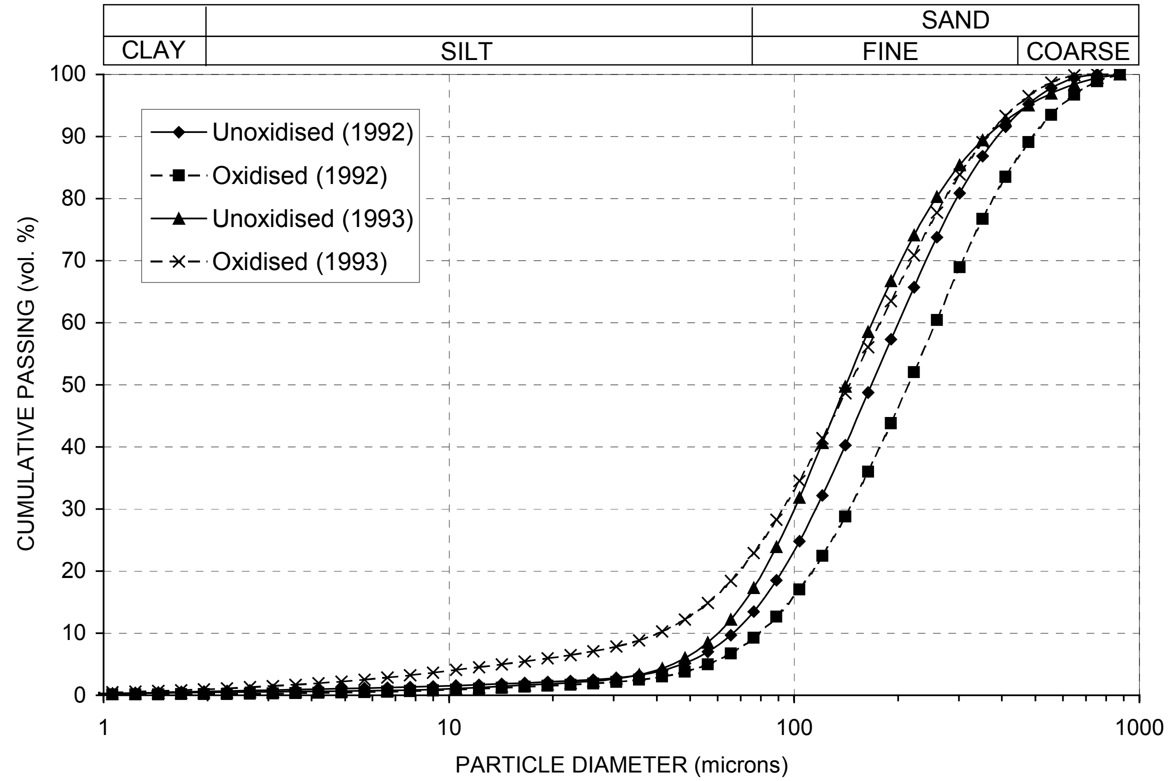

Figure 2-2: Grain size distribution of Mattabi tailings

A sample is considered acid generating if the ratio NP/AP<1.0 and AP>3.1 kg $CaCO_3$/t. If NP/AP>3.0 or AP<3.1 kg $CaCO_3$/t, the material is considered non-acid generating. Materials with 1.0<NP/AP<3.0 kg CaCO3/t and AP>3.1 kg $CaCO_3$/t are uncertain from an ABA point of view.

The results of ABA testing (Table 2-2) show that all tailings samples were strongly acid generating. The neutralization potential is very small or negative.

TABLE 2-1: ABA TEST RESULTS FOR MATTABI TAILINGS

Sample Type	*Oxidized (1992)*	*Oxidized (1993)*	*Unoxidized (1992)*	*Unoxidized (1993)*
Paste pH	2.95	4.29±0.19	5.41	4.44±0.92
S (total), %	20.3	19.6±1.5	18.4	26.4±1.7
AP, kg $CaCO_3$/t	634	613±47	575	825±53
NP, kg $CaCO_3$/t	-0.2	-0.15±0.21	6	-0.45±0.07
NP/AP	0	0	0.01	0

2.1.5 Pore Water Chemistry

The pore water compositions of oxidized and unoxidized tailings samples collected in the summer of 1992 are reported in Table 2-3. The chemistry of Sturgeon Lake water is also shown for reference. Oxidized tailings had significantly higher metal and sulphate pore water concentrations than unoxidized tailings. The most abundant metals were iron and zinc. Metal concentrations in Sturgeon Lake water were either very low or below detection limits.

TABLE 2-1: INITIAL TAILINGS PORE WATER CHEMISTRY (1992 SAMPLES)

Species	*Unoxidized tailings pore water (mg/L)*	*Oxidized tailings pore water (mg/L)*	*Sturgeon Lake water (mg/L)*
Al	0.62	252.81	<0.05
As	0.25	101.09	<0.05
Ca	487.46	548.84	12.5
Cd	0.13	16.75	<0.005
Cu	< 0.02	193.43	<0.005
Fe	1250	8300	<0.005
K	11.35	6.85	<1.00
Mg	1610	2740	1.79
Mn	405.76	572.33	0.001
Na	34.17	51.4	3.88
Pb	3.86	5.33	<0.05
SO_4	14370	41130	18.66
Se	< .50	1.57	<0.10
Zn	2540	6470	<0.005

2.2 METHODS

2.2.1 Description of Laboratory Columns

Eight 2-m high, 30-cm in diameter, transparent Plexiglas columns (MTWC-1 to MTWC-8) were tested (Figure 2-1). Each column was built with two 1-m sections. The bottom sections were filled with ~60 cm of relatively unoxidized tailings and ~40 cm of oxidized tailings.

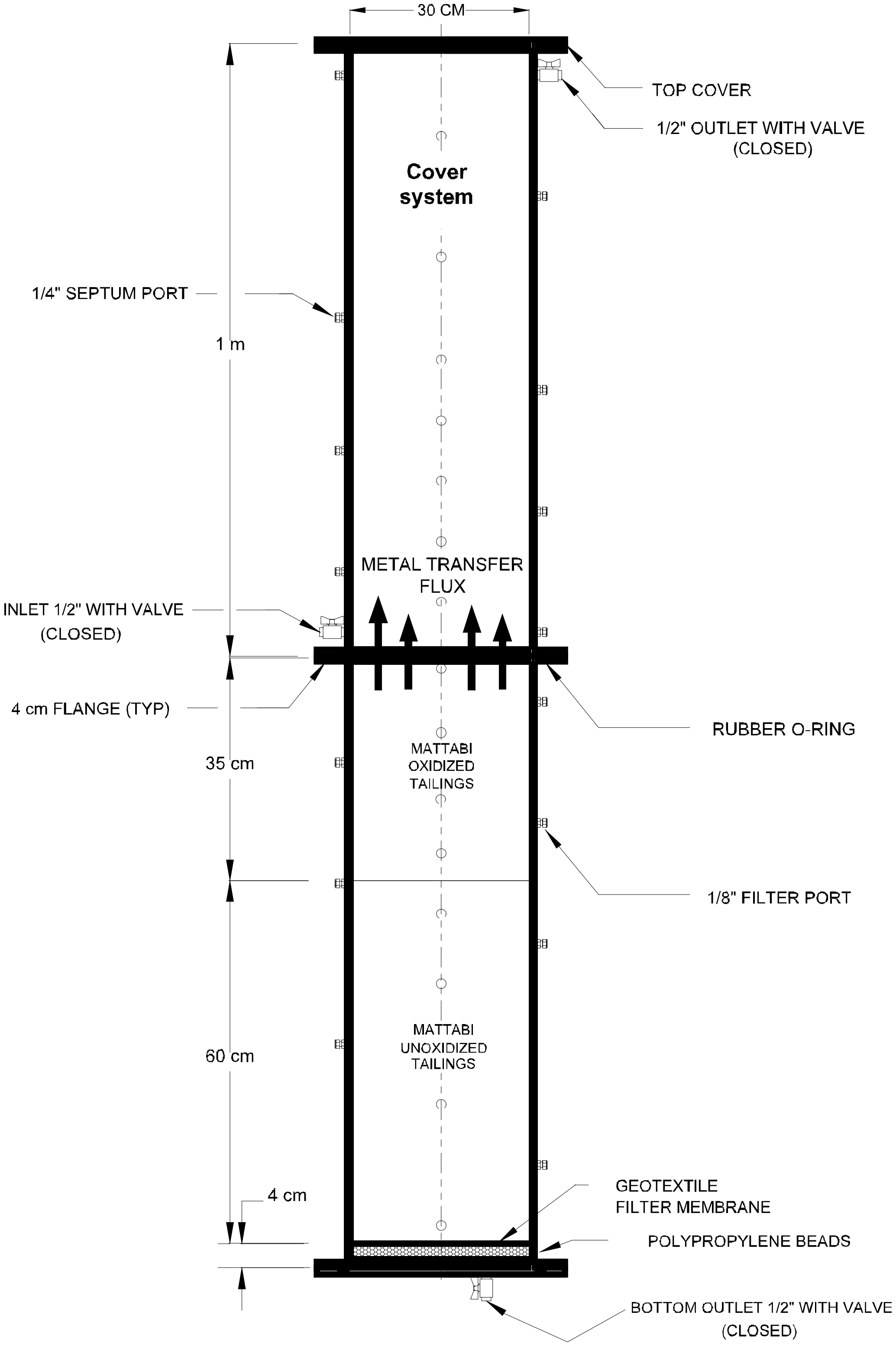

Figure 2-3: Schematic diagram of laboratory columns

Columns MTWC-1 and MTWC-2 were constructed first and packed with tailings collected in 1992. The other columns were packed with 1993 tailings. The top 10 cm of oxidized tailings were replaced with an attenuation layer in Columns MTWC-3 to MTWC-6. The attenuation layer consisted of sand in Columns MTWC-3 and MTWC-4, and of peat in Columns MTWC-5 and MTWC-6. After placement of the tailings in the bottom section of the columns, the top 1-m sections were attached and filled with Sturgeon Lake water (Columns MTWC-1 and MTWC-2) or deionised water (Columns MTWC-3 to MTWC-6). No water cover was installed in Columns MTWC-7 and MTWC-8. The four different column configurations were tested in duplicate, as indicated in Table 2-4.

TABLE 2-3: DESCRIPTION OF COLUMN CONFIGURATIONS

Column Identification	*Water thickness*	*Attenuation Layer*
MTWC-1 and MTWC-2	1 m	none
MTWC-3 and MTWC-4	1 m	10 cm sand layer
MTWC-5 and MTWC-6	1 m	10 cm peat layer
MTWC-7 and MTWC-8	no cover, saturated tailings	none

Each column was equipped with fourteen septum ports to allow sampling of the pore water in the tailings and in the attenuation layers. In Columns MTWC-1 to MTWC-6, fourteen filter ports allowed sampling of the water cover. A bottom outlet was also available to sample the seepage when water was allowed to flow through the tailings.

2.2.2 Experimental Protocol

The column tests began with a static period during which the bottom outlet was shut. This was followed by a dynamic period during which deionised water was added at the top of the column at a rate of 1 L per week, and seepage was collected at the bottom to simulate infiltration and seepage in the field. This rate of water addition was about 1.6 times the average infiltration rate in the field. Test protocols are summarised in Table 2-5.

2.2.3 Sampling and Analyses

Samples measuring 10-mL in volume were taken from each sampling port after 0, 7, 41, 51, 152, 347, 399, 465, 531, 620, 701 and 944 days for Columns MTWC-1 and MTWC-2, and after 0, 197, 163, 229, 317, 399, and 642 days for Columns MTWC-3 to MTWC-8. During the dynamic period, seepage samples were collected about every week during the first pore volume, and then about every month. The samples were preserved and analyzed for total dissolved iron, zinc, and sulphur by inductively coupled plasma spectrophotometry (ICP). Ferric and ferrous iron were determined by spectrophotometry and by titration with potassium dichromate, respectively. During the dynamic period, the seepage pH and acidity were measured at each sampling event. Acidity was determined by titration with a sodium hydroxide solution.

TABLE 2-4: DURATION OF STATIC AND DYNAMIC PERIODS AND RECOVERED VOLUME OF EFFLUENT DURING THE DYNAMIC PERIOD

Column Identification	Static period (Days)	Dynamic period (Days, PV$^+$)	Total (Days)
MTWC-1	348	605 (2.43)	953
MTWC-2	348	605 (2.59)	953
MTWC-3	183	468 (2.02)	651
MTWC-4	183	468 (2.07)	651
MTWC-5	183	468 (1.98)	651
MTWC-6	183	468 (2.00)	651
MTWC-7	227	424 (1.72)	651
MTWC-8	227	424 (1.69)	651

$^+$PV = Pore Volume. 1 PV is defined as the volume of pore water, in m^3, contained in 1 m^3 of tailings.

2.3 RESULTS

2.3.1 Static Tests

2.3.1.1 Concentration Profiles

Concentration profiles for total iron (Fe_T), ferric iron (Fe^{3+}), sulphate (SO_4^{2-}), and zinc (Zn^{2+}) in each column during the static period are shown in Figures II-1 to II-8*. There is good agreement between profiles obtained in duplicate columns. Concentration profile data are also presented in tabular form in Appendix V.

<u>Overlying water</u>

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* Roman numerals in figure numbers refer to the appendix where they can be found.

In columns without an attenuation layer, flooding the oxidized tailings resulted in significant transfer of contaminants from the tailings to the water cover. After 347 days of test for Columns MTWC-1 and MTWC-2, dissolved concentrations of Fe_T, Fe^{3+}, SO_4^{2-} and Zn^{2+} increased to 90 mg/L, 5 mg/L, 500 mg/L, and 24 mg/L respectively within the upper 80 cm of the water cover (Figures II-1 and II-2). In the 20 cm of water above the tailings, dissolved concentrations were even higher: 1000 mg/L for Fe_T, 20 mg/L for Fe^{3+}, 4000 mg/L for SO_4^{2-}, and 60 mg/L for Zn^{2+}. Variations in solute concentrations with depth indicate that the water cover was not well mixed. By contrast, field measurements of solute concentrations versus depth in water covers have shown that the water is well mixed except in the first millimetre above the tailings (St-Germain et al., 1997; Campbell, 1998). Average concentrations of Fe_T, SO_4^{2-}, and Zn^{2+} in the water covers at the end of the static period were respectively 257 mg/L, 927 mg/L and 20.2 mg/L in Column MTWC-1, and 115 mg/L, 594 mg/L, and 15.8 mg/L in Column MTWC-2.

Examination of the change in Zn^{2+} concentration profiles between 152 and 347 days in the bottom 20 cm of the water cover shows that the flux of Zn^{2+} was directed from the tailings to the water cover during the first 152 days (concentrations increasing with depth) but changed direction some time after 152 days since the concentration decreased with depth after 347 days. (Figures II-1d and II-2d).

In columns having a sand attenuation layer, the transfer of contaminants from the tailings to the water cover was considerably smaller than when no layer was present. Concentration profiles for Columns MTWC-3 and MTWC-4 (Figures II-3 and II-4) show that Fe_T, Fe^{3+}, SO_4^{2-} and Zn^{2+} concentrations were below 0.3mg/L, 0.05 mg/L, 50 mg/L, and 0.03 mg/L for all the water cover sampling ports after 163 days of static test.

The peat attenuation layer was less effective than sand for reducing the transfer of Zn^{2+} and SO_4^{2-} to the water cover. After 163 days of static test in Columns MTWC-5 and MTWC-6 (Figures II-5 and II-6), dissolved Zn^{2+} and SO_4^{2-} concentrations of 1.5 mg/L and 150 mg/L were measured in the water cover. However, Fe_T and Fe^{3+} concentrations were similar to those measured with a sand attenuation layer. These results can be explained by the presence of leachable zinc and sulphate in the peat used to make the layer. TABLE 2-1 shows the concentration of various metals in the peat and in the sand used in the columns. The peat contained 3300 µg/g zinc and 8100 µg/g sulphur. By contrast, the zinc and sulphur contents in the sand were only 96 µg/g and 261 µg/g, respectively. Note also that the peat had significantly higher copper and lead contents than the sand.

TABLE 2-5: ABUNDANCE OF SELECTED ELEMENTS IN PEAT AND SAND

µg/g	*Peat*	*Sand*

Al	3600	64500
As	48	<50
Ca	39400	15000
Cd	7.6	<2.5
Cu	388	43.2
Fe	7000	21800
K	286	9280
Mg	2800	8300
Mn	136	354
Na	827	24600
Pb	443	<25
S	8100	261
Se	18.4	<50
Si	N/A	318700
Zn	3300	96

Pore water

Initial zinc concentrations in pore water were much higher in Columns MTWC-1 and MTWC-2 (between 2000 and 4000 mg/L) than in the other columns (between 20 mg/L and 200 mg/L). These differences complicate the quantitative comparison of the effects of different cover configurations. By contrast, initial pore water concentrations of SO_4^{2-} and Fe_T were similar in all columns.

Differences in pore water concentrations between the bottom of the tailings column (unoxidized) and the top (oxidized) decreased with time. This may have been caused by diffusion of solutes from the oxidized to the unoxidized tailings. Examination of the evolution of solute concentration profiles with time in the pore water suggests that iron and sulphate diffused faster than zinc.

Pore water concentrations of Zn^{2+} decreased with time in the top 20 cm of tailings in Columns MTWC-1 to MTWC-6. The decrease was most pronounced in MTWC-1 and MTWC-2. This effect, combined with the net Zn^{2+} flux from the water cover to the tailings surface in the second half of the static period (see above), suggests the presence of a zone at the tailings surface where zinc was either precipitated or adsorbed.

2.3.1.2 Formation of a Hydrous Ferric Oxide Precipitate Layer at the Tailings Surface

A reddish hydrous ferric oxide precipitate was noted at the tailings/water interface in Columns MTWC-1, MTWC-2, MTWC-7, and MTWC-8 as early as day 1 of the tests. In columns where a sand or peat attenuation layer was present, a similar precipitate formed at the interface between the oxidized tailings and the attenuation layer. These precipitates are commonly formed as ferrous iron generated by iron sulphide oxidation dissolves in pore water and seeps to surface. The ferrous iron is then oxidized to ferric, which rapidly hydrolyses to form the reddish solid. The chemical reaction describing the hydrolysis of ferric iron is:

$$Fe^{3+} + 3H_2O = Fe(OH)_3(s) + 3\ H^+ \qquad \text{(Equation 2-1)}$$

This reaction, by producing hydrogen ions, may have significantly contributed to water acidification. Equilibrium thermodynamic calculations on the water chemistry at 81days in Column MTWC-1 using the computer program MINTEQA2 (Allison et al., 1990) confirmed the presence of supersaturated conditions with respect to the amorphous form of ferric oxide (or ferrihydrite) and goethite. The stability of the precipitate is described by the activity product:

$$pQ = -\log[Fe^{3+}][OH^-]^3 \qquad \text{(Equation 2-2)}$$

which normally ranges from 37.3 to 43.3 in solutions where hydrous ferric oxides form. Values of pQ in Columns MTWC-1 and MTWC-2 were 37.5 and 38.2, respectively, indicating the presence of freshly precipitated amorphous ferric hydroxide (St-Arnaud and Yanful, 1993). The chemistry of hydrous oxide precipitates and their relative stability have been examined in detail by Langmuir and Whittemore (1971).

The net fluxes of Zn^{2+} to the tailings surface measured both in the water cover and in pore water (see Section 2.3.1.1) is most likely explained by co-precipitation/sorption of Zn^{2+} with $Fe\ (OH)_3$ in the hydrous ferric oxide layer, as illustrated in Figure 2-1.

The chemical kinetics of metal sorption on amorphous metal hydroxides was described by Gadde and Laitinen (1974) and Kinniburg at al (1976). Reports by Music and Ristic (1992), and Morel and Hering (1993), state that, in general, heavy metal retention by amorphous minerals is highly reversible and pH-dependant. Blowes and Jambor (1990) also found that sorption and co-precipitation with hydroxide and sulphate minerals was a major removal mechanism for zinc.

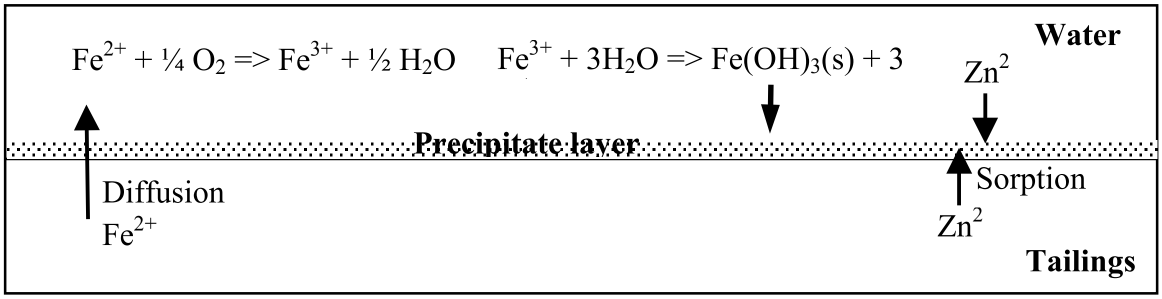


Figure 2-4: Schematic illustrating the formation of a hydrous ferric oxide precipitate and the co-precipitation/sorption of Zn^{2+}

The hydrous ferric oxide precipitate layers in Columns MTWC-2 and MTWC-8 were sampled at the end of the tests, and analyzed by inductively coupled plasma spectrophotometry (ICP). These layers measured between one and two millimetres in thickness. Zinc accounted for 1.28% and 0.18% of the precipitates in Columns MTWC-2 and MTWC-8, respectively. These results corroborate that zinc accumulated in the precipitate layer. The higher accumulation in Column MTWC-2 resulted probably from the larger initial zinc concentration in pore water.

2.3.1.3 Contaminant Fluxes and Loads to the Water Cover

Contaminant fluxes to the water cover during the static period were estimated from the changes in the mass of contaminants in the water cover:

$$F = \frac{1}{\Omega} \cdot \frac{dM_w}{dt} \qquad \text{(Equation 2-1)}$$

In the equation above, F is the flux of a given contaminant, M_w is the contaminant mass in the water cover at time t after the start of the static period, and Ω is the column cross sectional area. The contaminant mass in the water cover was obtained by numerical integration of its concentration, C, over the water column depth, H:

$$M_w = \int_0^H C\Omega\, dz \qquad \text{(Equation 2-2)}$$

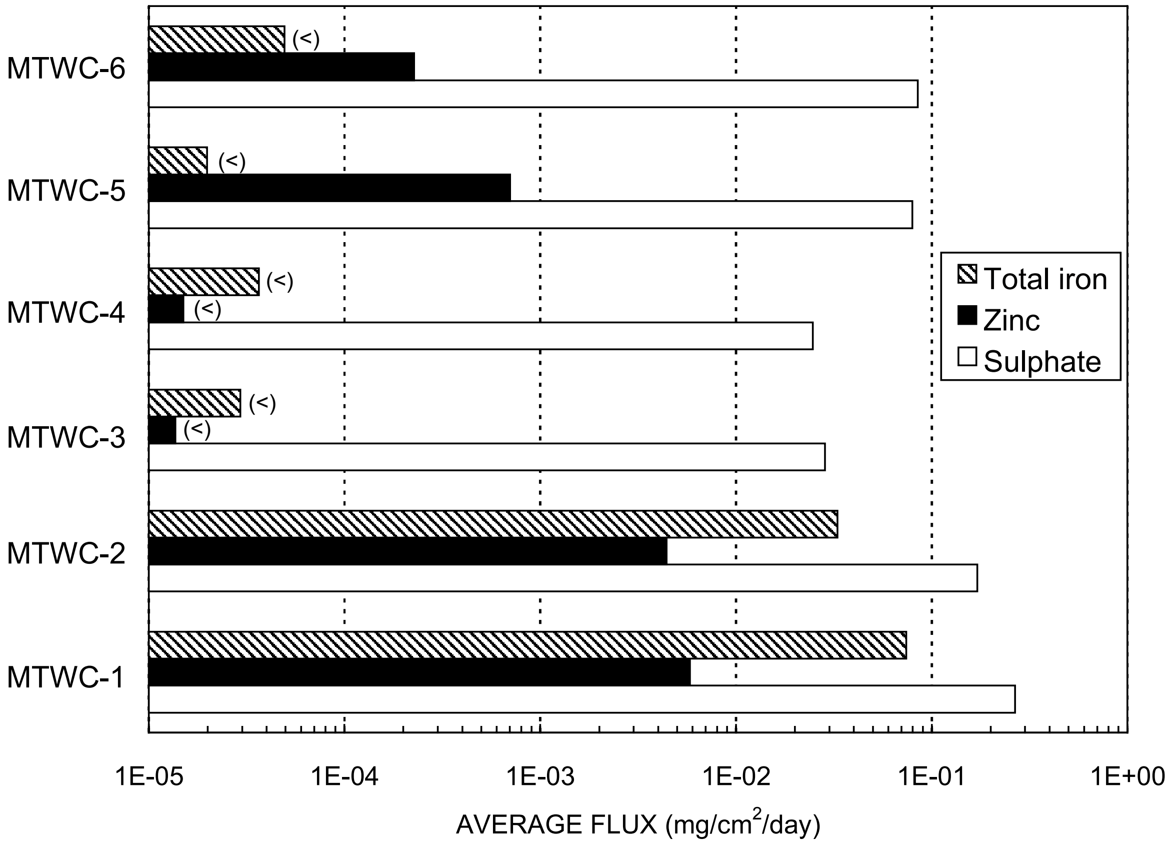
Note that C was taken equal to the analytical detection limit when the contaminant was not detected in the water cover. Hence, M_w was overestimated in these cases.

The average flux for the static period is given by:

$$F_{avg} = \frac{1}{\Omega} \cdot \frac{M_w(t_{stat})}{t_{stat}} \qquad \text{(Equation 2-3)}$$

where t_{stat} is the duration of the static period. The average fluxes of iron, zinc, and sulphate for Columns MTWC-1 to MTWC-6 are shown in Figure 2-1 and Table 2-7. When M_w is overestimated because of using detection limits instead of actual concentrations, only an upper limit is available for F_{avg}. This has been indicated by the symbol (<) on Figure 2-1. The reproducibility between duplicate columns was acceptable.

Contaminant fluxes were smaller in columns with attenuation layers. The lowest fluxes were measured with sand attenuation layers. Fluxes of Fe_T and Zn^{2+} were between 2 and 3 orders of magnitude lower in Columns MTWC-3 and MTWC-4 than in Columns MTWC-1 and MTWC-2.



The symbol (<) indicates that the actual average flux is smaller than shown on the figure.

Figure 2-5: Average fluxes of total iron, sulphate, and zinc to the water cover during the static period

TABLE 2-6: AVERAGE FLUXES (mg/cm^2/day) TO THE WATER COVER DURING THE STATIC PERIOD

Column	Fe_T	Fe^{3+}	Zn^{2+}	SO_4^{2-}
MTWC-1	7.41E-02	2.16E-03	5.83E-03	2.67E-01
MTWC-2	3.30E-02	5.85E-04	4.41E-03	1.71E-01
MTWC-3	<2.94E-05	<3.01E-05	<1.36E-05	2.84E-02
MTWC-4	<3.65E-05	<3.01E-05	<1.50E-05	2.47E-02
MTWC-5	<1.99E-05	<3.01E-05	7.02E-04	7.94E-02
MTWC-6	4.93E-05	<3.01E-05	2.27E-04	8.49E-02

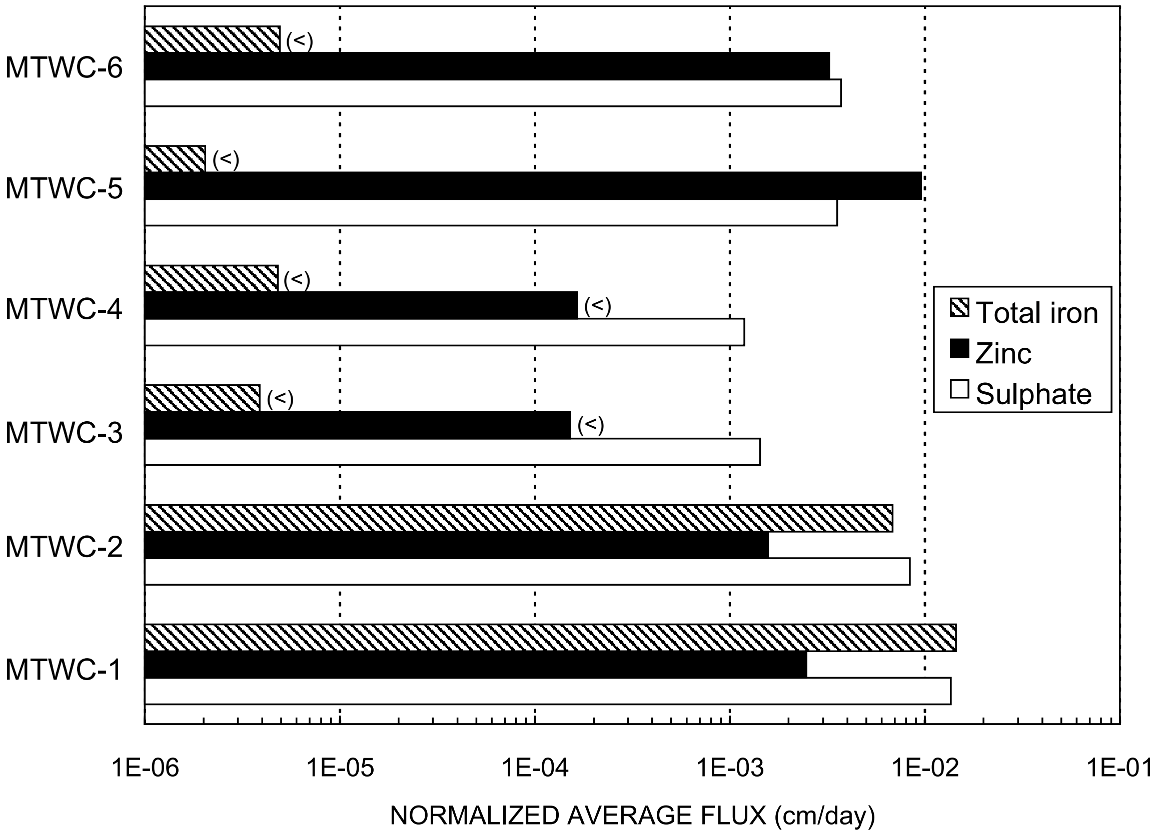
To evaluate the effect of different column configurations independently from variations in initial pore water concentrations, normalized average fluxes were calculated as follows:

$$\Phi_{avg} = \frac{F_{avg}}{C_{pw}^{i}} \qquad \text{(Equation 2-4)}$$

In this equation, Φ_{avg} is the normalized average flux of a given contaminant and C_{pw}^{i} is the initial average concentration of this contaminant in pore water. Figure 2-2 and TABLE 2-2 show the normalized average fluxes of total iron, sulphate, and zinc in Columns MTWC-1 to MTWC-6.

The results show that normalized contaminant fluxes can be effectively reduced by placing attenuation layers at the tailings/water interface. However, their effectiveness varies with the type of contaminant and the type of material used to construct the layer. The normalized average flux of total iron was reduced by more than 3 orders of magnitude when using either sand or peat as attenuation layer. However, the normalized average flux of zinc decreased by only one order of magnitude with a sand layer, and slightly increased with a peat layer. The normalized average flux of sulphate was reduced by one order of magnitude with the sand layer and by half an order of magnitude with the peat layer.

Under static conditions, the limiting effect of attenuation layers on contaminant fluxes is partly due to the low diffusion rate of contaminant throughout the layer. However, other mechanisms must operate to explain the large variations in efficiency that is observed for different attenuation layers and contaminants. The high normalized average zinc and sulphate fluxes measured with the peat layer likely originate from the leachable zinc and sulphur contents of the peat itself (TABLE 2-1).



The symbol (<) indicates that the actual normalized average flux is smaller than shown on the figure.

Figure 2-6: Normalized average fluxes of total iron, sulphate, and zinc to the water cover during the static period

TABLE 2-2: NORMALIZED AVERAGE FLUXES (cm/day) TO THE WATER COVER DURING THE STATIC PERIOD

Column	Fe_T	Fe^{3+}	Zn^{2+}	SO_4^{2-}
MTWC-1	1.44E-02		2.47E-03	1.35E-02
MTWC-2	6.81E-03		1.57E-03	8.35E-03
MTWC-3	<3.88E-06	<1.43E-05	<1.52E-04	1.42E-03
MTWC-4	<4.80E-06	<1.27E-05	<1.65E-04	1.18E-03
MTWC-5	<2.04E-06	<1.24E-05	9.52E-03	3.55E-03
MTWC-6	4.92E-06	<1.58E-05	3.22E-03	3.71E-03

The much higher reduction in the normalized average flux of iron compared to sulphate with both types of attenuation layer cannot be solely explained by differences in diffusion rates. When an attenuation layer is in place, the lower flux of ferrous iron to the water cover may enable the complete reaction of ferrous iron with the available dissolved oxygen. This would lead to a higher proportion of ferrous iron precipitating as ferric hydroxide. On the other hand, the available dissolved oxygen may not be sufficient to precipitate the large ferrous iron flux to the water cover when no attenuation layer is in place. The available oxygen is dependent on the degree of mixing in the water cover and will likely differ between laboratory column experiments and field applications.

Figures 2.7 to 2.9 show the evolution of Fe_T, SO_4^{2-} and Zn^{2+} loads to the water cover (Equation 2.4) as a function of time for Columns MTWC-1 and MTWC-2. The curves were adjusted by subtracting loads initially present in the water covers. Reproducibility between duplicate columns was best for Zn^{2+} and SO_4^{2-}, and poorest for Fe_T. Both the Fe_T and the SO_4^{2-} loads increased with time. The Zn^{2+} load increased during the first 150 days of test, but then decreased during the second half of the static period, in agreement with sorption of Zn^{2+} on hydrous ferric hydroxide precipitate.

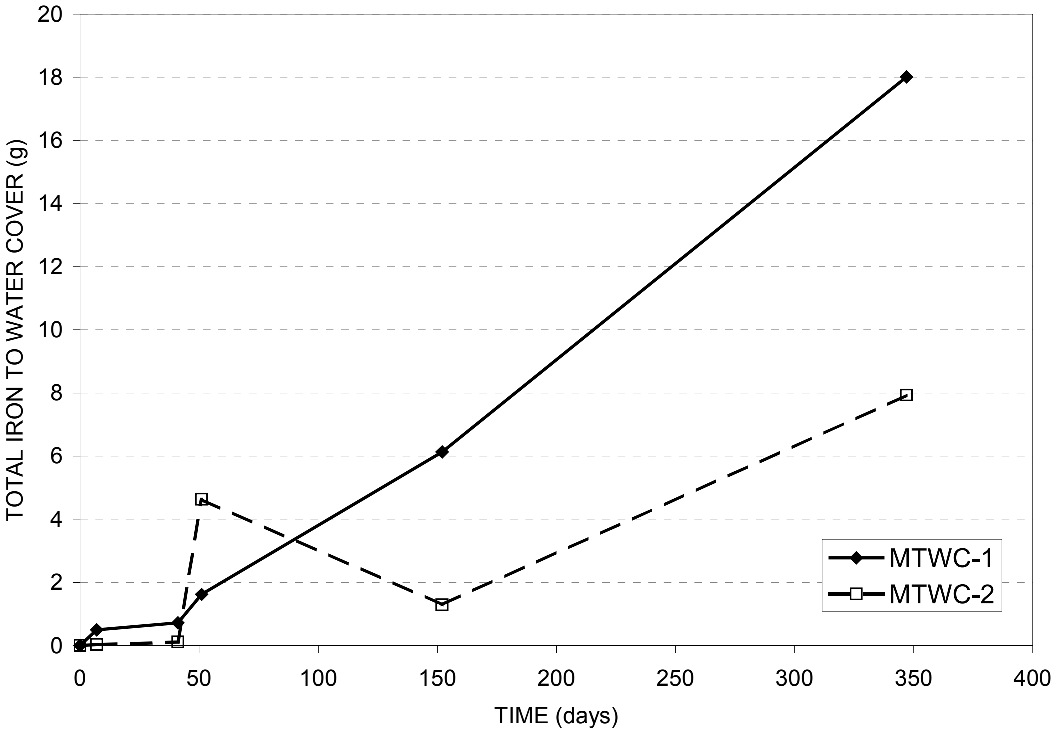


Figure 2-7: Total iron load to the water cover for MTWC-1 and MTWC-2, static period

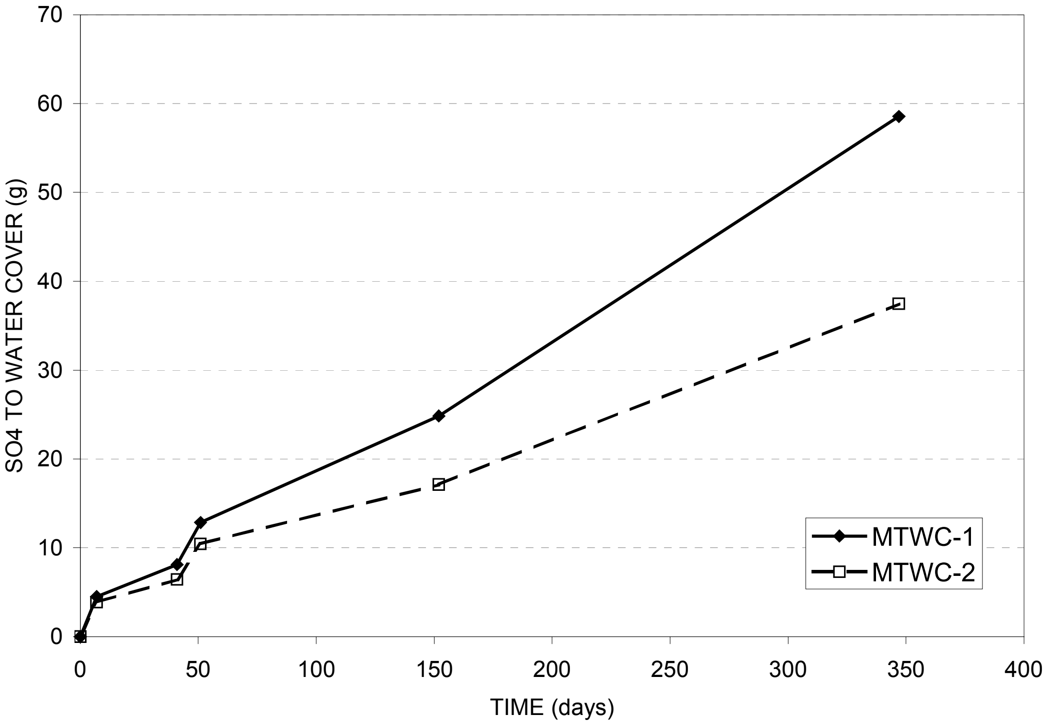


Figure 2-8: Sulphate load to the water cover for MTWC-1 and MTWC-2, static period

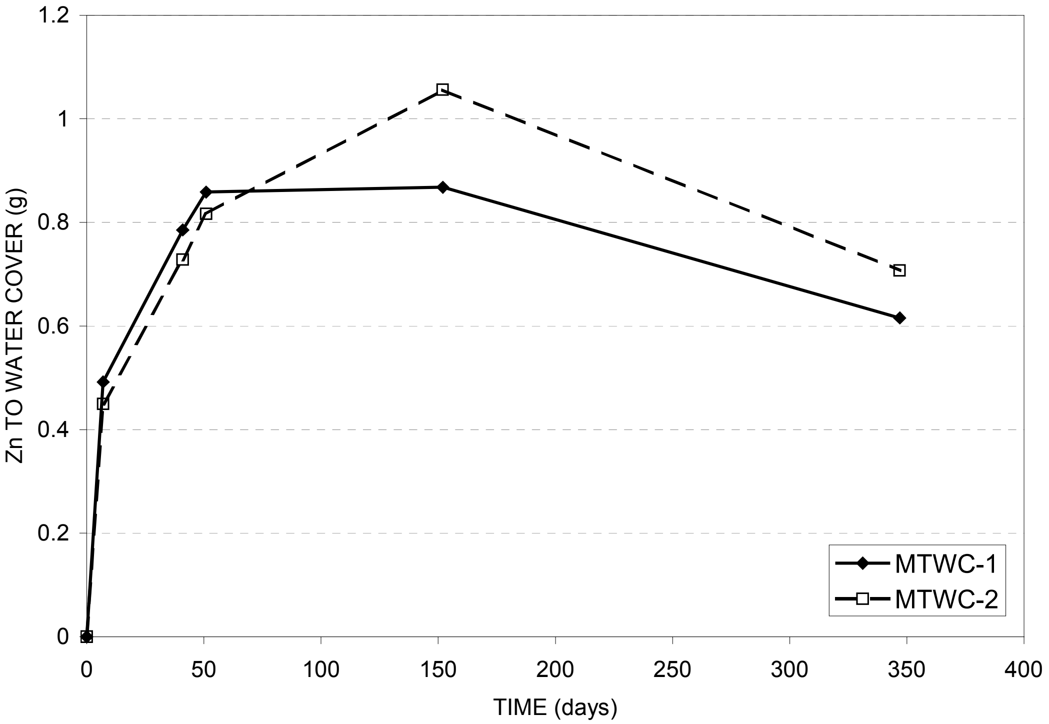


Figure 2-9: Zinc load to the water cover for MTWC-1 and MTWC-2, static period

2.3.1.4 Contaminant Net Release Rates

In this section, we examine the balance between mineral dissolution, precipitation/sorption reactions, and molecular diffusion in the columns during the static period. The net release rate of a given contaminant, NRR, is defined as the difference between the contaminant remobilization rate due to mineral dissolution or contaminant desorption on one hand and the rate of contaminant precipitation or sorption on the other hand. The units of NRR are mg/day. Released contaminants can either remain in the pore water or diffuse to the water cover. Hence, the NRR equals the rate of solute accumulation in both the pore water and the water cover:

$$NRR = \frac{dM_p}{dt} + \frac{dM_w}{dt} \qquad \text{(Equation 2-1)}$$

In the above equation, M_p is the contaminant mass in pore water, obtained by numerical integration of its concentration over the tailings depth. The average NRR over the entire duration of the static period is given by:

$$NRR_{avg} = \frac{M_p(t_{stat}) - M_p(t=0) + M_w(t_{stat}) - M_w(t=0)}{t_{stat}} \qquad \text{(Equation 2-2)}$$

Average net release rates for Fe_T, Fe^{3+}, Zn^{2+}, and SO_4^{2-} are shown in Figure 2-1 and Table 2-9. Negative values indicate that precipitation/sorption exceeded contaminant release due to dissolution of secondary minerals. Negative average NRRs were only obtained for Zn^{2+} in Columns MTWC-1 and MTWC-2, and for SO_4^{2-} in Column MTWC-2.

Average net release rates were highest in Columns MTWC-7 and MTWC-8, where no water cover was present. This result suggests that the water covers were effective at limiting net contaminant release rates. This effect could be explained by a lower oxygen flux to the tailings, and therefore less sulphide oxidation, in the presence of a water cover. In Columns MTWC-7 and MTWC-8, part of the available oxygen was also used to oxidize ferrous iron in the pore water as is evidenced by the formation of a ferric oxide precipitate at the tailings/air interface. Although this precipitate could scavenge contaminants, the higher net release rates compared to columns with water covers indicate that the scavenging effect was not sufficient to counteract the increase in contaminant release due to sulphide oxidation.

Net release rates in Columns MTWC-1 and MTWC-2 were either negative or much smaller than in the other columns. This may be due to a higher rate of precipitation/sorption in the absence of an attenuation layer, as there was more dissolved oxygen available at the tailings surface to oxidize Fe^{2+} into Fe^{3+}, which then precipitated as hydrous ferric oxide. Attenuation layers imposed a diffusion control on the oxygen required for oxidizing the ferrous iron above the tailings surface. Observed lower Fe^{3+}

concentrations at the tailings/water interface (between 7 and 40 mg/L) than at the sand-water or peat-water interfaces (between 200 and 300 mg/L) at the end of the static period corroborate that more iron precipitated in Columns MTWC-1 and MTWC-2.

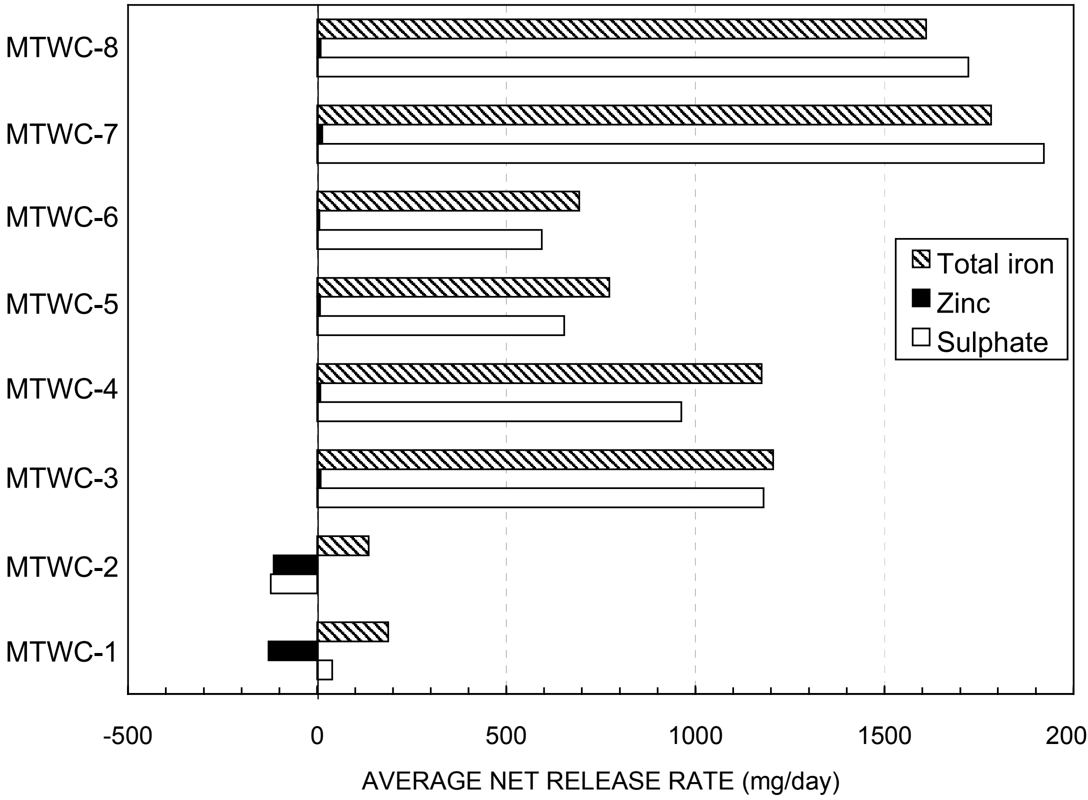


Figure 2-10: Average net release rates of total iron, sulphate, and zinc from the tailings during the static period

TABLE 2-8: AVERAGE NET RELEASE RATES (mg/day) DURING THE STATIC PERIOD

Column	*Fe_T*	*Fe^{3+}*	*Zn^{2+}*	*SO_4^{2-}*
MTWC-1	188	---	-129	40
MTWC-2	136	---	-115	-123
MTWC-3	1205	-208	9	1181
MTWC-4	1176	-249	8	963
MTWC-5	773	-257	7	653
MTWC-6	692	-159	6	594
MTWC-7	1782	-608	14	1921
MTWC-8	1610	-461	9	1722

The net masses of Fe_T, SO_4^{2-} and Zn^{2+} released from the tailings as a function of time for

Columns MTWC-1 and MTWC-2 are shown in Figures 2.11 to 2.13. Reproducibility between the two columns was acceptable.

In Column MTWC-2, there was a net Fe_T release during the static period (i.e. the dissolution rate of iron-bearing secondary minerals was higher than iron precipitation/sorption), except during the first seven days. The net iron release accelerated after the first 150 days (Figure 2-2) in both columns. Figure 2-3 shows that the iron load to the water cover also accelerated after 150 days.

Sulphate was consumed during the first 150 days, possibly by co-precipitation with ferric hydroxide (Figure 2-3). However, there was a net release of sulphate during the second half of the static period.

Figure 2-4 shows that zinc was removed at a more or less constant rate. This net removal likely resulted from co-precipitation/sorption reactions on the ferric hydroxide precipitate layer.

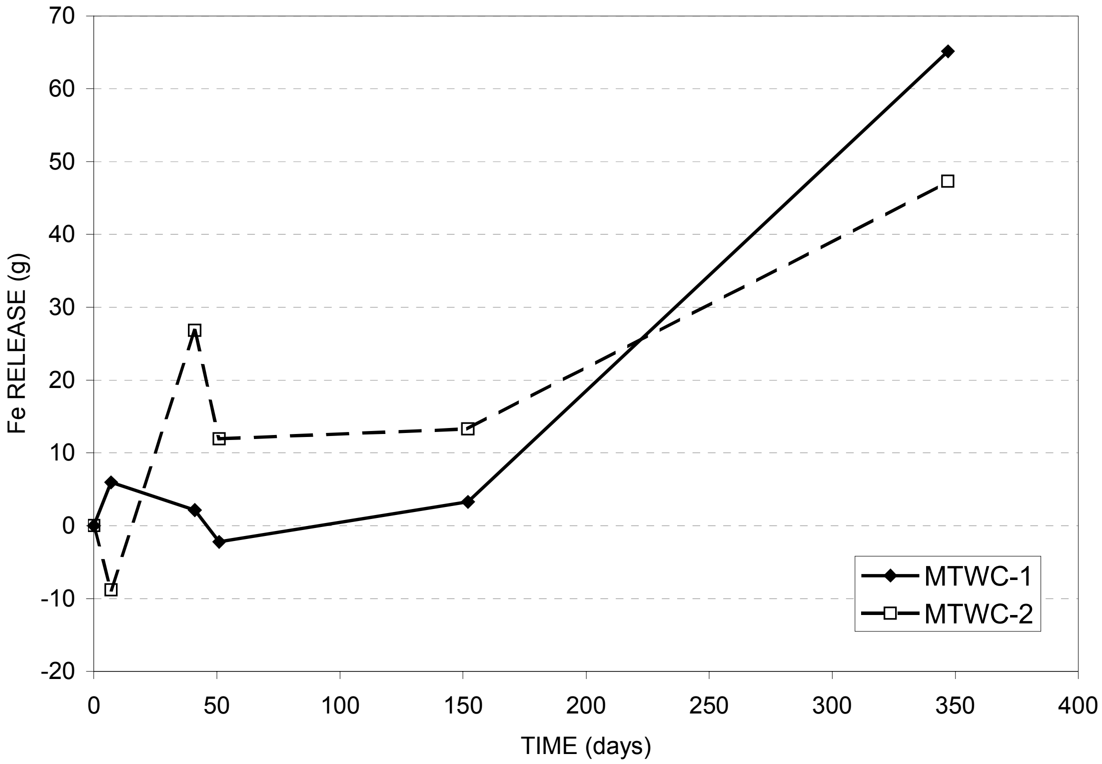


Figure 2-11 Net release of total iron in MTWC-1 and MTWC-2 during the static period

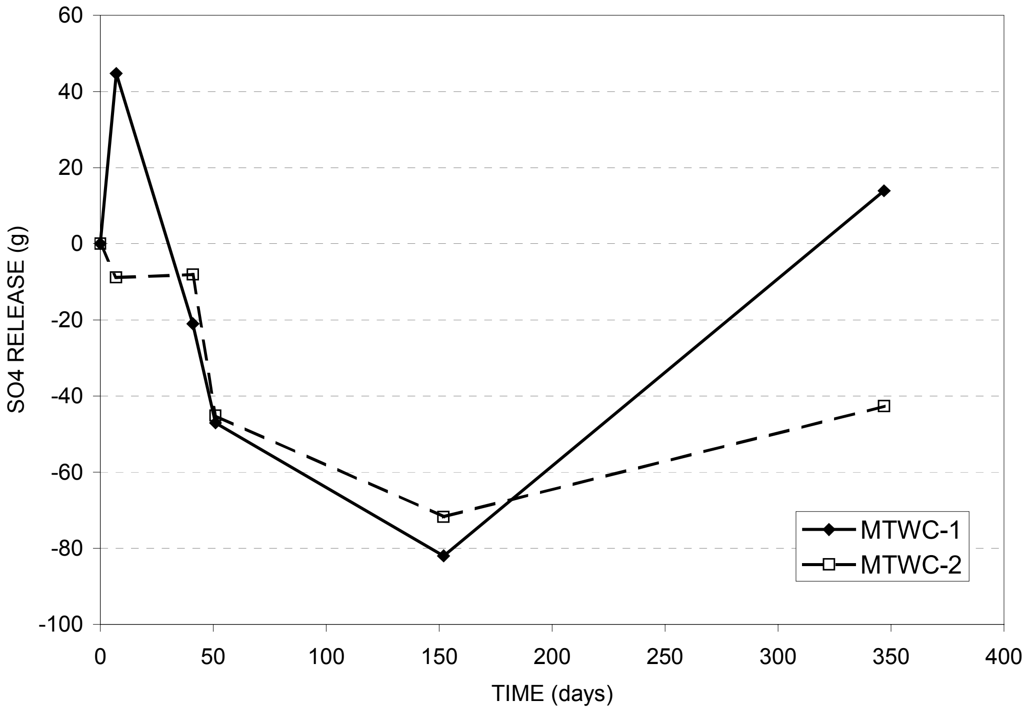


Figure 2-12: Net release of sulphate in MTWC-1 and MTWC-2 during the static period

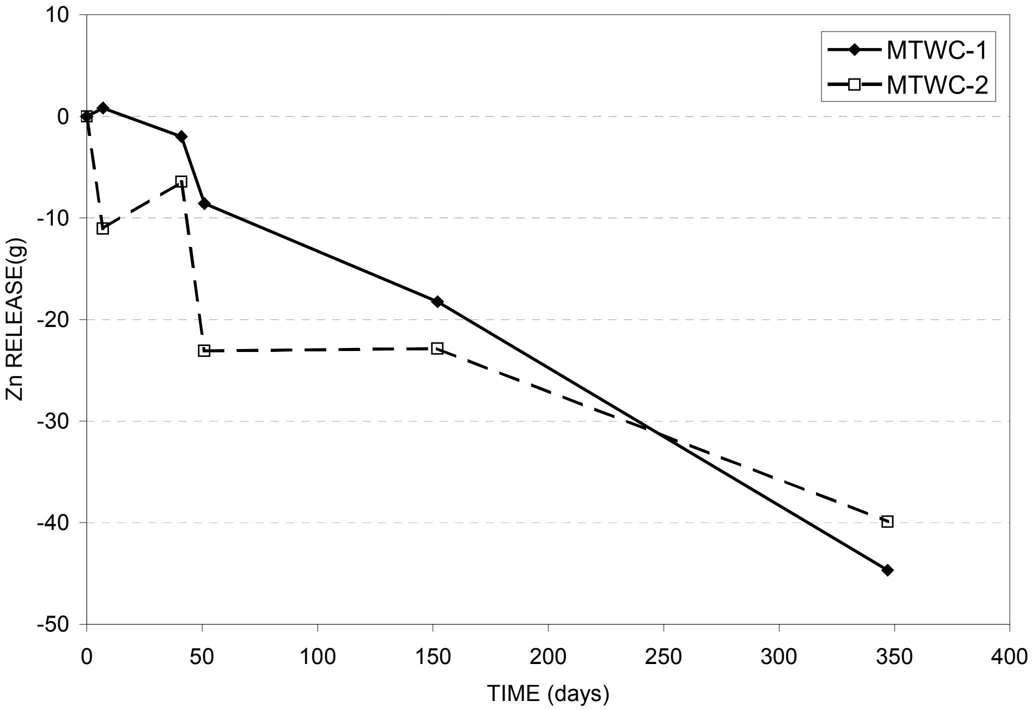


Figure 2-13: Net release of zinc in MTWC-1 and MTWC-2 during the static period

2.3.2 Dynamic Tests

2.3.2.1 Concentration Profiles

Concentration profiles for Fe_T, Fe^{3+}, SO_4^{2-}, and Zn^{2+} measured during the dynamic period (period during which deionised water was added at a constant rate on top of the columns) are shown in Figures III-1 to III-8. The last profile obtained during the static period (t = 347 days for MTWC-1 and MTWC-2, and t= 163 days for the other columns) is also shown on the figures for comparison. There is generally good agreement between measurements obtained in duplicate columns. Concentration profile data are also presented in tabular form in Appendix V.

Overlying water

Solute concentrations in the water cover became independent of depth soon after the start of the dynamic period. This is in contrast to the static period during which a concentration gradient existed within the bottom 20 cm of the water cover. This observation suggests that the water cover became well mixed during the dynamic period.

In columns with a water cover but no attenuation layer (MTWC-1 and MTWC-2), contaminant concentrations decreased throughout the water cover during the dynamic period. Figures III-1 and III-2 show that after 620 days[+], the Fe_T and SO_4^{2-} concentrations in the water cover decreased respectively to ~0.2 mg/L and ~200 mg/L. At that time, 1.12 pore volumes (P.V.) of water had been added to the column. The reduction in Zn^{2+} concentration was, however, much less pronounced. The Zn^{2+} concentration decreased from 20 mg/L at the end of the static period to ~10 mg/L after 531 days (0.75 P.V.), and remained above 6 mg/L during the rest of the dynamic period (Figures III-1d and III-2d). These elevated zinc concentrations may have been controlled by the solubility of a Zn–containing solid phase in the hydrous ferric oxide precipitate layer at the tailings/water interface. As noted in Section 2.3.1.2, this layer contained significant amounts of zinc.

In columns with a sand or peat attenuation layer (Figures III-3 to III-6), Fe_T and Fe^{3+} concentrations in the water cover remained very low (< 0.1 mg/L) during the dynamic period. Sulphate concentrations decreased from 40 mg/L to 20 mg/L in Columns MTWC-3 and MTWC-4, and from 150 mg/L to 40 mg/L in Columns MTWC-5 and MTWC-6. Zinc concentrations remained below 0.1 mg/L in the columns with a sand layer, and decreased from more than 0.5 mg/L to less than 0.2 mg/L in columns with a peat layer.

Pore water

Contaminant pore water concentrations decreased in all columns during the dynamic period. A displacement front moving gradually downwards was visible for Fe_T , Fe^{3+},

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[+] Times are calculated from the start of the column experiments. The dynamic period started at Day 348 in MTWC-1 and MTWC-2, at Day 183 in MTWC-3, MTWC-4, MTWC-5, and MTWC-6, and at Day 228 in MTWC-7 and MTWC-8.

SO_4^{2-}, and Zn^{2+} until about 0.7 pore volume (Figures III-1 to III-8). The absence of a sharp front, and the fact that the front reached the bottom of the columns before one pore volume of water was supplied to the columns, illustrate the effect of molecular diffusion.

By the end of the dynamic period, the zinc concentration decreased to less than 0.03 mg/L in the oxidized tailings in Columns MTWC-1 and MTWC-2, except in the top 5 cm of tailings where zinc concentrations ranging from 0.3 mg/L to 3 mg/L were measured. In the non-oxidized tailings, zinc concentrations ranged from 0.2 mg/L to 1 mg/L at the end of the dynamic period.

In columns MTWC-3 to MTWC-6, however, zinc concentrations in pore water did not decrease as much. Although they dropped below 0.1 mg/L within the top 20 cm of oxidized tailings, they remained above 30 mg/L at the bottom of the unoxidized tailings. Iron and sulphate pore water concentrations in Columns MTWC-3 to MTWC-6 were also higher than in Columns MTWC-1 and MTWC-2 at the end of the dynamic period. These differences between columns could be due to initial differences in pore water composition (see Section 2.3.1.1) or to variations in cover configuration or both. An attempt to distinguish between these two effects is presented in the next section and makes use of normalized metal loads to the effluent.

Columns with no water cover (MTWC-7 and MTWC-8) exhibited the highest pore water concentrations at the end of the dynamic period, especially near the top of the tailings where Fe_T , SO_4^{2-}, and Zn^{2+} remained above 20 mg/L, 40 mg/L, and 1 mg/L, respectively.

2.3.2.2 Seepage Water Quality

Figures IV-1 to IV-8 show the evolution of pH, acidity, Fe_T, Fe^{3+}, SO_4^{2-}, and Zn^{2+} in the seepage (i.e. the water collected at the bottom of the columns) as a function of seepage pore volumes. These data are also presented in tabular form in Appendix V. Reproducibility of the results between duplicate columns was satisfactory.

The seepage of all columns remained acid ($2.3<pH<4.3$) during the dynamic period. In general, the seepage pH dropped rapidly during the first 0.3 to 0.4 P.V. and then remained stable or decreased slightly. The only exceptions occurred for Columns MTWC-1 and MTWC-2, which exhibited an increase in seepage pH after 1.7 pore volumes. Seepage concentrations remained stable for all columns until the displacement front reached the bottom of the columns (after about 0.7 pore volume).

Figures 2.14 to 2.17 plot the seepage concentrations of Fe_T, SO_4^{2-}, and Zn^{2+} on a linear scale as a function of seepage volume. The plots start when 1 pore volume had been recovered.

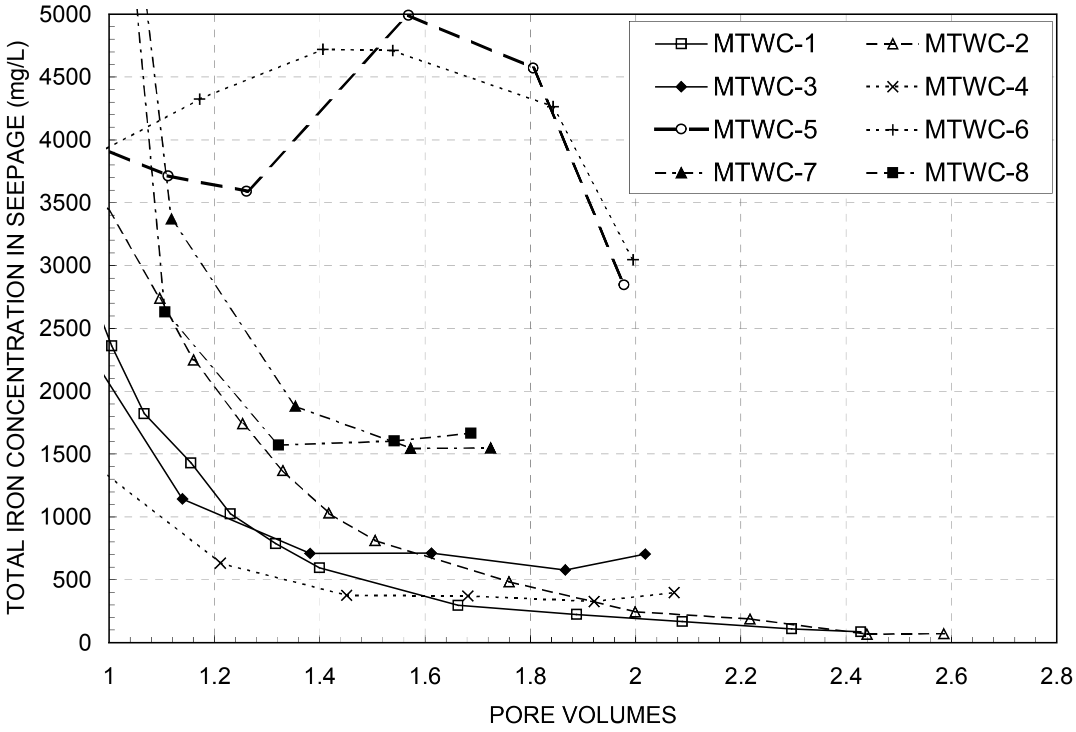


Figure 2-14: Evolution of total iron concentration in the seepage of all columns after 1 P.V.

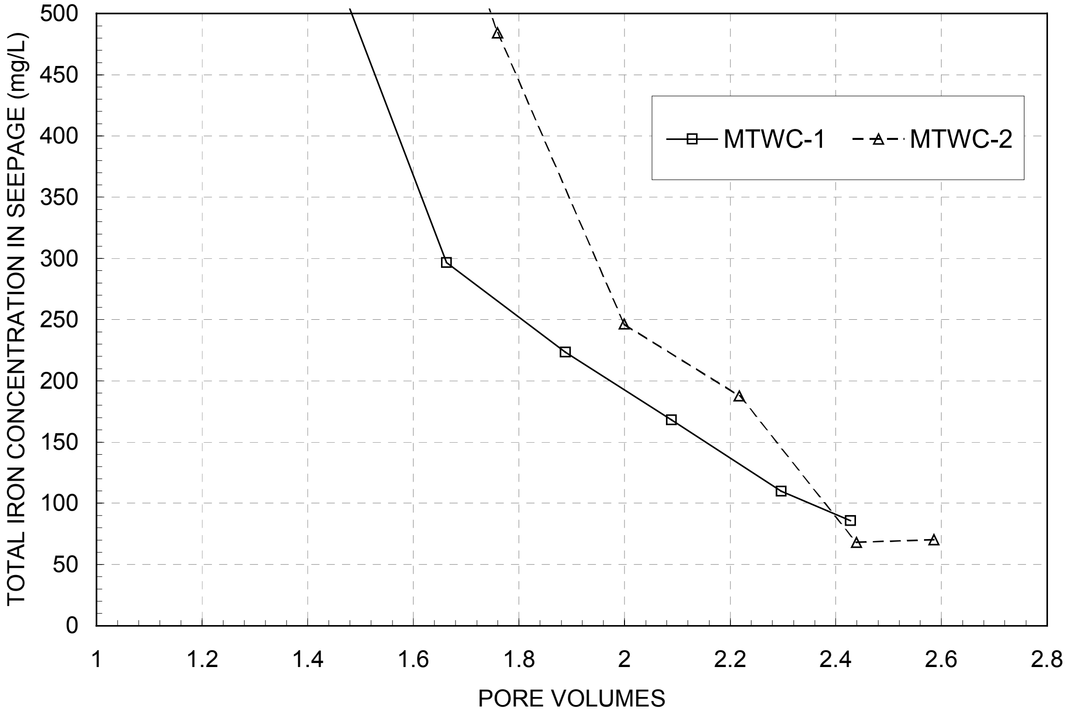


Figure 2-15: Evolution of total iron concentration in the seepage of Columns MTWC-1 and MTWC-2 after 1 P.V.

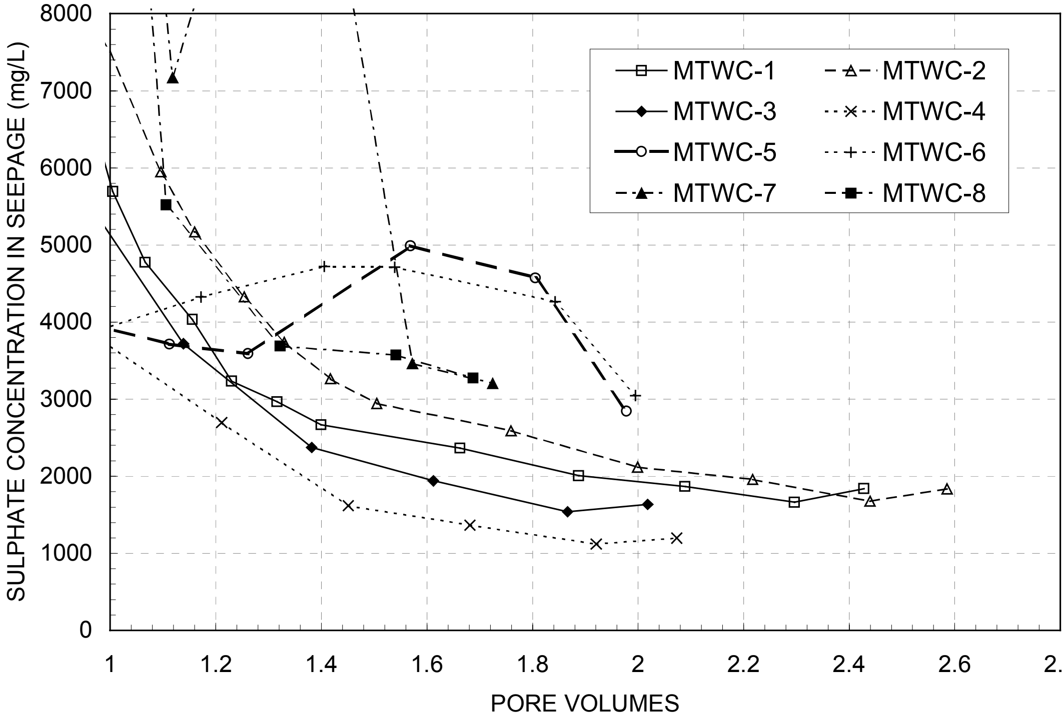


Figure 2-16: Evolution of sulphate concentration in the seepage of all columns after 1 P.V.

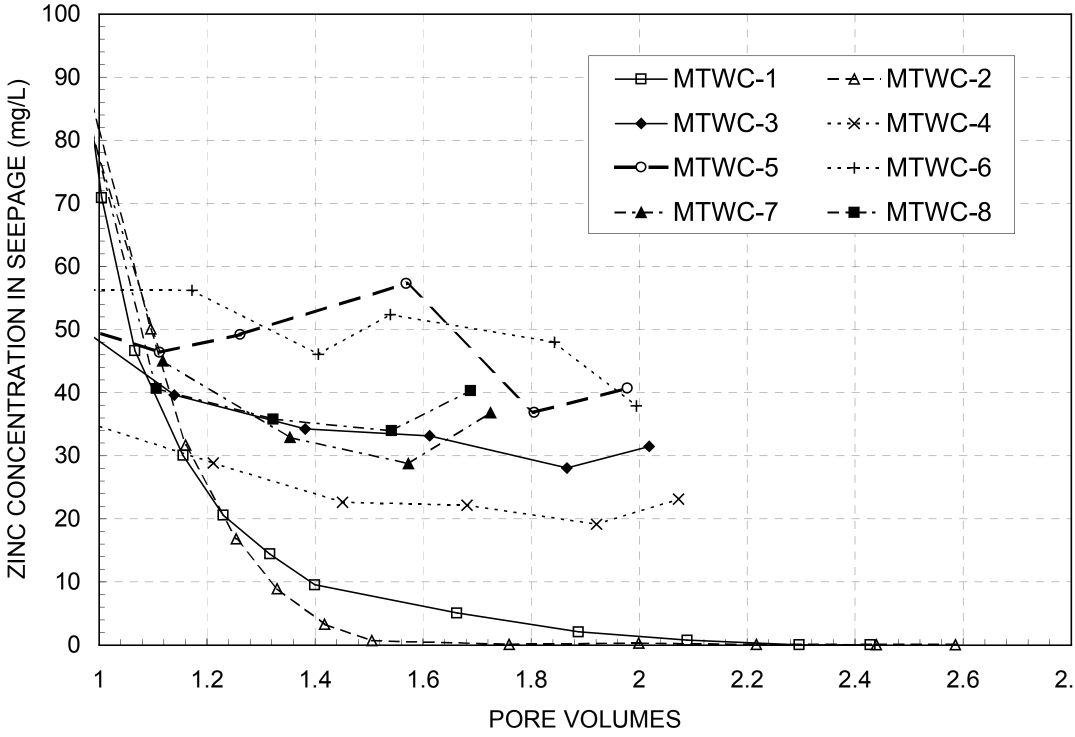


Figure 2-17: Evolution of zinc concentration in the seepage of all columns after 1 P.V.

At the end of the dynamic period, the concentrations of Fe_T in the seepage were still ~80 mg/L in columns with a water cover but no attenuation layer (MTWC-1 and MTWC-2), ~500 mg/L in columns with a sand layer (MTWC-3 and MTWC-4), ~3000 mg/L in columns with a peat layer (MTWC-5 and MTWC-6), and ~1600 mg/L in columns with no water cover (Figure 2-1). In Columns MTWC-1 and MTWC-2, the Fe_T concentration was still decreasing by the end of the dynamic period (Figure 2-2).

Seepage SO_4^{2-} concentrations were stable in all columns at the end of the tests (Figure 2-3). The SO_4^{2-} concentrations were ~1900 mg/L in the columns MTWC-1 and MTWC-2, ~1400 mg/L in the columns with a sand layer, ~4000 mg/L in the columns with a peat layer, and ~3500 mg/L in the columns without a water cover.

The Zn^{2+} concentrations at the end of the dynamic period were very low (0.03 mg/L) and stable in Columns MTWC-1 and MTWC-2 (Figure 2-4). However, they were much higher in all the other columns (between 25 mg/L and 40 mg/L). These results are consistent with pore water concentration profiles (see previous section), and suggest that most of the mobile zinc in Columns MTWC-1 and MTWC-2 was initially dissolved in the pore water. By contrast, a significant portion of the mobile zinc in the other columns was likely contained in a solid phase whose solubility maintained an elevated Zn^{2+} concentration in the pore water.

From the above, we can conclude that the time or pore volumes of water required to reach low contaminant concentrations in the tailings seepage is very dependent on the geochemical characteristics of the tailings. Column MTWC-1 and MTWC-2 tailings could be successfully flushed with a few pore volumes of infiltrating water. However, the tailings in Columns MTWC-3 to MTWC-8 will likely produce seepage having elevated solute concentrations for a very long time. The presence of an attenuation layer at the water/tailings interface seemed to have relatively little influence on the seepage water quality.

Cumulative loads of acidity, total iron, ferric iron, sulphate, and zinc in seepage as a function of time are shown in Figures IV-9 to IV-16. Rates of contaminant removal were highest and approximately constant during the first ~0.7 P.V., but decreased quickly after the displacement front reached the bottom of the columns. Zinc and total iron loads in the seepage of Columns MTWC-1 and MTWC-2 reached asymptotic values at the end of the tests, suggesting that nearly all the mobile iron and zinc had been removed.

Figures 2-18 and 2-19 compare the columns on the basis of cumulative loads of acidity, Fe_T, SO_4^{2-}, and Zn^{2+} collected in the first 1.7 P.V. of seepage. Columns MTWC-1 and MTWC-2 yielded the lowest acidity, iron, and sulphate loads, but the highest zinc loads, because they had the highest mass of zinc in pore water at the start of the dynamic period.

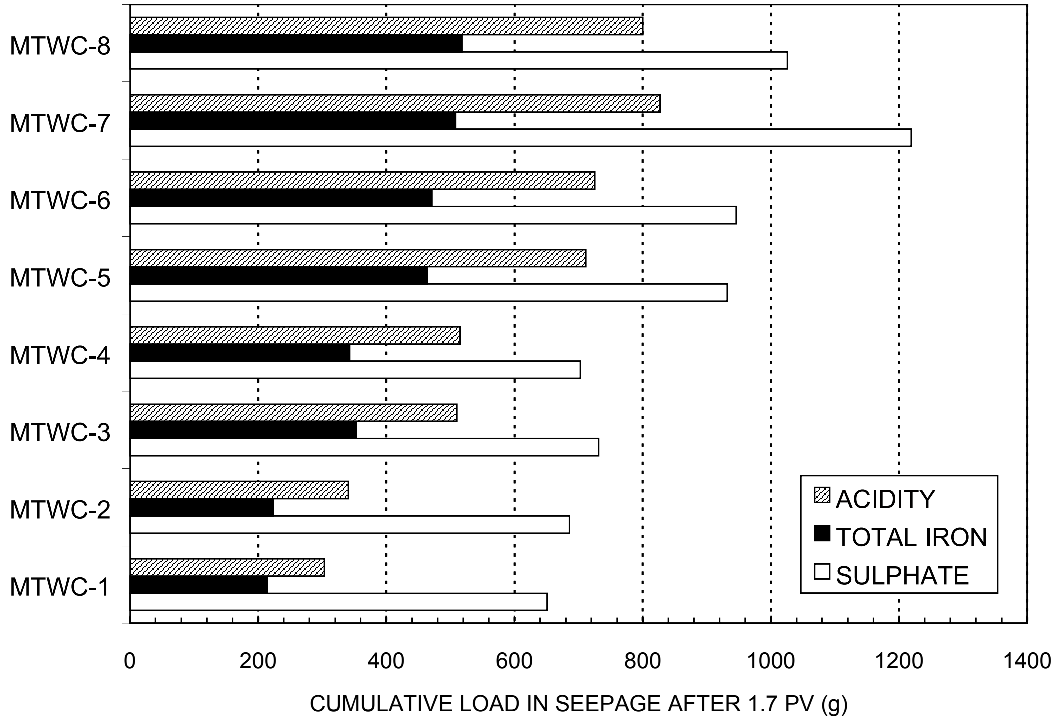


Figure 2-18: Cumulative loads of acidity, total iron, and sulphate collected in the first 1.7 P.V. of seepage

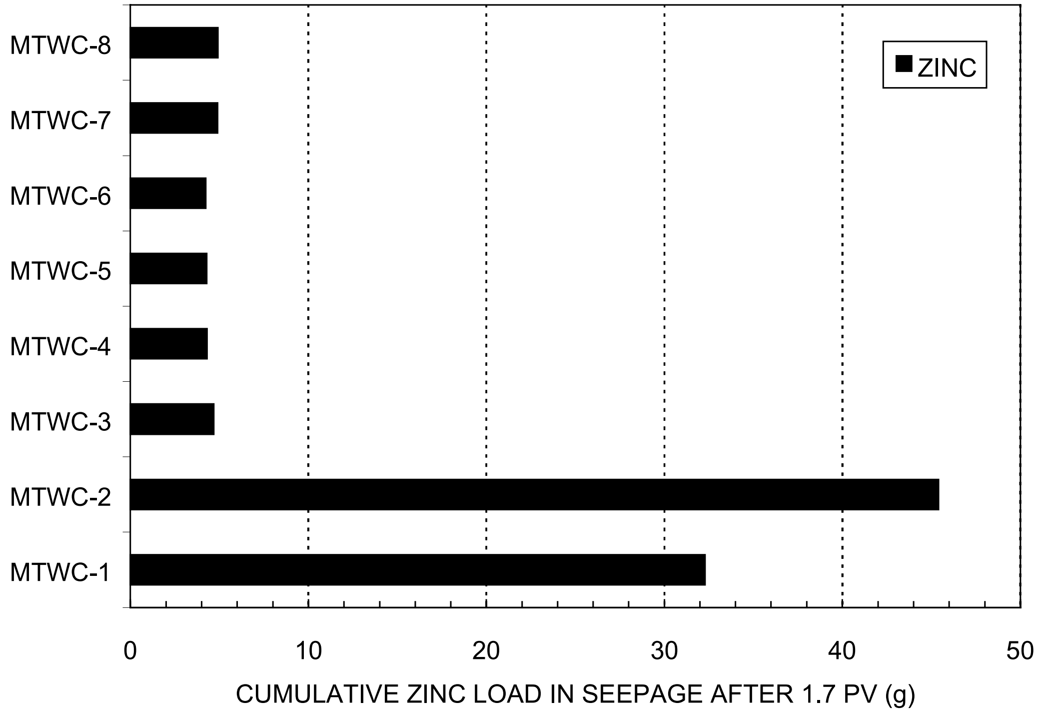


Figure 2-19: Cumulative load of zinc collected in the first 1.7 P.V. of seepage

To differentiate the effects of column configurations from those of contaminant mass in pore water at the start of the dynamic period, we calculated normalized cumulative loads, μ:

$$\mu = \frac{M_{eff}(1.7\,P.V.)}{M_{pw}^{i}} \qquad \text{(Equation 2-1)}$$

where M_{eff} (1.7 P.V.) is the cumulative load of a given contaminant collected in the first 1.7 pore volume of seepage and M_{pw}^{i} is the contaminant mass in pore water at the start of the dynamic test. Plots of μ for Fe_T, SO_4^{2-}, and Zn^{2+} in all columns are shown in Figure 2-7.

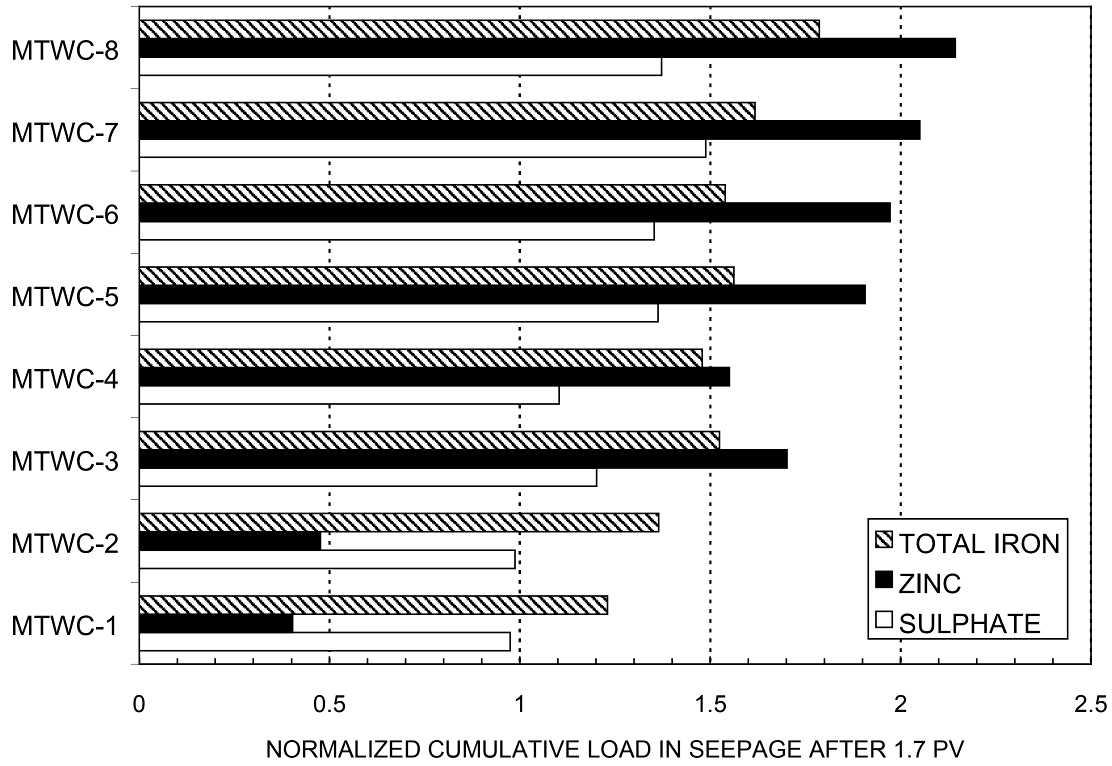


Figure 2-20: Normalized cumulative loads of acidity, total iron, and sulphate collected in the first 1.7 P.V. of seepage

Except for Zn^{2+} and SO_4^{2-} in Columns MTWC-1 and MTWC-2, normalized loads were larger than unity. This indicates that, in general, more Fe_T, SO_4^{2-}, and Zn^{2+} reported to the seepage than initially dissolved in the pore water. The normalized zinc load of ~ 0.45 for Zn^{2+} in Columns MTWC-1 and MTWC-2 suggests that about half of the zinc initially present in pore water precipitated or adsorbed on the hydrous ferric oxide layer.

Table 2-10 presents the ranking of different column configurations on the basis of normalized metal loads in seepage. Rank 1 corresponds to the smallest load. The ranking was the same whether Fe_T, SO_4^{2-}, or Zn^{2+} loads were considered. The fact that the column configuration without a water cover ranked last (highest metal load) may be due to increased sulphide oxidation because of more dissolved oxygen in the pore water. The water cover without attenuation layer ranked first. This configuration reduced Fe_T, Zn^{2+}, and SO_4^{2-} normalized loads in the column seepage by 1.3, 4.8, and 1.4 times when compared to the no-cover configuration. By comparison, the water cover with a sand layer only reduced Fe_T, Zn^{2+}, and SO_4^{2-} loads by 1.1, 1.3 and 1.2 times when compared to the no-cover configuration. Hence, the water cover without attenuation layer appears to be the best configuration for reducing metal loads in the seepage. This may be because in addition to potentially leaching metals (as is the case for peat), attenuation layers may limit the amount of oxygen available to oxidize Fe^{2+} into Fe^{3+}, and thus result in less iron precipitation and less zinc sorption on ferric hydroxide precipitates. The limiting effect of attenuation layers on the oxygen available to oxidize ferrous iron was suggested earlier when discussing contaminant net release rates (Section 2.3.1.4).

TABLE 2-9: RANKING OF COLUMN CONFIGURATIONS BASED ON NORMALIZED METAL LOADS IN SEEPAGE

Column Configuration	*Rank*
Water cover alone	1
Water cover + Sand layer	2
Water cover + Peat layer	3
No cover	4

2.3.3 Mathematical Modelling

2.3.3.1 Concentration Profiles During the Static Period

Modelling of metal transfer from the tailings to the water cover during the static period was attempted using a simple one-dimensional diffusion equation:

$$\frac{\partial C}{\partial t} = D_e \frac{\partial^2 C}{\partial z^2} - \rho K \frac{\partial C}{\partial t} \qquad \text{(Equation 2-1)}$$

where C is the concentration of metal at depth z and time t, D_e is the effective diffusion coefficient for the metal in tailings, ρ is dry bulk density of tailings, and K is the distribution/partitioning (sorption) coefficient.

A computer model of metal transfer for Columns MTWC-1 and MTWC-2 was constructed by taking the initial chemical profiles at t=1 day and assuming that no reaction or sorption was present (K = 0). A Zn^{2+} diffusion coefficient of 8 x 10^{-6} cm^2/s in water was assumed, based on values reported by Ellis et al. (1983). Concentration profiles at different times were simulated using the computer program POLLUTE (Rowe and Booker, 1990).

The predicted profiles (Figure 2-1) show Zn^{2+} concentrations in the water cover increasing rapidly near the water/tailings interface at the beginning of the simulation, because of high Zn^{2+} concentrations in the tailings immediately below the interface. At the end of the 365-day simulation, the predicted zinc load to the water cover was 316 mg and the average zinc flux was 0.0012 mg/day/cm^2. These model results are lower than the experimentally measured zinc load of ~ 630 mg (Figure 2-5) and flux of 0.005 mg/day/cm^2. In the top 60 cm of the water cover, modelled Zn^{2+} concentrations are well below measured concentrations (Figures II-1d and II-2d) at all times. Hence, diffusion alone cannot account for the Zn^{2+} transport to the water cover and the actual shape of the concentration profiles. Previous sections of this report suggest that sorption/co-precipitation reactions are an important mechanism for controlling the zinc concentration in the water cover.

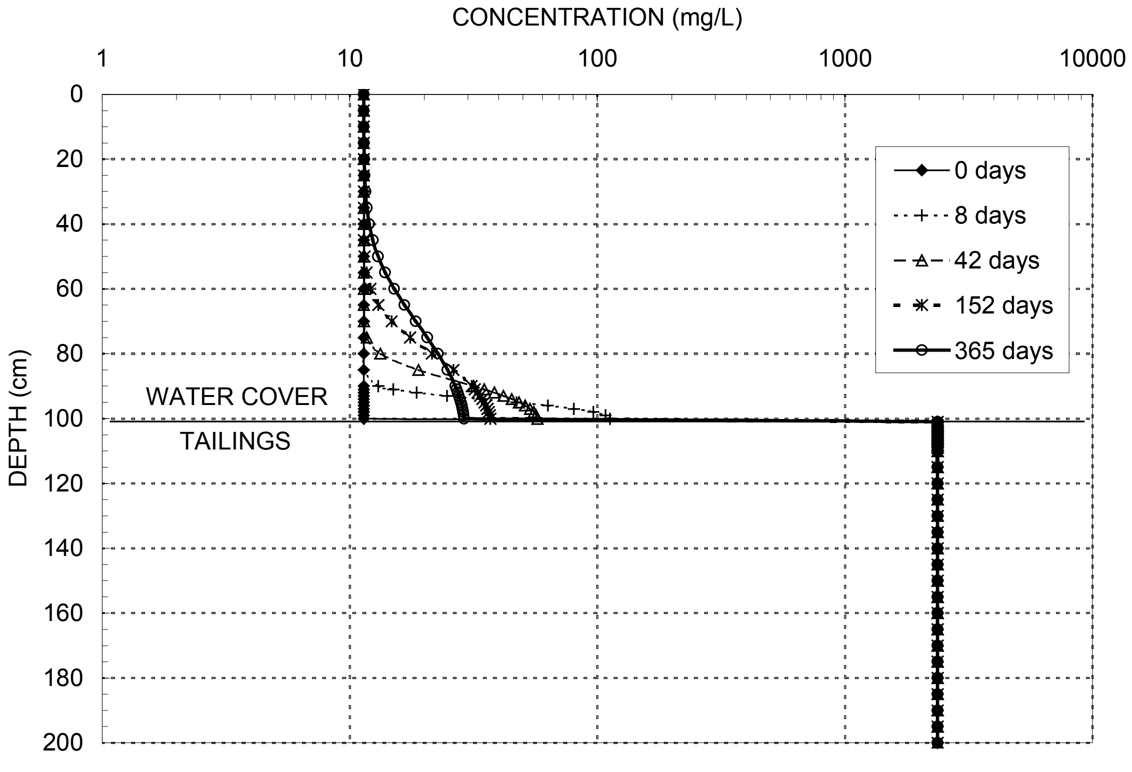


Figure 2-21: Concentration profiles predicted by POLLUTE for zinc in Columns MTWC-1 and MTWC-2 during the static period

The fact that measured Zn^{2+} concentrations were independent of depth in the top 80 cm of the water cover indicates that some mixing of the water cover occurred in the laboratory columns. This mixing may also have lowered the Zn^{2+} concentration just above the tailings/water, thus increasing the concentration gradient and the zinc flux to the water cover.
Additional shortcomings of the model are its inability to reproduce the decrease in Zn^{2+} concentration observed in the 10 cm above the tailings after 152 days and the propagation of the zinc depletion front in the pore water. This is likely because the model does not account for Zn^{2+} sorption on hydrous ferric oxide precipitate.

2.3.3.2 Average Concentrations in the Water Cover During the Dynamic Period

Figures 2.22 to 2.24 plot the evolution of Fe_T, SO_4^{2-}, and Zn^{2+} average concentrations in the water covers of Columns MTWC-1 and MTWC-2, as a function of seepage volume. Average concentrations were calculated from measured concentration profiles. These data are compared to the predictions of a mixing model that simply assumes dilution of solutes in the water cover resulting from the addition of deionised water at the top of the columns. The mixing model predictions are only relevant when the water cover is well mixed, i.e. after 0.58 P.V. for Column MTWC-1 and after 0.3 P.V. for Column MTWC-2.

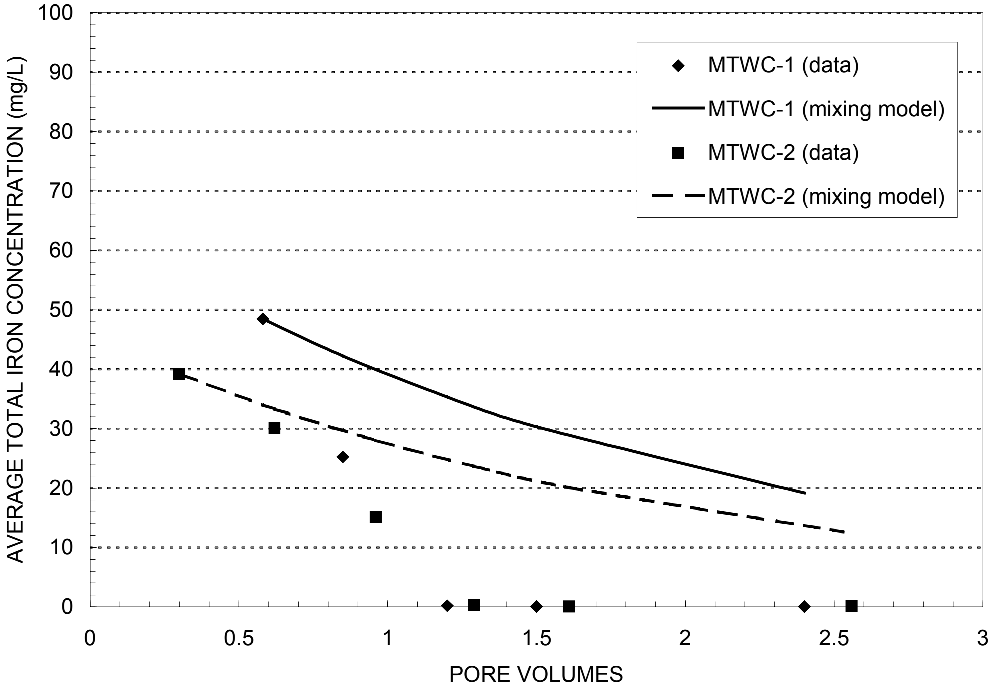


Figure 2-22: Evolution of average total iron concentration in the water cover (experimental data and mixing model) for MTWC-1 and MTWC-2 during the dynamic period

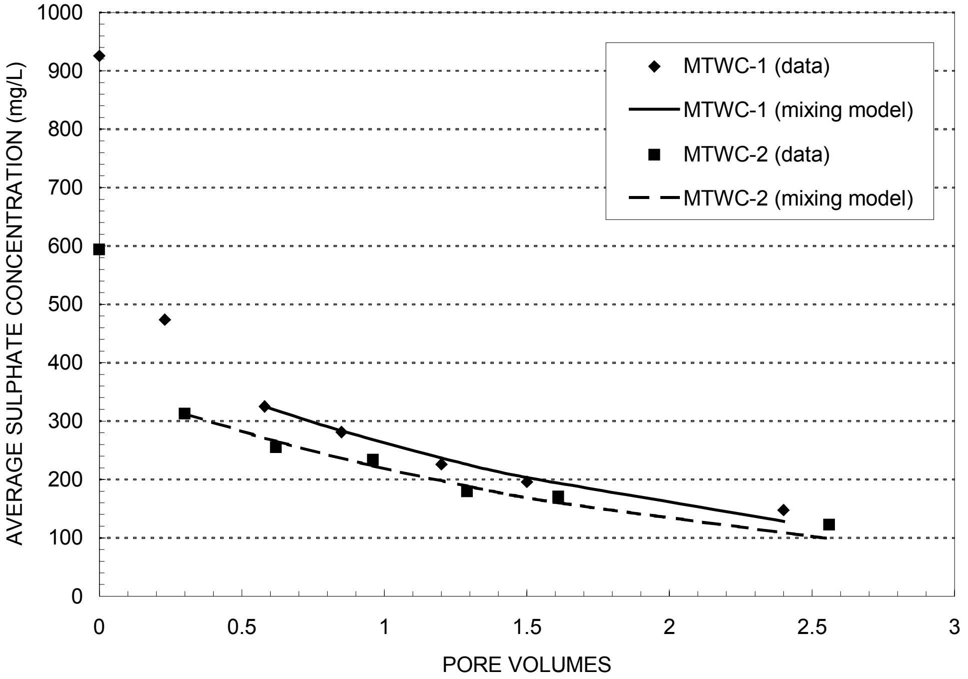


Figure 2-23: Evolution of average sulphate concentration in the water cover (experimental data and mixing model) for MTWC-1 and MTWC-2 during the dynamic period

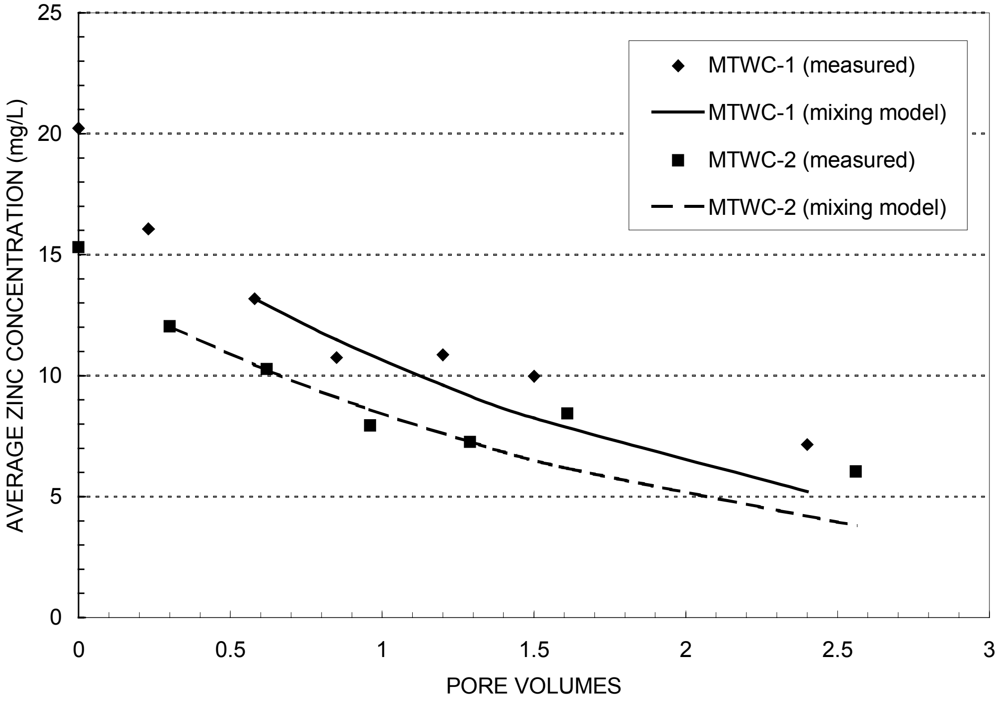


Figure 2-24: Evolution of average zinc concentration in the water cover (experimental data

and mixing model) for MTWC-1 and MTWC-2 during the dynamic period
Figure 2-1 shows that the average Fe_T concentration dropped much faster than predicted by mixing alone. This confirms that iron in the water cover was removed by precipitation. The average SO_4^{2-} concentration followed the mixing model quite closely (Figure 2-2). By contrast, the average Zn^{2+} concentration decreased more slowly than predicted by mixing alone, especially after 1.3 P.V. (Figure 2-3). This strongly suggests that Zn^{2+} was released from the hydrous oxide layer during the dynamic period.

2.3.3.3 Seepage Concentrations

The transport of contaminant species in the pore water during the kinetic period was modelled by the one-dimensional advection-dispersion equation:

$$n\frac{\partial C}{\partial t} = nD\,\frac{\partial^2 C}{\partial z^2} - nv\frac{\partial C}{\partial z} - \rho K\,\frac{\partial C}{\partial t} \qquad \text{(Equation 2-1)}$$

where n is the tailings porosity, D is the coefficient of hydrodynamic dispersion, and v is the water velocity in the tailings (nv is the Darcy velocity).

The time evolution of column seepage concentrations was simulated with the computer program POLLUTE. The columns were represented as two layers: one layer for the water cover, another for the tailings. The concentration profile for each contaminant at the start of the dynamic period defined the initial conditions. A field-measured porosity of 0.51 was used in the first simulations. However, simulations of Fe_T and SO_4^{2-} concentrations in the seepage of Column MTWC-1 and MTWC-2 (Figure 2-1, Figure 2-2 and Figure 2-3) showed that a porosity of 0.45 was more successful at reproducing the initial decrease in concentrations ($0.5<PV<0.8$). This could indicate that the columns were more tightly packed than the tailings in the field.

The best fits were obtained for dispersion coefficients equal to 5.3×10^{-6} cm^2/s for Fe, 1.1×10^{-5} cm^2/s for SO_4^{2-} and 2.1×10^{-5} cm^2/s for Zn^{2+}. The tail of the SO_4^{2-} curve, which shows the seepage concentration stabilizing at about 1800 mg/L, could not be adequately simulated. The persistence of a high SO_4^{2-} concentration may be explained by mineral dissolution, since equilibrium thermodynamic calculations with the computer program MINTEQ show that the pore water was slightly undersaturated with respect to gypsum.

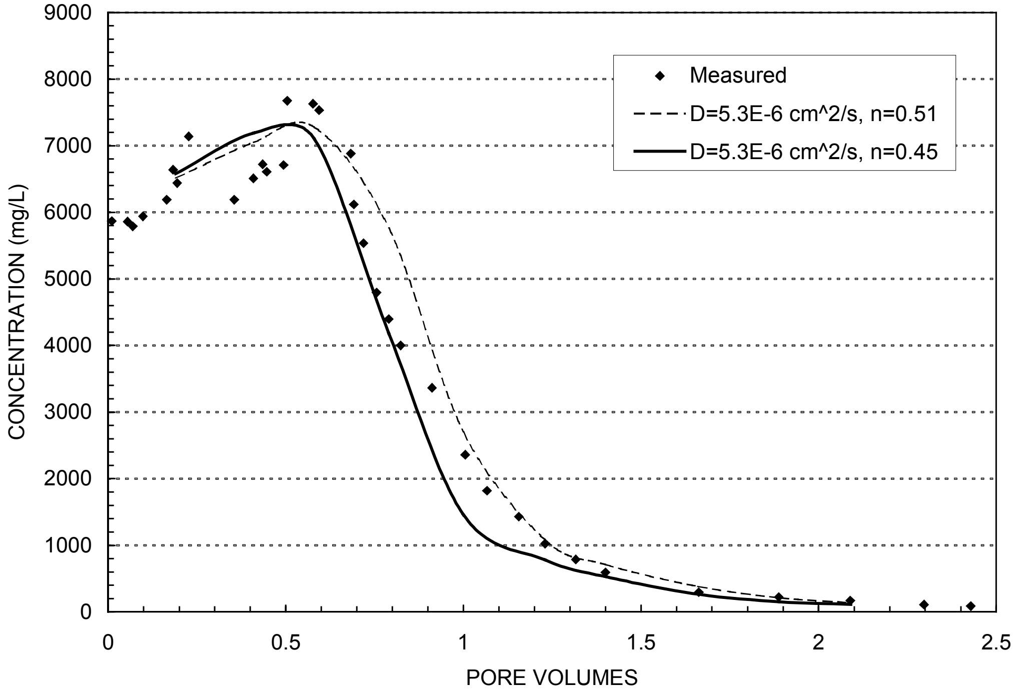


Figure 2-25: Comparison of predicted and measured concentrations of dissolved total iron in seepage of MTWC-1

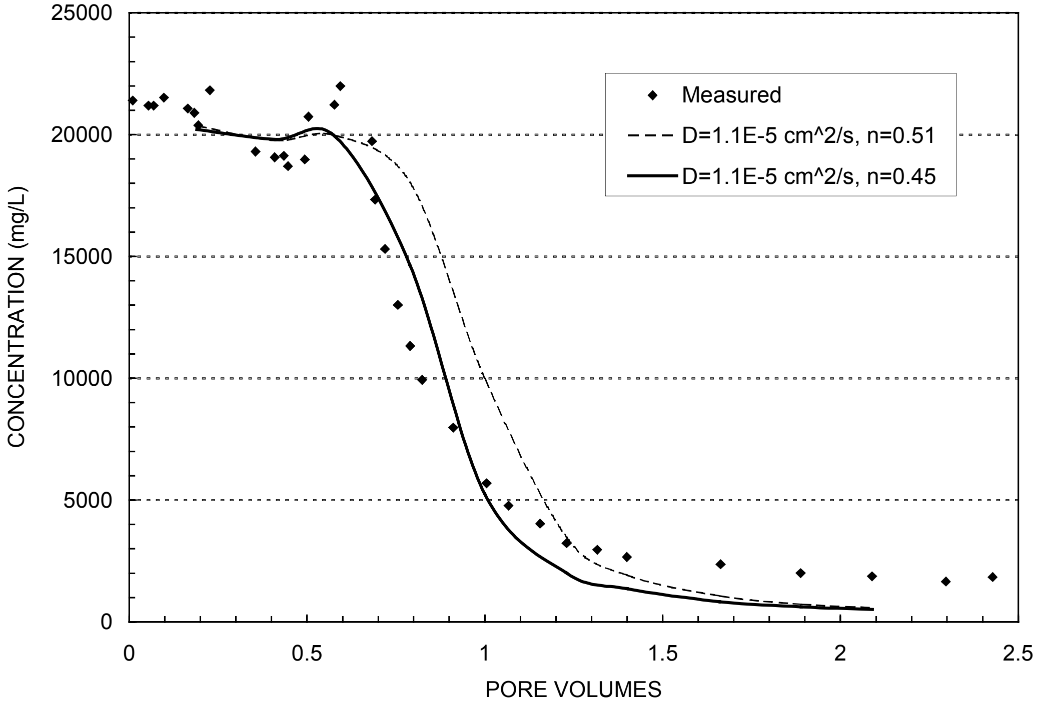


Figure 2-26: Comparison of predicted and measured concentrations of dissolved sulphate in seepage of MTWC-1

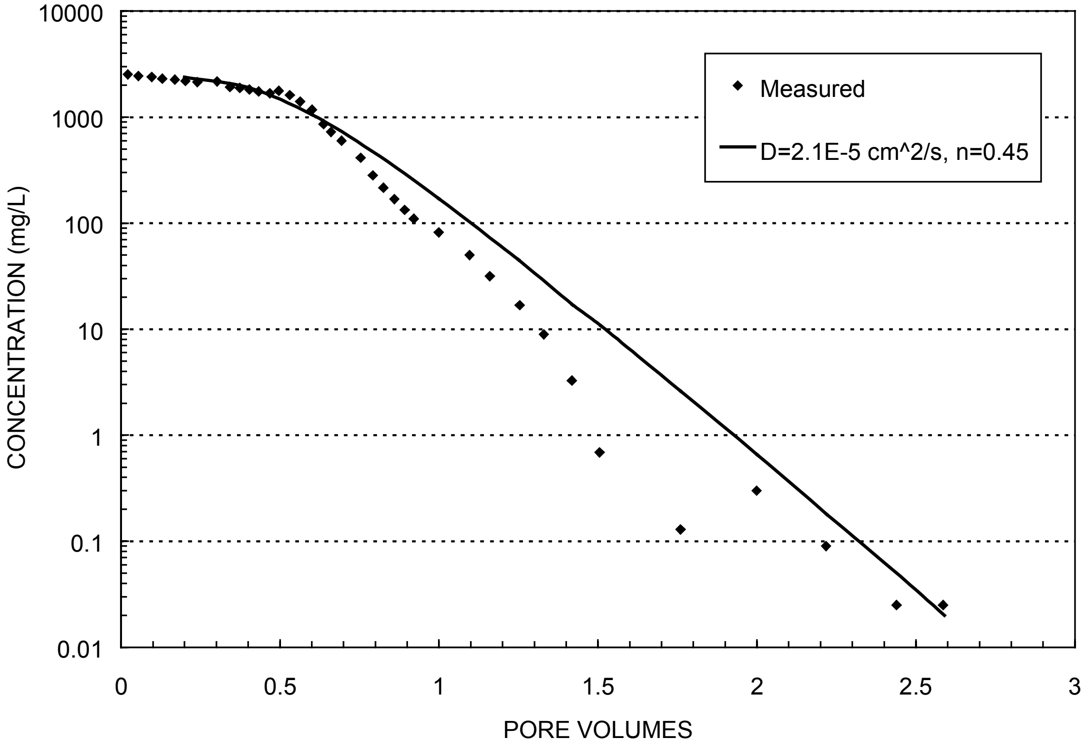


Figure 2-27: Comparison of predicted and measured concentrations of dissolved zinc in seepage of MTWC-2

2.4 SUMMARY OF FINDINGS FOR LABORATORY COLUMN EXPERIMENTS

2.4.1 Static tests

- Directly flooding the oxidized Mattabi tailings without installing an attenuation layer caused the release of solutes from pore water solution and soluble mineral phases to the water cover. Average total iron, sulphate and zinc concentrations in the water cover reached 257 mg/L, 927 mg/L and 20.2 mg/L approximately one year after flooding.

- Solute fluxes from the tailings to the water cover were greatly reduced by placing an attenuation layer (sand or peat) at the tailings-water interface. This is because diffusion of solutes through the layer is a very slow process, and is therefore effectively opposed by downward infiltration. When a sand layer was used, the average total iron, sulphate, and zinc concentrations in the water cover were below 0.3 mg/L, 50 mg/L, and 0.03 mg/L approximately half a year after flooding. The peat layer was less effective because of its own leachable zinc and sulphate contents.

- Average iron and zinc fluxes to the water covers (calculated over a one year period) were reduced by 2 to 3 orders of magnitude using a sand layer. Sulphate fluxes were reduced by 1 order of magnitude. Normalized solute fluxes obtained by dividing average fluxes by solute concentrations in the pore water before flooding also decreased in the presence of an attenuation layer.

- Because the pore water of Mattabi tailings was rich in ferrous iron, flooding was accompanied by the precipitation of a thin layer of hydrous ferric oxide at the tailings/water interface or at the interface between the tailings and the attenuation layer. This was due to the oxidation of ferrous iron by dissolved oxygen and subsequent hydrolysis of ferric iron.

- In the columns without attenuation layer, sorption of zinc on the hydrous ferric oxide precipitate was likely responsible for the decrease of zinc concentration in the water cover and in the pore water after 150 days following flooding.

- The water covers, with or without attenuation layers, were successful at reducing the net release of contaminants from the tailings to the water cover and to the pore water when compared to non-flooded tailings. This is attributed to the ability of water covers to limit further sulphide oxidation.

2.4.2 Dynamic tests

- Dilution of the water cover by the addition of deionised water and flushing of the solutes by infiltration into the tailings caused concentrations in the water covers to decrease during the dynamic period.

- When no attenuation layer was present, the total iron, sulphate and zinc concentrations decreased respectively to ~0.2 mg/L, ~200 mg/L and ~6 mg/L after 620 days (1.12 P.V.). The persistence of elevated zinc concentrations is likely explained by chemical equilibrium with a Zn–containing solid phase in the hydrous ferric oxide layer at the tailings/water interface.

- In columns with sand or peat attenuation layers, solute concentrations in the water cover remained very low or even further decreased during the dynamic period.

- Pore water concentrations decreased in all columns during the dynamic period. Displacement fronts moving gradually downwards were visible for iron, sulphate and zinc. Breakthrough occurred at approximately 0.7 pore volume.

- The presence of a water cover accelerated the decrease in pore water concentrations, especially near the top of the tailings, when compared with tailings left exposed to the atmosphere.

- The seepage of all columns remained acid ($2.3 < pH < 4.3$) during the entire dynamic period. The tailings were flushed with approximately 2 pore volumes during this period.

- Seepage concentrations remained elevated and stable for all columns until the displacement front reached the bottom of the columns (after about 0.7 P.V.) and decreased afterwards.

- At the end of the dynamic period, the iron, sulphate and zinc concentrations had reached almost asymptotical values, except for iron in the columns with a water cover but no attenuation layer, which was still decreasing. Iron concentrations were still quite elevated in all columns (ranging from 80 to 3000 mg/L). Sulphate concentrations ranged from 1400 to 4000 mg/L. The zinc concentration was very low (0.03 mg/L) in columns with a water cover but no attenuation layer, but between 25 and 40 mg/L in all other columns.

- Compliance of seepage water with applicable regulatory limits may not be achievable, even in the long term, without treatment.

3 FIELD CELL TEST

3.1 CONSTRUCTION OF THE TEST CELL

In the fall of 1991, a test cell was constructed in an oxidized portion of the Mattabi tailings area, up-slope of the tailings pond (Figure 3.1). The cell was 70 m x 70 m in plan, as measured between the centre lines of the perimeter dykes. The tailings in the cell measured approximately 54 m x 54 m in plan. Details of the construction appear in Geocon (1993b). A summary of the more relevant aspects of the test cell construction taken from this reference is given below.

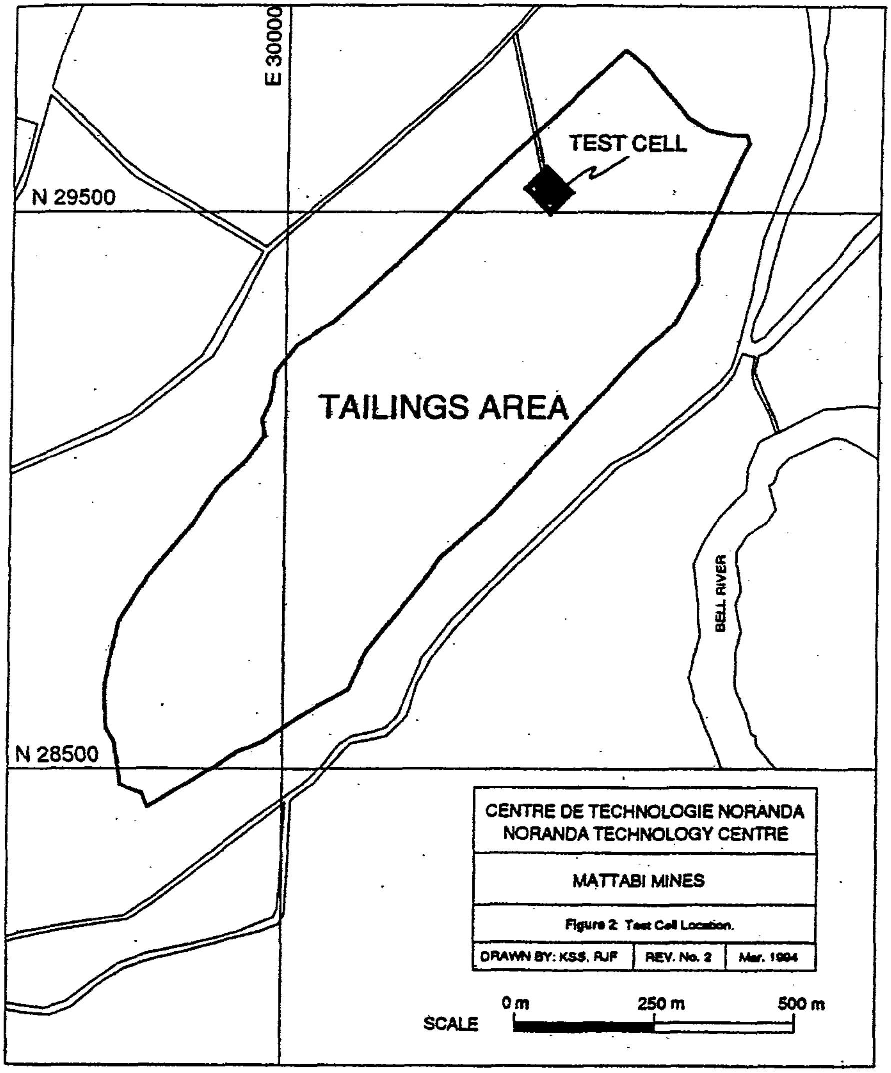


Figure 3-1: Location of the test cell on Mattabi tailings area

3.1.1 General

The schedule and components of the test cell construction are summarized in TABLE 3-1.

TABLE 3-1: SCHEDULE AND COMPONENTS OF TEST CELL CONSTRUCTION

DATE	DESCRIPTION
Oct. 2/91	Started construction of access road across tailings beach to test cell location
Oct. 2 to 7/91	Placed rock fill for construction of 250 m long access road across tailings beach
Oct.7 to 20/91	Placed till fill for till platform around entire perimeter of test cell to a height of about 1 to 1.5 m above tailings surface
Oct. 19 to 21/91	Excavated test pits T1 to T10 through till platform to define till/tailings boundary and the backfilled test pits
Oct. 21 to Nov. 12/91	Placed and compacted 0.5 to 3.5 m thickness of till fill on till platform to construct embankment of test cell dykes to a height of 1.5 to 4.5 m above tailings surface
Oct. 24/91	Installed settlement plate SP8 on till platform of south dyke before embankment fill placed
Nov. 11 to 14/91	Installed settlement plates SP1 to SP7, installed still well pipe and bench mark at north dyke, trimmed interior slopes of dykes.
Nov. 14/91	Construction of test cell completed

3.1.2 Constructibility of Earth Fill Dykes on Tailings Beach

One of the objectives of the test cell was to confirm the feasibility of constructing earth fill water retention dykes on the tailings beach. In order to provide a low permeability embankment section, a silty glacial till with about 25 to 30 percent sizes passing the No. 200 sieve was used to construct the dykes of the test cell. The dykes were constructed by first placing an end-dumped platform to a height of about 1 m above the tailings surface and then placing the remaining height of the embankment in compacted lifts. The south dyke was constructed to a height of 4.5 m and the north dyke to a height of 1.5 m. The height of the east and west dykes was variable and between these heights.

The test cell project confirmed the constructability of an earth fill dyke on the tailings beach and the main observations in this regard are as follows:

(1) It was found that the height of the first lift of till (i.e. the end-dumped till

platform) should extend at least 1 to 1.5 m above the tailings surface to provide adequate trafficability to trucks hauling the fill. When the height of the initial lift was less than 1 m, trafficability problems were experienced on the till platform.

(2) Thirty-five ton tandum trucks were used to haul the glacial till fill. It was found that the fully-loaded trucks could not be adequately supported on the till platform and therefore the trucks were operated with only a half load. It is expected that Volvo-type trucks or equivalent should perform better than the tandum trucks under similar conditions.

(3) The till for the end-dumped platform was spread initially with a D7 dozer, however this dozer was found to be too heavy for this spreading operation. AD3 dozer was then used for spreading till and this unit was found to be too small although the job was completed with the D3 dozer. It is considered that a wide track D5/D6 size dozer would have been the most appropriate unit for spreading the till during construction of the till platform.

(4) In some cases the glacial till for the platform was spread into a shallow depth of free water ponded on the tailings surface. In these cases it was found that the till was susceptible to wetting from the bottom up by capillary action and such wetting resulted in a reduction of trafficability at the surface of the platform. Even in the absence of ponded surface water such wetting of the till also occurred due to free water that was "squeezed" from the saturated tailings by the weight of the till platform fill. Based on compaction trails and trafficability observations it was found that compaction of the till platform surface with two passes of the vibratory compactor (with vibration) directly after till spreading reduced the extent of wetting and the resulting undesirable effects of poor trafficability. Construction of the till platform has indicated that the optimum method for placement of end-dumped till on saturated tailings is dependent on site specific conditions/materials/equipment and has to be developed on a trial and error basis.

(5) Approximately 1/3 of the till platform was constructed over geotextile placed directly on the tailings surface before till placement. The amount of till platform settlement which occurred in areas with geotextile was essentially similar to that which occurred in areas without geotextile. No significant "mud waves" or shear displacement occurred in areas with or without the geotextile. Therefore the geotextile was not essential to limit displacement of the tailings during till platform construction. However, the geotextile acted as a separator between the tailings and the till fill and it is considered that use of a geotextile would also reduce displacement for conditions where the tailings are of lower shear strength in comparison with the test cell area.

(6) The glacial till used for construction of the till platform and compacted lifts of embankment fill was delivered to the site at a moisture content of about 7 to 10 percent compared to the optimum moisture content of about 7.5 percent obtained from the standard proctor compaction test. Even though the moisture content was slightly above the optimum for compaction, the till platform and the compacted

lifts of till were successfully constructed. However till at a larger moisture content could not have been used and this was evident when significant softening of such till occurred. One of the important factors contributing to the successful construction of the test cell was the good quality (low moisture content) till used during construction.

(7) It was necessary to stop till placement operations during significant rainfall events and then to allow a period of drying before continuation of till placement. This is a typical requirement when constructing a dyke with compacted silty till material.

(8) Construction of the test cell dykes confirmed the constructability of low permeability water retention dykes across the tailings beach at the Mattabi tailings deposit.

3.1.3 Settlement and Frost Action

Settlement observations indicated that 0.4 m of deformation occurred during construction of the south dyke to a height of 4.5 m and that post construction settlement of about 0.07 m was essentially complete in a period of about 9 months. It is concluded that practically all of the settlement was due to consolidation of the tailings and that most of the settlement occurred during the construction period. The above observation indicates that long-term settlement (and loss of freeboard) for internal dams constructed on tailings should not be a significant problem.

Frost action on the glacial till over two winter and spring thaw periods was not severe and this is attributed in part to the well compacted condition of the till.

3.1.4 Seepage Loss and Hydraulic Stability

After allowance was made for the effects of precipitation and evaporation, the total seepage loss from the test cell ranged from about 60 m^3/day to 20 m^3/day. Practically all of this seepage occurred through the tailings below the test cell dykes since the compacted till dykes represented a low permeability material compared to the tailings. The back-calculated coefficient of permeability of the tailings was 1.2×10^{-3} cm/s. This value is in reasonable agreement with the range of 0.8 to 2.2×10^{-3} cm/s which could be estimated from the grain size characteristics of the tailings. The estimated seepage loss has a significant effect on the feasibility of various tailings closure options.

The observation of sand boils in the tailings at the downstream toe area of the test cell dykes indicated the need for appropriate measures such as low hydraulic gradient or toe drainage measures to ensure hydraulic stability with respect to piping in the tailings.

3.2 TAILINGS CHARACTERIZATION

The tailings beneath the test cell had an average depth of about 14 m. Dry densities ranged from 1.5 to 2.1 g/cm^3; specific gravity and porosity averaged 3.6 and 51%, respectively. The tailings were poorly graded and consisted, on average, of fine sand (60%), coarse sand (20%) and silt sized (20%) particles. The average d_{50} was about 0.15 mm. Combination of X-ray diffraction and chemical analysis results showed that sulphides accounted for 37% of the tailings mass. The dominant silicate minerals were quartz (21%), chlorite (11%), muscovite (10%), and albite (2.5%). Gypsum (0.6%) and goethite (2.7%) were also identified. All percentages refer to the total tailings mass. Petrographic examination of the tailings (Freymond, 1994) revealed that pyrite was the dominant sulphide mineral followed by pyrrhotite, which was extensively oxidized near the surface of the tailings area. Trace amounts of sphalerite, arsenopyrite, and chalcopyrite were also present.

These tailings were relatively young and had probably only been oxidizing for about 10 years. The oxidized portion of the tailings showed mineral oxidation and precipitation patterns similar to other tailings impoundments (e.g. Blowes and Jambor 1990), where a sulphide-depletion zone is underlain by an active-oxidation zone, and further underlain by a secondary-mineral precipitation zone. The secondary mineral precipitation was typically amorphous ferric hydroxide, or a more crystalline ferric oxyhydroxide or hydroxysulphate (Freymond, 1994).

3.3 METHODS

3.3.1 Test Cell Operation and Monitoring

During the winter following construction of the cell, snow and ice accumulated in the test cell. Snowmelt and rain during the spring elevated the water table from below to above the tailings surface. By July 1992, the depth of water covering the tailings had reached approximately 1 m in the deepest parts of the cell. Two 30-m long wooden rafts were placed at a 90º angle, and fixed to the south and east embankments to provide access to the centre of the test cell (Figure 3-1).

On July 7, surface water samples were collected in the water cover. In this sampling event as in the ones following, surface water samples were collected by lowering a silicone tubing a few centimetres below the surface and pumping 500 mL of water using a portable peristaltic pump. Water samples were collected in duplicate or triplicate. The samples were filtered through 0.45-mm filters, acidified, and then analyzed for Al, As, Ca, Cd, Cu, Fe, K, Mg, Mn, Na, Pb, S, Se, and Zn by inductively-coupled plasma-atomic emission spectroscopy (ICP-AES). Concentration differences between replicates samples were generally small and within the limits of analytical error. Field measurements of solute concentration variations with depth in other water cover studies (e.g., Ljungberg et al., 1997) have demonstrated that the water column is well mixed during the ice-free season due to wind-induced waves and natural convection. Moreover, because of the relatively small dimensions of the cell and the homogeneity of the tailings, it was assumed that the water chemistry would be independent of location in the cell.

Since a closure option for the Mattabi site involved flooding the tailings with water from nearby Sturgeon Lake, rain and snowmelt water was pumped out of the cell between July 7 and 9, 1992. Starting on July 11, Sturgeon Lake water was pumped into the cell at a rate of 3.5 m^3/min through a pipe located on the north side (Figure 3-2). The total volume of water in the test cell after flooding was 4200 m^3. The water depth was 1.0 m on the north side of the cell and 1.7 m on the south side, as the surface of the tailings in the test cell sloped at about 0.7^o downward from north to south. The surface water was sampled again on July 14.

Regular monitoring of water level in the cell began on July 14 and continued until October 3, 1992. During this interval, precipitation, class A pan evaporation, temperature, and humidity were also measured. There was no monitoring between October 1992 and July 1993.

In July 1993, the test cell was instrumented with a pressure transducer to automate monitoring of the surface-water elevation. Monitoring of the water level resumed on July 22 1993 and continued until December 1993. The surface water was sampled on July 25, 1993.

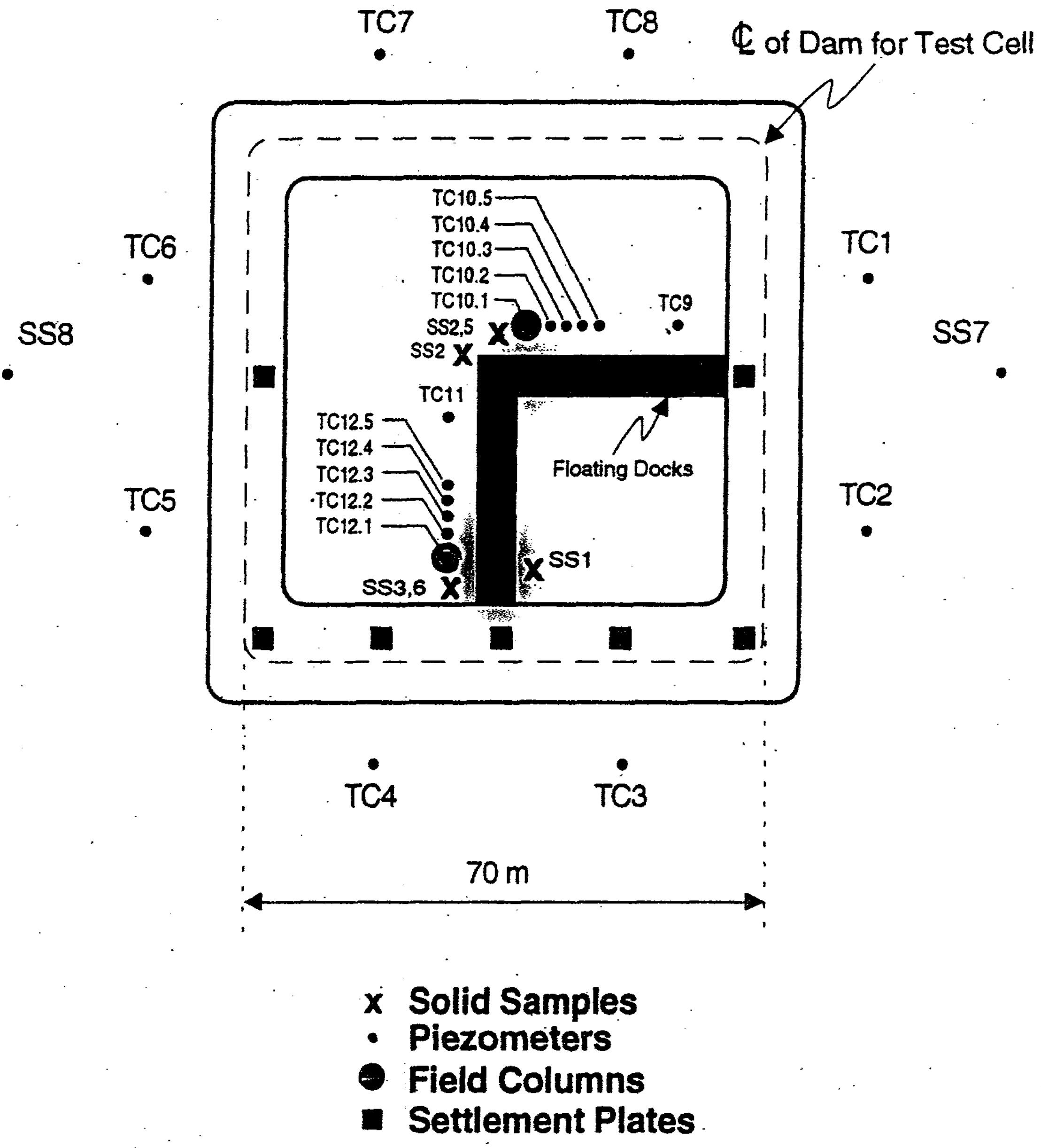
Starting on July 26 1993, Sturgeon Lake water was again added to the cell. When the flooding was complete (August 3rd), the cell contained 5200 m^3 of water. Additional surface water samples were collected on August 1, September 13, October 12, and November 3, 1993.

To measure pore water concentrations, the test cell was instrumented with four groundwater-monitoring stations (TC9 to TC12) in the summer of 1992 (Figure 3-4). Two of the stations each consisted of five piezometers (TC10.1 to TC10.5 and TC12.1 to TC12.5) that were installed from 30 cm to about 5 m in depth beneath the tailings surface. Each piezometer consisted of a 1-in. PVC pipe fitted with a ¾ x 12 in. piezometer tip. The two other stations (TC9 and TC11) each consisted of one piezometer that was installed at a depth of 1 m beneath the tailings surface.

In addition core samples of tailings were obtained before adding Sturgeon Lake water to the test cell in July 1992 and in July 1993. On each occasion, cores were collected at two locations within the test cell to about 1-m depth using thin-walled aluminium tubes. Cores were also collected outside the test cell near TC2 and TC6. In July 94, four cores were collected: two inside the test cell near TC 10 and TC 12, and two outside the cell near TC2 and TC 6. Slices of the cores were squeezed to recover pore water samples representative of various depth intervals. These samples were analyzed in the same manner as surface water samples.

Figure 3-2: Photograph of flooded test cell

Figure 3-3: View of test cell with pipeline in place to supply fresh water from Sturgeon Lake. Photograph taken on May 20, 1992 before the water was pumped out (July 7-9, 1992).



Note: Diagram not to scale.

Figure 3-4: Test cell instrumentation and sampling locations

3.3.2 Seepage Loss Analysis

Seepage loss from the test cell was established by carrying out a water balance analysis using the monitoring data collected during the test (Geocon, 1993b). The water balance was evaluated using the following equation:

$$SL = P - E - H \qquad \text{(Equation 3-1)}$$

where SL is the seepage loss, P the factored precipitation, E the factored evaporation, and H the change in storage or cell water level (negative for drop).

The factored precipitation included an allowance for runoff from the interior slopes of the test cell dykes. This was achieved by increasing the measured precipitation by 10% (that is, using a factor of 1.1). The resulting factored precipitation was then assumed to represent the rise in cell water level due to a precipitation event. Since the vertically projected area of the interior slope of the dykes represented approximately 20% of the water surface area in the cell, the factoring procedure translated into a runoff coefficient of 0.5 for the compacted till slopes of the dykes (Geocon, 1993b). This procedure assumed that there was negligible runoff from the crest of the dykes, a reasonable assumption since the crest was flat.

To obtain the factored (estimated) evaporation from the test cell, the measured class A evaporation was reduced by a factor of 0.8, which was slightly higher than the typical value of 0.7 used for lakes (Fisheries and Environment Canada, 1978). The value of 0.8 was used to allow for the much shallower depth of water in the test cell (Geocon, 1993b).

As an example, for the period July 14-17, 1992, the test cell water level dropped 33.8 mm and 21.4 mm of rainfall was recorded, while pan evaporation was measured to be 13 mm. Applying factors of 1.1 and 0.8 to precipitation and evaporation, respectively, and noting that the water level change is –33.8 mm, the seepage loss is calculated to be [21.4 (1.1)- 13 (0.8)- (-33.8)] mm or ~ 47 mm. The water surface area in the cell on July 15 (middle of period) was estimated to be 3427.42 m^2, and the elapsed time between measurements on July 14 and July 17 was 2.71 days. The rate of total seepage from the test cell for the period July 14-17 is then [(3427.42)(0.0470)/2.71] m^3/day or 59.4 m^3/day. Seepage rates were calculated for other days in a similar fashion.

3.4 RESULTS

3.4.1 Evolution of Water Cover Volume and Water Surface Elevation

The variations of the water cover volume and water surface elevation with time for the monitoring periods of 1992 and 1993 are shown in Figure 3-1 and Figure 3-2, respectively. The elapsed time on the horizontal axis is calculated from July 14, 1992. The volume reached a maximum after each flooding event, and then decreased during the

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following summer and fall as evaporation and seepage exceeded precipitation. Note that the water elevation decreased below the tailings surface elevation in the north end of the cell after September 18, 1992 and after October 12, 1993. Hence a portion of the tailings surface in the northern part of the test cell (approximately 15 to 25% of the total cell area) became exposed to the atmosphere after these dates.

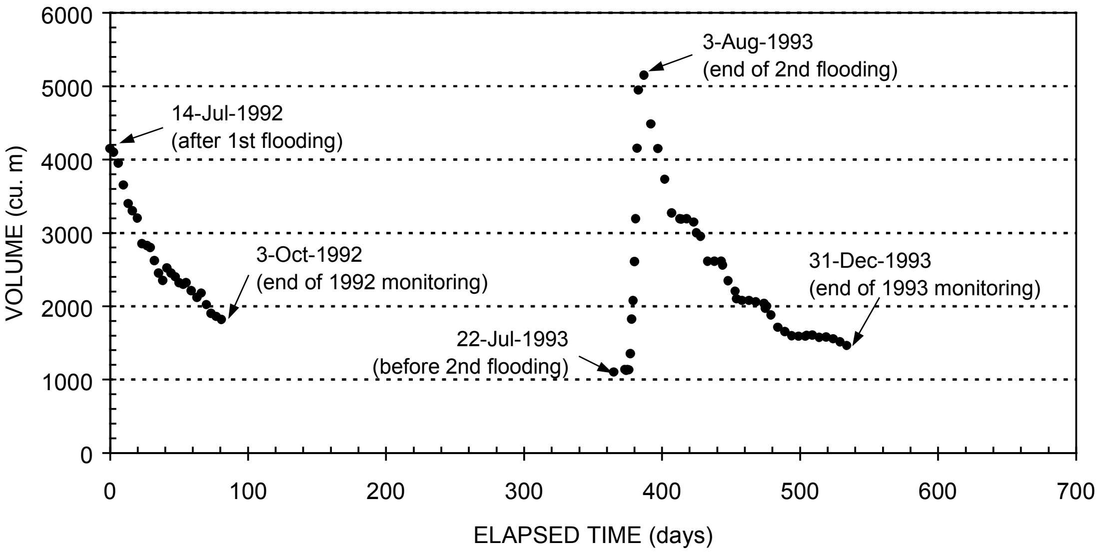

Figure 3-5: Water cover volume in test cell as a function of time

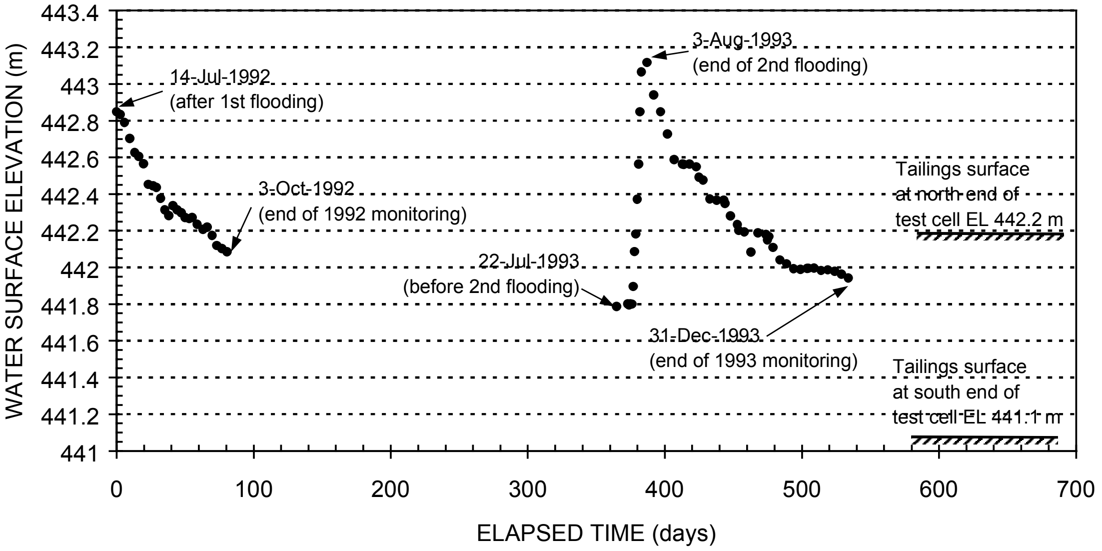

Figure 3-6: Water surface elevation in test cell as a function of time

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3.4.2 Water Cover Chemistry

Average dissolved concentrations of selected elements in the water cover for various sampling event are shown in TABLE 3-1. Sturgeon Lake water chemistry is also included for comparison. All solute concentrations decreased during the first flooding of the cell with Sturgeon Lake water in 1992, presumably as a result of dilution, but then increased between the end of flooding and July 25, 1993. On that date, Fe and Zn reached elevated concentrations of 466 mg/L and 3.79 mg/L, respectively.

TABLE 3-2: AVERAGE DISSOLVED CONCENTRATIONS OF SELECTED ELEMENTS AND PH IN THE WATER COVER AT VARIOUS SAMPLING DATES AND COMPARISON WITH STURGEON LAKE WATER

Element (mg/L)	7-Jul-92 (before 1st flooding)	14-Jul-92 (after 1st flooding)	25-Jul-93 (before 2nd flooding)	1-Aug-93 (during 2nd flooding)	13-Sep-93	12-Oct-93	03-Nov-93	Sturgeon Lake water
Aℓ	9.08	0.47	21.8	4.86	3.03	0.56	0.44	<0.05
As	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.05
Ca	257	71	302	532	627	596	648	12.5
Cd	<0.02	<0.01	<0.02	<0.02	<0.02	<0.02	<0.02	<0.005
Cu	0.12	<0.02	0.1	<0.02	<0.02	<0.02	0.025	<0.005
Fe	974	58	466	54	0.58	0.12	0.31	<0.005
K	6.7	2.3	6	<5	5.8	<5	5.8	<1
Mg	233	19	182	194	196	190	189	1.8
Mn	29	2.2	24	6.1	3.2	3	3.1	0.001
Na	11	3.3	17	25	24	22	23	3.9
Pb	<0.15	<0.05	0.4	<0.25	<0.25	<0.25	<0.25	<0.05
S	1152	118	951	806	791	746	787	6.22
Se	0.15	0.05	<0.50	<0.5	0.5	<0.50	0.5	<0.1
Zn	11.7	0.39	3.79	0.69	0.74	0.66	0.69	<0.005
pH	3.2					5.7		

During the second flooding (between July 26 and August 3, 1993), solute concentrations decreased, except for Ca and Mg. The evolution of solute concentrations after the second flooding differed markedly from that after the first flooding. Between August 1, 1993 and November 3, 1993, most solute concentrations decreased or remained stable. The pH of the water cover increased as a result of flooding from 3.2 on July 7th 1992 to 5.7 on October 12, 1993.

TABLE 3-2 shows the evolution of dissolved masses of Al, Ca, Fe, Mg, Mn, S (mostly as sulphate), and Zn in the water cover on sampling events. These masses were determined as the product of solute concentrations and the volume of water in the cover at the various sampling dates. Note that solute masses could not be calculated for July 7, 1992 because the exact volume of the water cover was not measured on that day. All solute masses increased in the year that followed the first flooding of the cell.

TABLE 3-3: DISSOLVED MASSES OF SELECTED ELEMENTS IN THE WATER COVER AT VARIOUS SAMPLING DATES

Element (kg)	14-Jul-92 (after 1st flooding)	25-Jul-93 (before 2nd flooding)	1-Aug-93 (during 2nd flooding)	13-Sep-93	12-Oct-93	03-Nov-93
Aℓ	1.9	24.7	24.1	9.1	1.2	0.9
Ca	294	342	2632	1877	1249	1267
Fe	240	527	265	1.7	0.2	0.6
Mg	81	206	960	587	398	369
Mn	9.0	26.7	30.1	9.5	6.2	6.0
Na	14	19	123	73	46	44
S	489	1076	3989	2367	1563	1540
Zn	1.6	4.3	3.4	2.2	1.4	1.3

During the second flooding (between July 26 and August 3, 1993), the masses of Ca, Mg, Na and S increased dramatically, the masses of Al and Mn remained relatively stable, and the masses of Fe and Zn decreased. After the second flooding was complete, the masses of all solutes decreased with time. Iron differed from other solutes in that its mass began to increase again after October 12, 1993. This increase may have been caused by either the dissolution of the hydrous ferric oxide precipitate that formed on the surface of tailings (Figure 3-1), or sulphide oxidation in the tailings. Sulphide oxidation may have been a significant factor because a portion of the tailings became exposed to the atmosphere after October 12, 1993.

Figure 3-7: Photograph of test cell showing hydrous ferric oxide precipitate

3.4.3 Characterization of the Hydrous Ferric Oxide Precipitate Layer

On July 1992, before Sturgeon Lake water was pumped to the cell, a 3 to 4-mm thick iron hydroxide precipitate was seen coating the surface of the tailings below the water cover. This precipitate had formed during the previous spring when snowmelt and rainwater had accumulated in the cell. Analysis of precipitate samples revealed the presence of 2200 mg/kg of zinc. To determine the mobility of the zinc, the sample was also leached using the USEPA Toxicity Characteristic Leaching Procedure (USEPA, 1986), which involves shaking the sample in an acetic acid/sodium acetate buffer solution at pH 4.9 for a period of 18 hours. Zinc concentration in the final leachate was 4.5 mg/L, which represented approximately 2 % of the mass of zinc present in the precipitate (St-Arnaud and Yanful, 1993).

These results confirm that a fraction of the zinc initially transferred to the water cover is able to adsorb or co-precipitate within the ferric hydroxide precipitates. However, zinc in the precipitate remains available for further re-dissolution, subject to external factors such as pH variations.

3.4.4 Metal and Sulphate Fluxes to the Water Cover

In this section, the average fluxes of solutes to the water cover are estimated between sampling events in 1993. By definition, positive fluxes indicate a movement of solutes towards the water cover. The difference between the masses $M_w(t_2)$ and $M_w(t_1)$ of a given solute in the water cover determined at times t_1 and t_2 is related to the total solute flux F_T to the water cover and the area of flooded tailings, Ω, in the test cell as follows:

$$M_w(t_2) - M_w(t_1) = F_T \Omega (t_2 - t_1) \qquad \text{(Equation 3-1)}$$

The total solute flux can be written as the sum of the advective flux of solute carried by the seepage and the net flux of solute to the water cover:

$$F_T = F_A + F_N \qquad \text{(Equation 3-2)}$$

The advective flux to the water cover is negative since seepage removes solutes from the water cover. It is related to the seepage rate S and the solute concentration in the water cover, C_w, between times t_1 and t_2 by:

$$F_A = -\frac{1}{\Omega.(t_2 - t_1)} \int_{t_1}^{t_2} S\, C_w.dt \qquad \text{(Equation 3-3)}$$

Combining Equations 3-2 to 3-4 yields the following expression for the net solute flux:

$$F_N = \frac{1}{\Omega.(t_2 - t_1)} \left(M_w(t_2) - M_w(t_1) + \int_{t_1}^{t_2} S\, C_w.dt \right) \qquad \text{(Equation 3-4)}$$

The net flux, if positive, represents the rate of solute release to the water cover due to dissolution or desorption from mineral phases present in the tailings or in the ferric hydroxide precipitate layer. Diffusion from pore water to the cover is not believed to have played a major role given the significant downward advective fluxes due to seepage losses. A negative net solute flux indicates the rate of solute removal from the water cover by precipitation or adsorption on the ferric hydroxide precipitate layer.

The integral in Equation 3-5 can be estimated numerically from the concentration versus time data (TABLE 3-1) and estimates of seepage rates between sampling events. Seepage losses were determined almost daily by the method presented in Section 3.3.2. Average seepage rates calculated over each week of monitoring are shown in Figure 3-1. Net solute fluxes were estimated using average seepage rates for the periods between surface water sampling events in 1993 (TABLE 3-1).

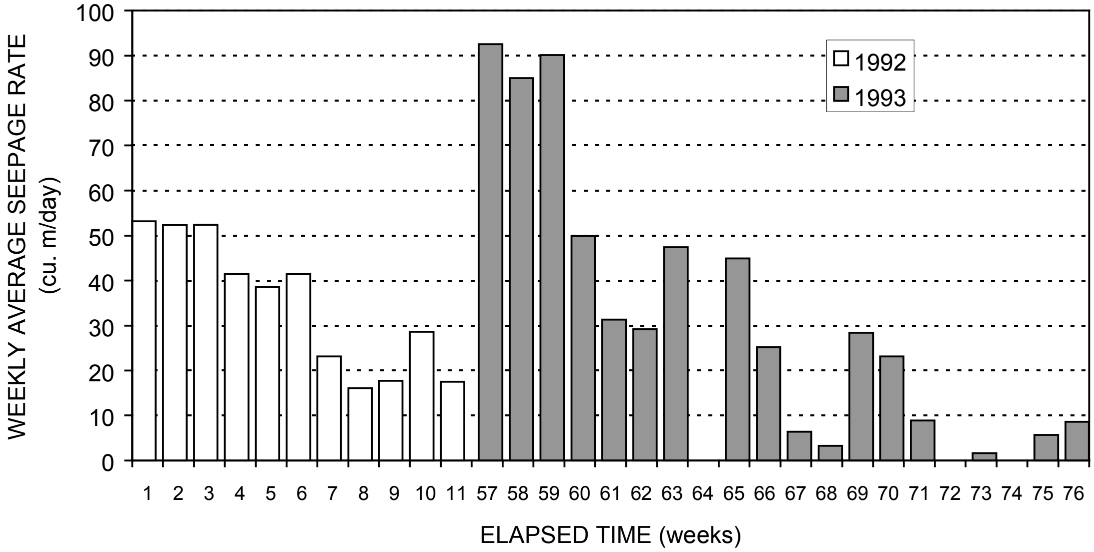

Figure 3-8: Weekly average seepage rates versus time

TABLE 3-4: AVERAGE SEEPAGE RATES USED IN THE CALCULATION OF SOLUTE FLUXES

Period	*Seepage Rate, S (m^3/day)*
July 25 – August 1	46.1
August 1 -September 13	63.5
September 14 – October 12	29.7

Note: All data are for 1993.

As an illustration of the procedure for calculating the net fluxes, consider the estimated test cell volume and measured zinc concentrations in the water cover on September 13 and October 12, 1993 (Table 3-5). From the measured zinc concentration of 0.74 mg/L (i.e. 0.74 g/m^3) and the test cell water volume of 2994 m^3, for September 13, 1993, the mass of zinc is 0.74 x 2994 or 2215.6 g. Similarly the mass of zinc in the water cover on October12 is 1382.7 g. Using the estimated average seepage rate of 29.7 m^3/day (Table 3-4) and an average zinc concentration of (0.74 + 0.66)/2 mg/L or 0.70 mg/L, the net flux of zinc to the water cover during the 28 days between September 13 and October 12, 1993, is calculated to be -0.0031 g/m^2/day, as shown in TABLE 3-2. The negative sign means that zinc is actually removed from the water cover.

TABLE 3-5: SAMPLE CALCULATION OF NET SOLUTE FLUXES

Date	Test cell water volume (m^3)	Zn (mg/L)	Zn (g)
September 13, 1993	2994	0.74	2215.6
October 12, 1993	2095	0.66	1382.7

Average seepage rate = 29.7 m^3/day (Table 1); Area of tailings surface = 54 m x 54 m;
Net flux of zinc to water cover during Sept 13 –Oct 12, 1993 (28 days) using Equation 3-4:

$$[\{(1382.7-2215.6)\text{g}/(28\ \text{days}) + (29.7\ \text{m}^3/\text{day})\ (0.74 + 0.66)/2\ \text{g/m}^3\}/\ (54\ \text{m})/(54\ \text{m})]$$

or -0.0031 g/m^2/day = -3.1E-04 mg/cm^2/day

TABLE 3-3 presents net fluxes for various solutes between sampling events in 1993, calculated using the above procedure. Note that net solute fluxes are not shown after October 12, 1993 because part of the tailings in the cell became exposed to the atmosphere after that date. Moreover, net solute fluxes were not calculated for 1992 due to lack of sufficient concentration data. A sensitivity analysis on net solute fluxes with respect to the seepage rates was performed since seepage rates carry the most uncertainty among the parameters required to calculate net solute fluxes. Net solute fluxes were calculated assuming both an underestimation and an overestimation of the seepage rates by 10%. The results indicated that the order of magnitude and the sign of the net solute fluxes were not affected by such an error in the seepage rate.

TABLE 3-6: CALCULATED NET SOLUTE FLUXES (mg /cm^2/day) TO THE WATER COVER IN 1993

Solute	Jul. 25, 1993 – Aug. 1, 1993	Aug. 1, 1993 – Sept. 13, 1993	Sept. 13, 1993 – Oct. 12, 1993
Aℓ	1.8E-02	-3.3E-3	-7.8E-03
Ca	11.9	6.6E-01	-1.5E-01
Fe	-8.8E-01	-1.51E-01	-1.5E-03
Mg	4.0	1.3E-01	-3.5E-02
Mn	4.0E-02	-6.3E-03	-9E-04
Na	5.4E-01	1.3E-02	-9E-03
S	15.7	4.3E-01	-2.0E-01
Zn	-7.0E-04	6.0E-04	-3.1E-04

The flooding of 1993 (July 26 to August 3) resulted in a net release (by dissolution or desorption) of Al, Ca, Mg, Mn, Na and S (as sulfate) to the water cover, as shown by the positive value of the corresponding net fluxes during the period July 25 - August 1, 1993. In contrast, Fe and Zn displayed negative fluxes of –0.88 mg/cm^2/day and –0.0007 mg/cm^2/day, respectively, and were likely removed from the water cover by precipitation or sorption.

As time progressed, however, the majority of fluxes decreased steadily. In the two to three months that followed, precipitation and/or sorption reactions began removing the solutes that had previously been released to the cover during flooding. This is demonstrated by the fact that all the net fluxes were negative between September 13 and October 12. Iron continued to be precipitated, but at a smaller rate than during flooding. Zinc appears to have been dissolved or desorbed at a small rate of 0.0006 mg/cm^2/day in the August 1st- September 13 period, but the net Zn flux became negative again during the next period.

Direct comparison of net solute fluxes determined in the field cell with those in the laboratory columns is not possible because flooding procedures were quite different in the two types of experiments. In the field cell, parts of the tailings were already covered by contaminated water when flooding took place, whereas this was not the case at the start of the static period in the columns. Moreover, water was added at a constant rate to the water cover in the columns during the dynamic period, whereas the field cell was flooded twice over a short period of time in 1992 and 1993, and then the water cover volume was allowed to decrease.

3.4.5 Pore Water Quality

Plots of pH, redox potential, and solute concentrations in pore water versus depth obtained from piezometers and cores near or at the locations of TC 10 and TC12 are shown in Figures VI-1 to VI-10 in Appendix VI. Note that depths are measured from the tailings surface. Solute concentrations obtained from cores collected outside the cell near TC2 and TC6 are shown in Figures VI-11 to VI-19.

In July 1992, the pore water composition in the upper ~25 cm of tailings (corresponding to the unsaturated zone before installation of the test cell) was close to that measured in laboratory columns MTWC-3 to MTWC-8. Total iron concentrations ranged from 2000 to 6500 mg/L at TC10 and from 140 to 2000 mg/L at TC12; sulphate concentrations ranged from 9000 to15000 mg/L at TC 10 and from 3000 mg/L to 12000 mg/L at TC12; and zinc concentrations ranged from 100 mg/L to 300 mg/L at TC 10 and from 20 mg/L to 100 mg/L at TC 12. The zinc concentration in the test cell pore water was an order of magnitude lower than in Columns MTWC-1 and MTWC-2.

In July 1992, the pore water pH in the upper 25 cm of tailings was low (2.8<pH<3.5), and the redox potential was high (300-400 mV), thus indicating oxidizing conditions. Below that zone, the pH increased (3.5<pH<6), and the redox potential decreased (100-280 mV), as expected for depths that were not exposed to oxygen. The slightly acidic pH in the unoxidized zone may have been due to downward migration of oxidation products. The passage from the oxidized to the unoxidized zone inside the test cell was marked by an increase in total iron, sulphate, manganese, calcium, magnesium, sodium, and potassium pore water concentrations (particularly at TC 12), but a decrease in zinc and aluminium concentrations. By contrast, pore water samples from cores outside the test cell showed a decrease in sulphate, manganese, magnesium, sodium, and potassium, and no change in total iron and calcium concentrations when moving from the oxidized to the unoxidized zone. This suggests that solutes inside the test cell migrated from the oxidized zone to the unoxidized zone as a result of increased water infiltration between the construction of the test cell in July 1991 and the retrieval of the first cores in July 1992.

After flooding the test cell in July 1992 and July 1993, significant decreases in solute concentrations were observed in the upper 1-m of tailings because solute fluxes to the water cover and downward displacement of the pore water by infiltrating water with lower concentrations. The only notable exceptions were for calcium and potassium concentrations. The calcium concentration likely increased because of the decline in sulphate concentration and the equilibrium with gypsum. The downward migration of solutes was accompanied by an increase in total iron, sulphate, manganese, zinc, potassium, and aluminium concentrations at greater depths. This could result in a more contaminated seepage from the tailings area following the implementation of a water cover, until flushing of the oxidation products is complete.

TABLE 3-1 compares the net solute fluxes to the water cover during the 1993 flooding (July 25 to August 1) with the solute concentrations both in the water cover and in the shallow pore water on the eve of flooding (July 25, 1993). Shallow pore water samples were extracted from the top 20 cm of cores collected inside the test cell. The data suggests that the net fluxes of some solutes to the water cover were not primarily controlled by diffusion to or from the pore water. For example, although the concentrations of Al, Mg, Mn and S were higher in the water cover than in the shallow pore water, the net flux of these solutes was toward the water cover (i.e. positive). In the case of Zn, the net flux was negative although Zn concentrations were higher in the shallow pore water than in the water cover. These observations are consistent with solute concentrations in the water cover being strongly affected by precipitation-adsorption-dissolution reactions at the hydrous ferric oxide precipitate covering the tailings surface.

TABLE 3-7: EVIDENCE FOR CONTROL OF METAL FLUXES TO THE WATER COVER BY PRECIPITATION - SORPTION - DISSOLUTION OF HYDROUS FERRIC OXIDE PRECIPITATE

Element	Pore water in top 20 cm of tailings on July 25th, 1993 (mg/L) (1)	Water cover on July 25th, 1993 (mg/L)	Average flux for July 25th-Aug 1st, 1993 (mg/cm^2/day)
Aℓ	0.27, 0.30	21.8	1.8E-02
Ca	543, 595	302	11.9
Fe	159, 379	466	-8.8E-01
Mg	85, 147	182	4.0
Mn	11, 21	24	4.0E-02
Na	26, 28	17	5.4E-01
S	677, 879	951	15.7
Zn	11.7, 4.6	3.8	-7.0E-04

Note: (1) Values represent concentrations measured in pore water extracted from two core samples

4 SUMMARY AND RECOMMENDATIONS

4.1 EVOLUTION OF WATER CHEMISTRY OVER FLOODED OXIDIZED TAILINGS WITHOUT ATTENUATION LAYER

The laboratory column and field cell tests have shown that directly flooding oxidized Mattabi tailings without installing an attenuation layer causes the release of metals and sulphate from pore water solution and soluble mineral phases to the water cover. In the columns, average total iron, sulphate and zinc concentrations in the water cover reached respectively 257 mg/L, 927 mg/L and 20.2 mg/L approximately one year after flooding. Corresponding concentrations in the field cell water cover one year after the flooding of July 1992 were 466 mg/L, 2850 mg/L and 3.8 mg/L, respectively. Differences between concentrations measured in the laboratory and in the field tests were likely due to differences in initial pore water compositions and soluble mineral contents between the columns and the test cell.

Because the pore water of Mattabi tailings was rich in ferrous iron, the establishment of a water cover was accompanied by the precipitation of a thin layer of hydrous ferric oxide precipitate on the surface of the tailings. This was due to the oxidation of ferrous iron by dissolved oxygen and subsequent hydrolysis of ferric iron. The precipitate contributed to the removal of zinc and other metals from the cover by sorption reactions both in the columns and in the field test cell.

Dilution of the water cover by addition of deionised water (laboratory columns) or rain and snowmelt (field test cell), flushing of solutes by water infiltration from the cover to the tailings, and removal of some metals by precipitation and sorption on the hydrous ferric oxide precipitate progressively reduced solute concentrations in the water cover. In July 1994, i.e. two years after the first flooding of the filed test cell, metal concentrations in the test cell water cover met regulatory discharge limits: As<0.5 mg/L, Cu<0.3 mg/L, Fe < 3 mg/L, Pb < 0.2 mg/L and Zn < 0.5 g/L. However, the water cover pH remained lower than the minimum of 6.0. It is estimated that about 1855 mm of water infiltrated during this period. In the laboratory column water covers, the zinc concentration decreased much more slowly than in the field test cell and was still ~6 mg/L after 620 days of simulated infiltration, which translates into ~955 equivalent field days given average field infiltration rates.

The persistence of elevated zinc concentrations in the laboratory column water covers is likely explained by geochemical equilibrium of the overlying water with a Zn–containing solid phase in the hydrous ferric oxide layer at the tailings/water interface. Hence, the hydrous ferric oxide precipitate, although contributing to the decrease of zinc concentrations in the column water cover during the first year of testing, later acted as a source of soluble zinc as metal concentrations in the water cover and pore water decreased. In the field cell, the zinc content in the precipitate layer (0.22%) was less than in the laboratory columns (1.28%), presumably because of lower initial pore water concentrations. As a result, zinc did not leach as much, and discharge limits were met in the water cover two years after first flooding the cell, as pointed out above. Hence, the geochemical characteristics of the oxidized tailings (pore water composition, soluble minerals) have a large influence on the time required to achieve discharge limits in the water cover.

4.2 EFFECT OF SAND AND PEAT ATTENUATION LAYERS

Attenuation layers made of sand or peat were only tested in the laboratory columns. Fluxes of metals from the tailings to the water cover were greatly reduced by placing an attenuation layer at the tailings-water interface. This was primarily because diffusion of metals from the oxidized tailings through the attenuation layer and to the water cover is a very slow process. Moreover, the attenuation layer also imposes a diffusion control on the availability of dissolved oxygen to the tailings, and therefore limits further tailings oxidation more effectively than a simple water cover.

When a sand layer was used, the water cover met discharge limits during the entire duration of the tests. The average total iron, sulphate, and zinc concentrations in the water cover were below 0.3mg/L, 50 mg/L, and 0.03 mg/L approximately half a year after flooding. The peat layer was less effective because of its own leachable zinc content: after 163 days of test, the zinc concentration was still 1.5 g/L in one of the columns. Hence, it is important to ensure that material used to build the attenuation layer has low contaminant levels so that it does not contribute to the contamination of the water cover. A careful and detailed characterization of this material is therefore very important. In general, peat obtained around the vicinity of mining sites does not appear to be a good candidate for building attenuation layers as it is often a source of iron and other metals in water cover applications (Davé, 1999)

4.3 EVOLUTION OF SEEPAGE QUALITY

Seepage water quality was only measured in the laboratory column tests. Seepage concentrations were initially very high (similar to pore water concentrations) and remained stable for all columns until the displacement front reached the bottom of the columns (at about 0.7 P.V.), after which they decreased over time as infiltrating water flushed the contaminated pore water. The presence of a water cover accelerated the decrease in seepage concentrations when compared with tailings left exposed to the atmosphere, probably as a result of reducing further tailings oxidation.

The time or pore volumes of infiltration water required to meet discharge limits in the seepage depends on the distribution of the contaminants in the tailings. When contaminants are mostly contained in the pore water, discharge limits may be achievable after flushing the tailings with ~ 3 pore volumes. However, when a significant portion of the contaminants is contained in soluble solid phases, concentrations in the seepage stabilized at elevated values and long-term seepage treatment will be required. The presence of an attenuation layer at the water/tailings interface seemed to have relatively little influence on the seepage water quality.

Long-term maintenance of water covers generally requires that seepage losses from the facility be minimal. In this case, the contaminated pore water will remain in place for many years, and seepage treatment, if part of the closure plan, can be expected to be long lasting.

If the seepage rate is high, as was the case in this study, large volumes of seepage will need to be intercepted and treated. Economic considerations suggest that at sites with high seepage rates, a water cover may be suitable only if it can be supplemented with gravity-fed fresh water from a nearby source to the cover, and thus compensate for seepage losses. In this situation, treatment costs for the seepage will increase after flooding due to higher infiltration rates. Although the quality of seepage will increase over time, treatment may still be required in the very long term since solute concentrations may reach near-asymptotic values that are still above discharge limits, as was the case in some of our tests. Hence, the establishment of a water cover over oxidized tailings is not recommended at sites with significant seepage losses.

5 RESEARCH TEAM

The NTC team included B. Aubé, J. Boucher, L. Catalan, R. Freymond, S. Payant, J.F. Ricard, K. Shikatani , P. Simms, L. St-Arnaud, P. Tibble, M. Woyshner, and E. Yanful. Final data analysis and reporting was done by L. Catalan. L. Bernier helped with the interpretation of the mineralogical data.

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APPENDIX I

ELEMENTAL COMPOSITION DATA FOR MATTABI TAILINGS

ELEMENTAL COMPOSITION OF MATTABI TAILINGS (ug/g)

	Al	As	Ca	Cu	Fe	K	Mg	Mn	Na	Pb	S
1992 oxidized tailings	27203.16	1996.95	3129.39	856.16	220627.95	3564.53	6642.28	575.24	3315.77	1719.37	202758.56
1992 unoxidized tailings	31426.56	1439.66	4160.67	479.92	199397.48	3198.41	7406.48	907.73	1434.93	1328.39	184341.81
1993 oxidized tailings	39300.62	1573.55	1243.26	915.37	241308.08	5837.49	6117.02	1575.82	1081.03	1169.32	195818.13
1993 unoxidized tailings	28515.61	861.24	959.70	1028.48	265196.98	2374.61	2110.98	893.15	724.33	2063.75	263793.44

	Si	Ti	Zn	SO4	OTHER
1992 oxidized tailings	139570.44	766.16	6047.88	5733	381226.16
1992 unoxidized tailings	165698.84	1284.27	5360.22	3314	392134.63
1993 oxidized tailings	142741.45	1504.68	3324.36	1594.00	356489.82
1993 unoxidized tailings	120856.02	1280.46	1755.36	1496.33	307585.88

APPENDIX II

SOLUTE CONCENTRATION PROFILES FOR COLUMNS – STATIC PERIOD

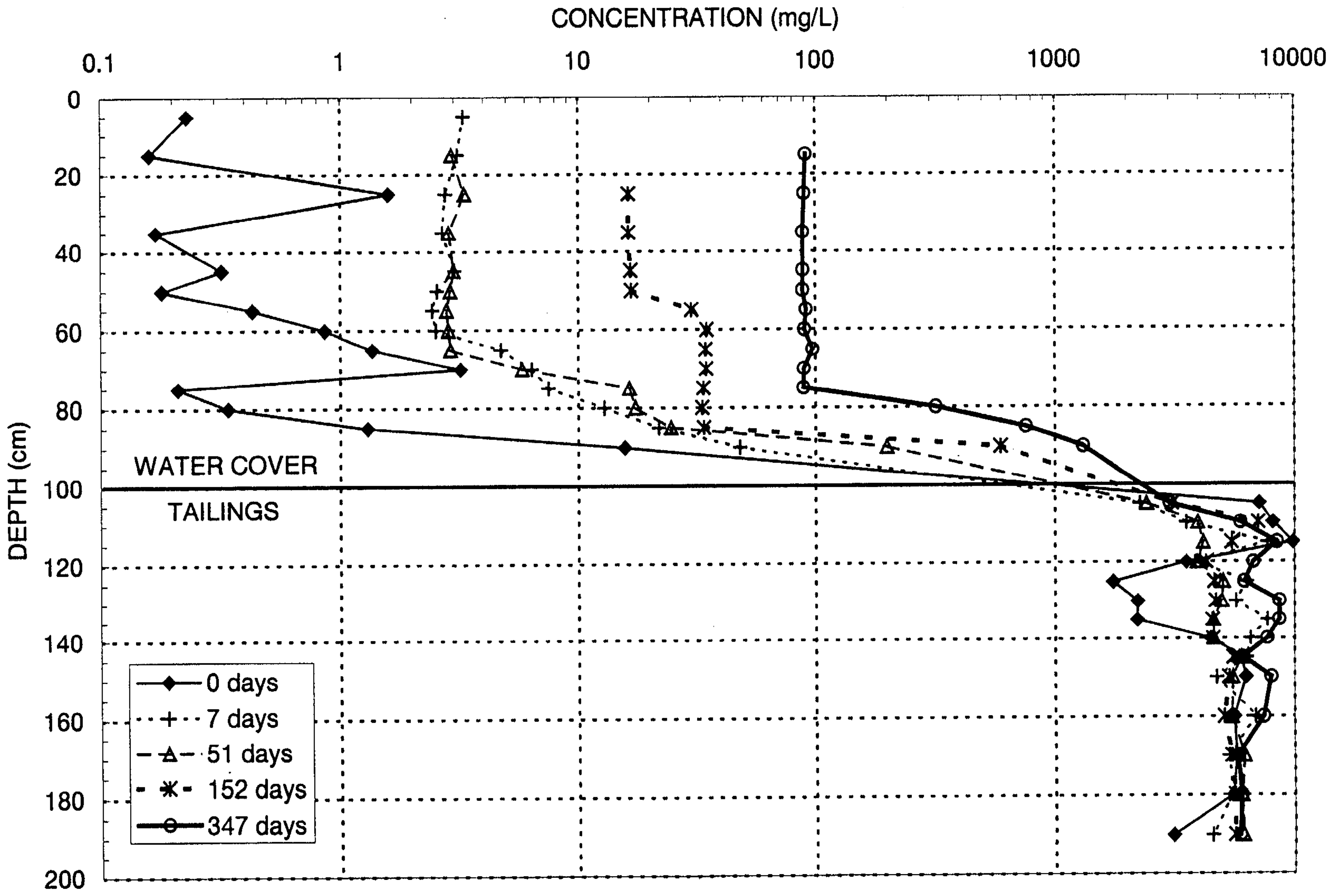

Figure II-1a: Dissolved total iron concentration profiles for MTWC-1, static period

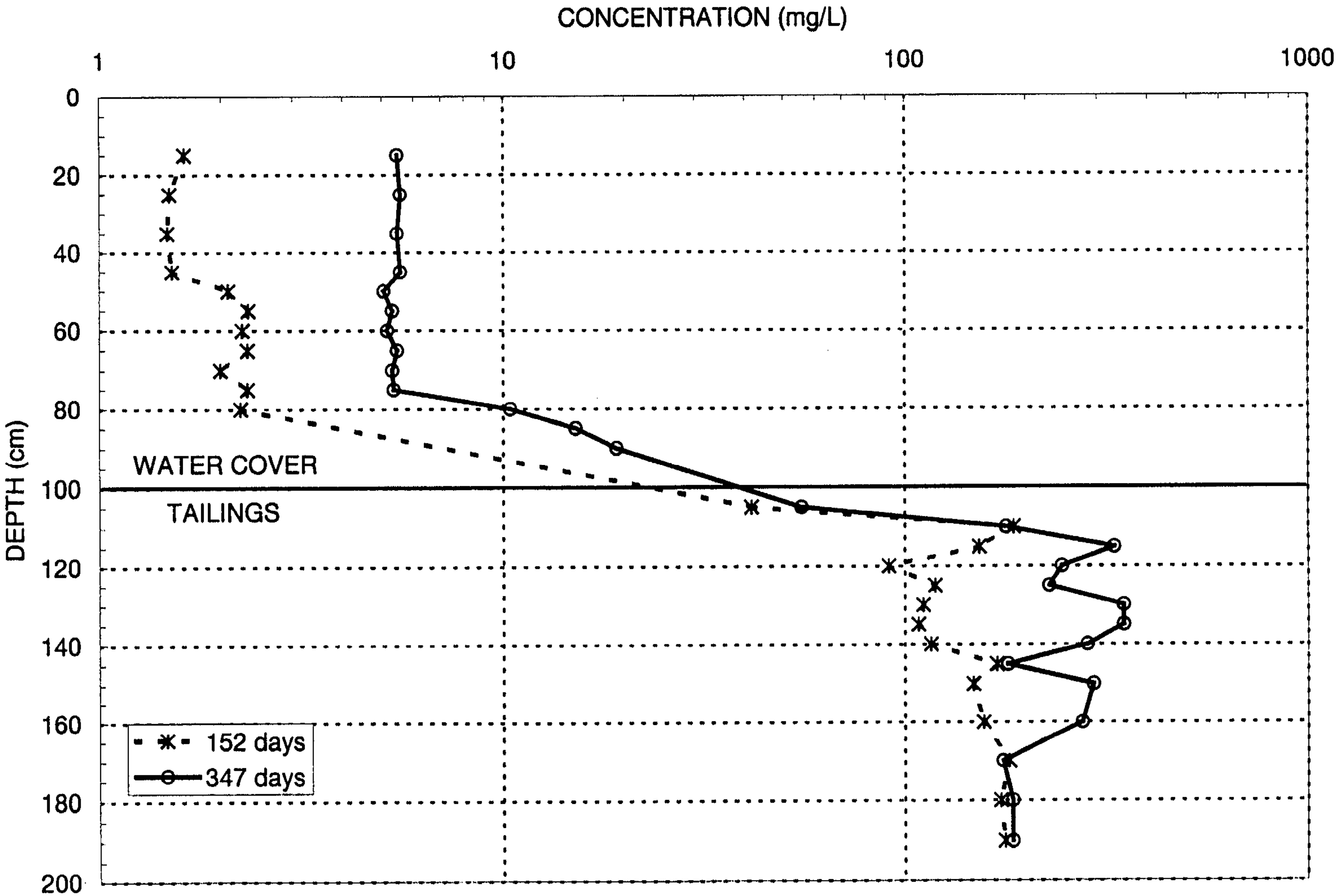

Figure II-1b: Ferric iron concentration profiles for MTWC-1, static period

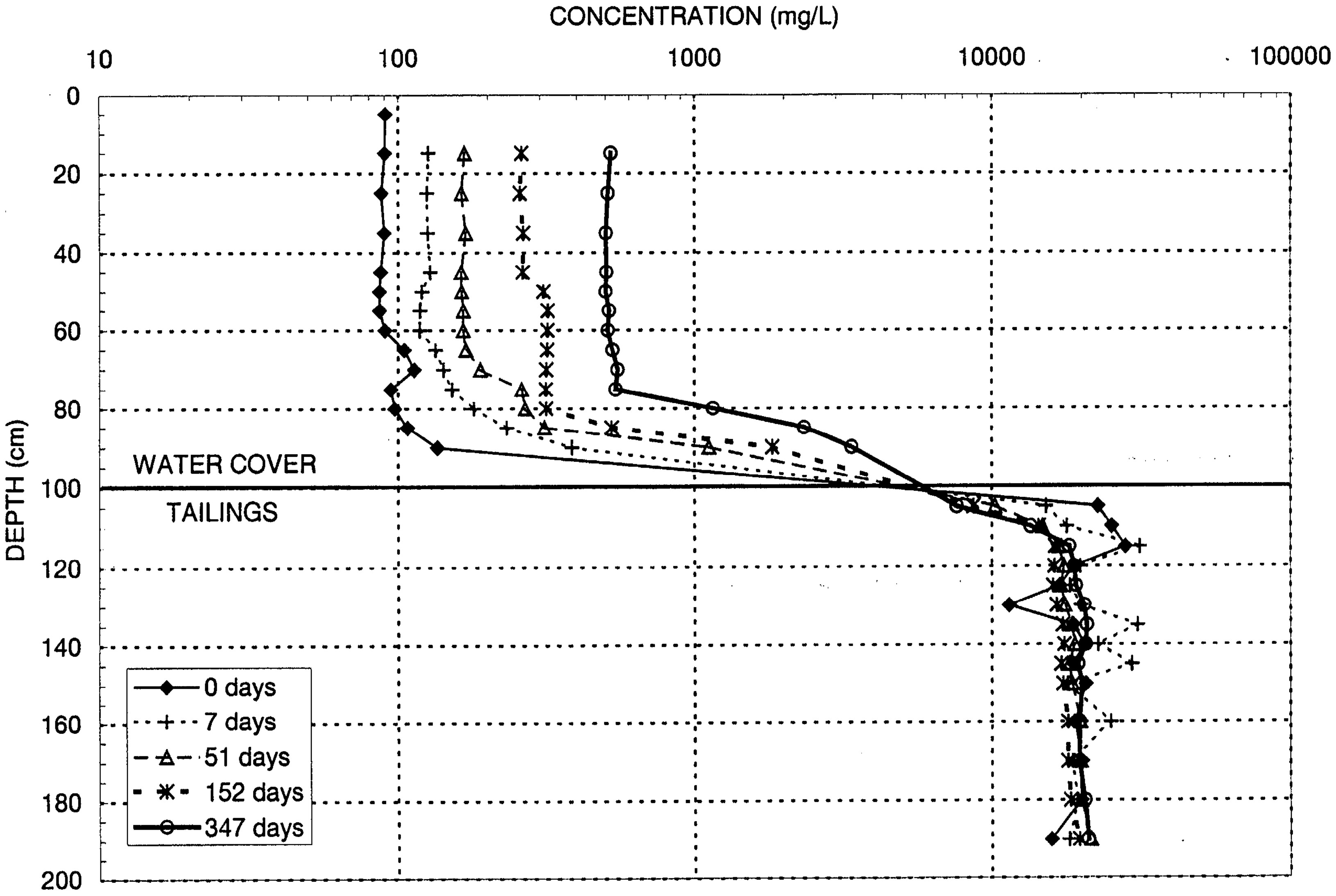

Figure II-1c: Dissolved sulphate concentration profiles for MTWC-1, static period

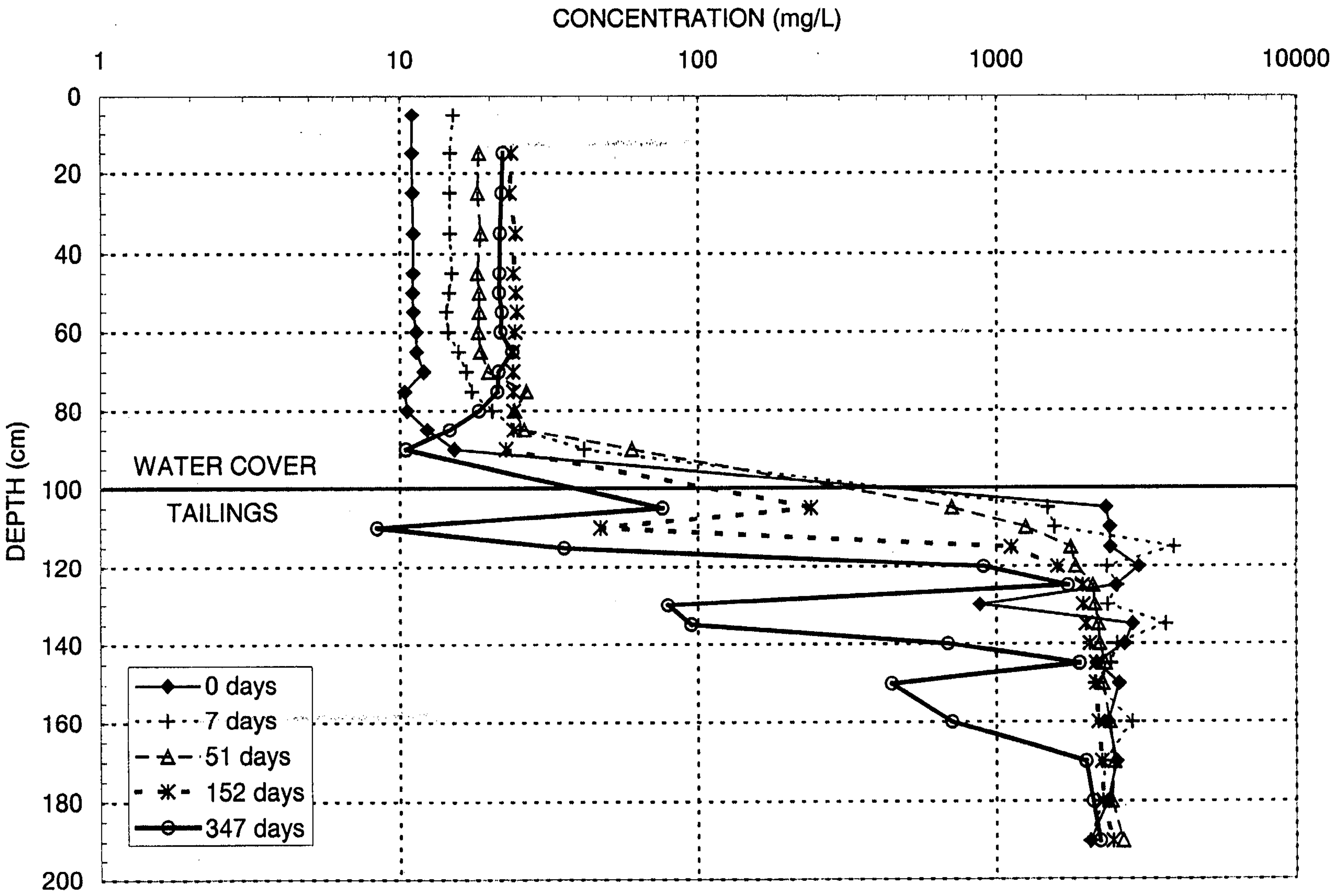

Figure II-1d: Dissolved zinc concentration profiles for MTWC-1, static period

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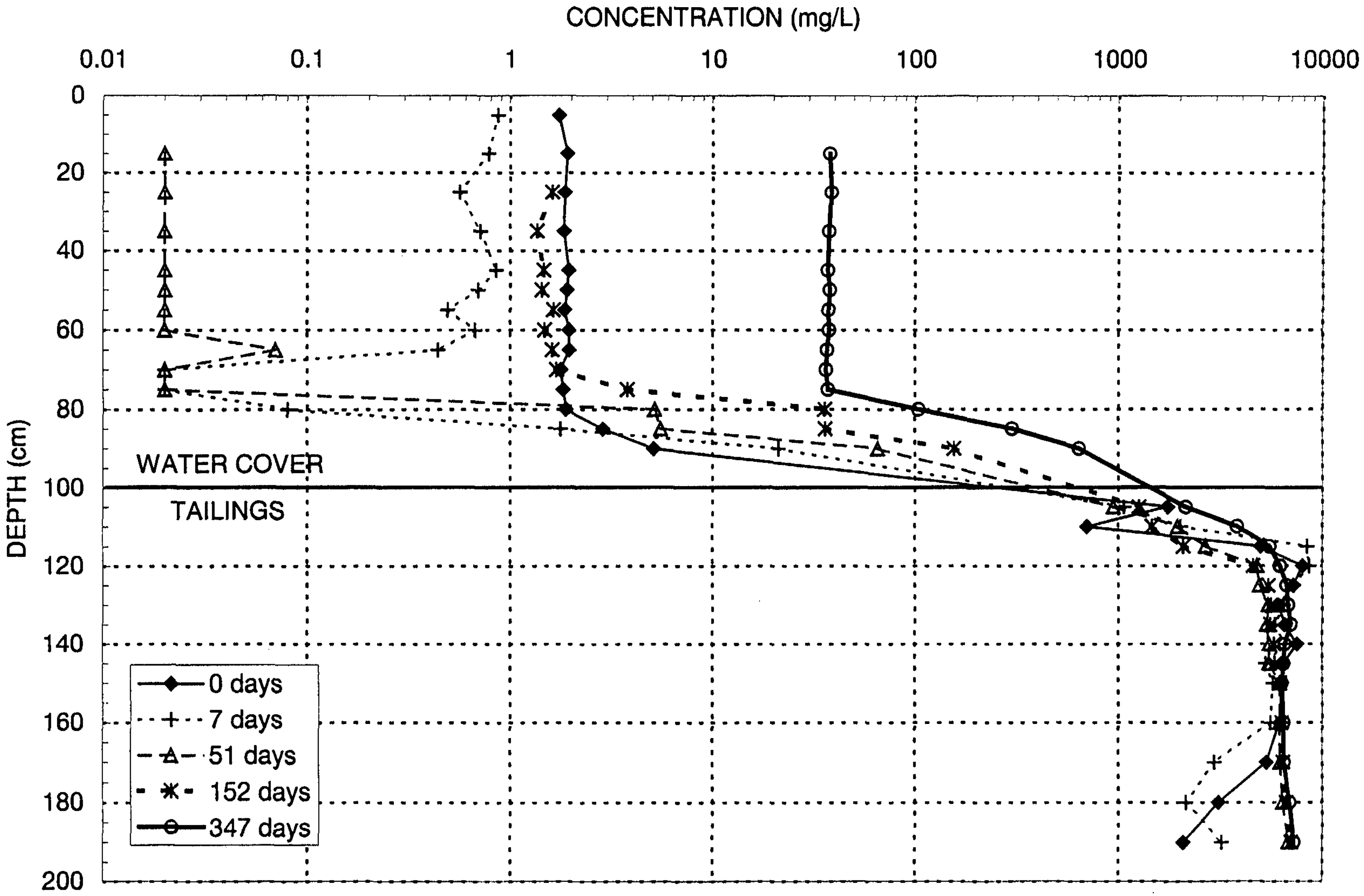

Figure II-2a: Dissolved total iron concentration profiles for MTWC-2, static period

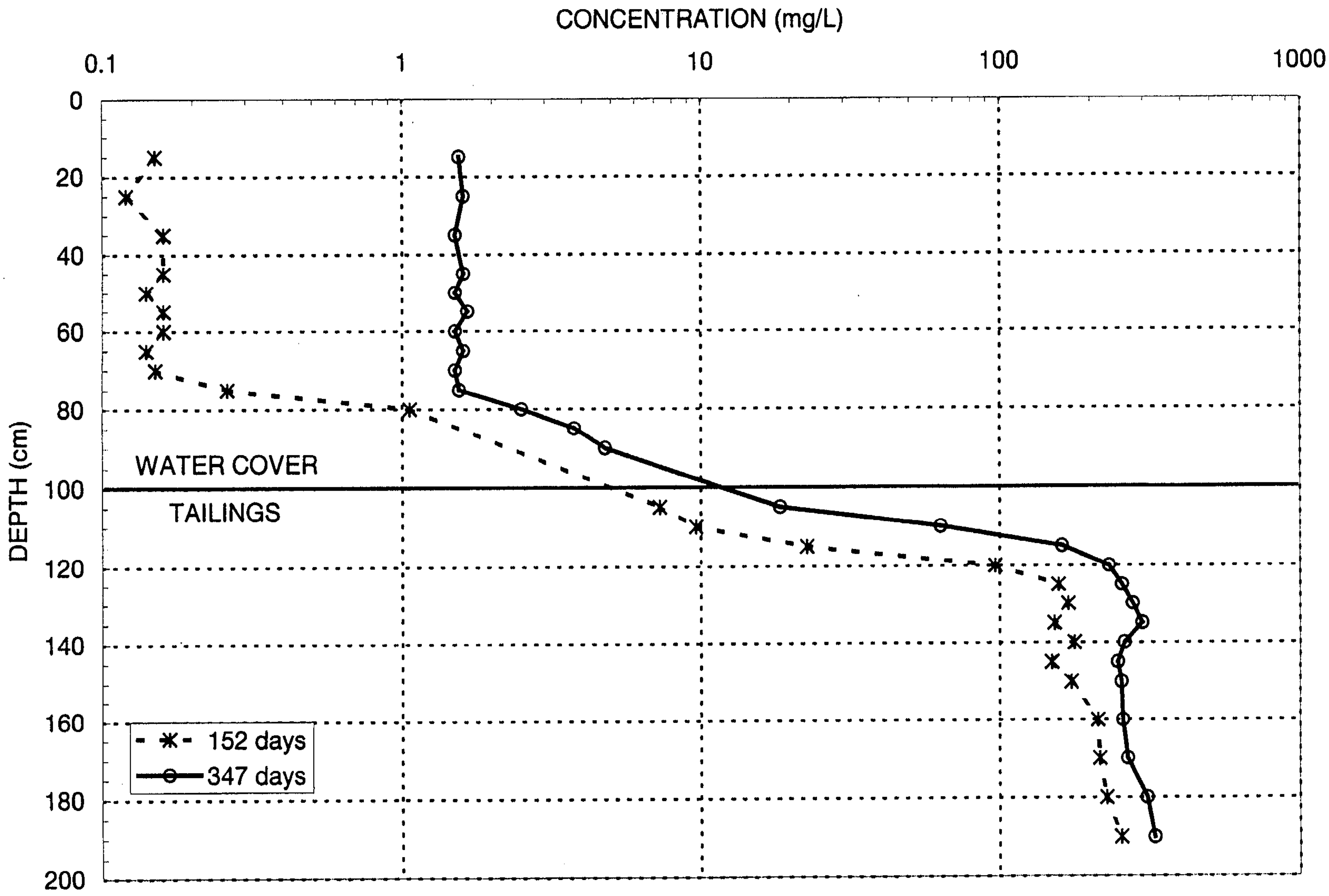

Figure II-2b: Ferric iron concentration profiles for MTWC-2, static period

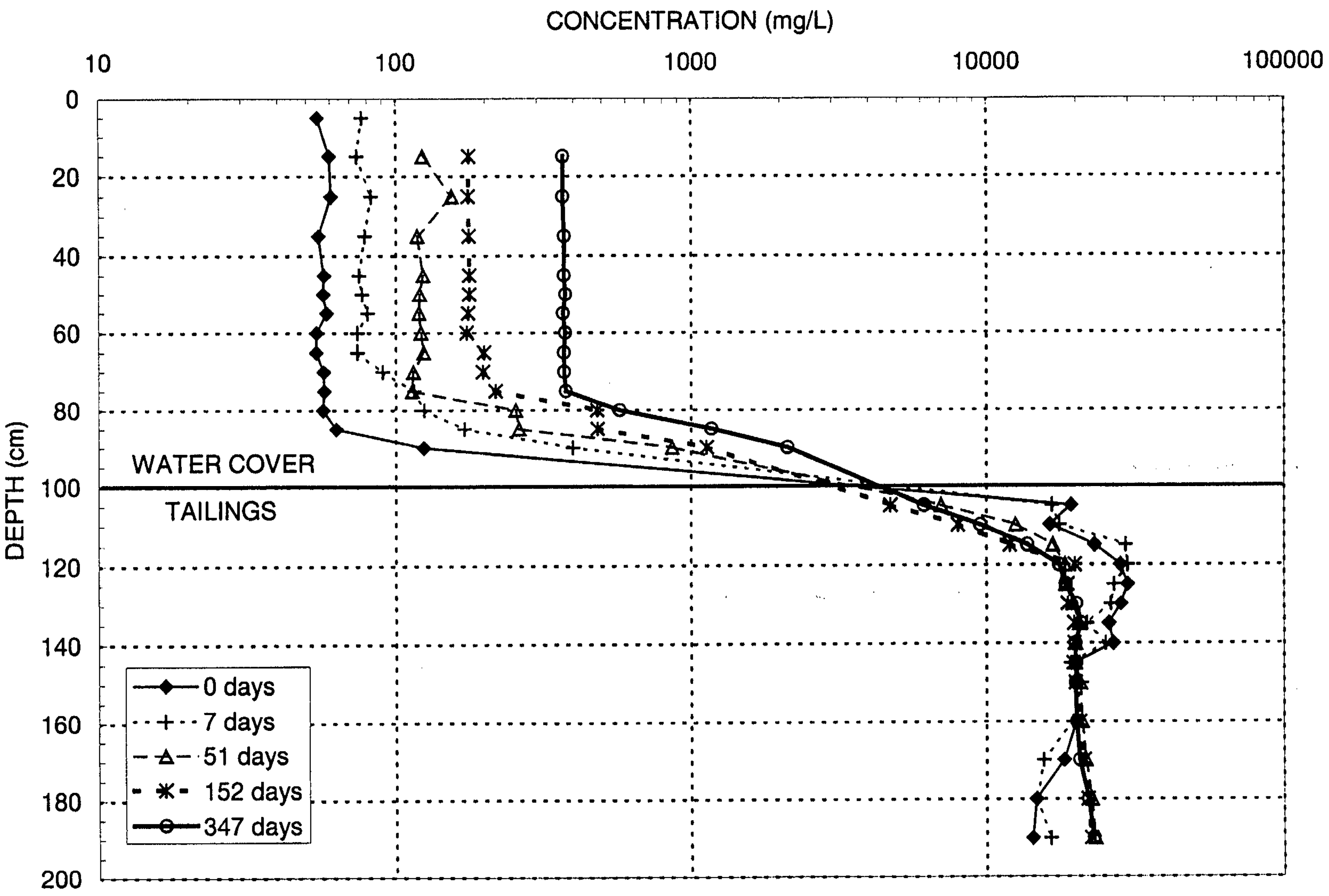

Figure II-2c: Dissolved sulphate concentration profiles for MTWC-2, static period

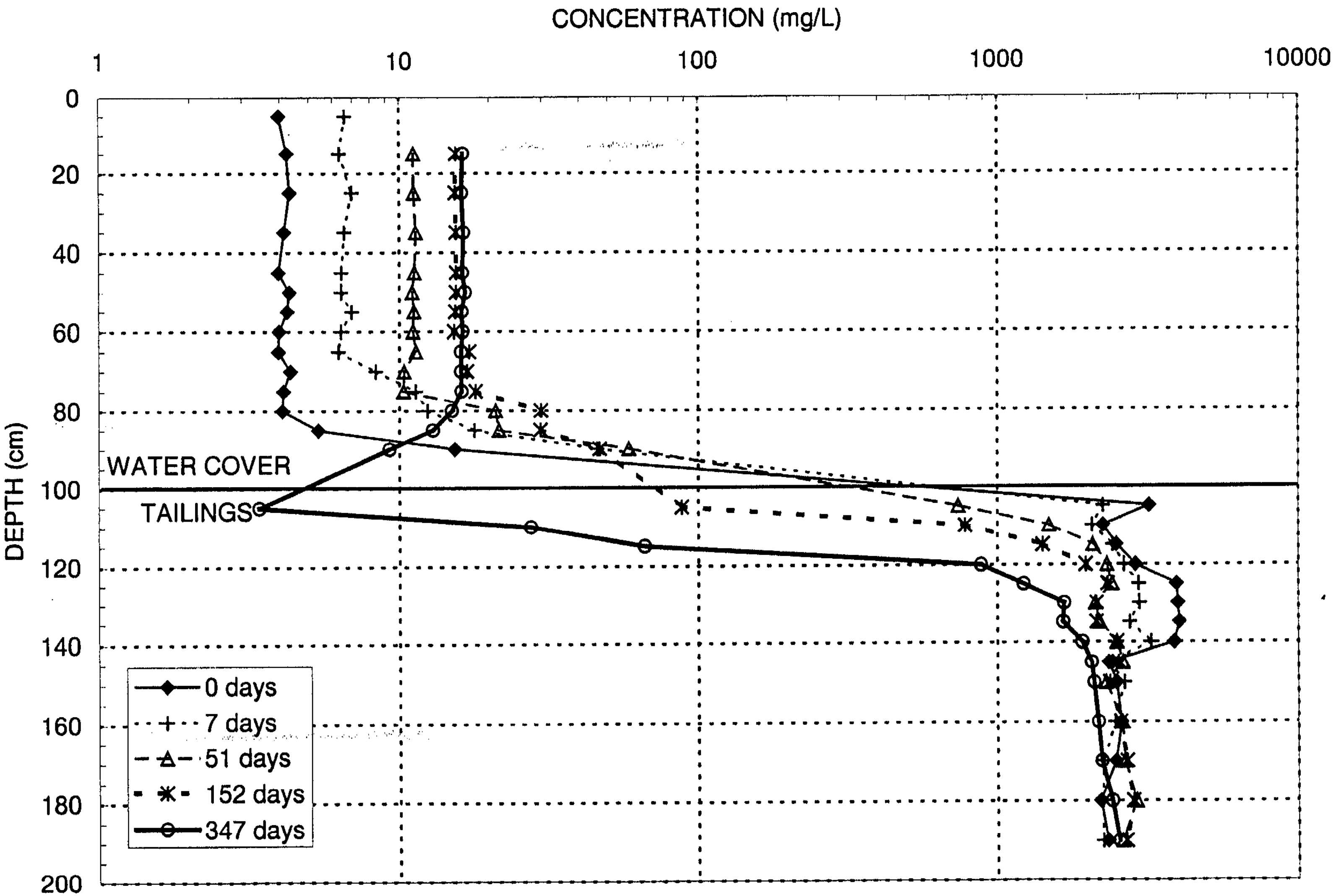

Figure II-2d: Dissolved zinc concentration profiles for MTWC-2, static period

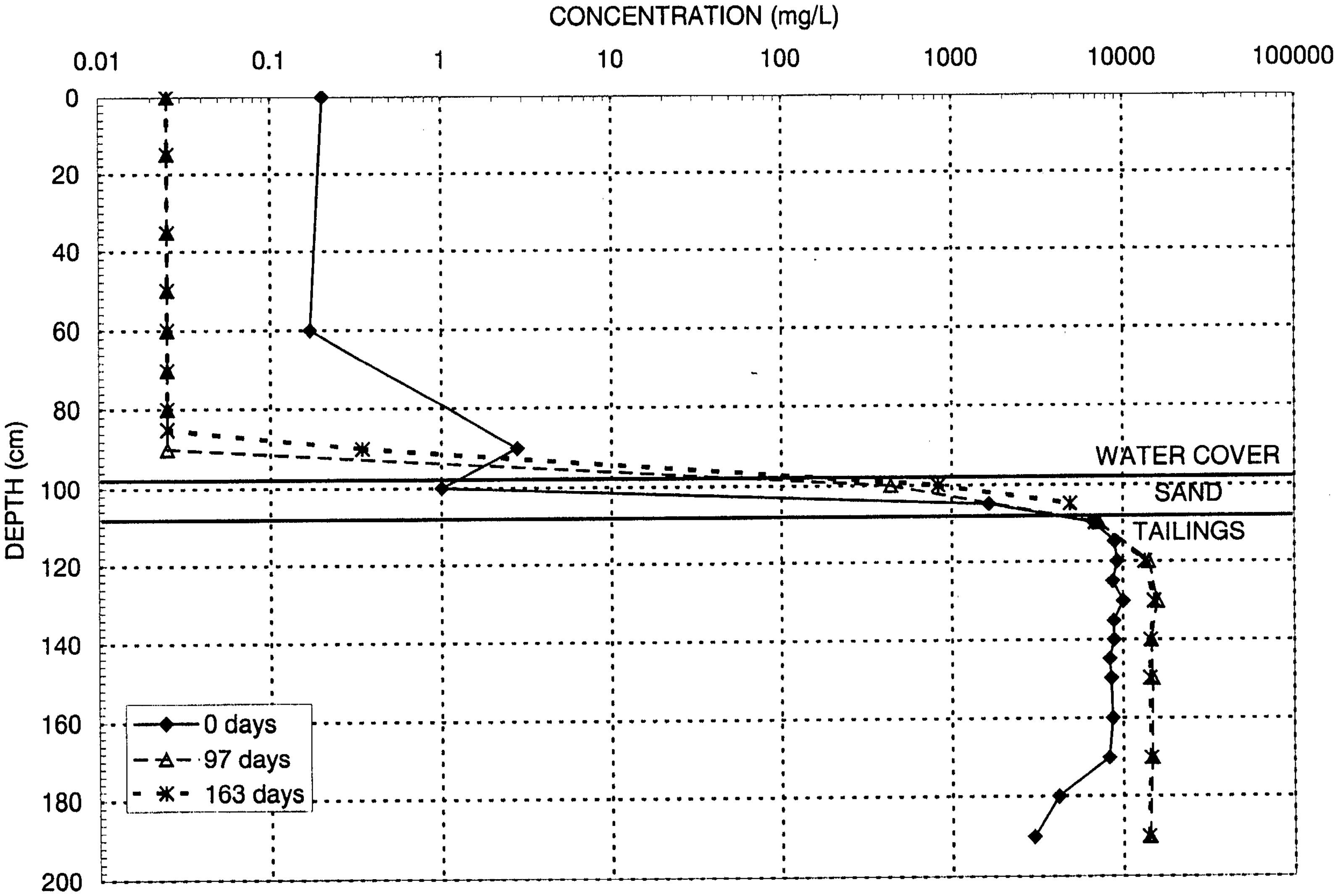

Figure II-3a: Dissolved total iron concentration profiles for MTWC-3, static period

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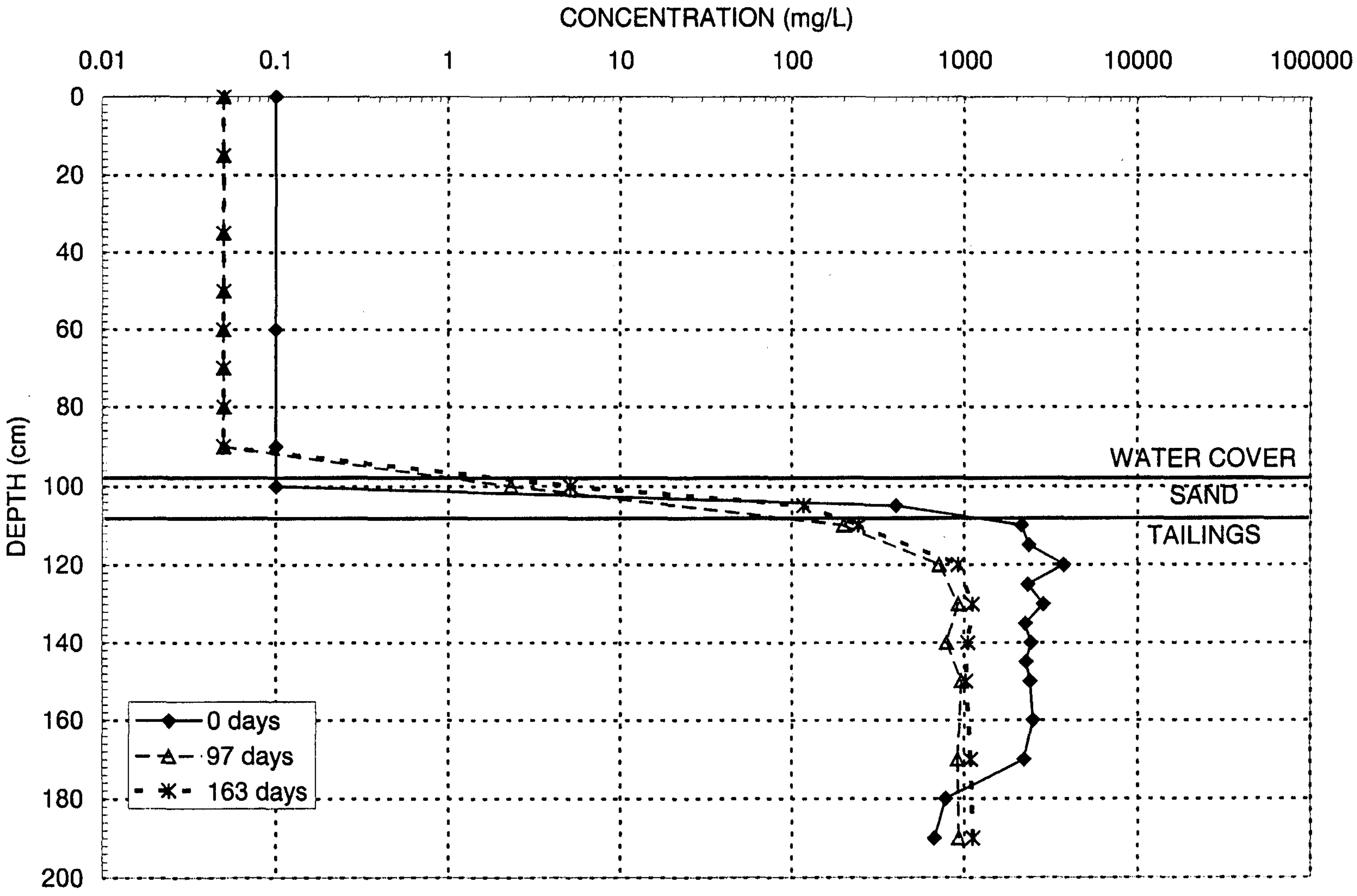

Figure II-3b: Ferric iron concentration profiles for MTWC-3, static period

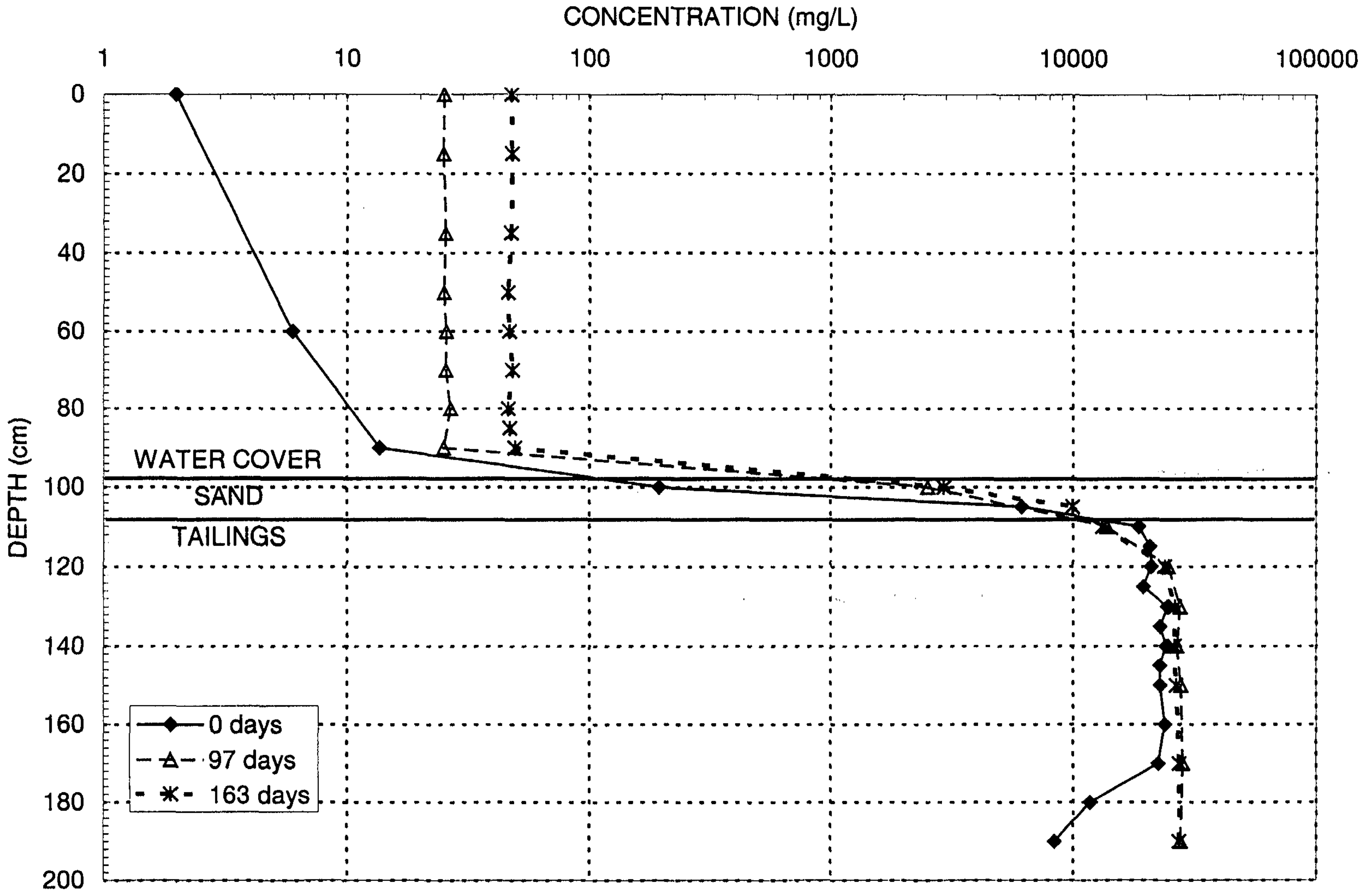

Figure II-3c: Dissolved sulphate concentration profiles for MTWC-3, static period

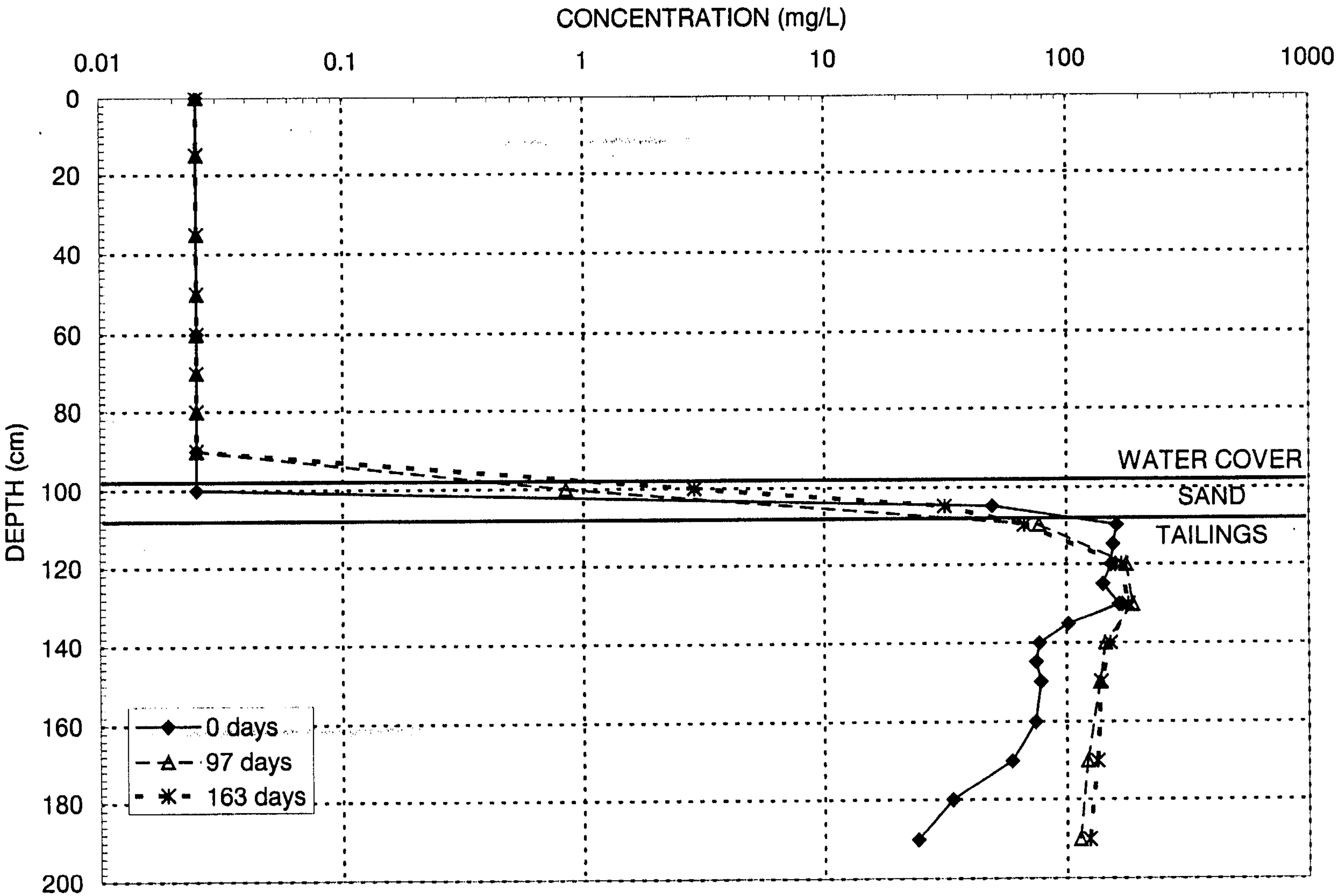

Figure II-3d: Dissolved zinc concentration profiles for MTWC-3, static period

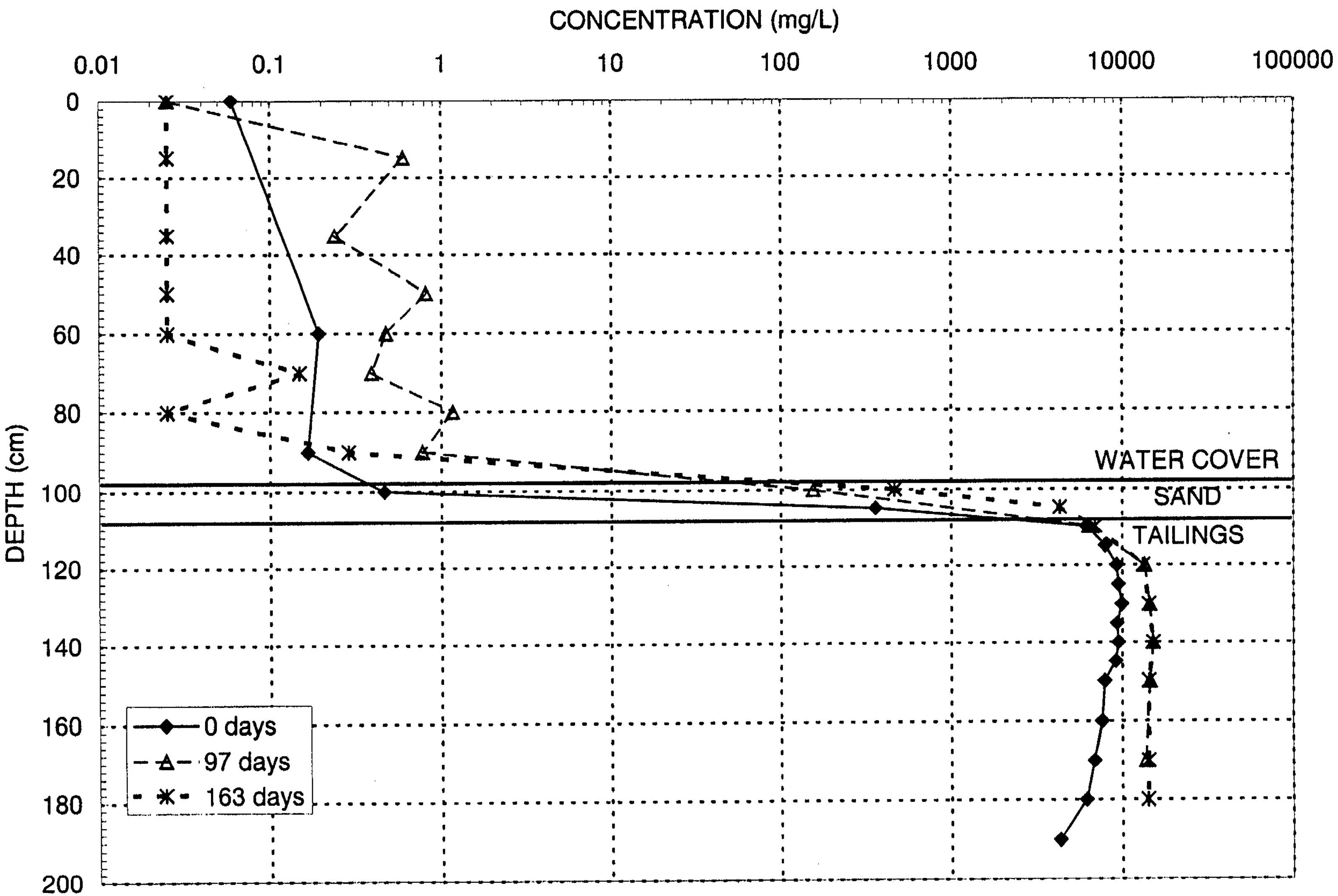

Figure II-4a: Dissolved total iron concentration profiles for MTWC-4, static period

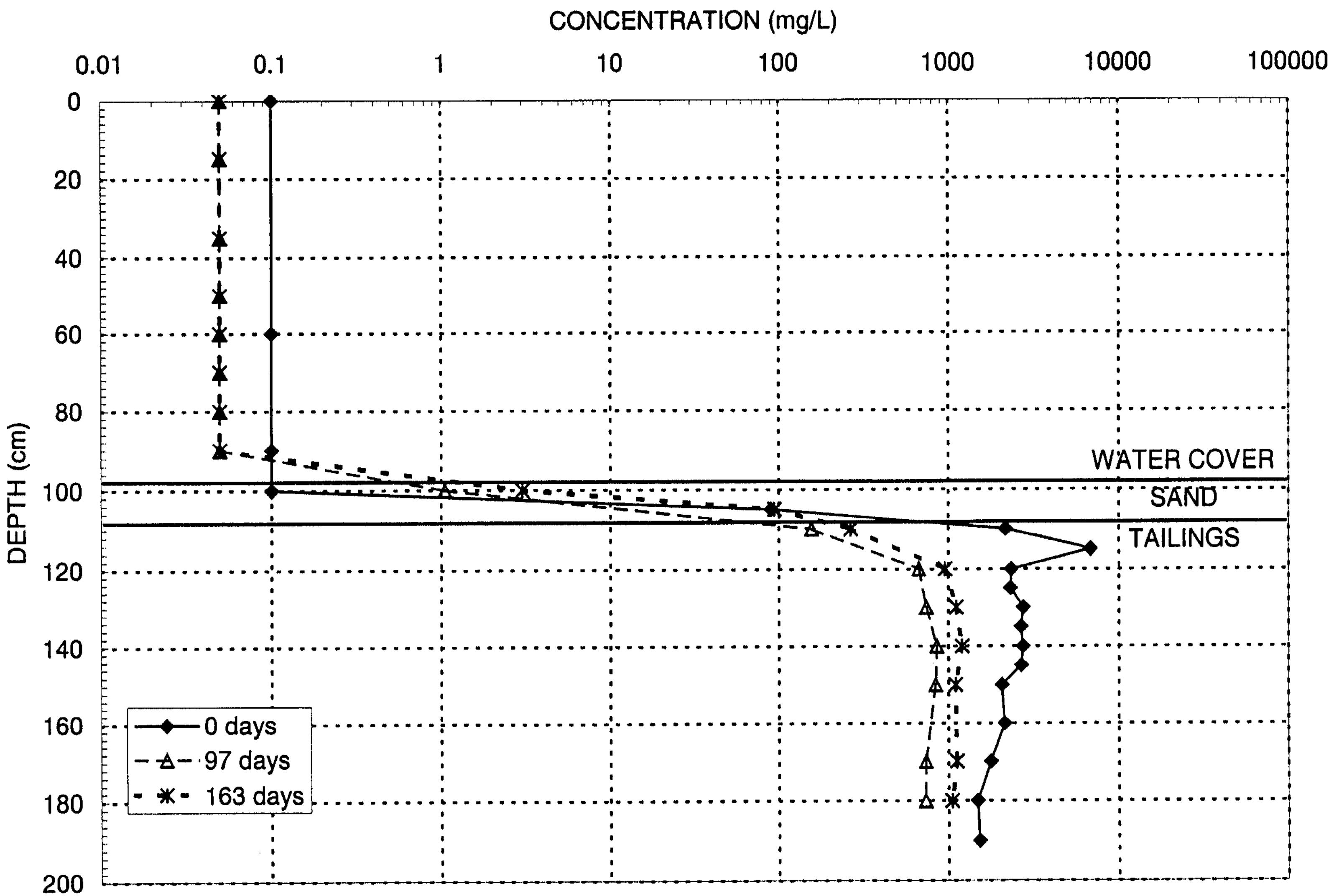

Figure II-4b: Ferric iron concentration profiles for MTWC-4, static period

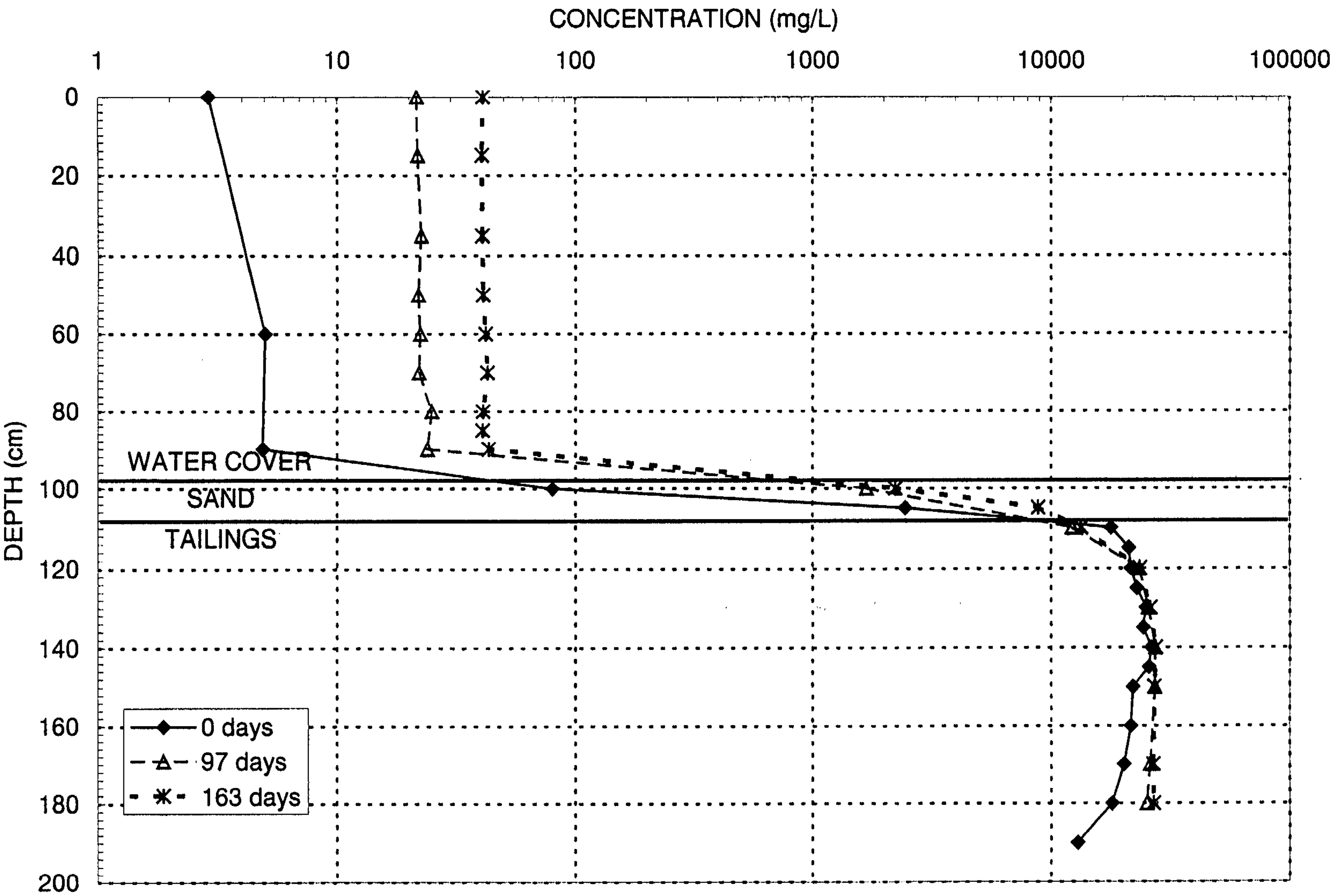

Figure II-4c: Dissolved sulphate concentration profiles for MTWC-4, static period

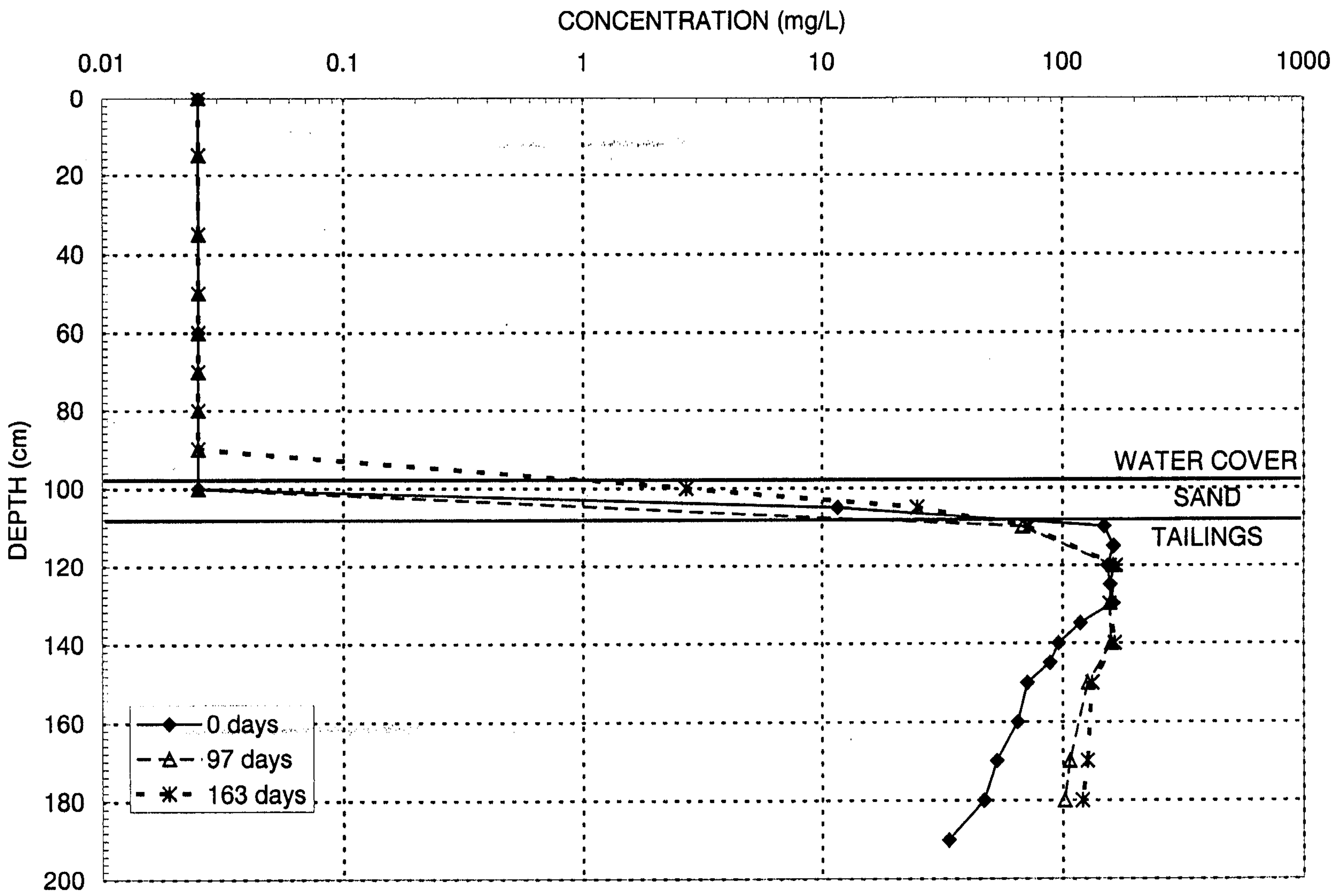

Figure II-4d: Dissolved zinc concentration profiles for MTWC-4, static period

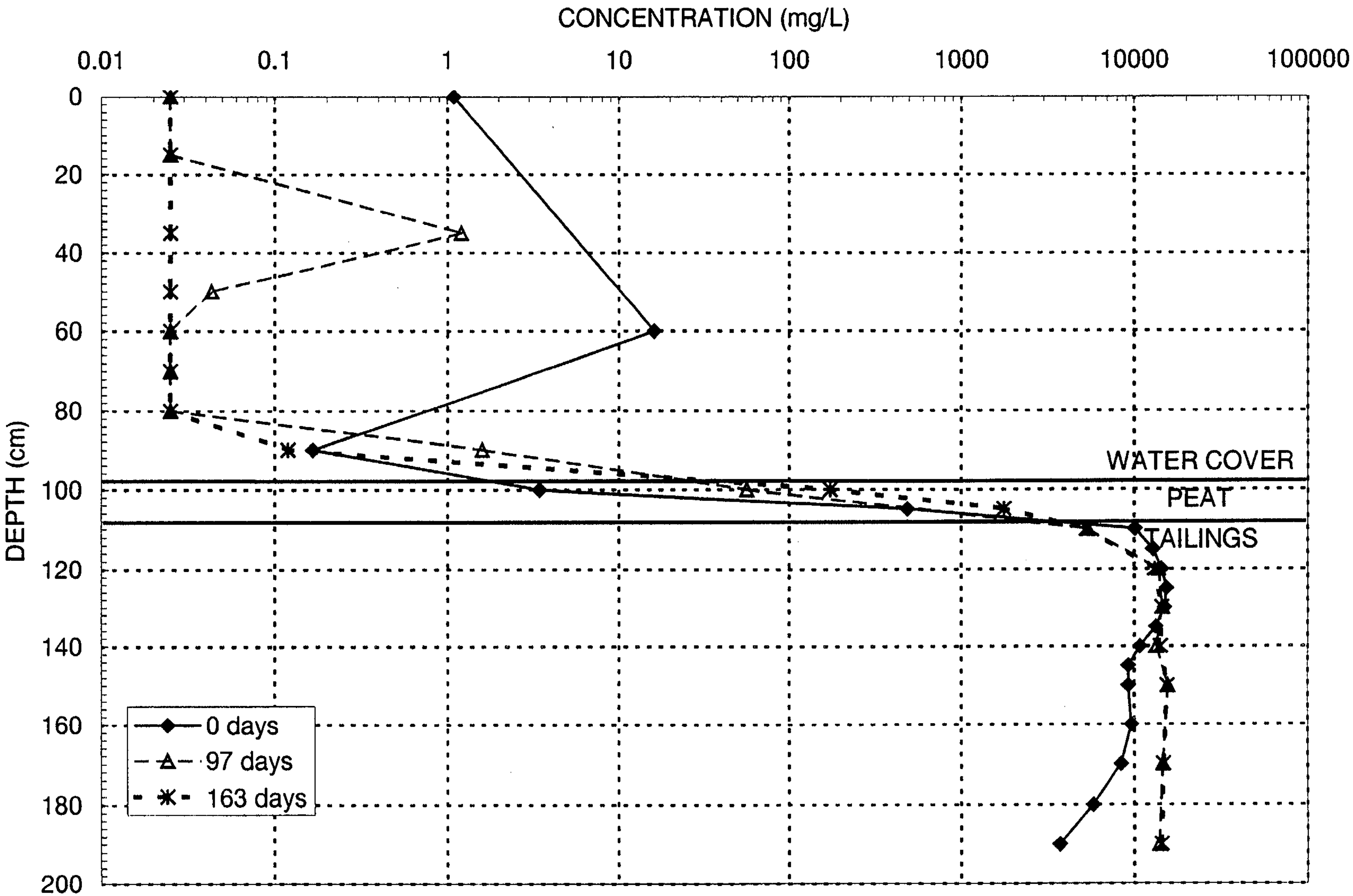

Figure II-5a: Dissolved total iron concentration profiles for MTWC-5, static period

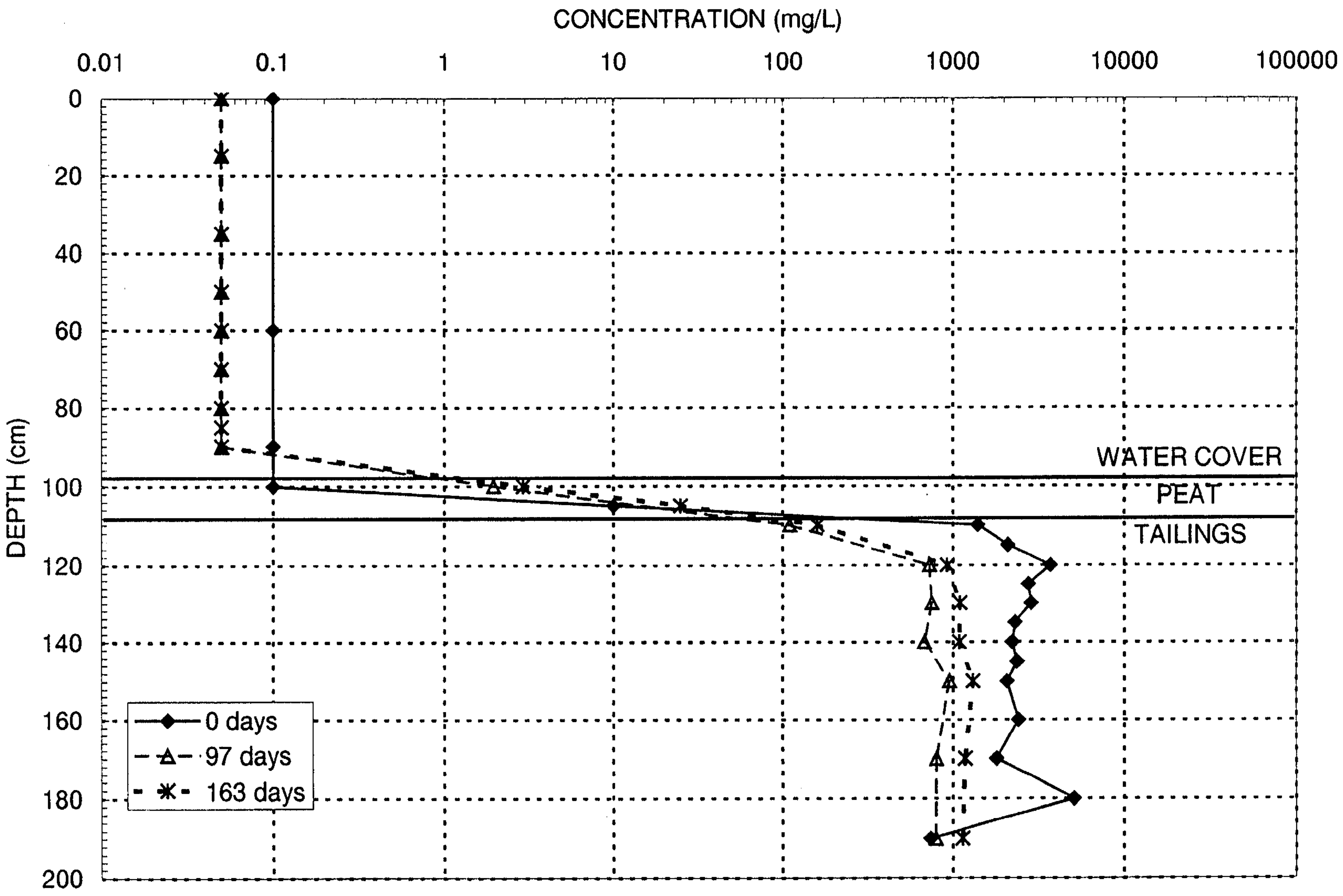

Figure II5b: Ferric iron concentration profiles for MTWC-5, static period

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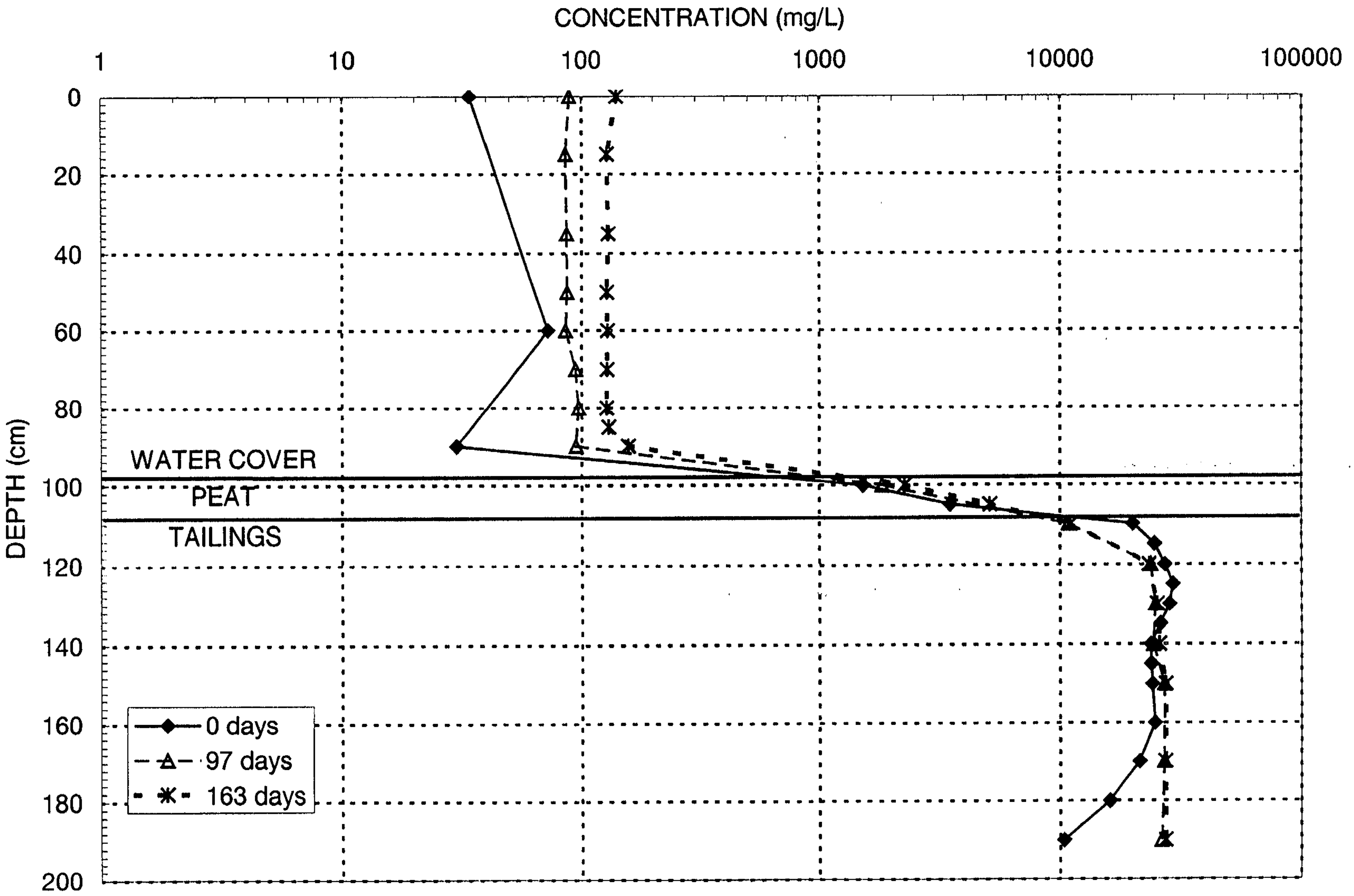

Figure II-5c: Dissolved sulphate concentration profiles for MTWC-5, static period

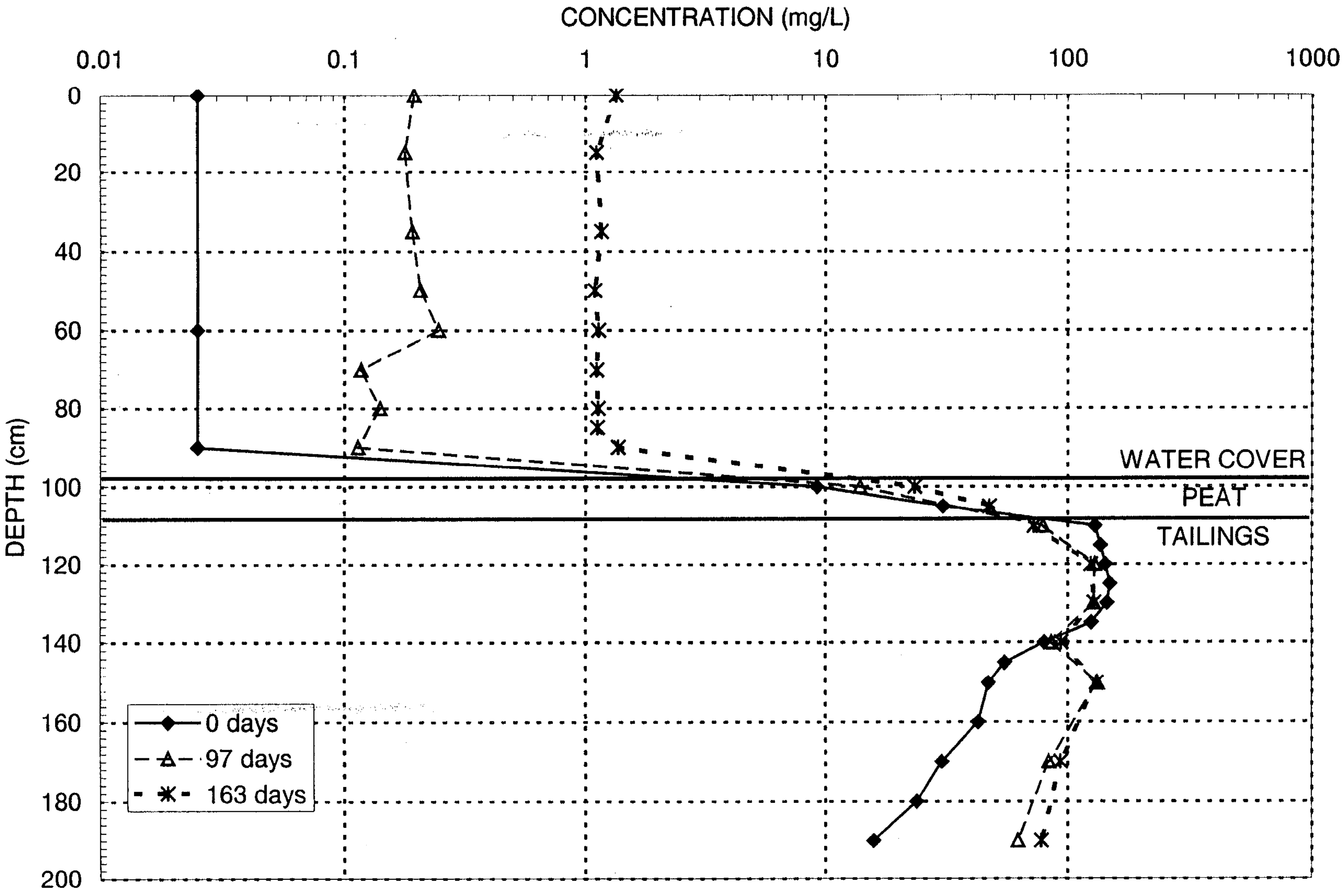

Figure II-5d: Dissolved zinc concentration profiles for MTWC-5, static period

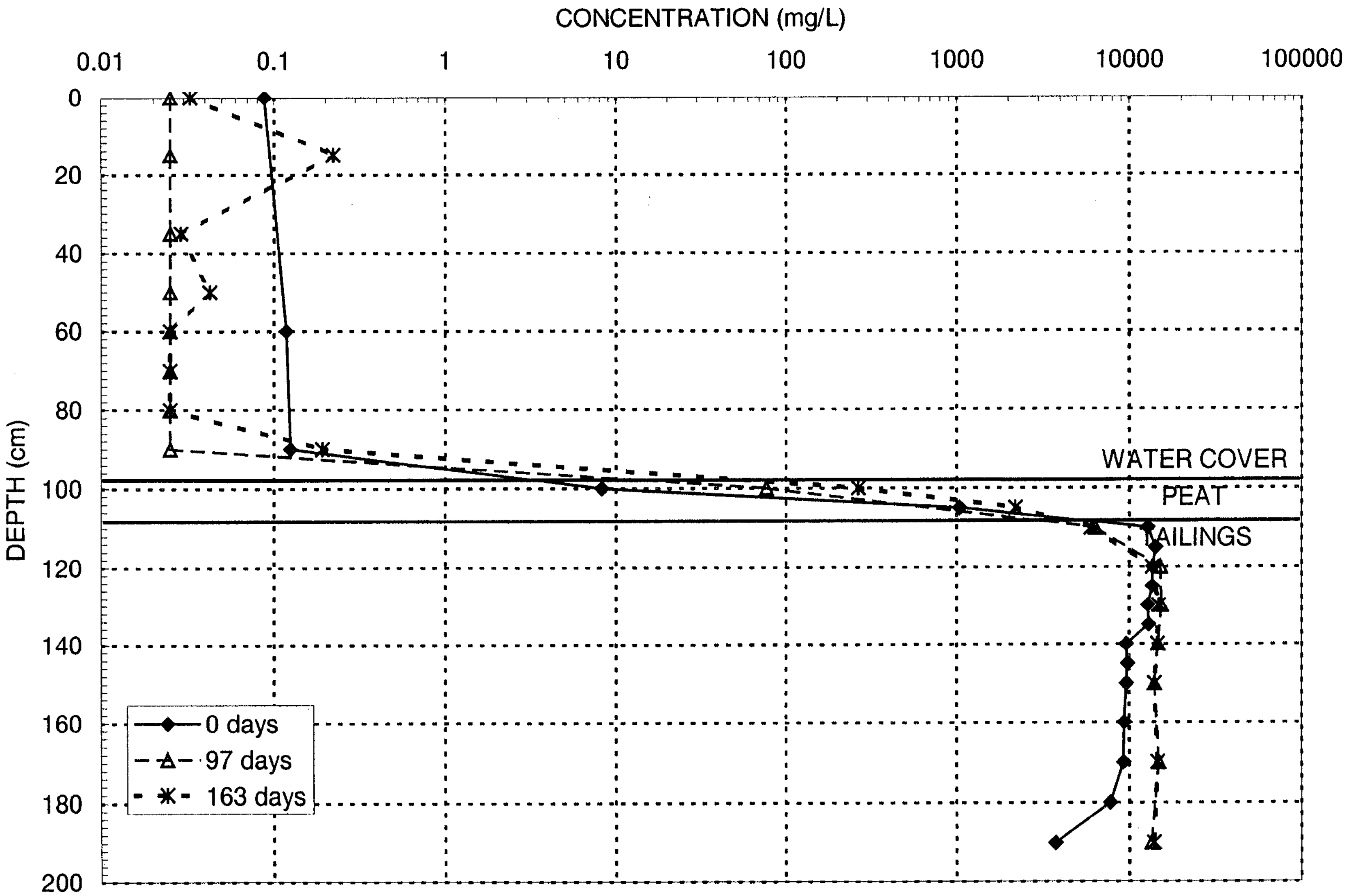

Figure II-6a: Dissolved total iron concentration profiles for MTWC-6, static period

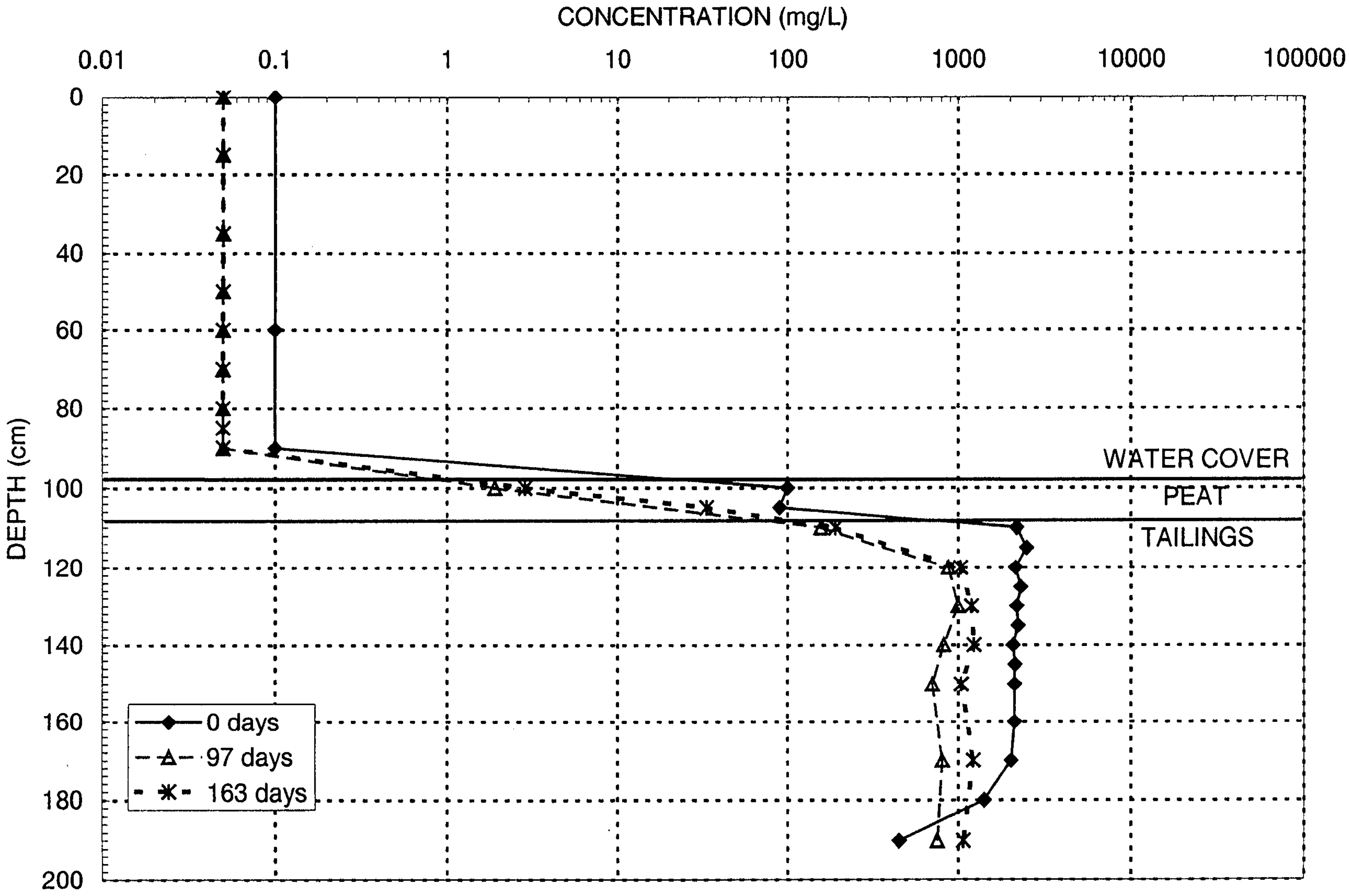

Figure II-6b: Ferric iron concentration profiles for MTWC-6, static period

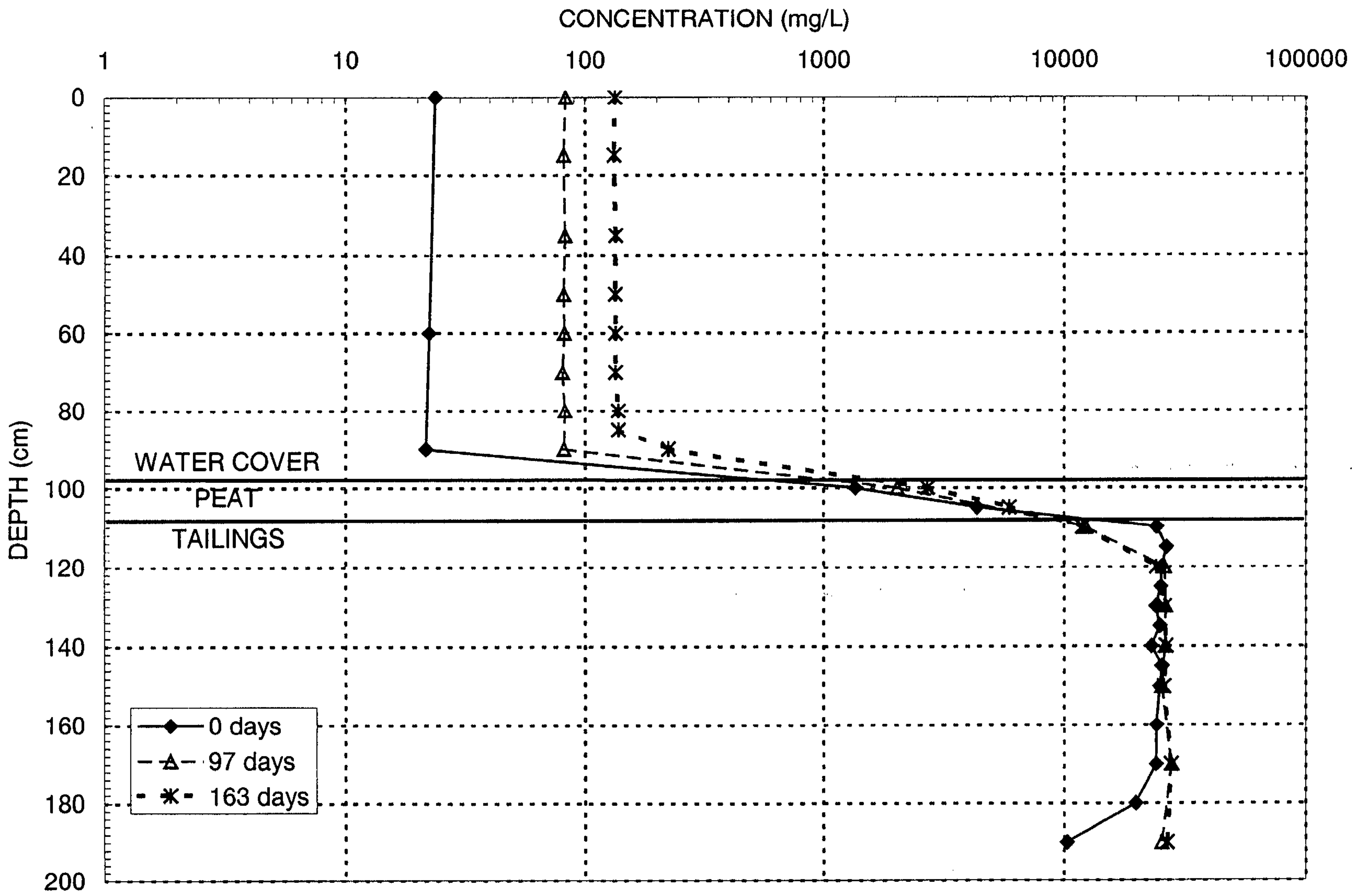

Figure II-6c: Dissolved sulphate concentration profiles for MTWC-6, static period

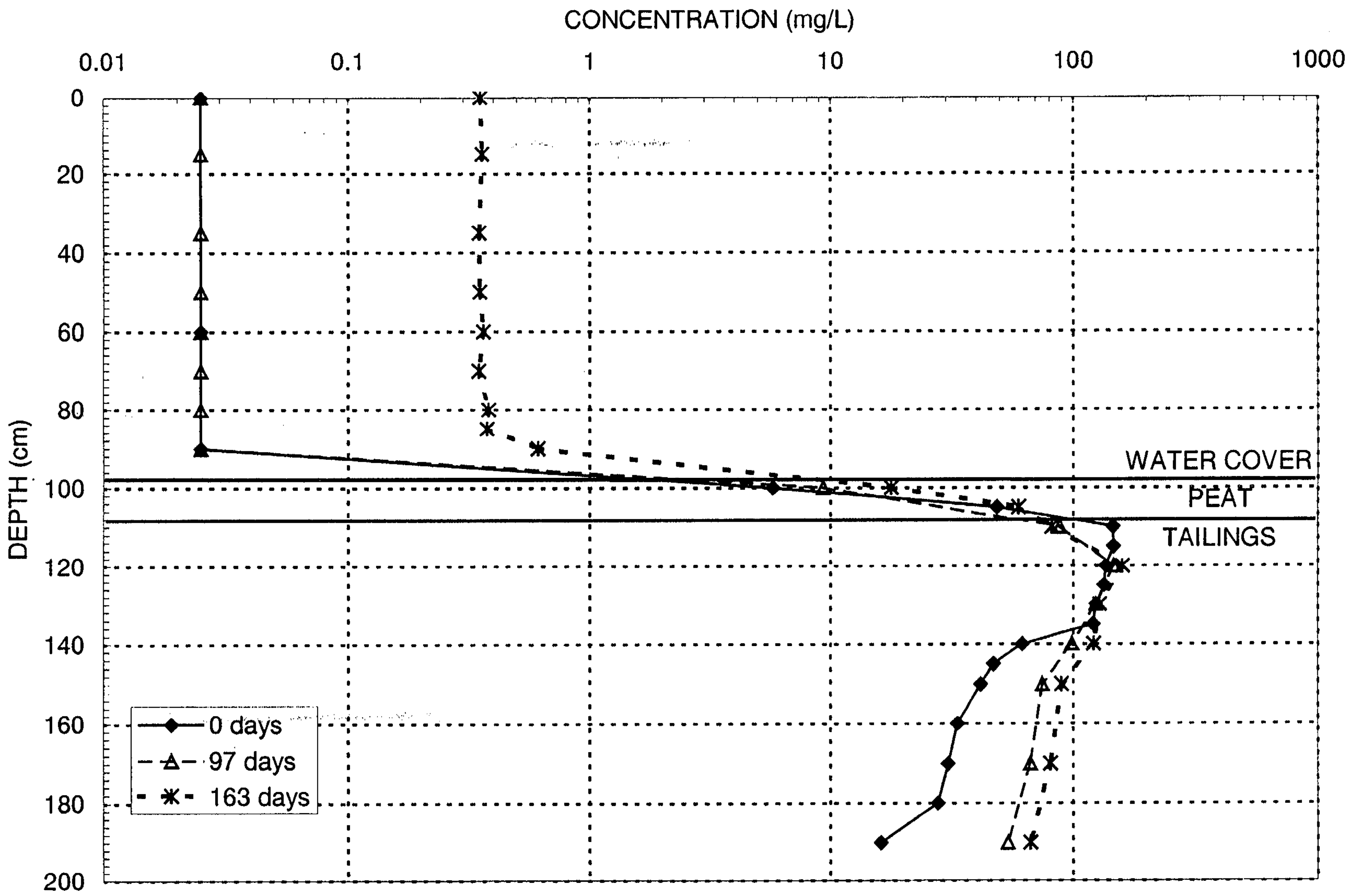

Figure II-6d: Dissolved zinc concentration profiles for MTWC-6, static period

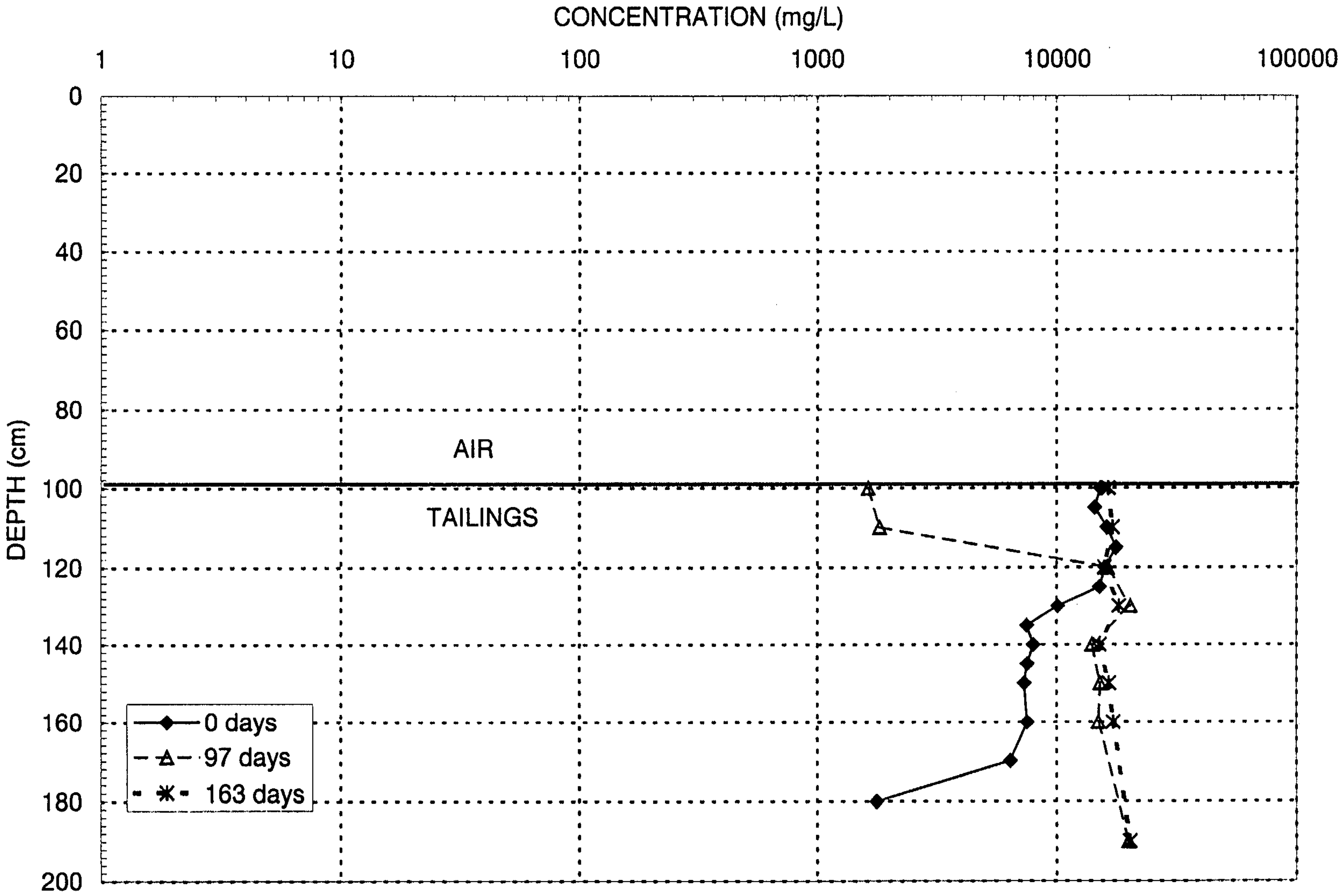

Figure II-7a: Dissolved total iron concentration profiles for MTWC-7, static period

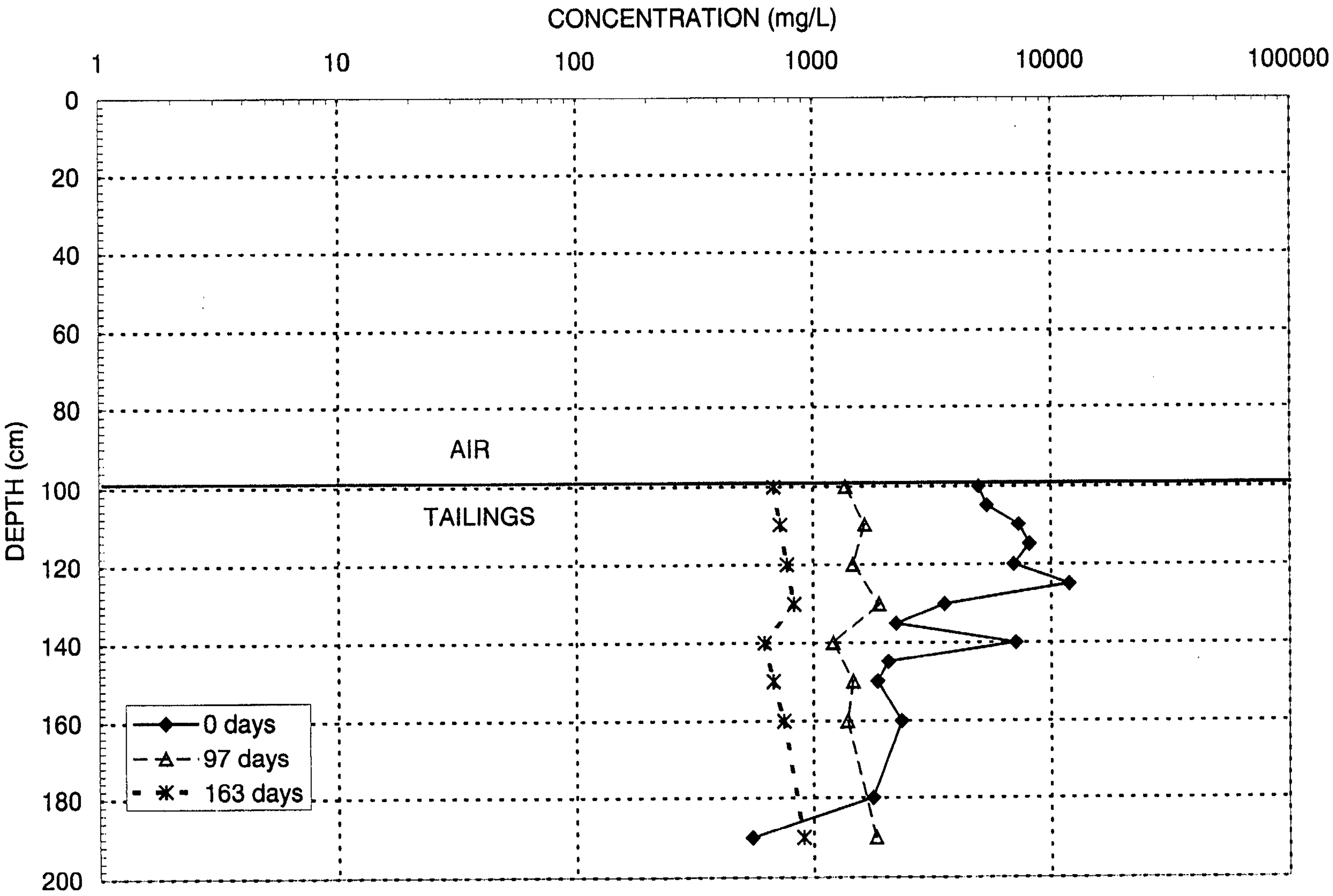

Figure II-7b: Ferric iron concentration profiles for MTWC-7, static period

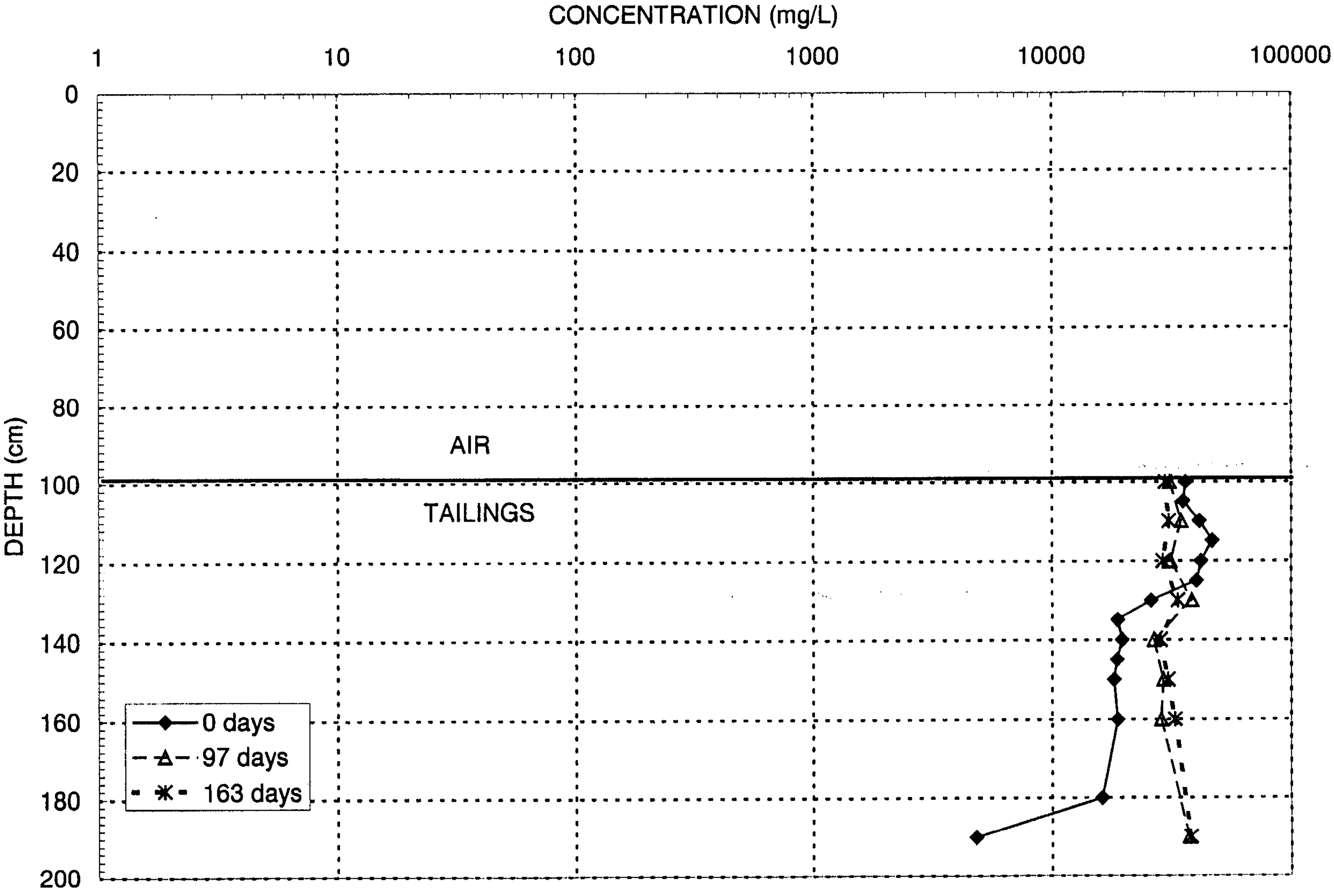

Figure II-7c: Dissolved sulphate concentration profiles for MTWC-7, static period

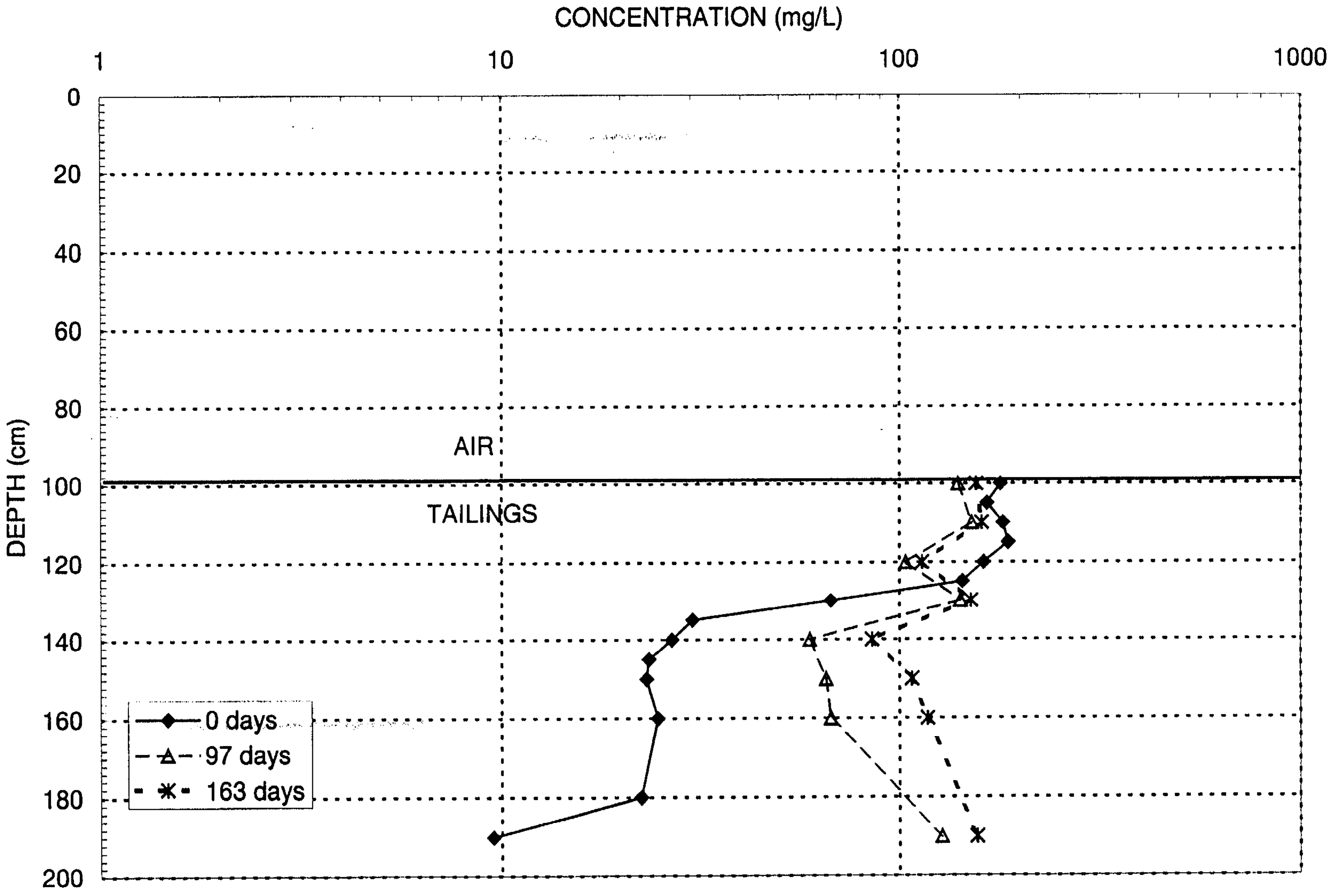

Figure II-7d: Dissolved zinc concentration profiles for MTWC-7, static period

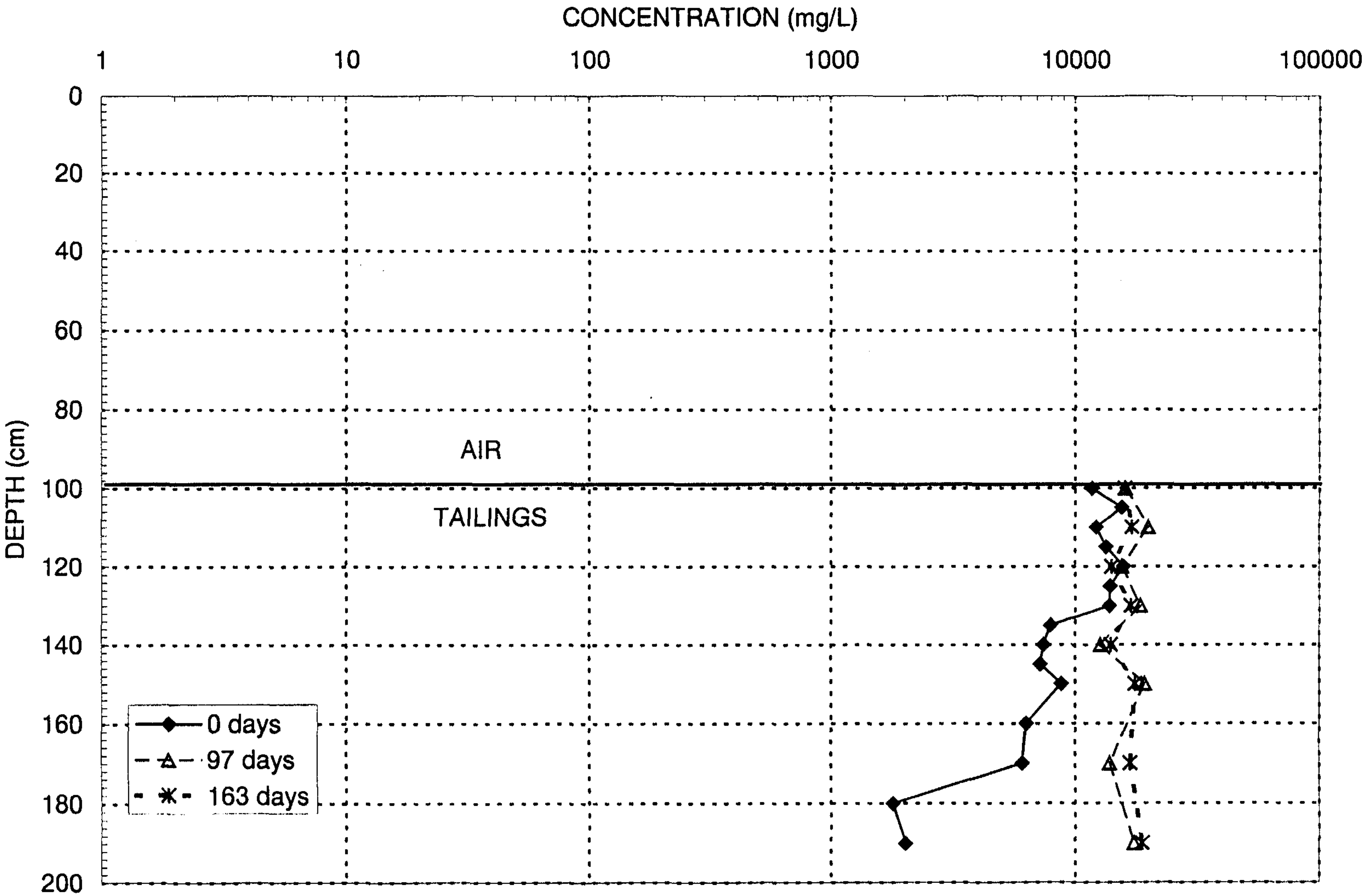

Figure II-8a: Dissolved total iron concentration profiles for MTWC-8, static period

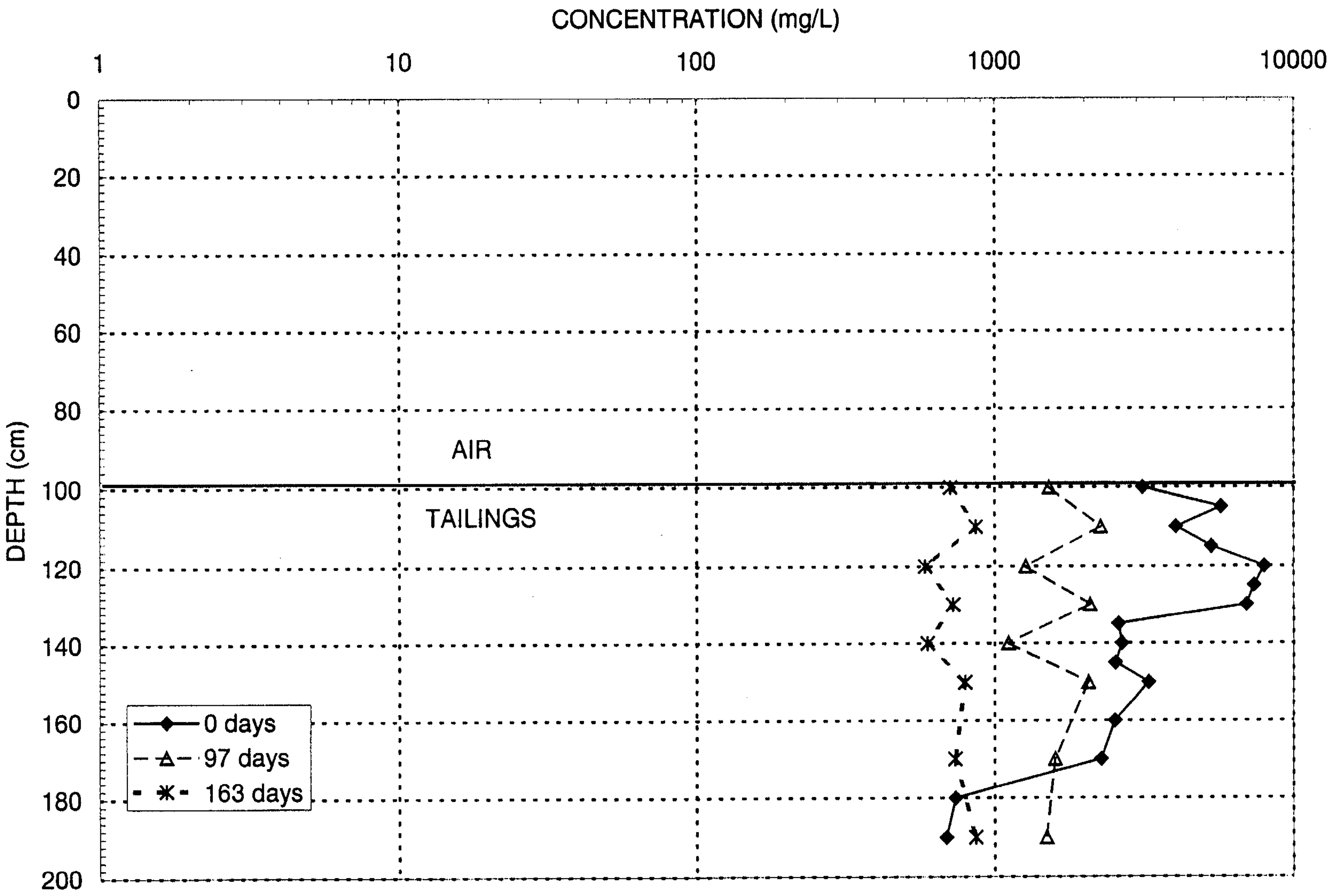

Figure II-8b: Ferric iron concentration profiles for MTWC-8, static period

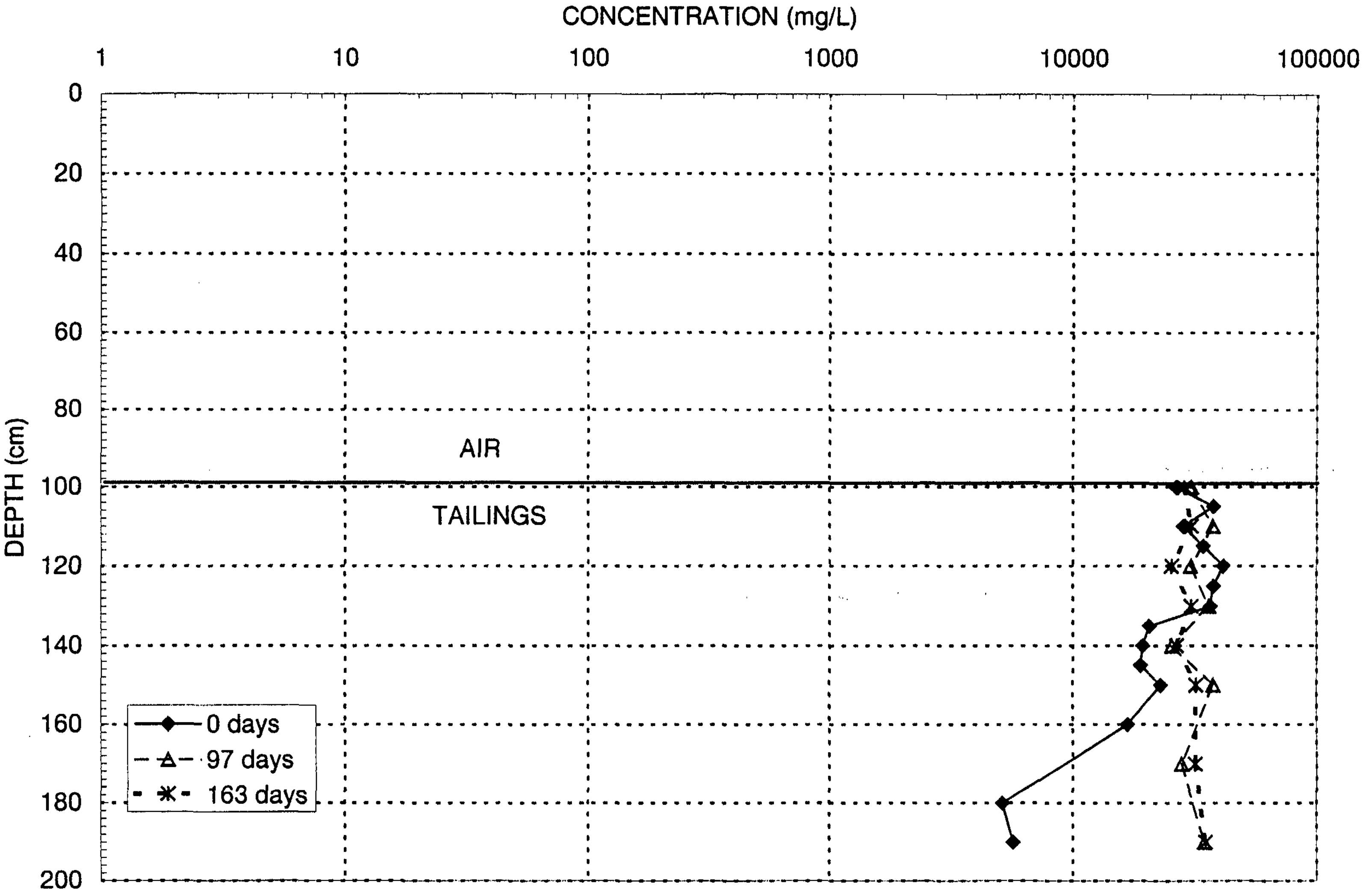

Figure II-8c: Dissolved sulphate concentration profiles for MTWC-8, static period

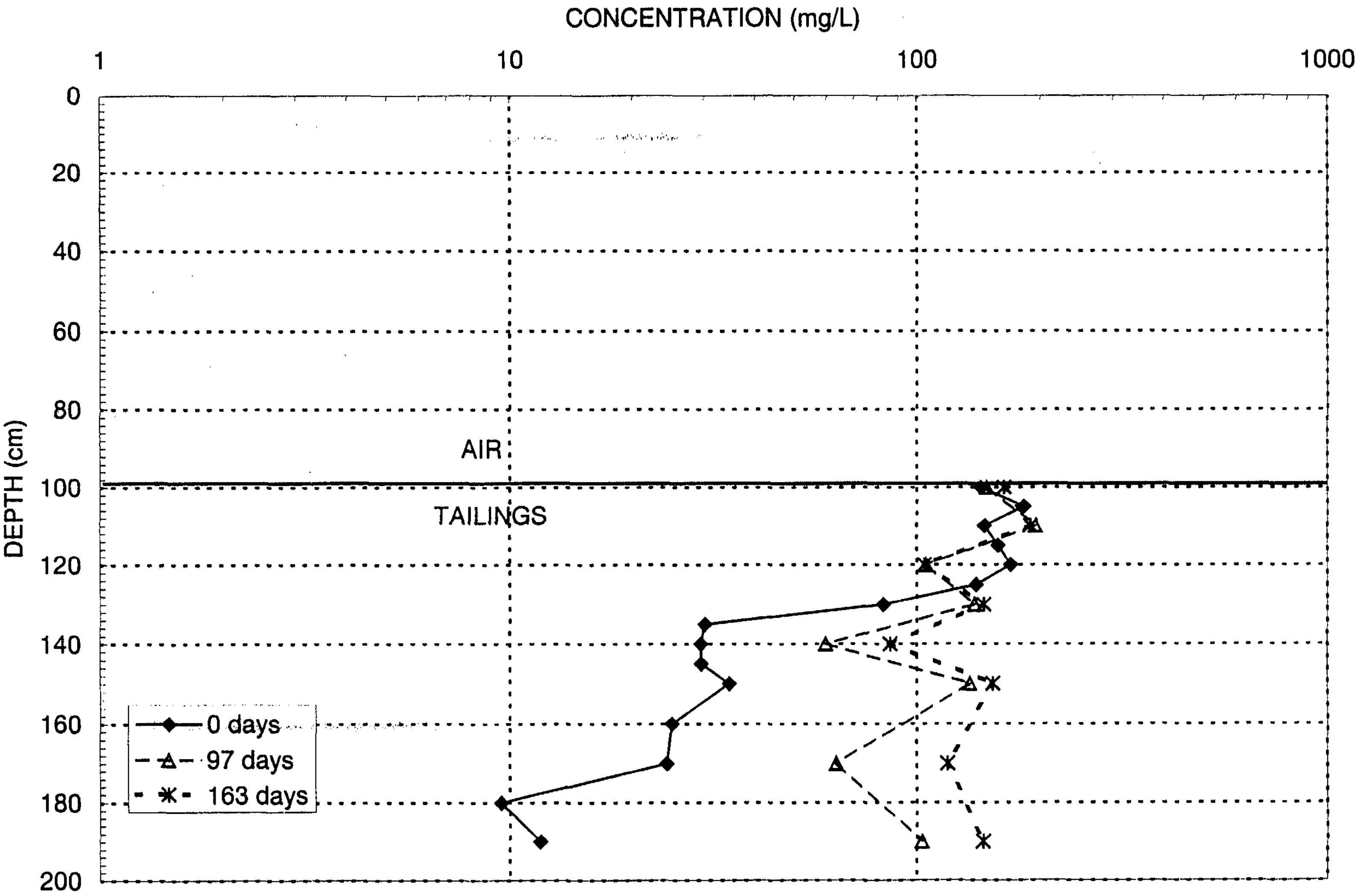

Figure II-8d: Dissolved zinc concentration profiles for MTWC-8, static period

APPENDIX III

SOLUTE CONCENTRATION PROFILES FOR COLUMNS – DYNAMIC PERIOD

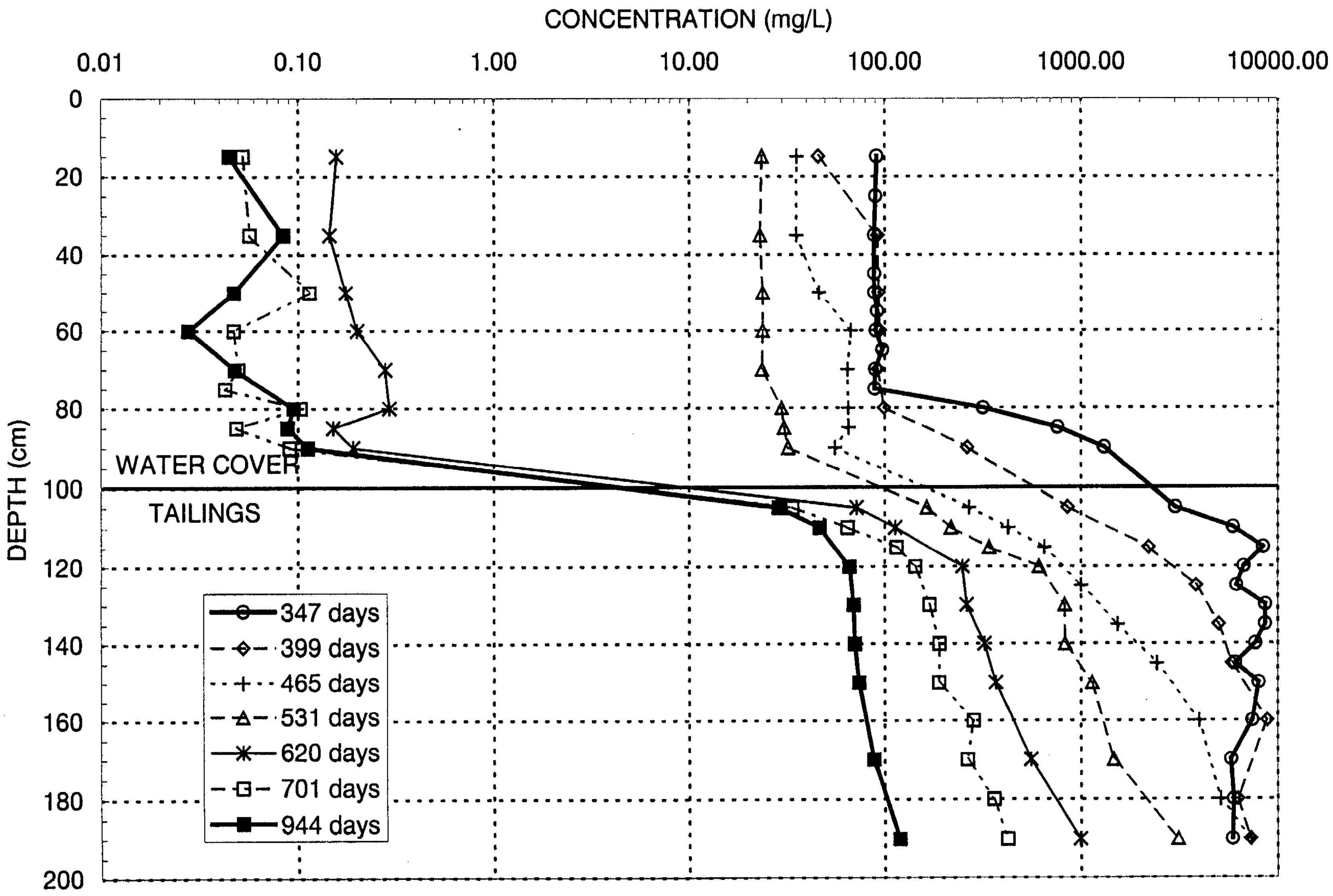

Figure III-1a: Dissolved total iron concentration profiles for MTWC-1, dynamic period

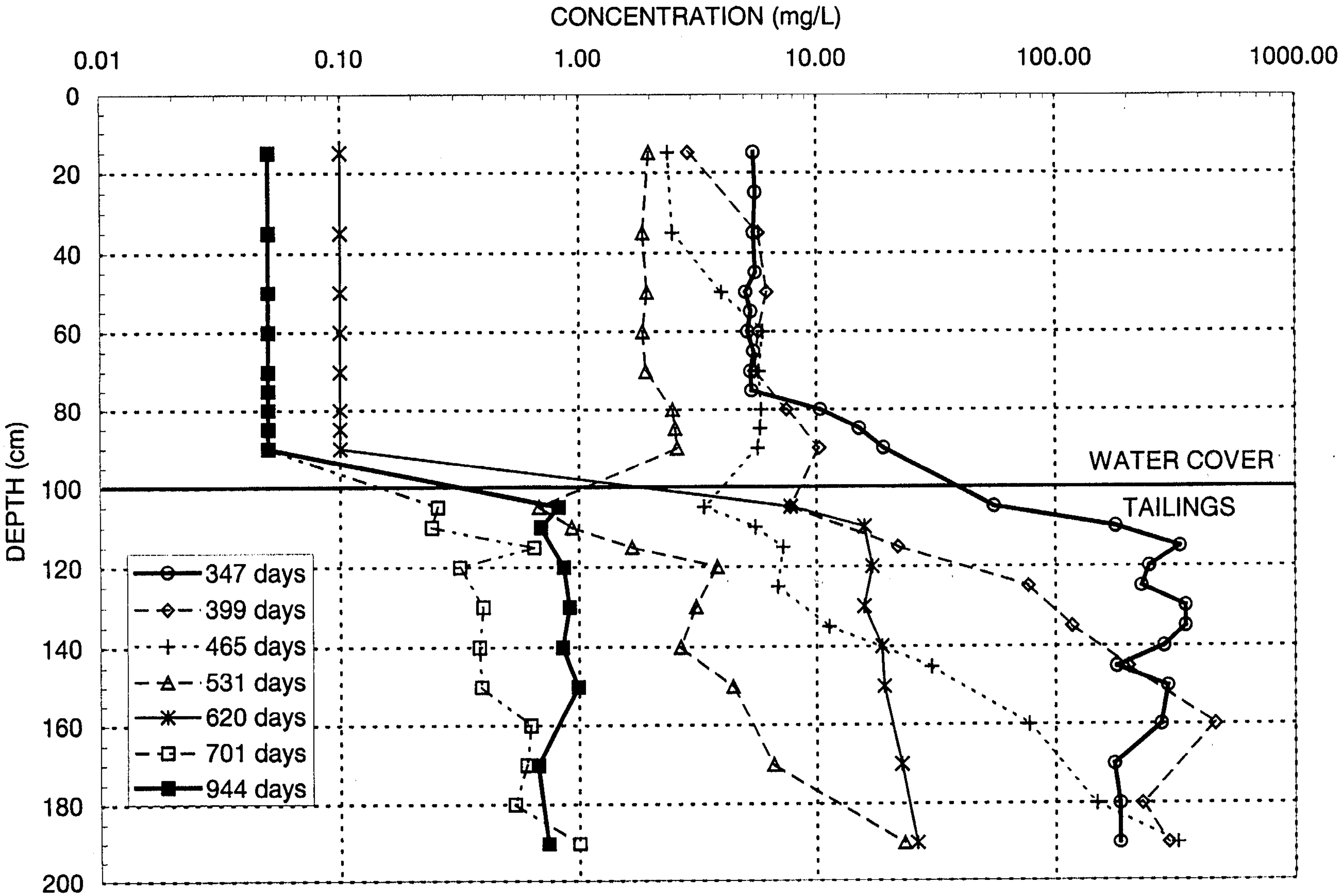

Figure III-1b: Ferric iron concentration profiles for MTWC-1, dynamic period

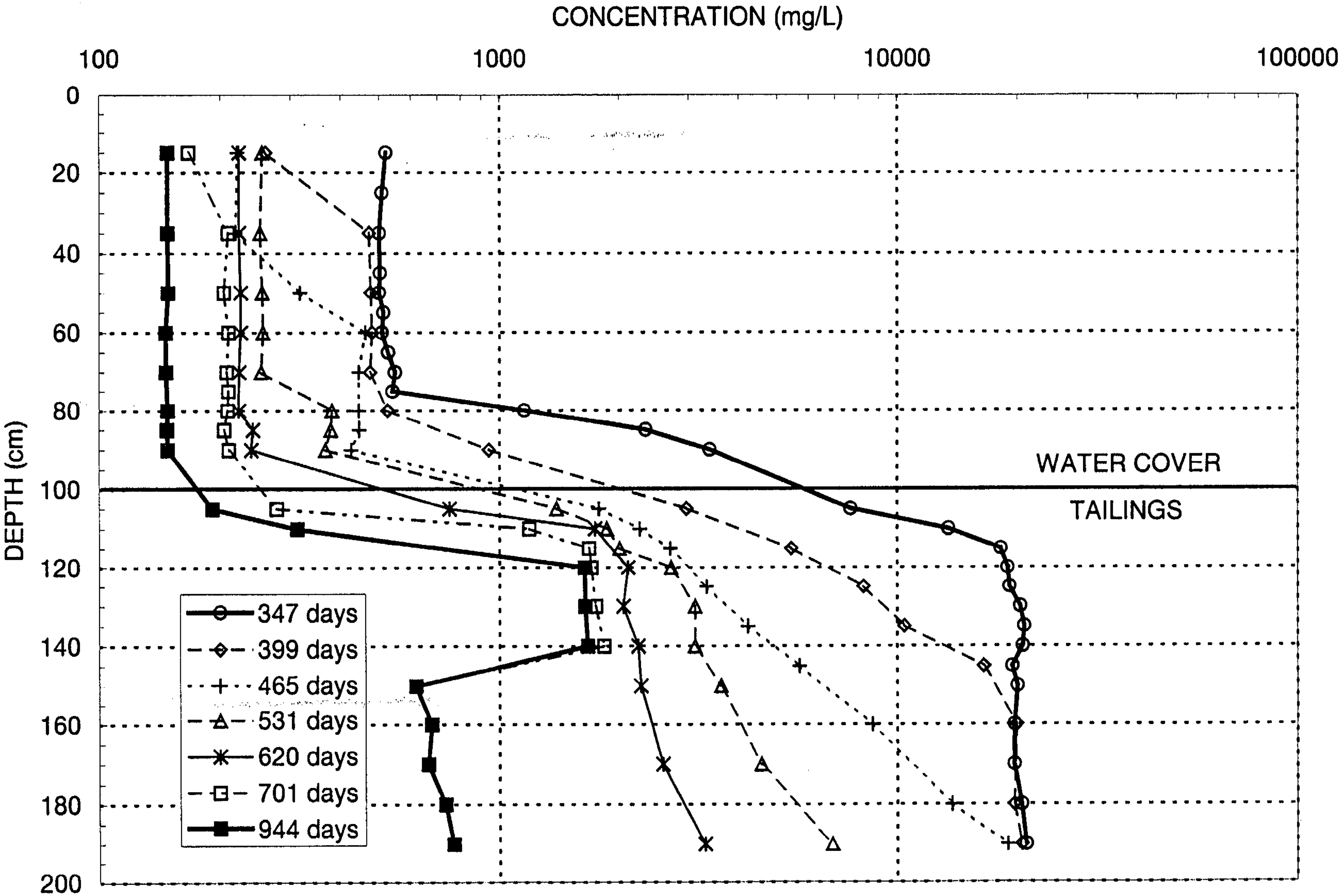

Figure III-1c: Dissolved sulphate concentration profiles for MTWC-1, dynamic period

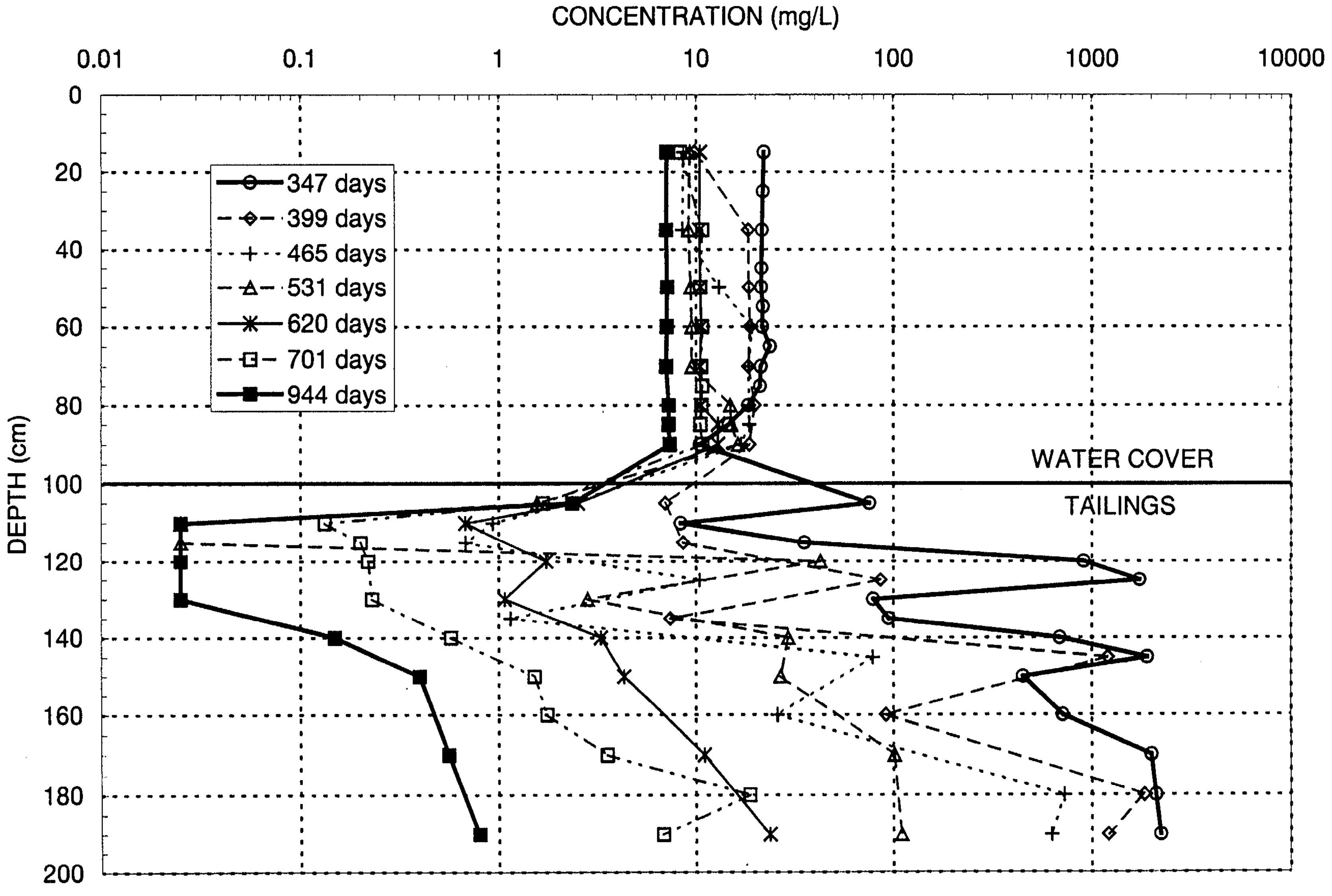

Figure III-1d: Dissolved zinc concentration profiles for MTWC-1, dynamic period

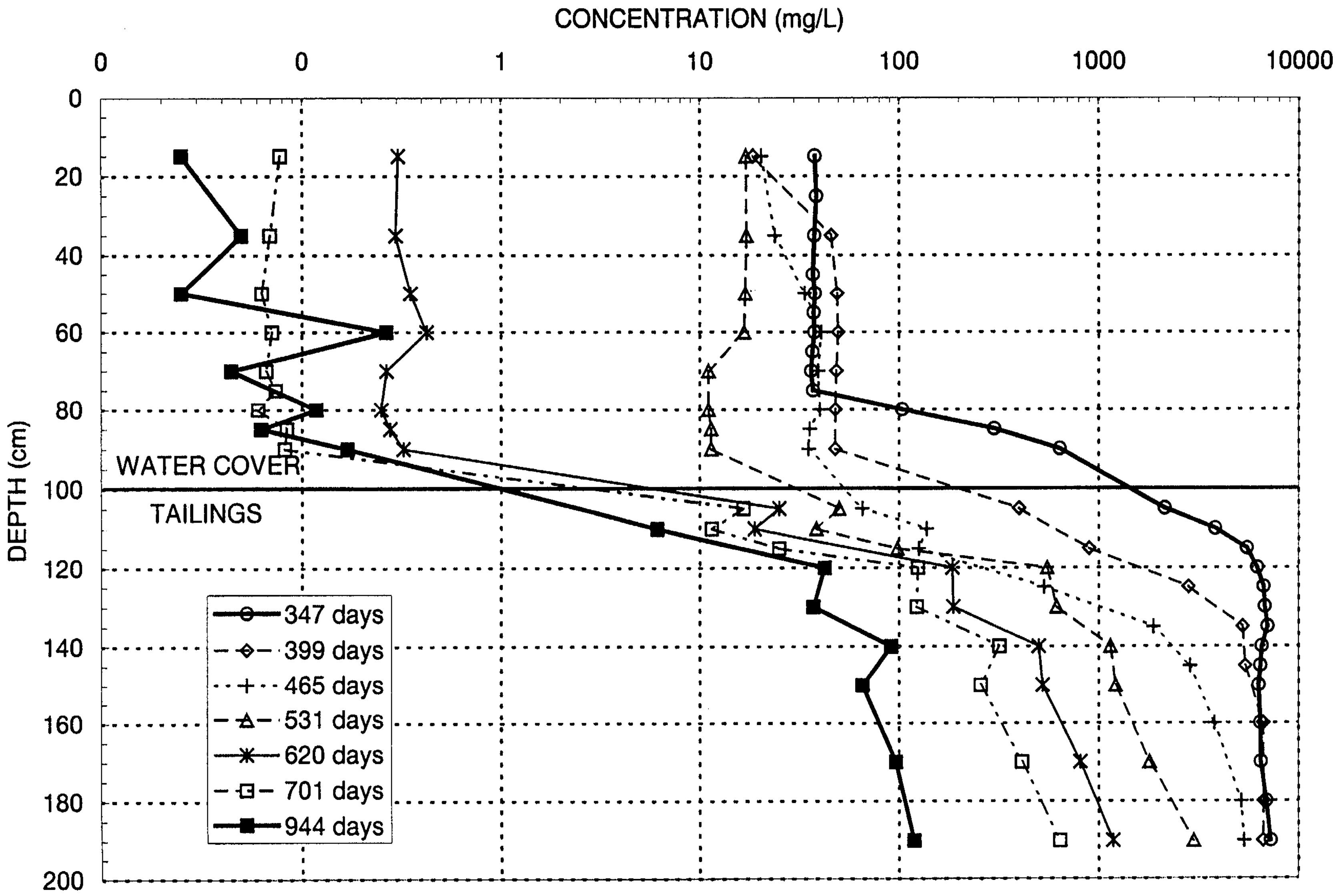

Figure III-2a: Dissolved total iron concentration profiles for MTWC-2, dynamic period

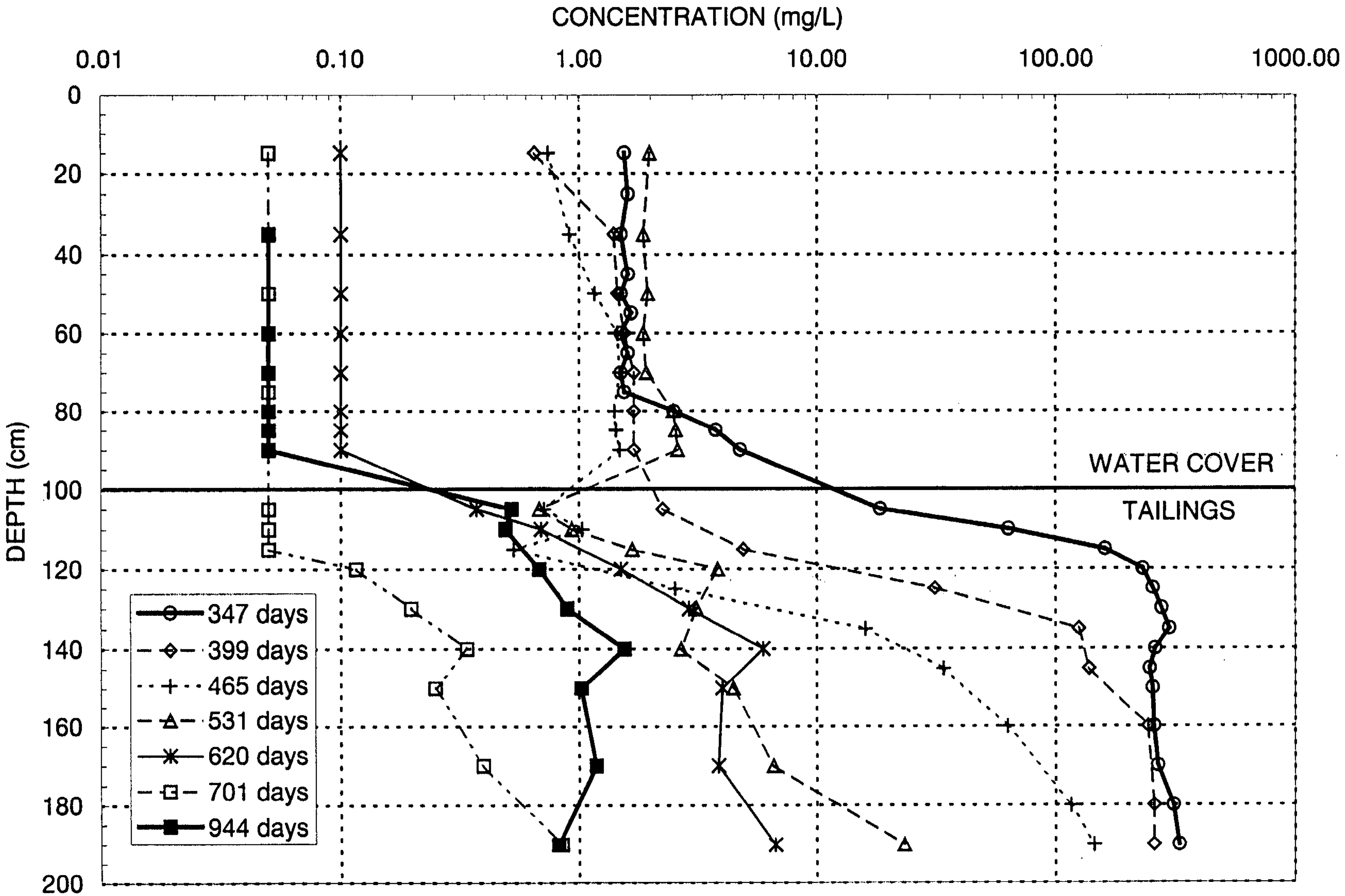

Figure III-2b: Ferric iron concentration profiles for MTWC-2, dynamic period

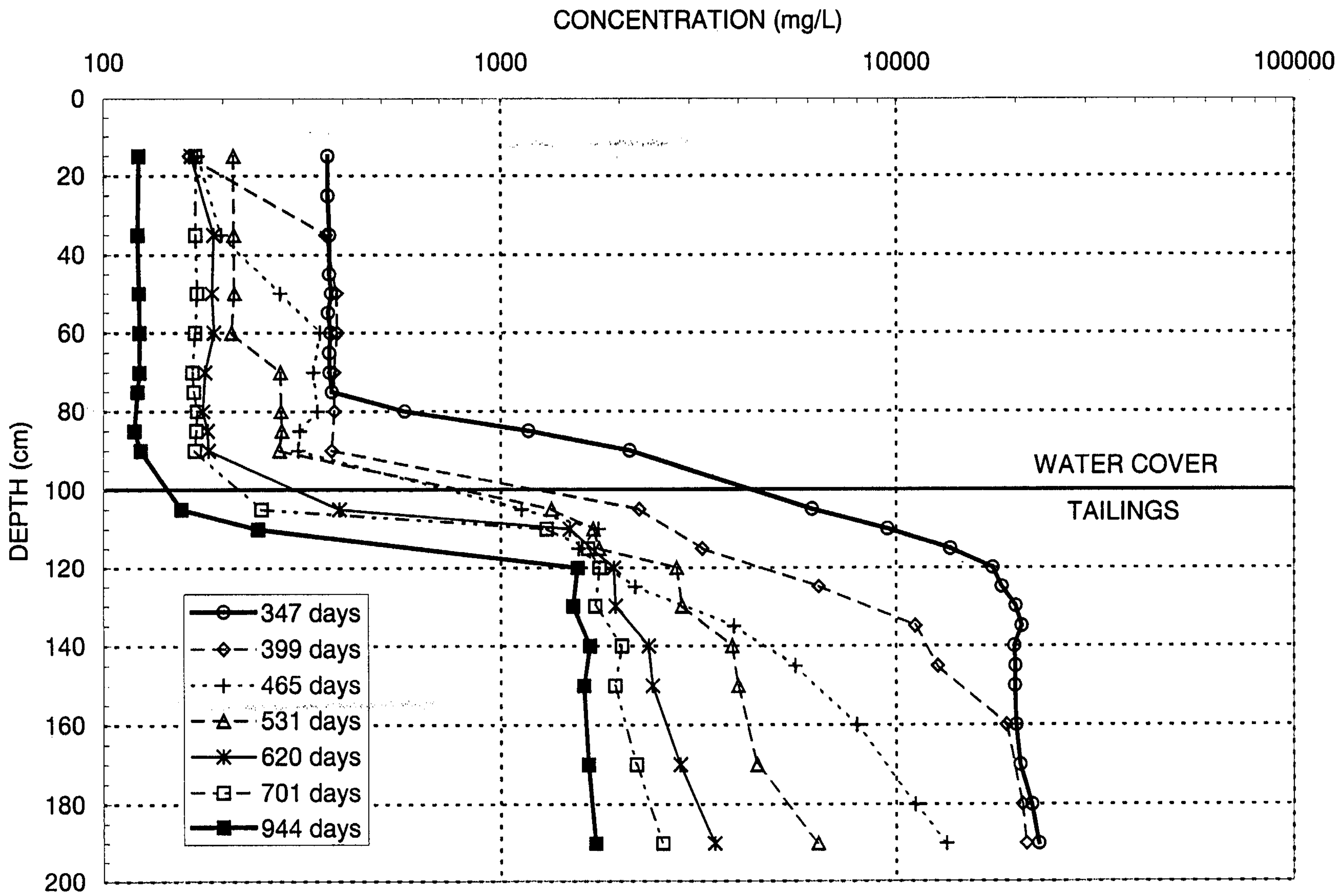

Figure III-2c: Dissolved sulphate concentration profiles for MTWC-2, dynamic period

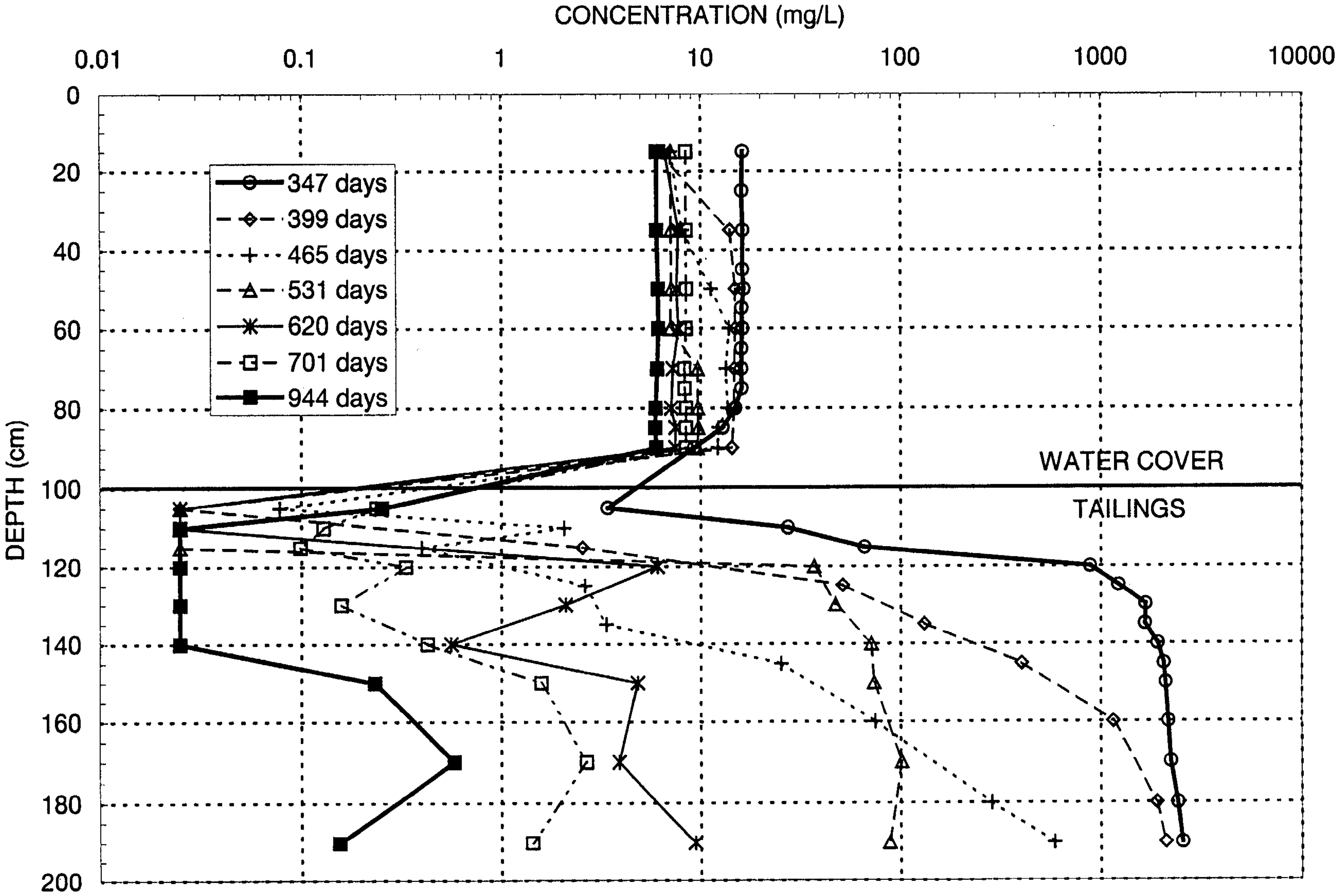

Figure III-2d: Dissolved zinc concentration profiles for MTWC-2, dynamic period

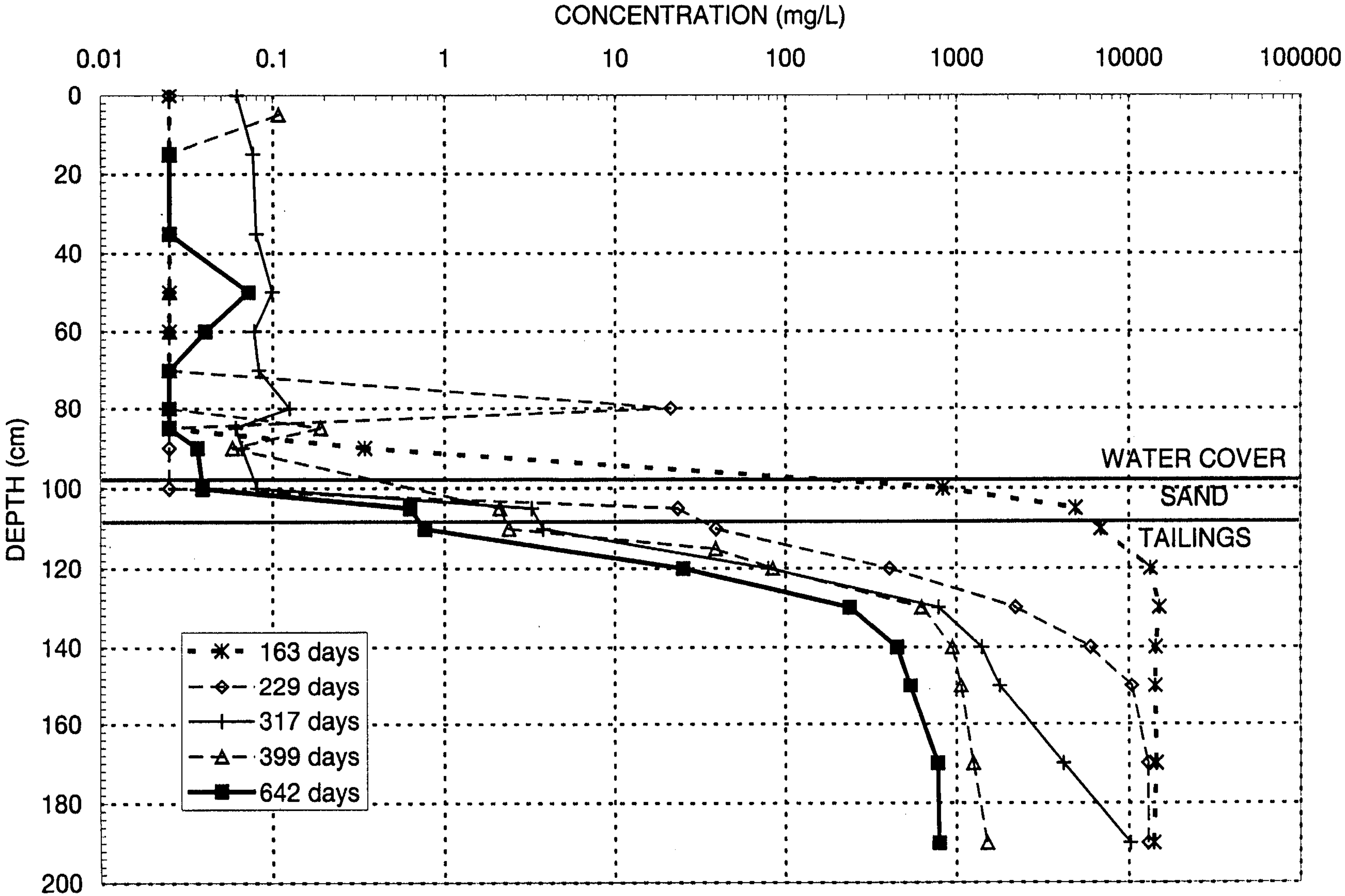

Figure III-3a: Dissolved total iron concentration profiles for MTWC-3, dynamic period

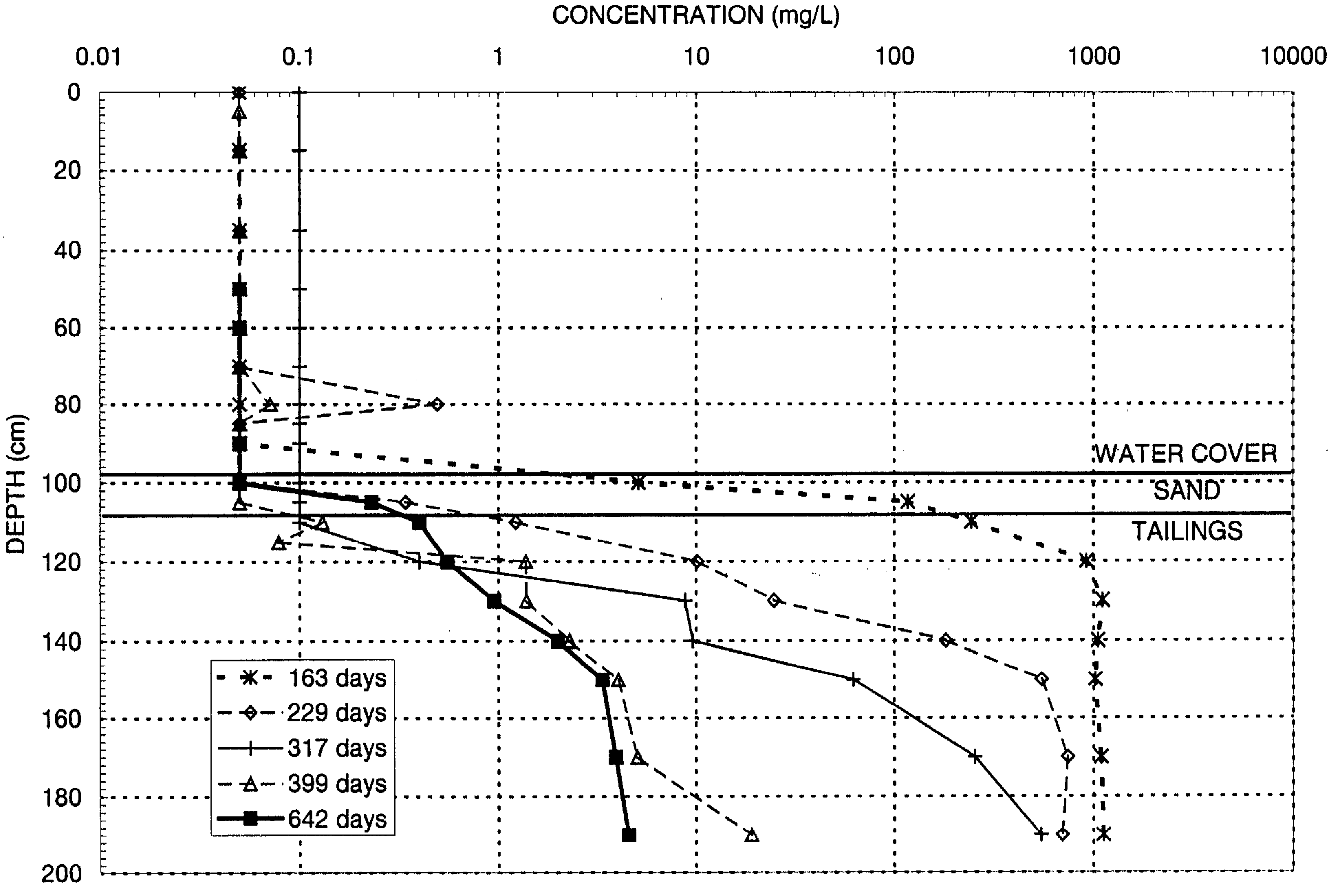

Figure III-3b: Ferric iron concentration profiles for MTWC-3, dynamic period

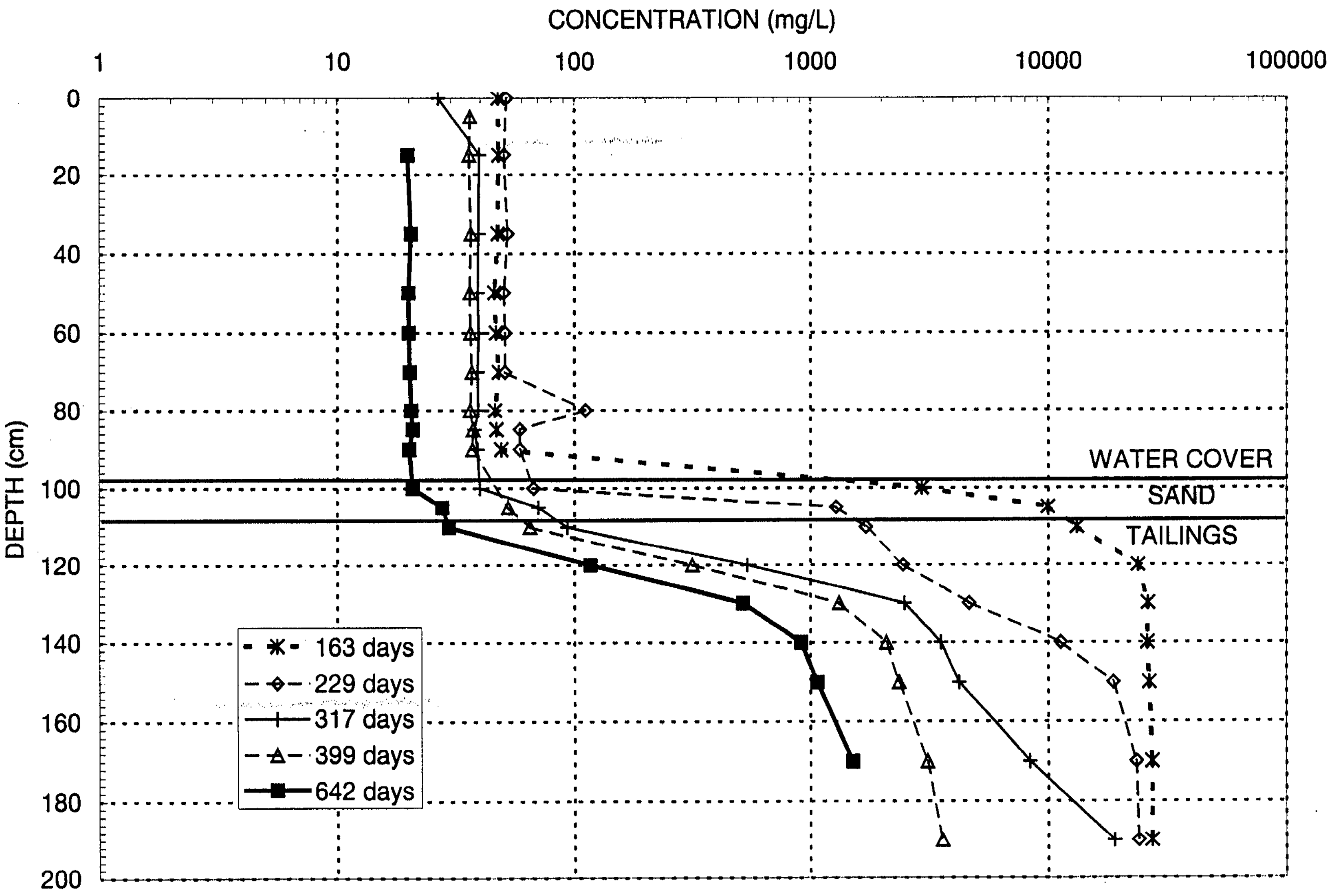

Figure III-3c: Dissolved sulphate concentration profiles for MTWC-3, dynamic period

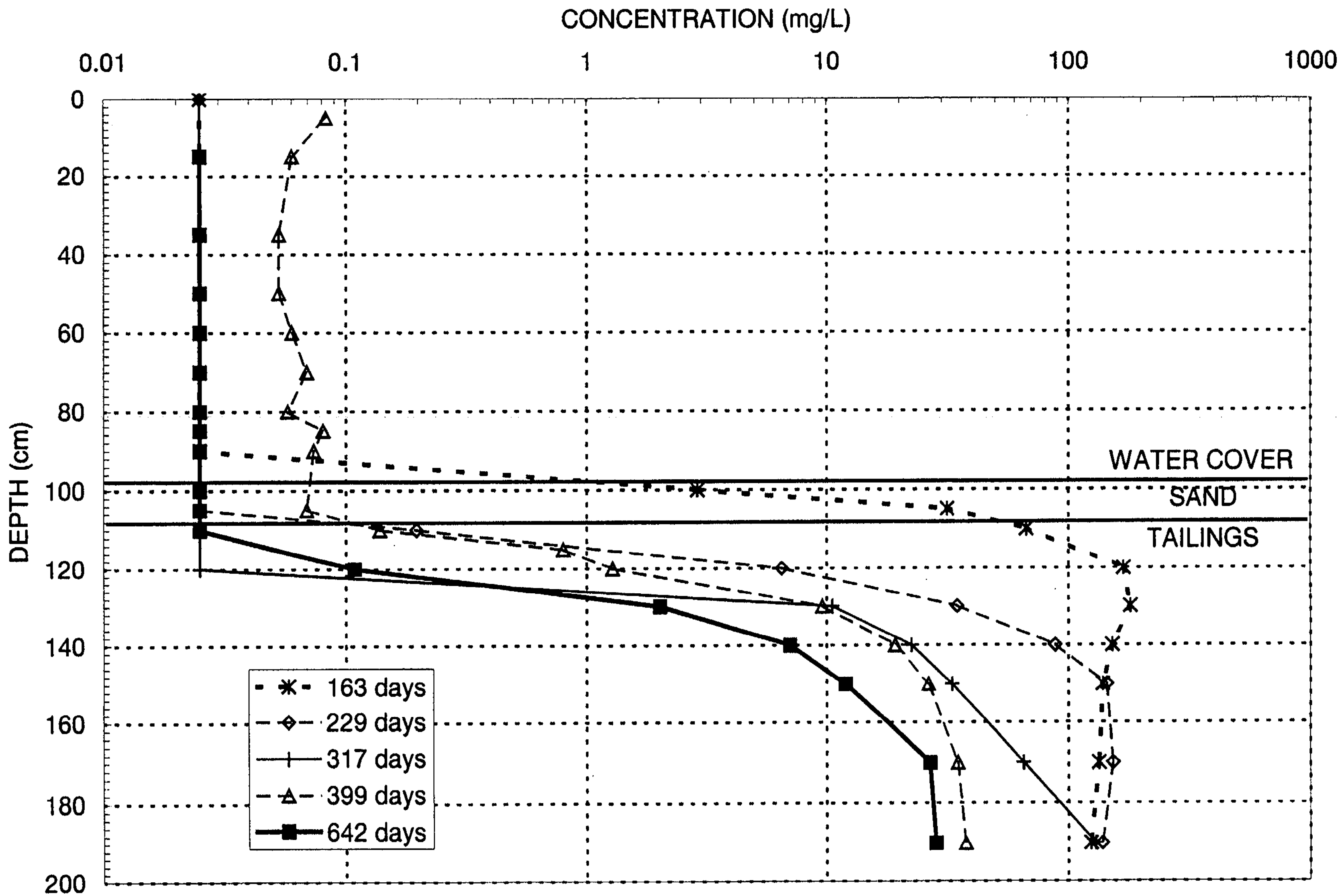

Figure III-3d: Dissolved zinc concentration profiles for MTWC-3, dynamic period

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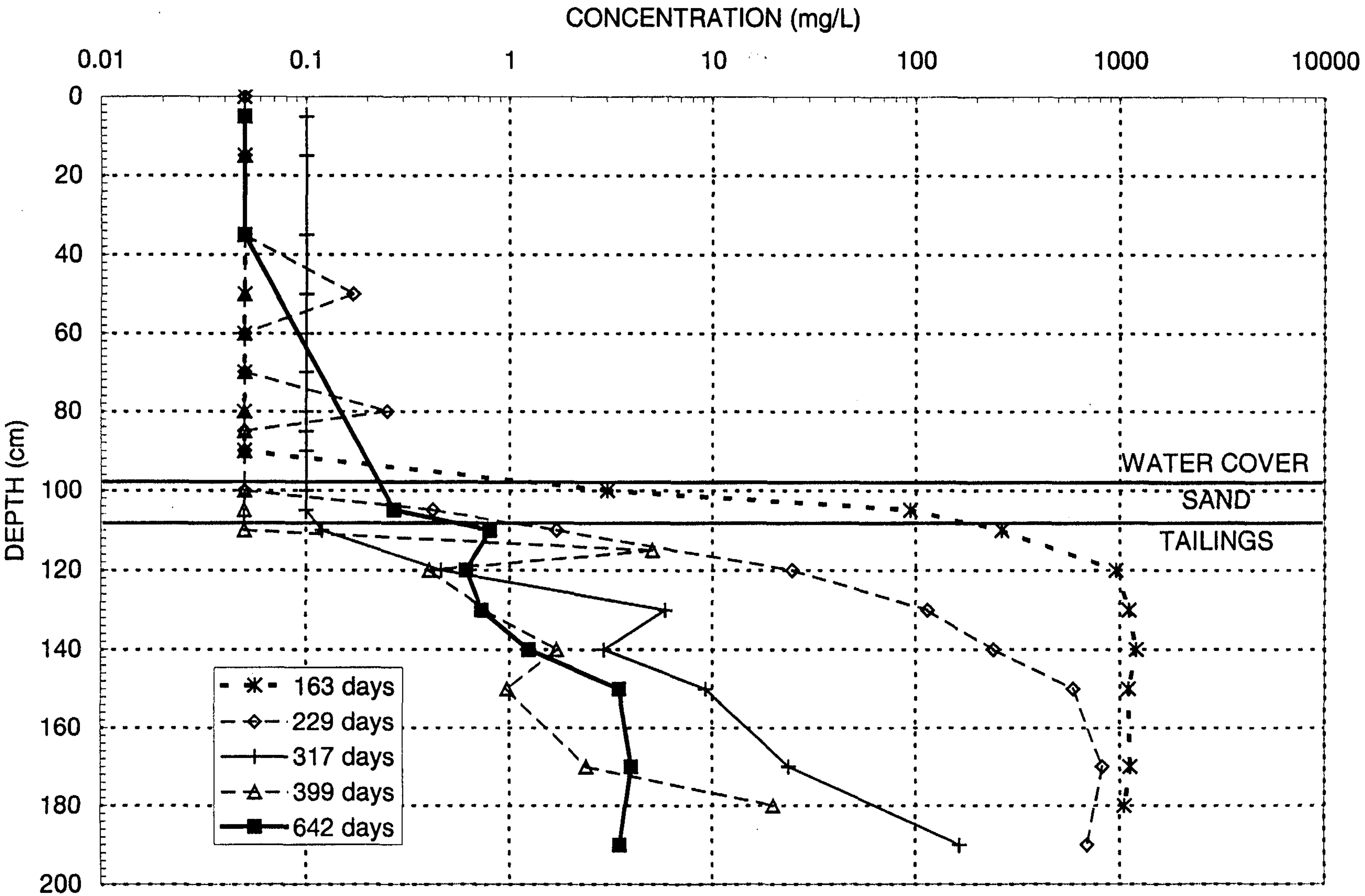

Figure III-4b: Ferric iron concentration profiles for MTWC-4, dynamic period

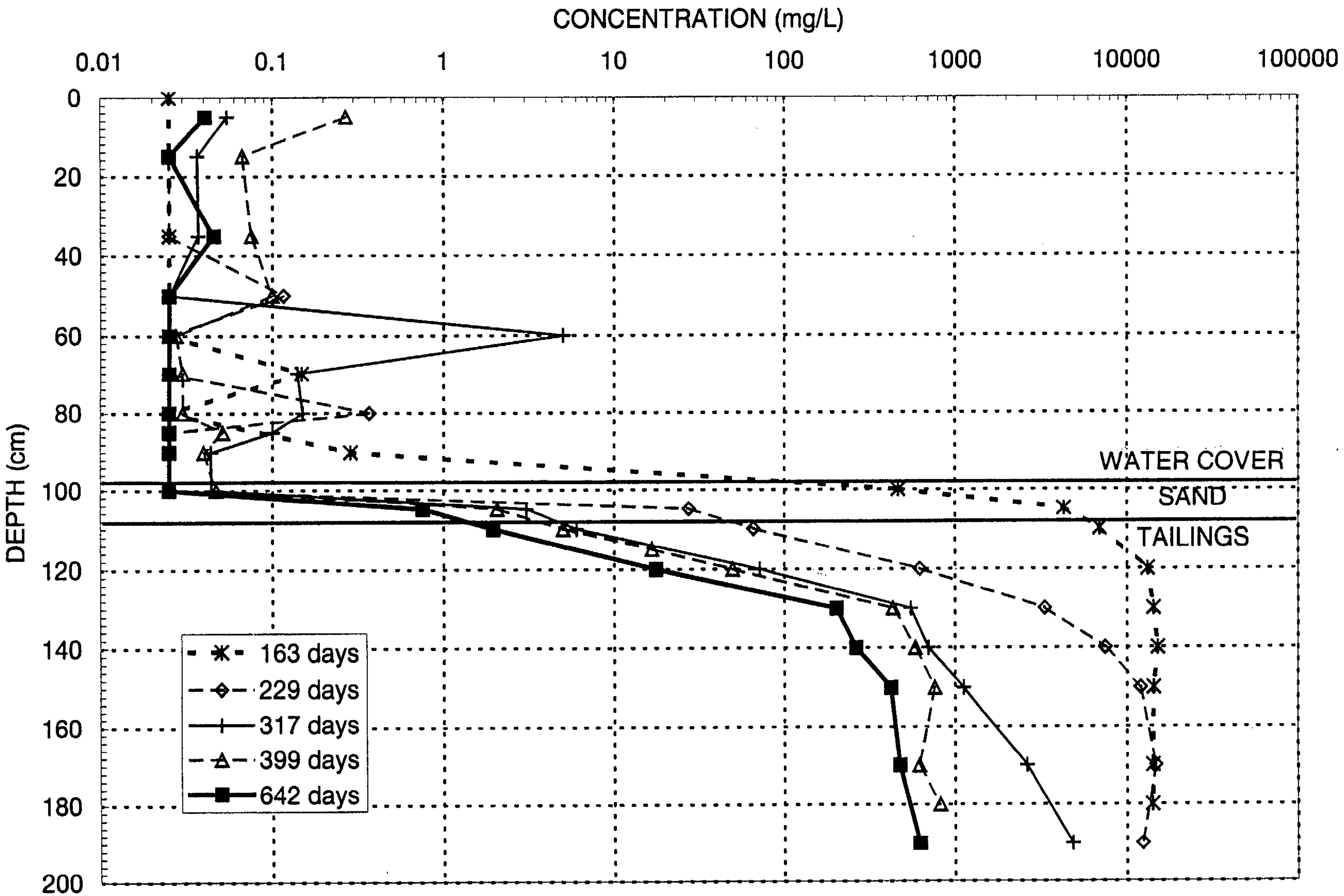

Figure III-4a: Dissolved total iron concentration profiles for MTWC-4, dynamic period

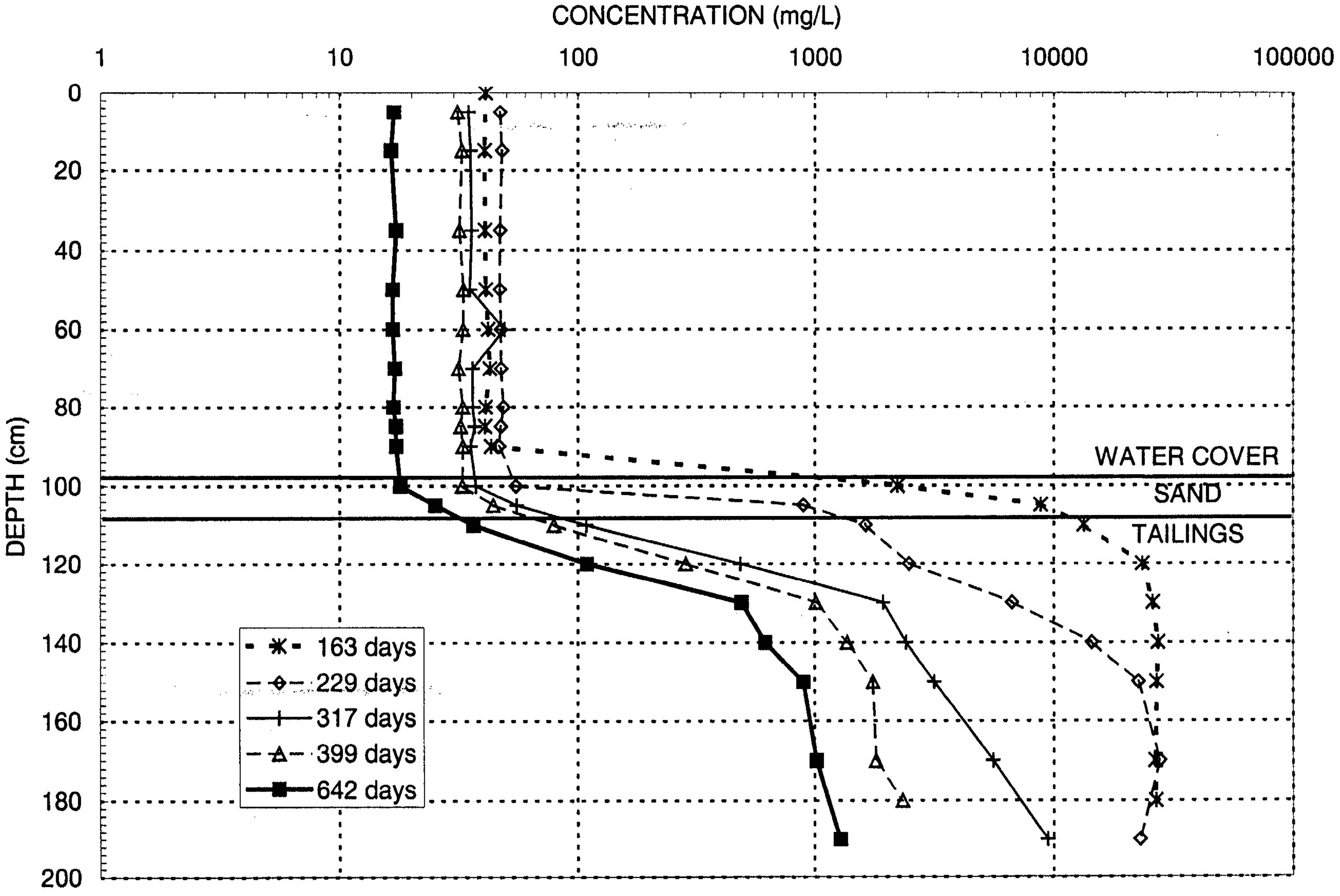

Figure III-4c: Dissolved sulphate concentration profiles for MTWC-4, dynamic period

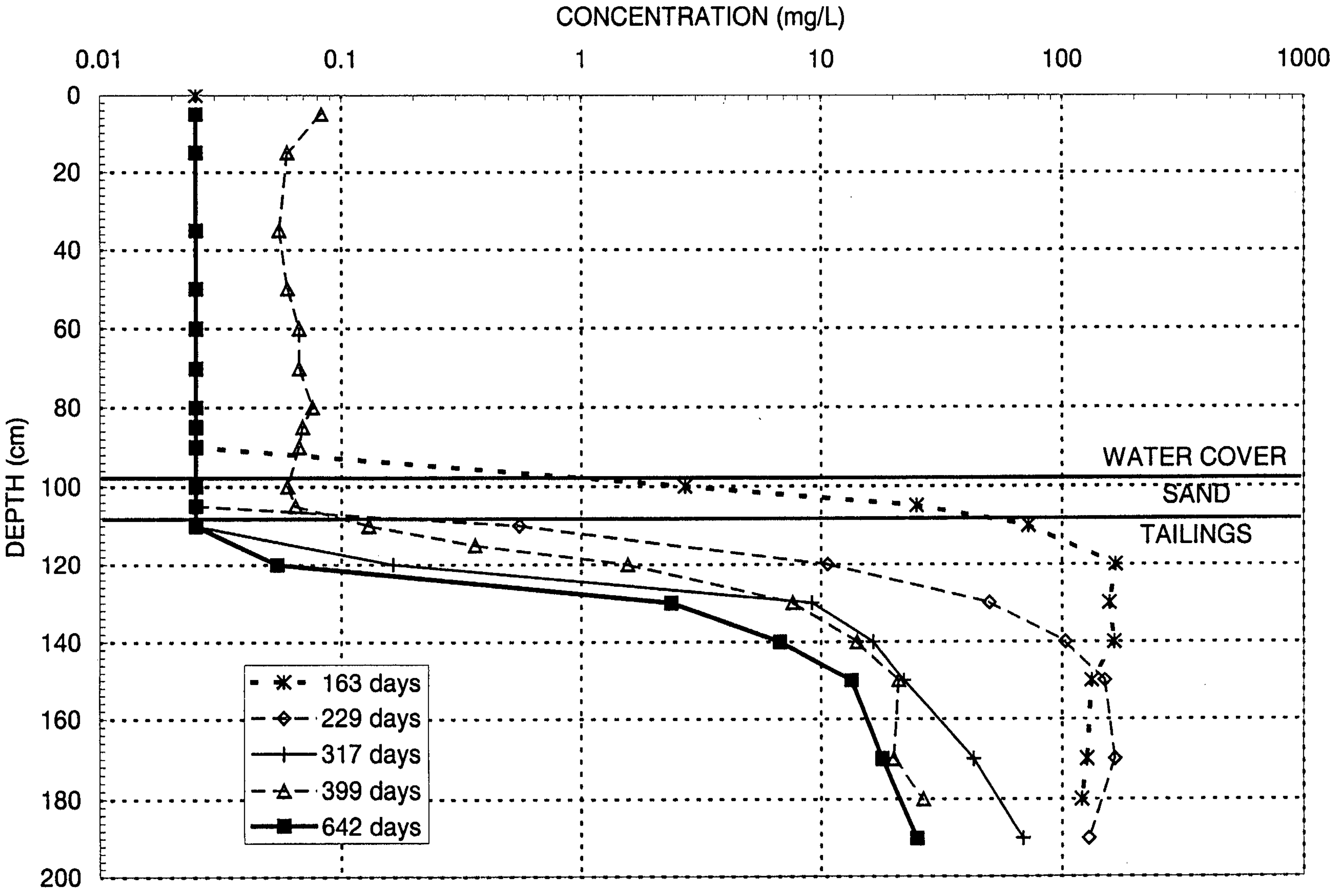

Figure III-4d: Dissolved zinc concentration profiles for MTWC-4, dynamic period

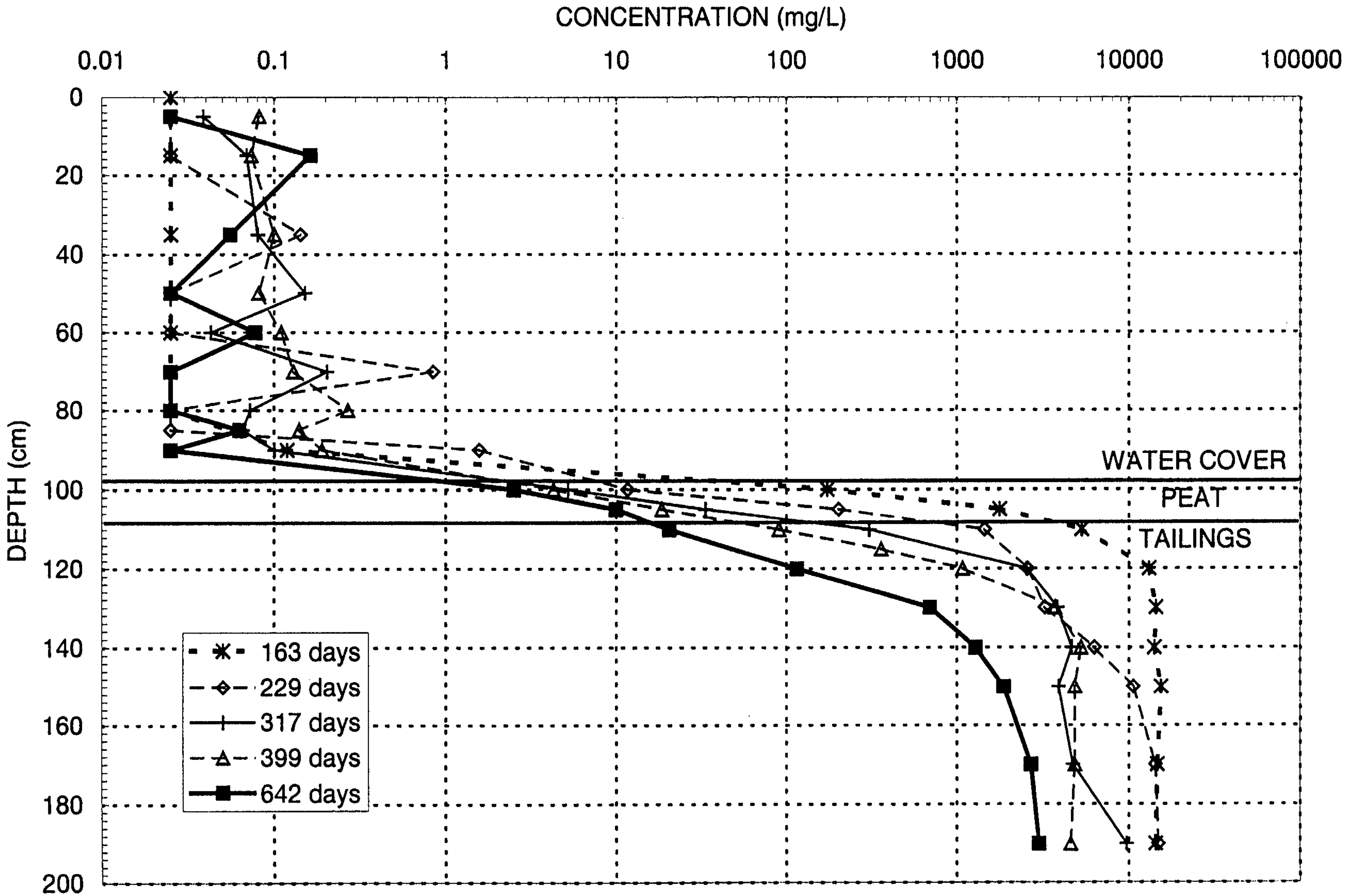

Figure III-5a: Dissolved total iron concentration profiles for MTWC-5, dynamic period

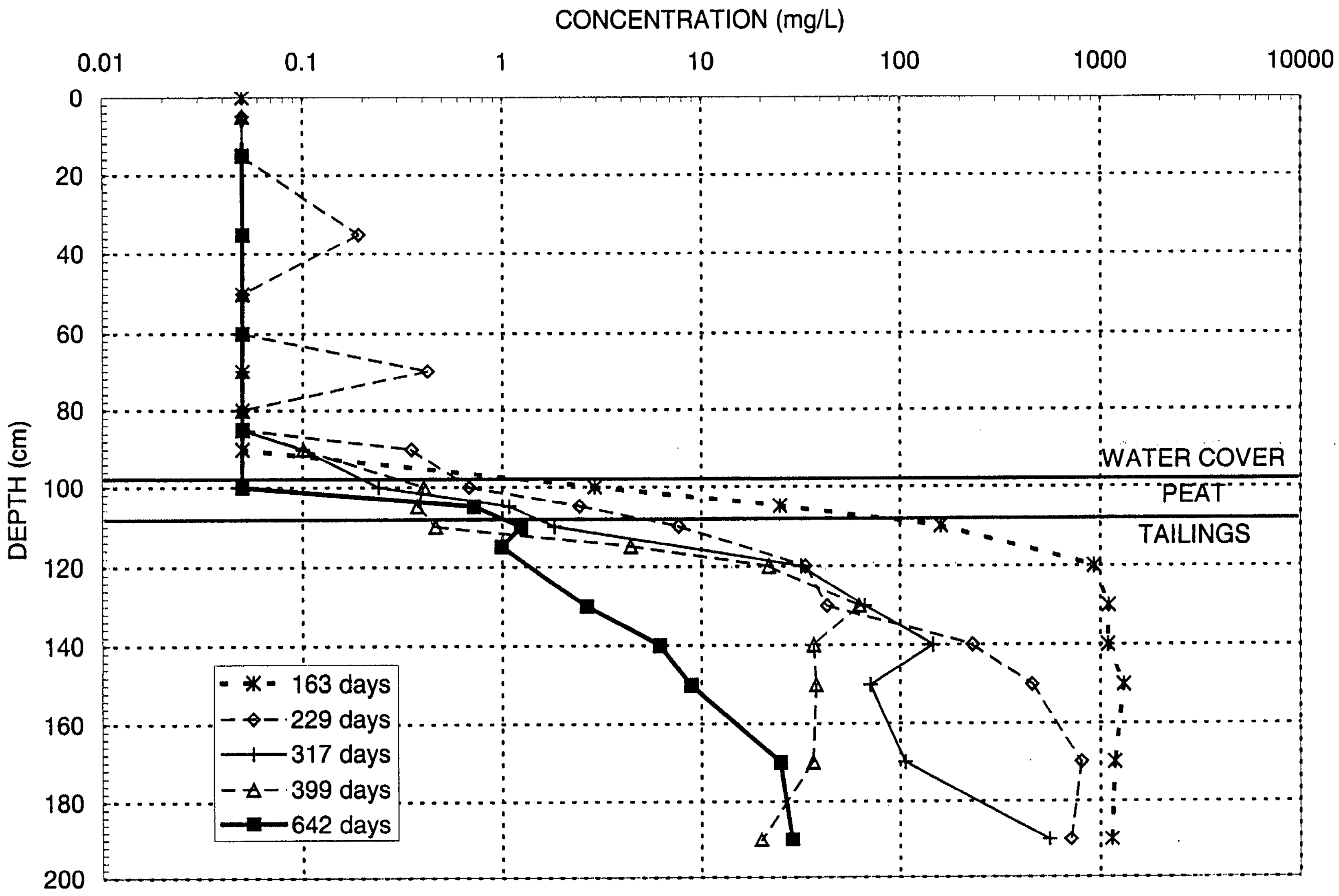

Figure III-5b: Ferric iron concentration profiles for MTWC-5, dynamic period

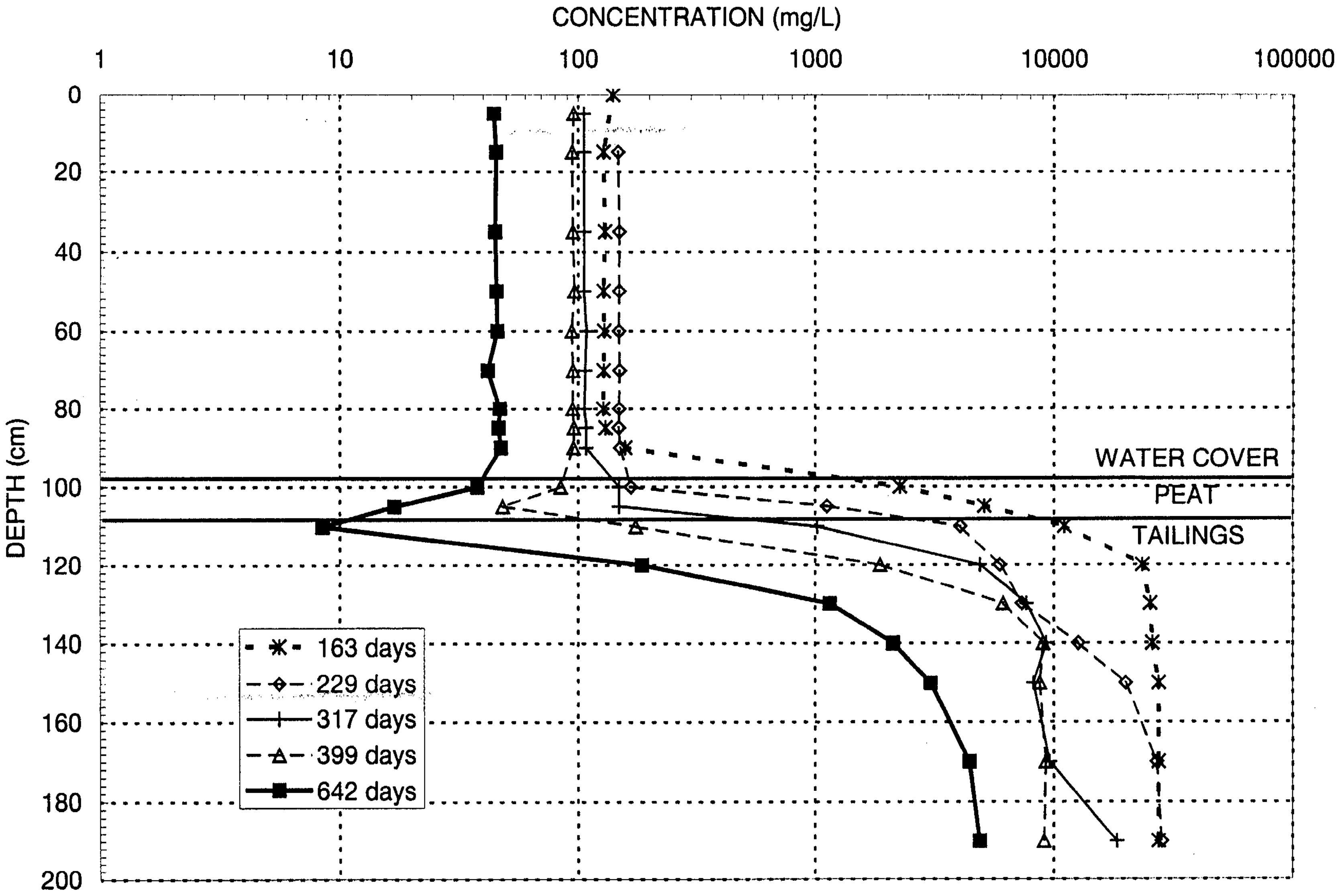

Figure III-5c: Dissolved sulphate concentration profiles for MTWC-5, dynamic period

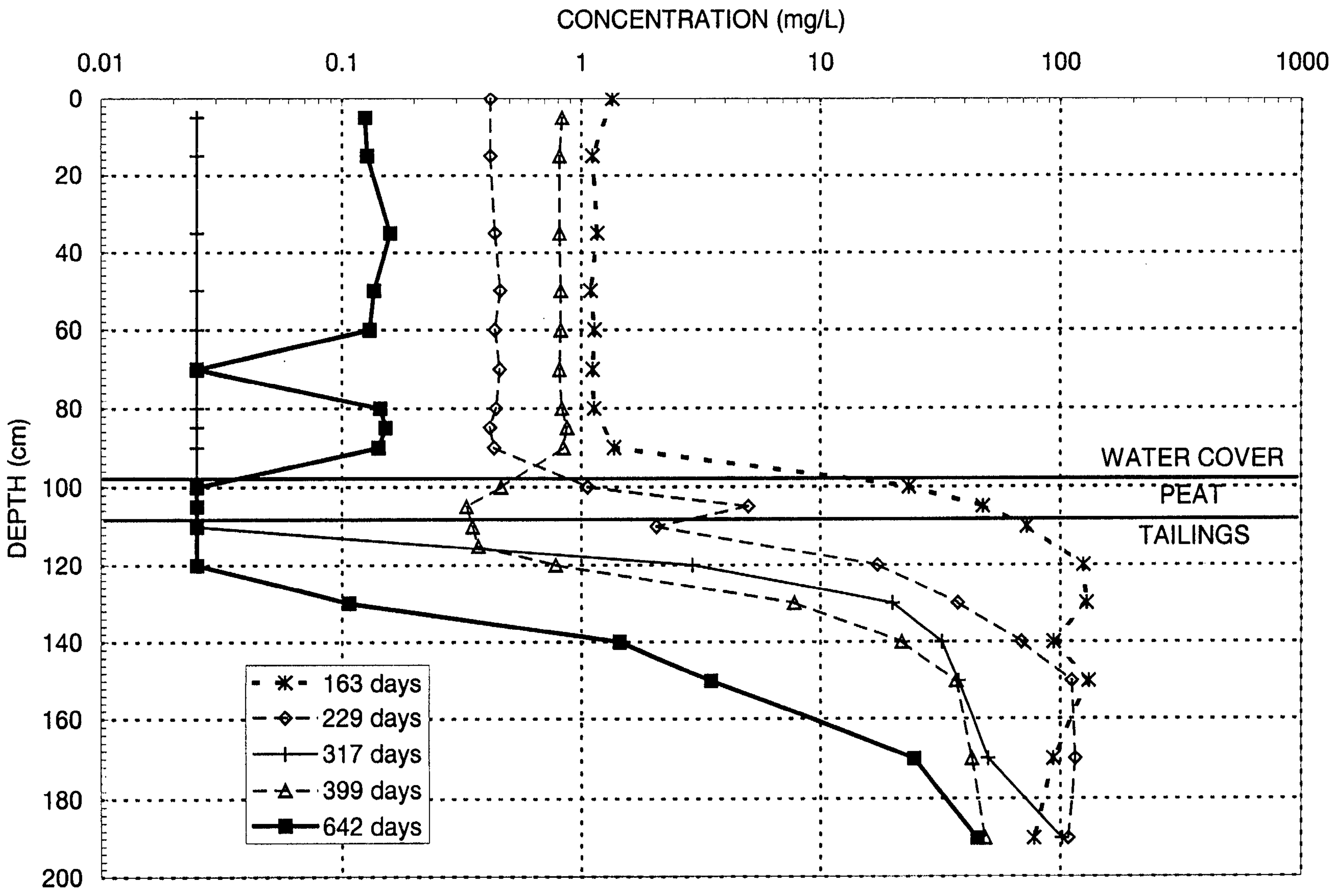

Figure III-5d: Dissolved zinc concentration profiles for MTWC-5, dynamic period

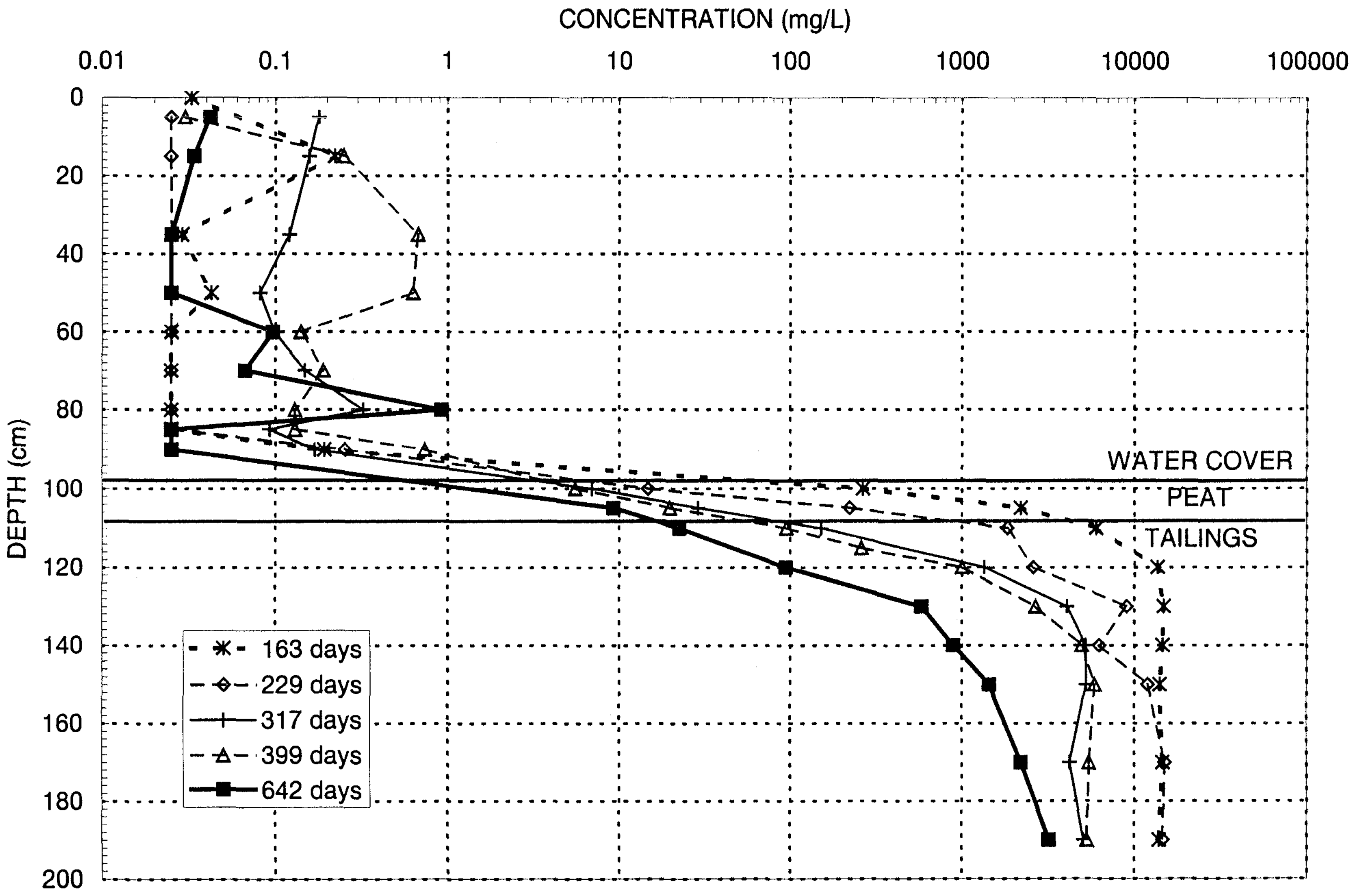

Figure III-6a: Dissolved total iron concentration profiles for MTWC-6, dynamic period

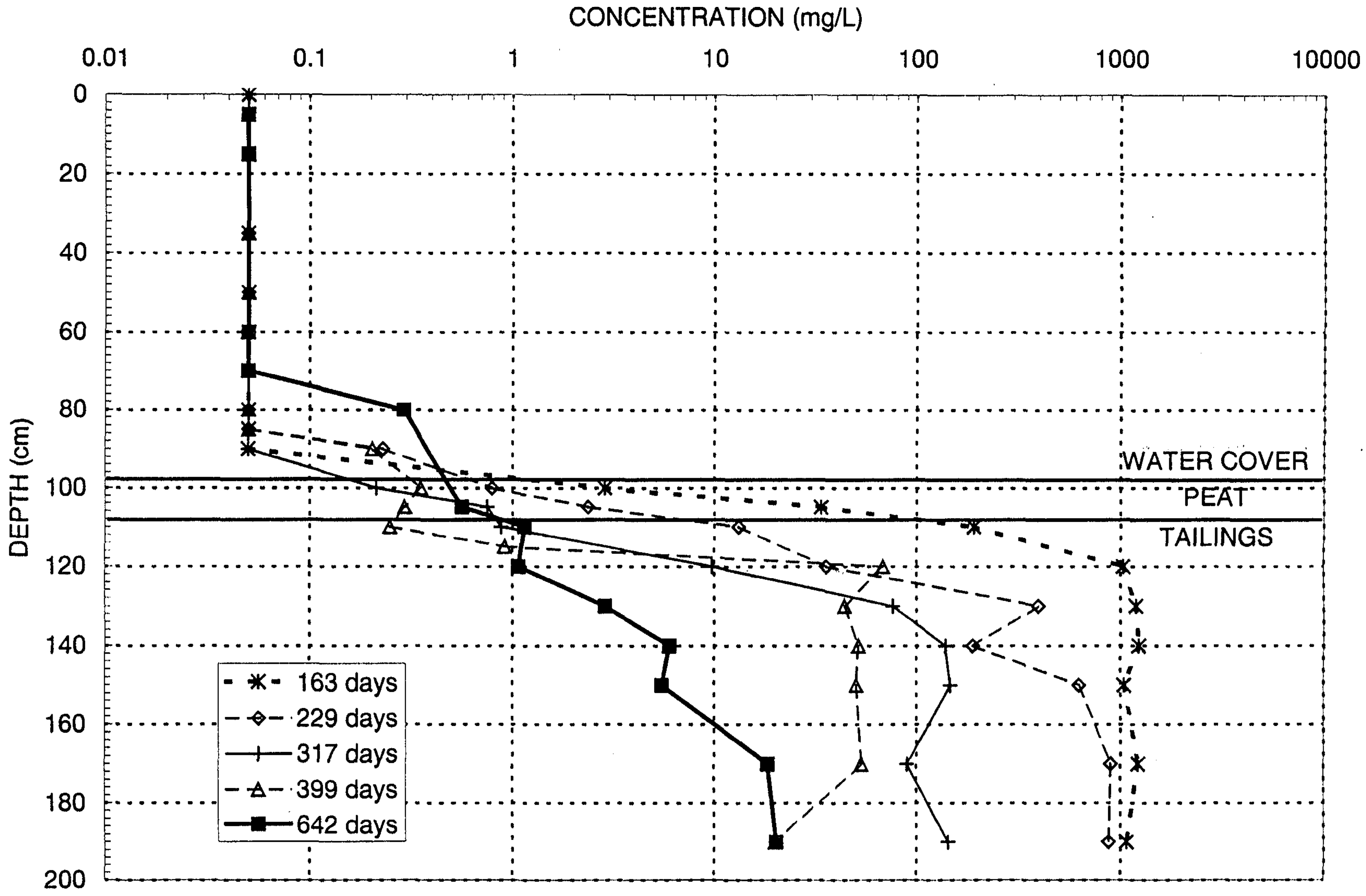

Figure III-6b: Ferric iron concentration profiles for MTWC-6, dynamic period

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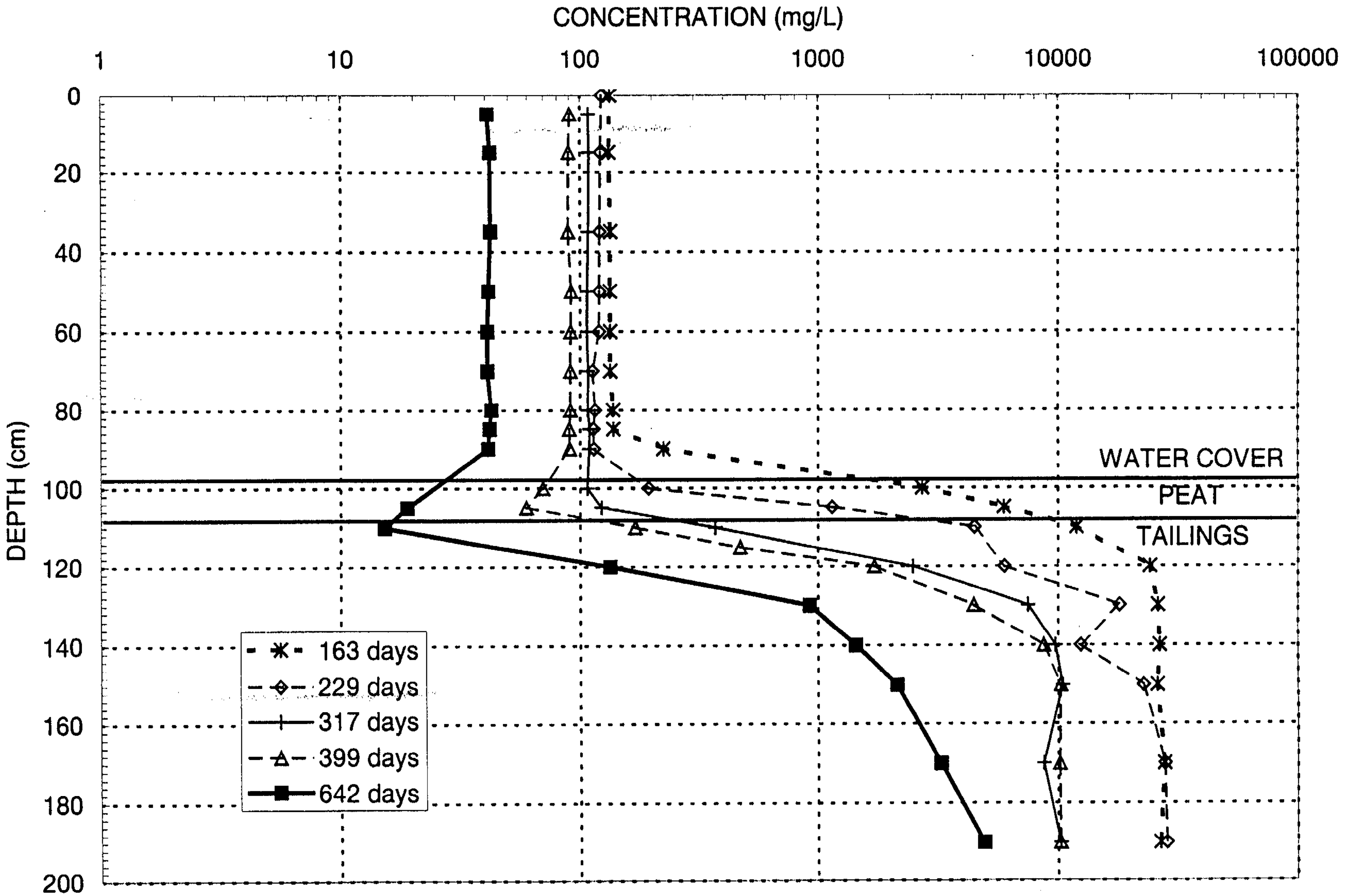

Figure III-6c: Dissolved sulphate concentration profiles for MTWC-6, dynamic period

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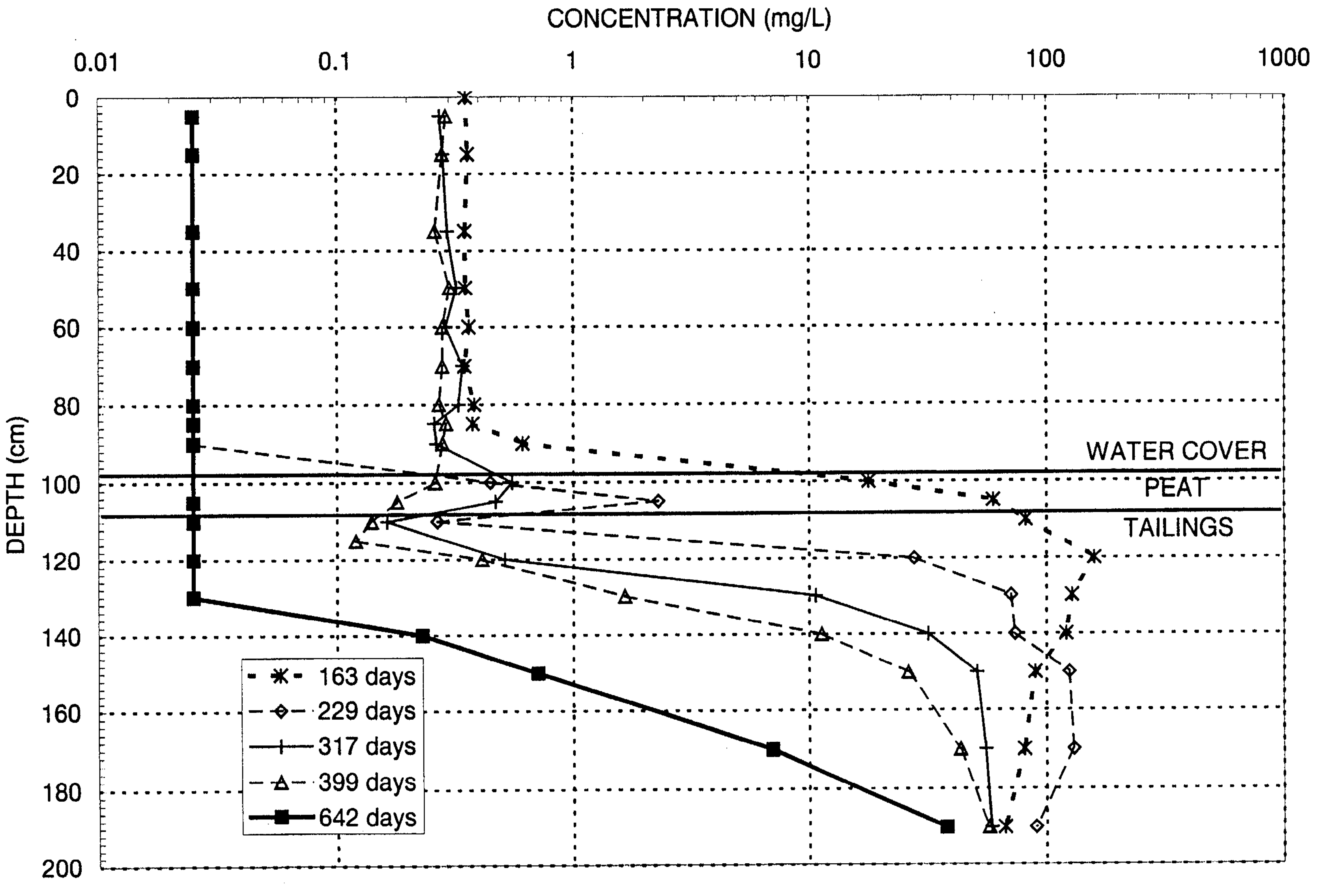

Figure III-6d: Dissolved zinc concentration profiles for MTWC-6, dynamic period

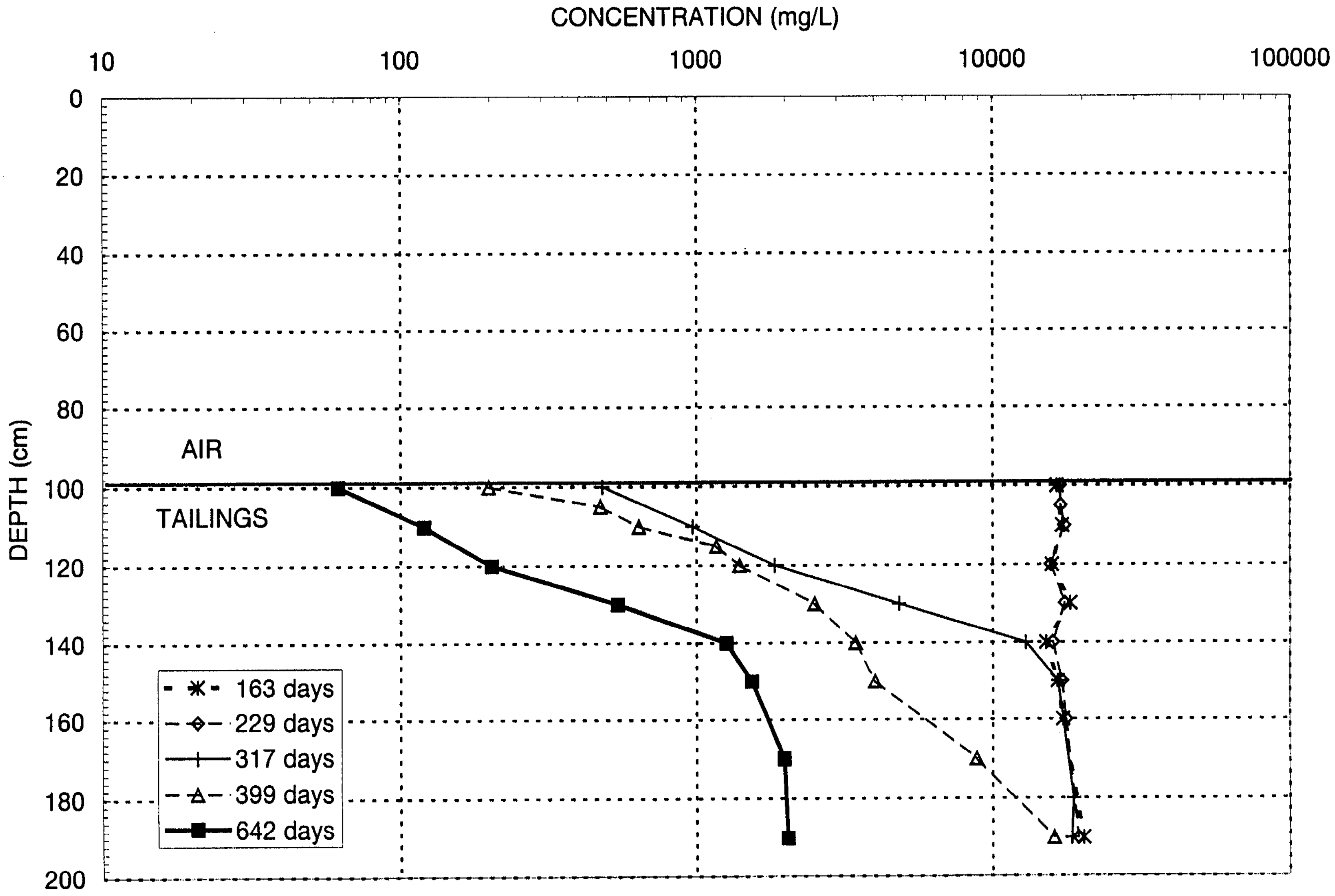

Figure III-7a: Dissolved total iron concentration profiles for MTWC-7, dynamic period

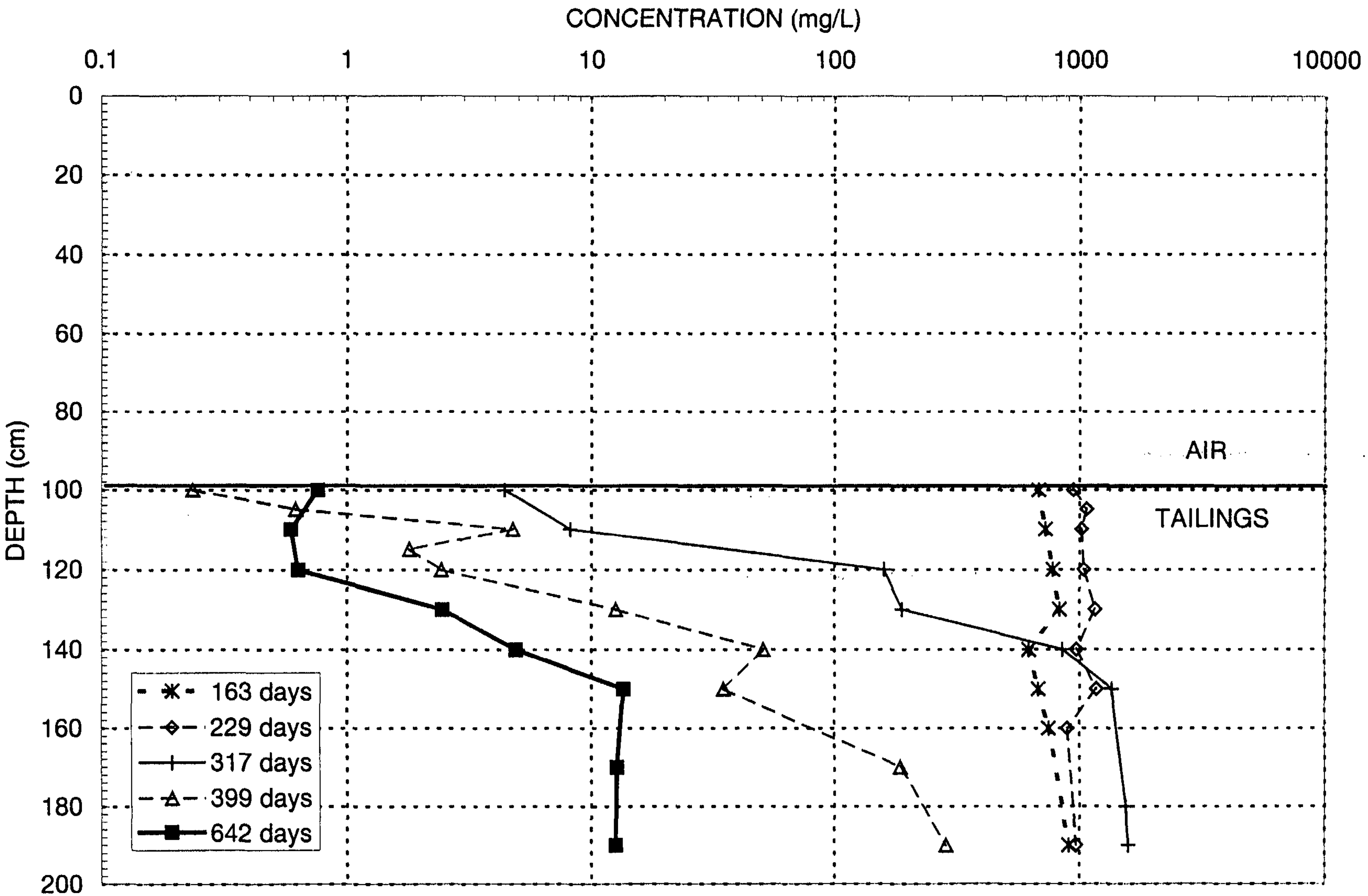

Figure III-7b: Ferric iron concentration profiles for MTWC-7, dynamic period

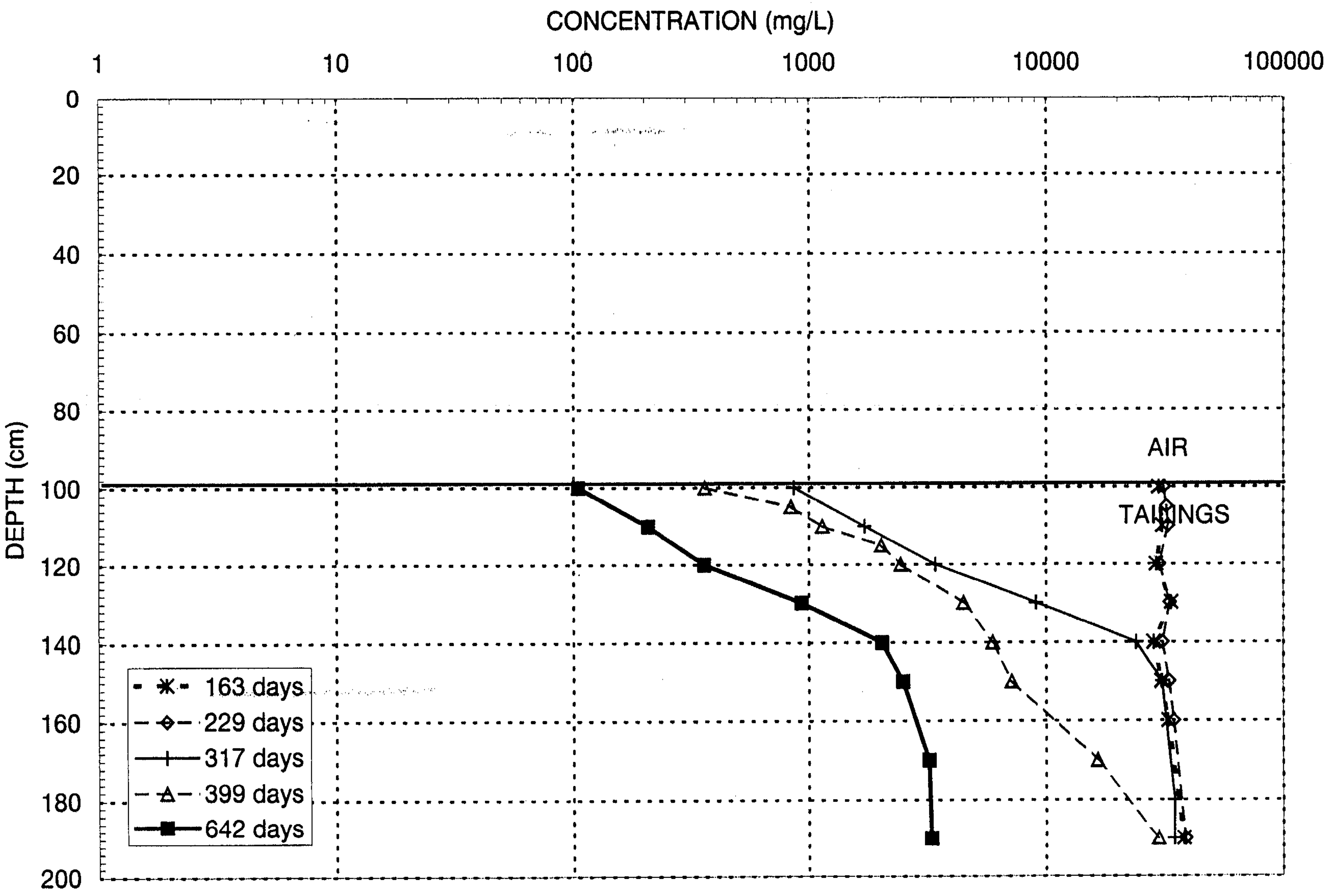

Figure III-7c: Dissolved sulphate concentration profiles for MTWC-7, dynamic period

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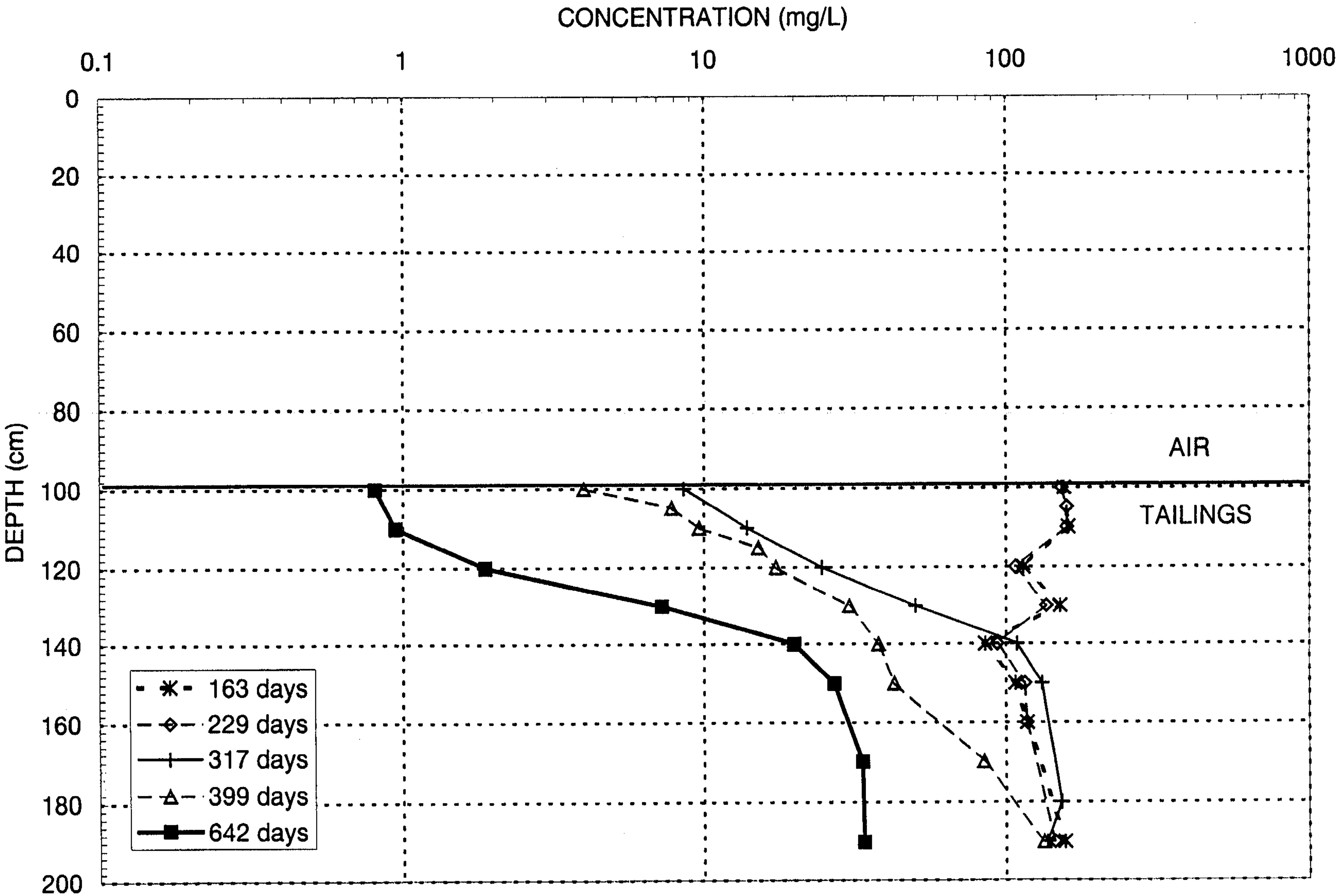

Figure III-7d: Dissolved zinc concentration profiles for MTWC-7, dynamic period

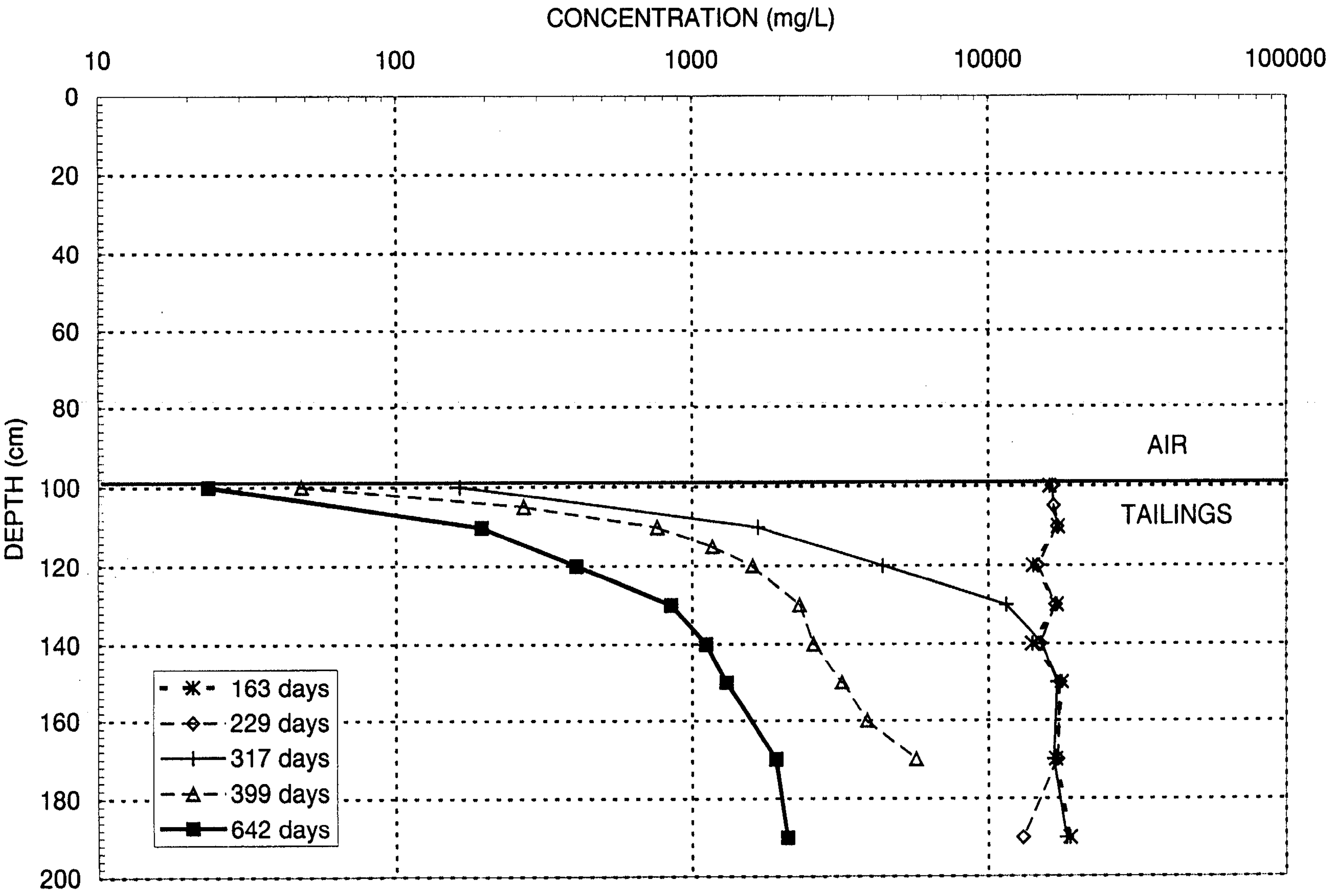

Figure III-8a: Dissolved total iron concentration profiles for MTWC-8, dynamic period

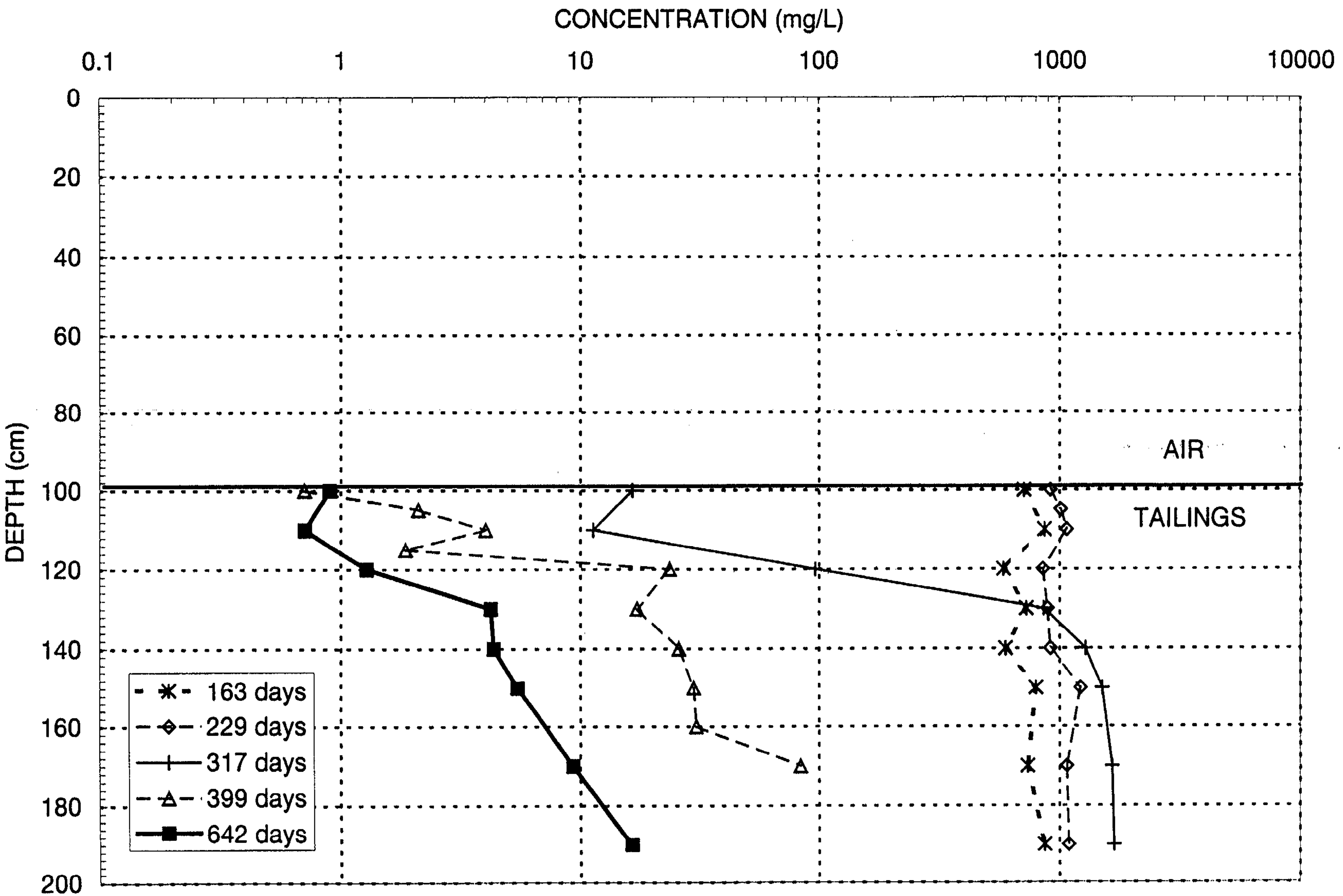

Figure III-8b: Ferric iron concentration profiles for MTWC-8, dynamic period

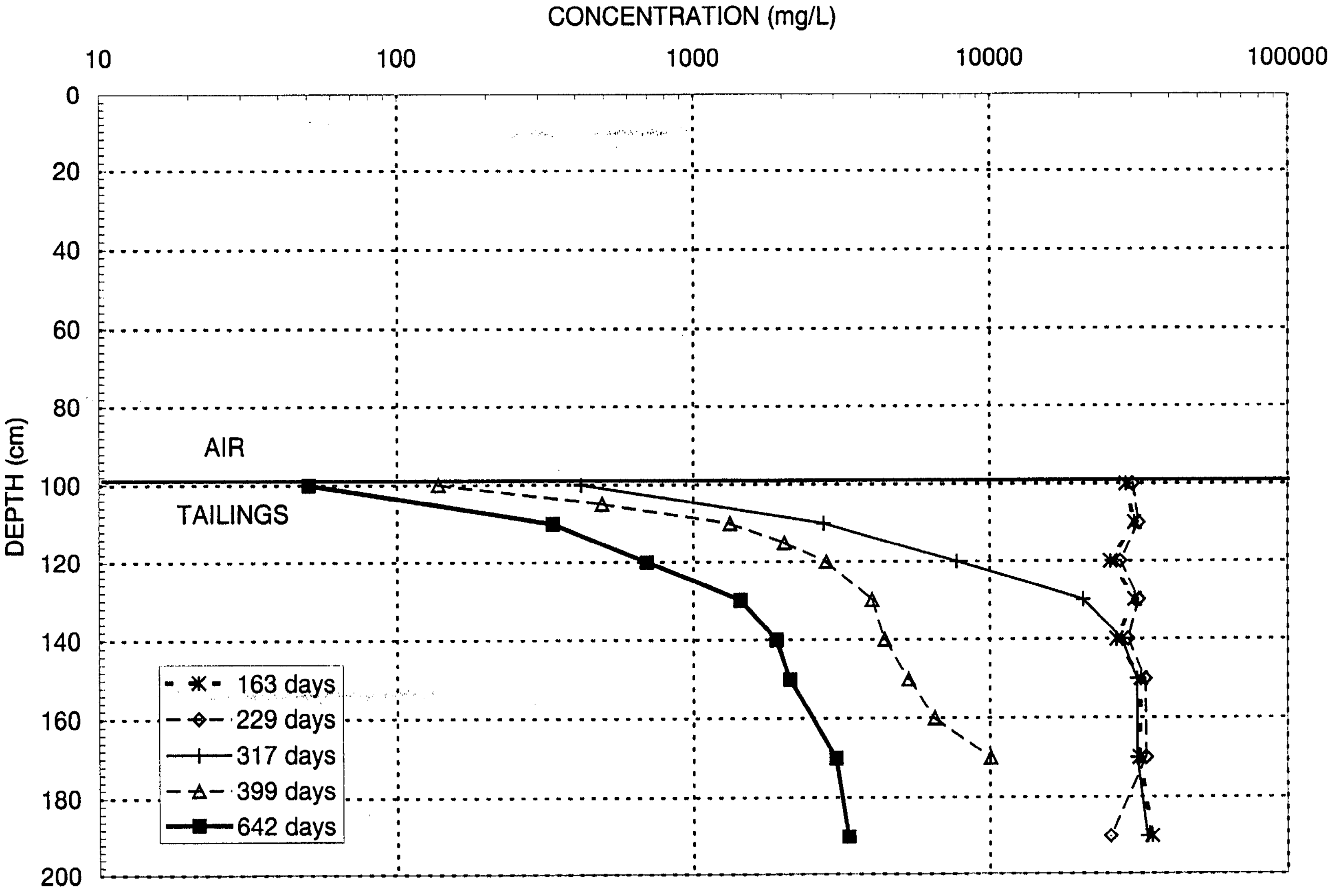

Figure III-8c: Dissolved sulphate concentration profiles for MTWC-8, dynamic period

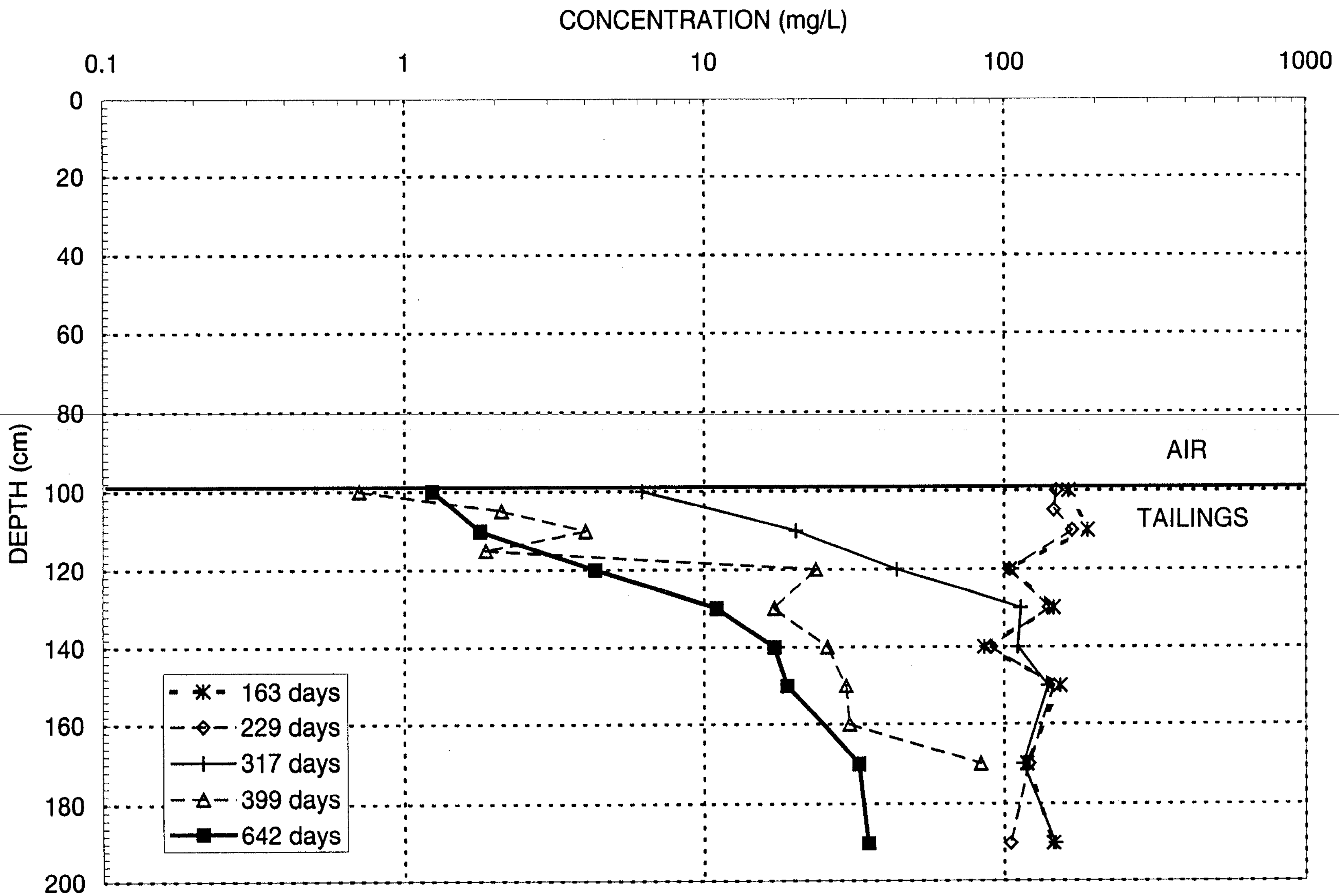

Figure III-8d: Dissolved zinc concentration profiles for MTWC-8, dynamic period

APPENDIX IV

EVOLUTION OF SEEPAGE WATER QUALITY FOR COLUMNS

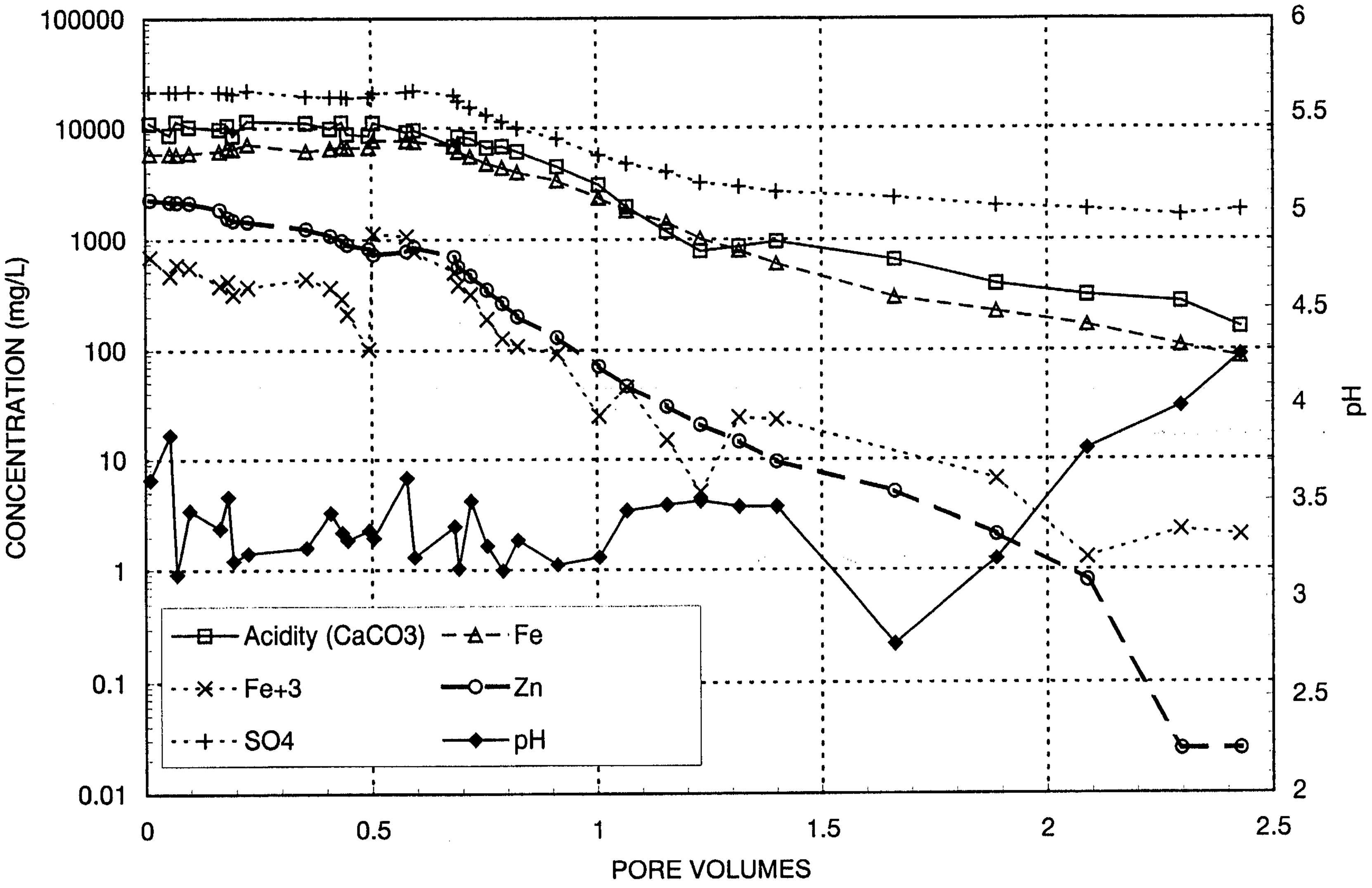

Figure IV-1: Seepage water quality for MTWC-1

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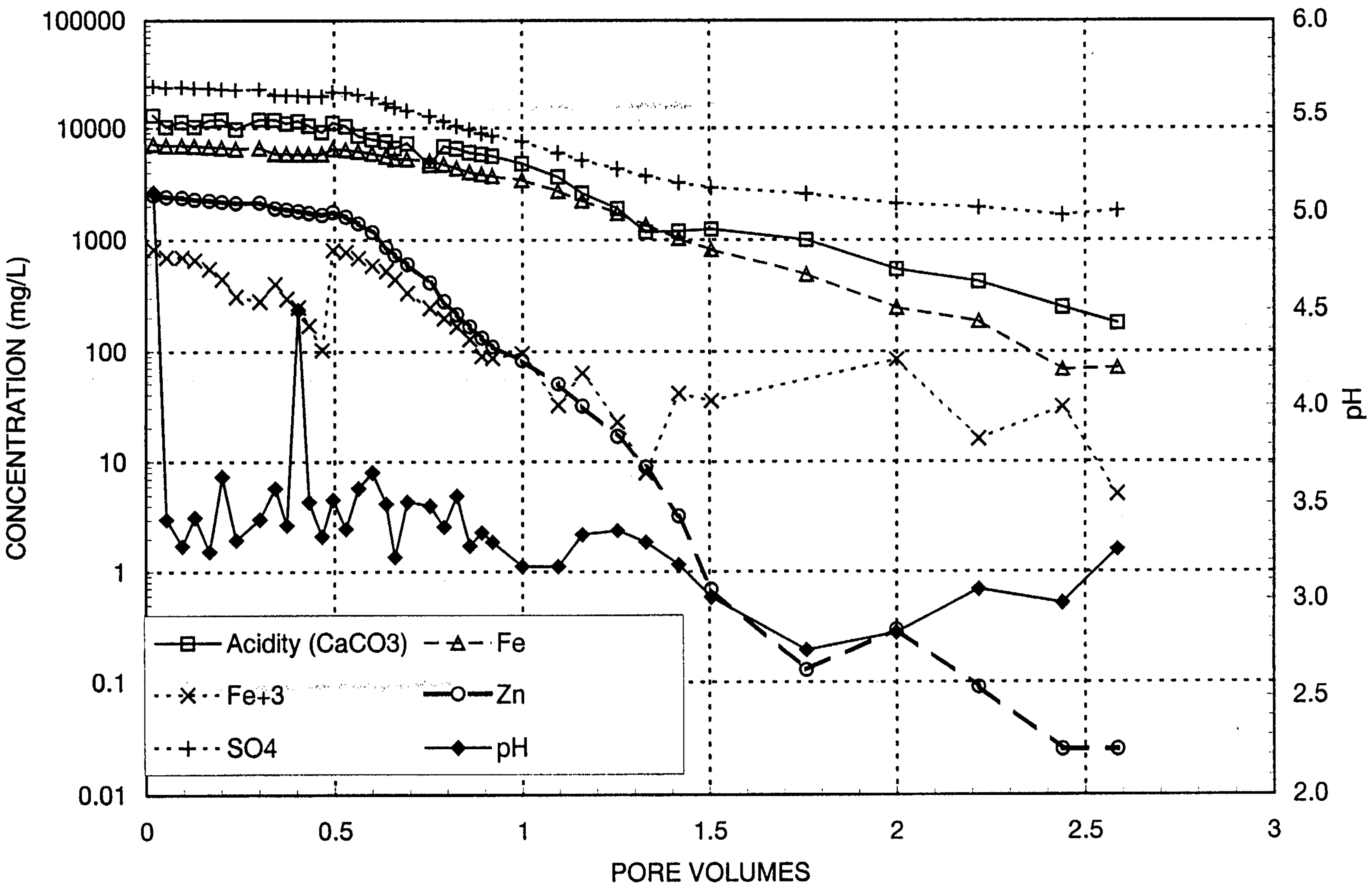

Figure IV-2: Seepage water quality for MTWC-2

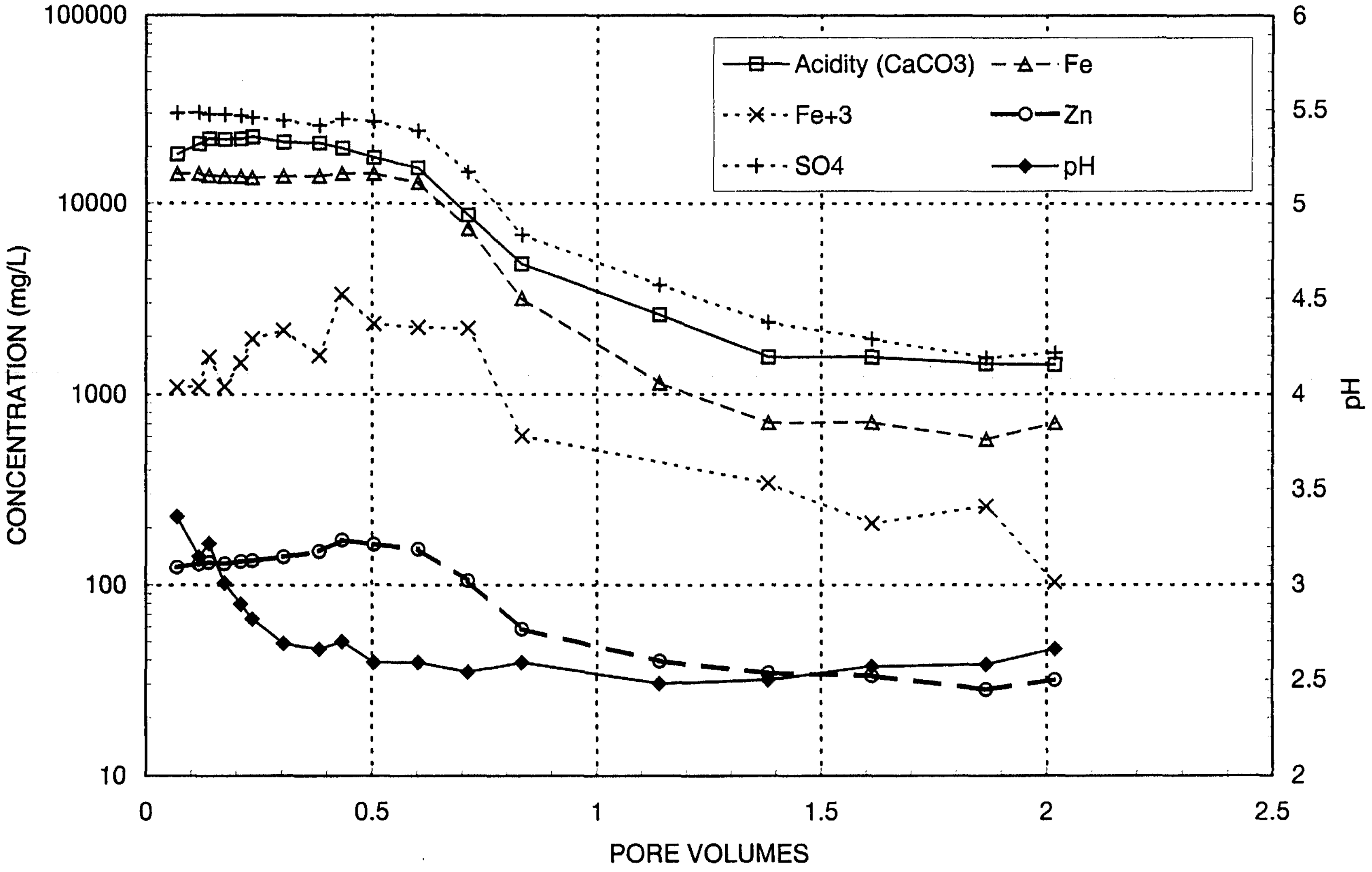

Figure IV-3: Seepage water quality for MTWC-3

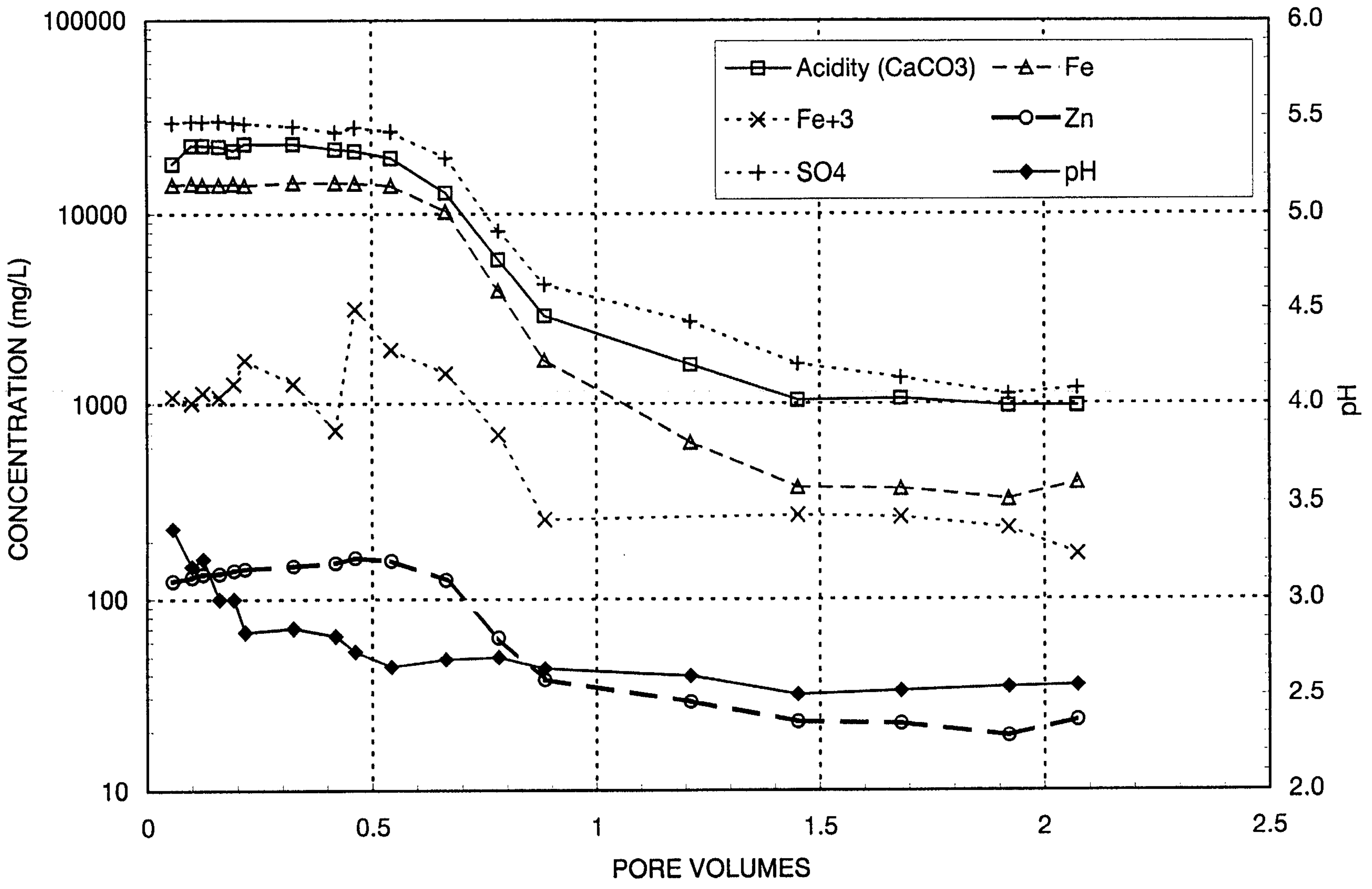

Figure IV-4: Seepage water quality for MTWC-4

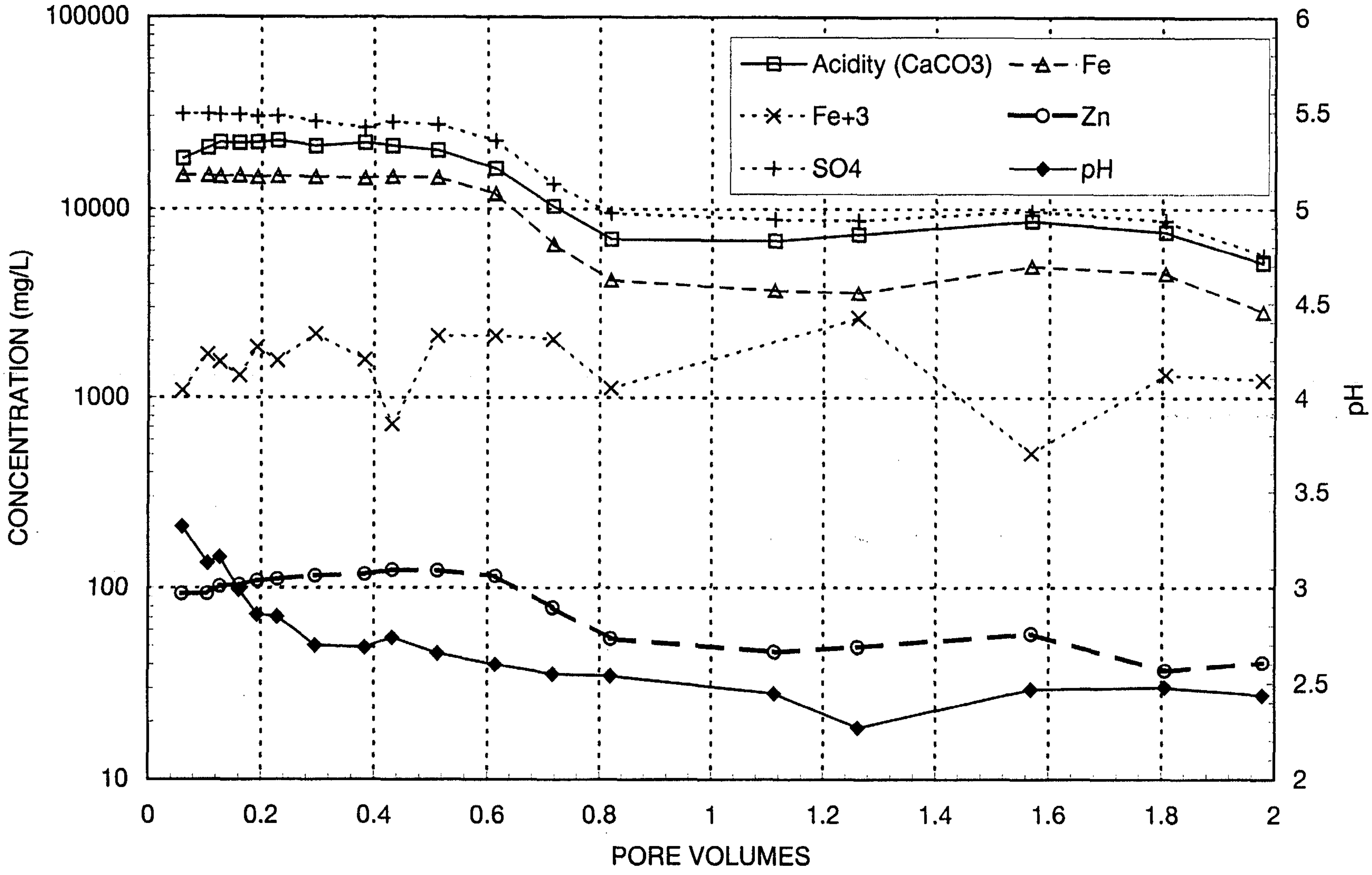

Figure IV-5: Seepage water quality for MTWC-5

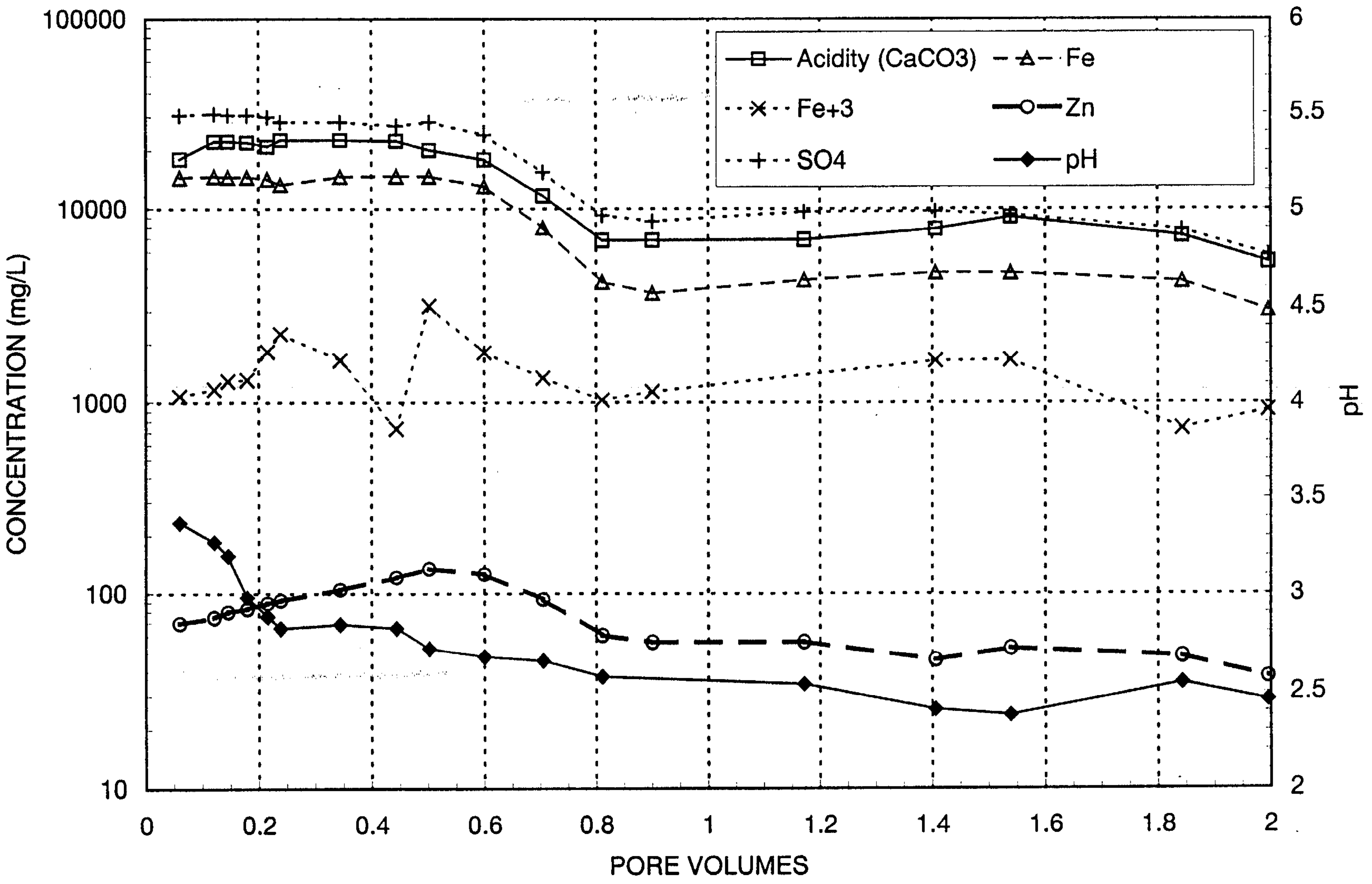

Figure IV-6: Seepage water quality for MTWC-6

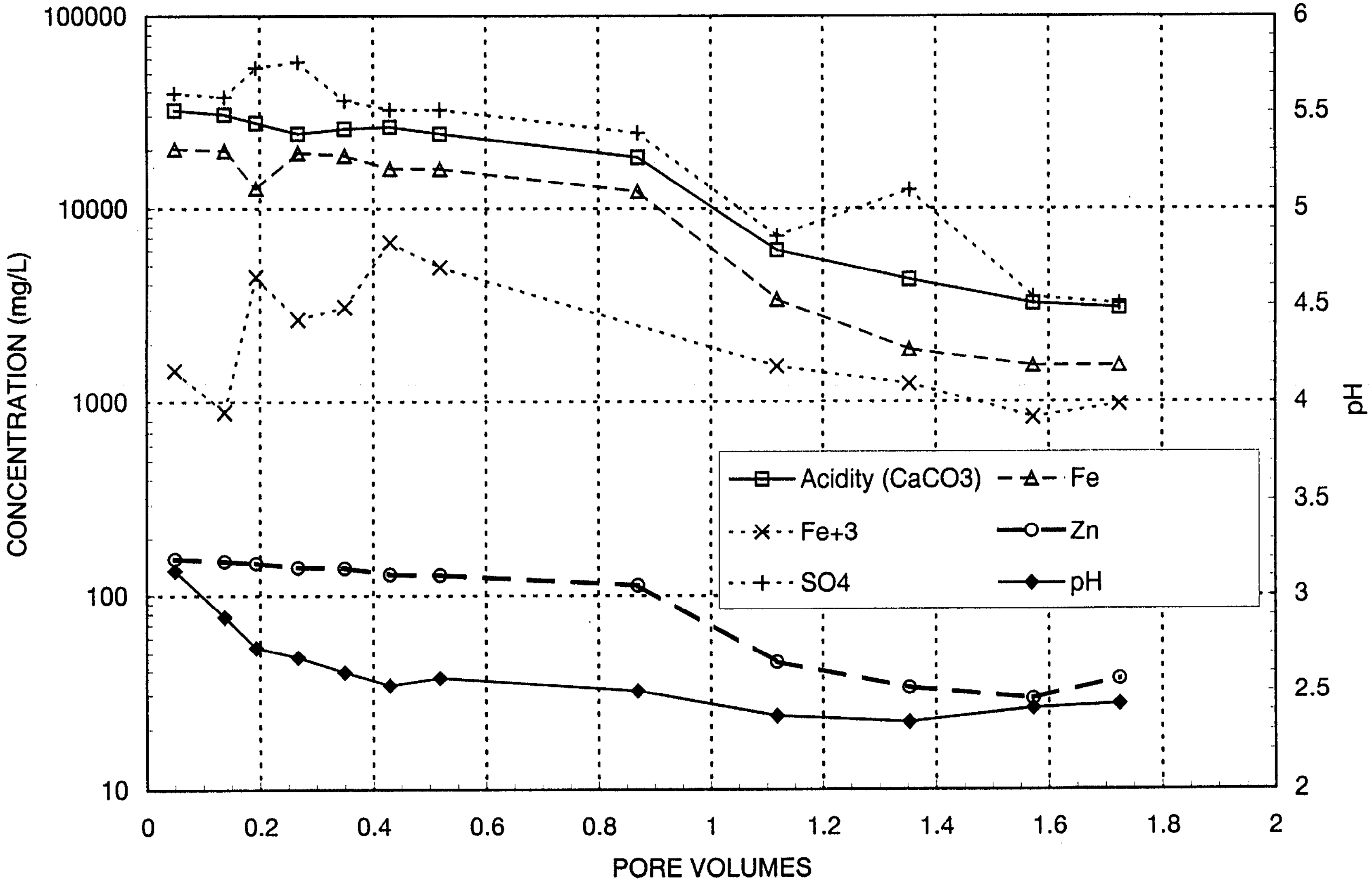

Figure IV-7: Seepage water quality for MTWC-7

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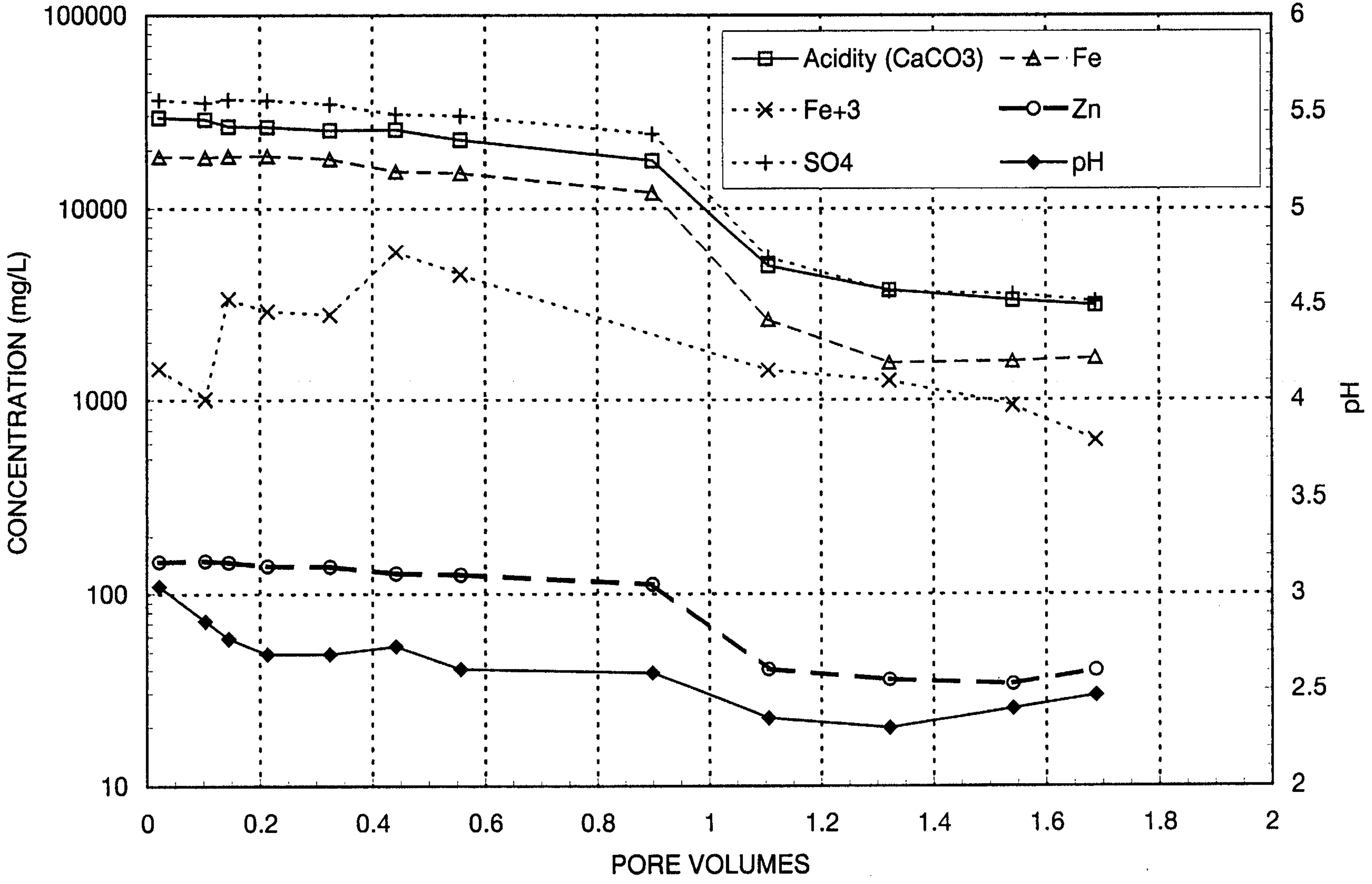

Figure IV-8: Seepage water quality for MTWC-8

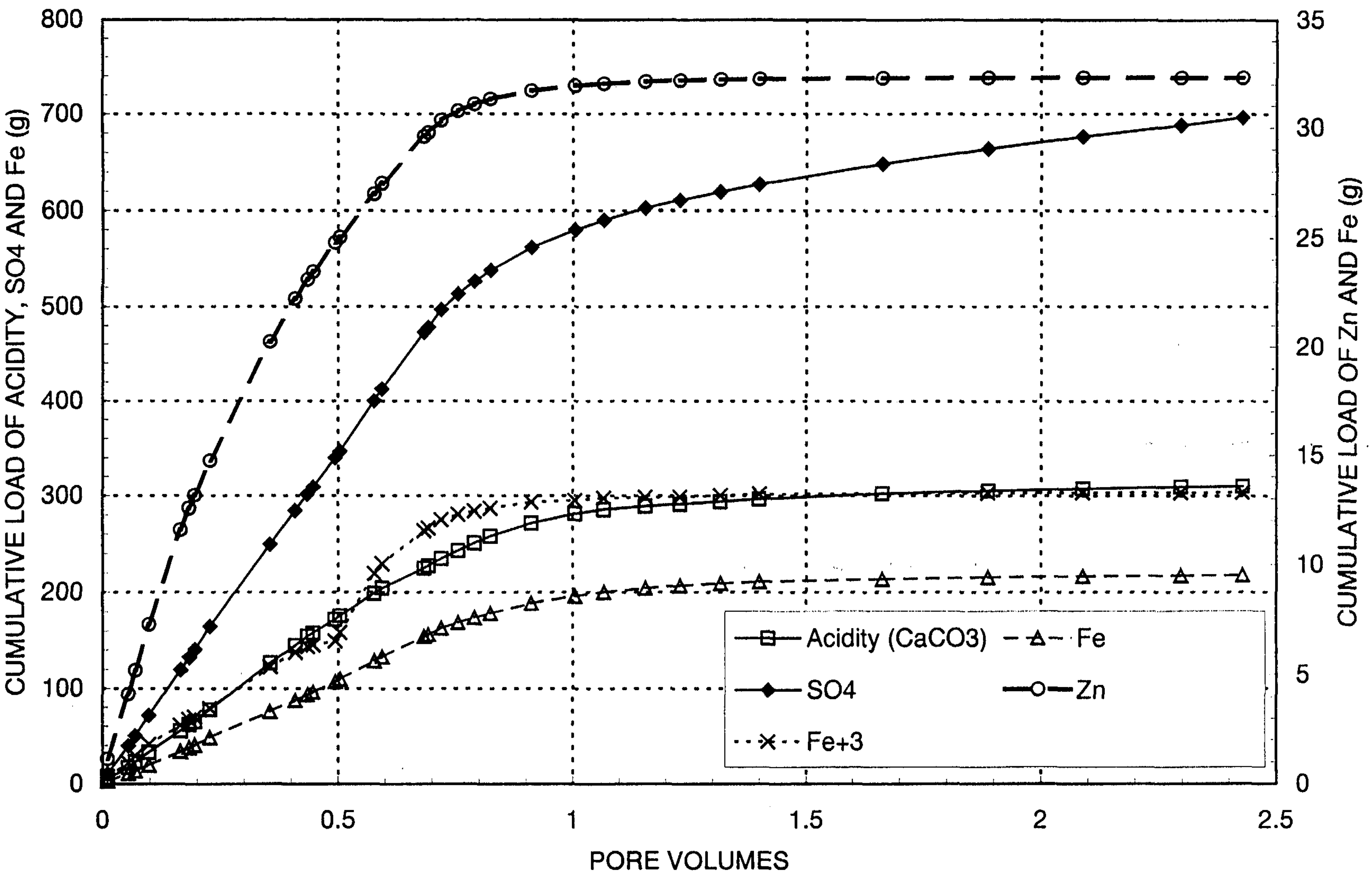

Figure IV-9: Cumulative loads in seepage of MTWC-1

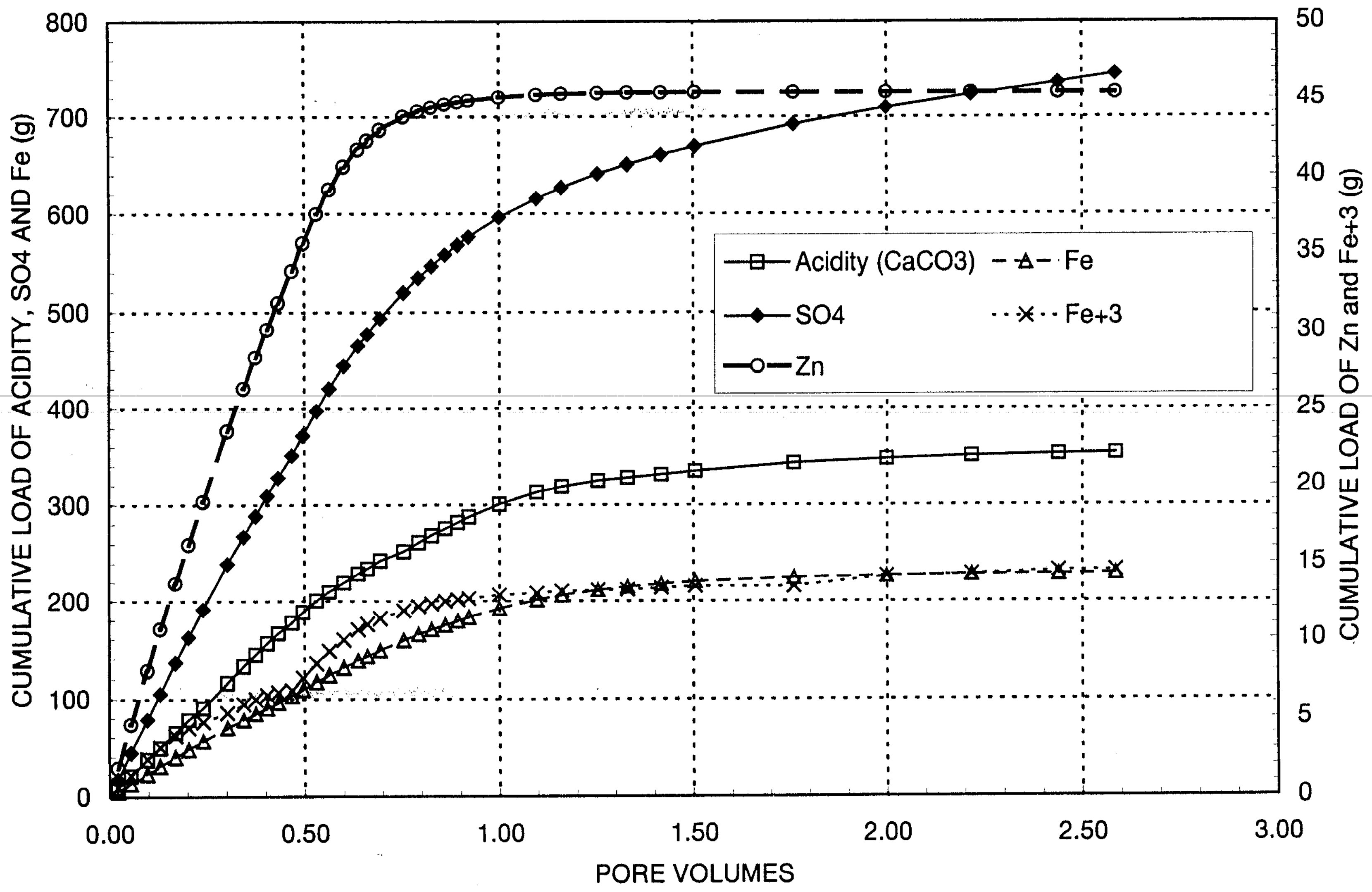

Figure IV-10: Cumulative loads in seepage of MTWC-2

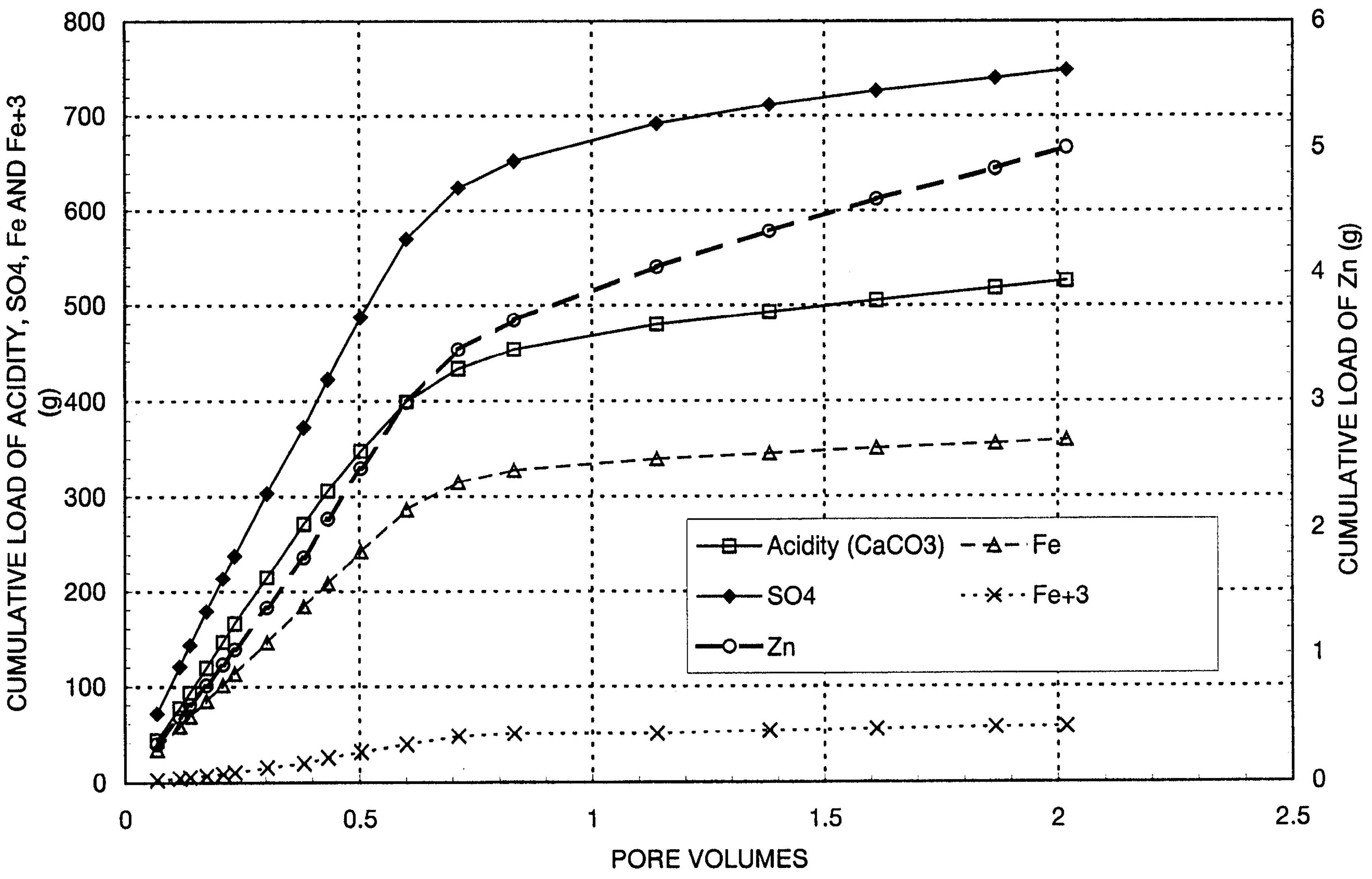

Figure IV-11: Cumulative loads in seepage of MTWC-3

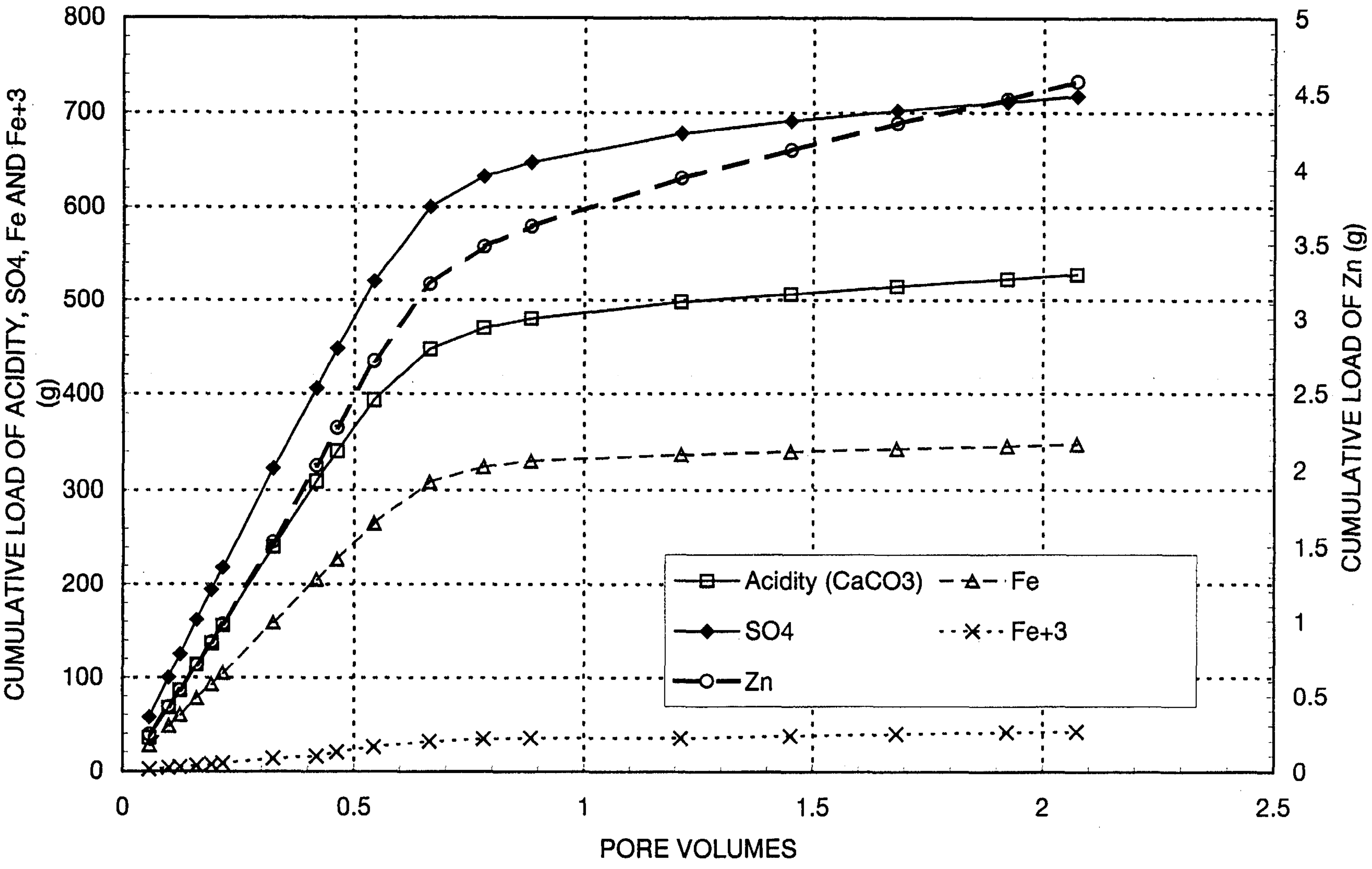

Figure IV-12: Cumulative loads in seepage of MTWC-4

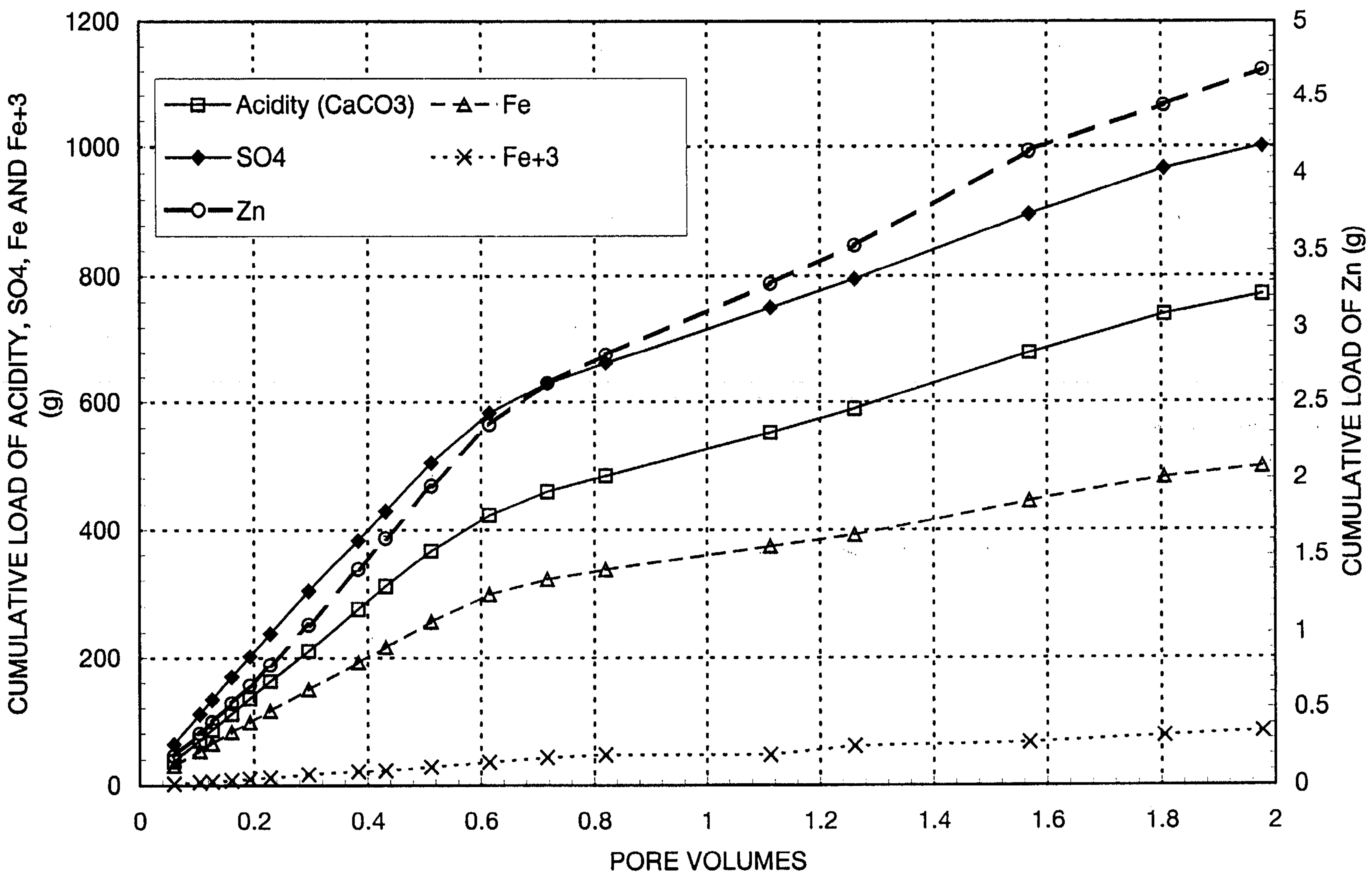

Figure IV-13: Cumulative loads in seepage of MTWC-5

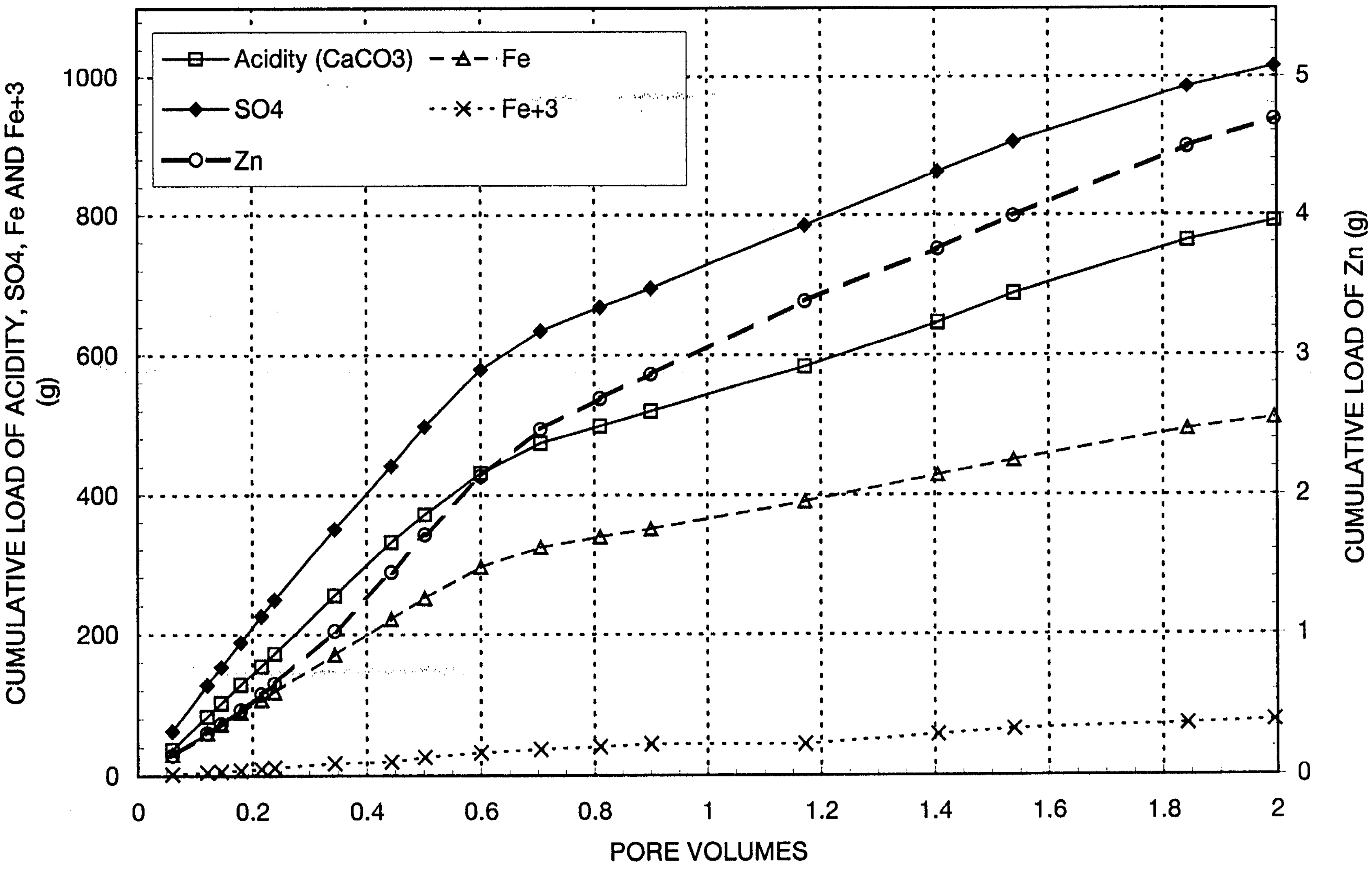

Figure IV-14: Cumulative loads in seepage of MTWC-6

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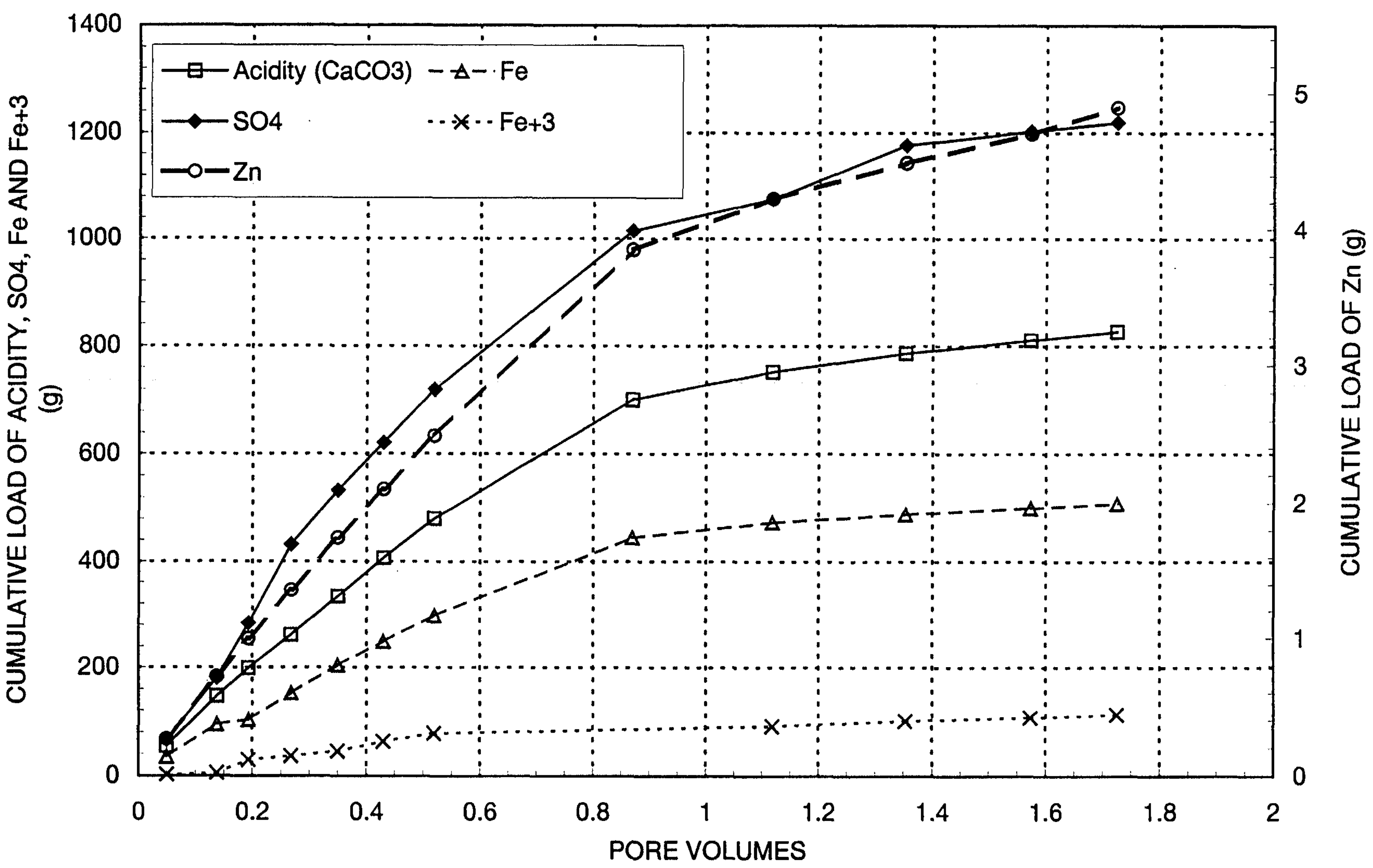

Figure IV-15: Cumulative loads in seepage of MTWC-7

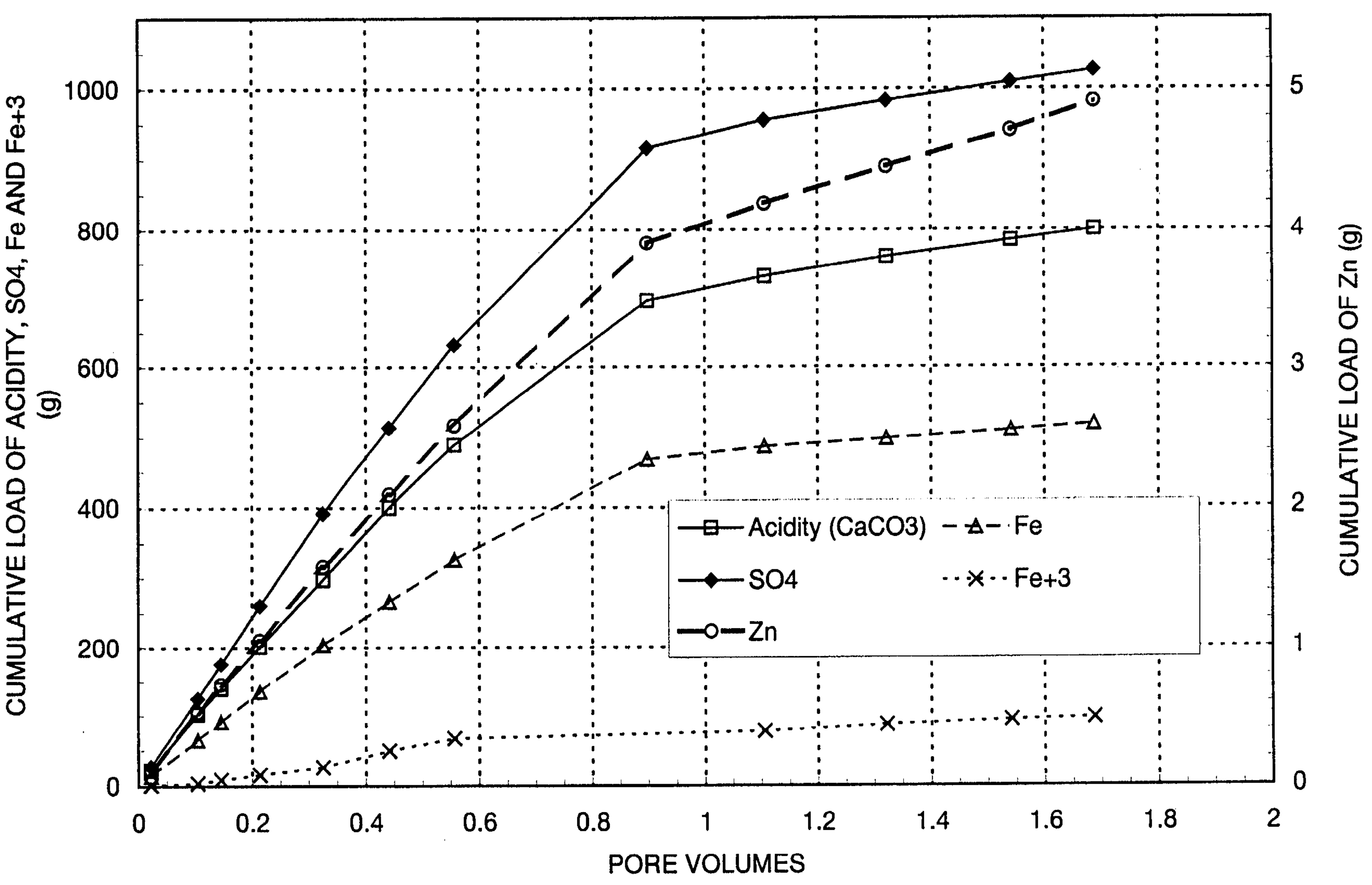

Figure IV-16: Cumulative loads in seepage of MTWC-8

APPENDIX V

COLUMN TESTS DATA

Iron concentration profile data for column MTWC-1

		SPECIES Fe (mg/L)											
		Static profile #1	Static profile #2	Static profile #3	Static profile #4	Static profile #5	Static Kinetic profile	Kinetic profile #1	Kinetic profile #2	Kinetic profile #3	Kinetic profile #4	Kinetic profile #5	Kinetic profile #6
		DATE											
		11/09/92	18/09/92	22/10/92	01/12/92	10/02/93	08/24/93	15/10/93	20/12/93	24/02/94	24/05/94	12/08/94	12/04/95
Depth	Sampling port	Time elapsed (days)											
		0	7	41	51	152	347	399	465	531	620	701	944
0	W1-15	–	–	–	–	–	–	–	–	–	–	–	
5	W1-14	0.23	3.29	–	–	–	–	–	–	–	–	–	
15	W1-13	0.16	3.1	2.99	2.93	107.11	91.12	45.95	35.59	23.58	0.16	0.05	0.04
25	W1-12	1.59	2.76	3.5	3.32	16.27	89.72	–	–	–	–	–	
35	W1-11	0.17	2.68	3.47	2.85	16.26	88.54	91.80	35.37	23.05	0.14	0.06	0.08
45	W1-10	0.32	3.02	3.26	2.99	16.57	88.49	–	–	–	–	–	
50	W1-9	0.18	2.55	3.13	2.89	16.69	88.38	92.86	46.21	23.77	0.17	0.11	0.05
55	W1-8	0.43	2.43	3.2	2.79	29.98	91.17	–	–	–	–	–	
60	W1-7	0.86	2.52	3.21	2.84	34.71	89.76	94.23	67.15	23.76	0.20	0.05	0.03
65	W1-6	1.36	4.73	3.54	2.9	34.34	97.28	–	–	–	–	–	
70	W1-5	3.19	6.37	3.04	5.8	34.58	89.37	92.06	64.80	23.65	0.28	0.05	0.05
75	W1-4	0.21	7.48	7.08	16.34	33.6	89.00	–	–	–	–	0.04	
80	W1-3	0.34	12.84	12.57	17.34	33.19	317.25	99.09	65.34	29.80	0.29	0.10	0.09
85	W1-2	1.3	21.69	11.3	24.47	33.74	756.88	–	65.75	30.73	0.15	0.05	0.09
90	W1-1	15.63	47.9	85.13	198.38	592.02	1310.00	264.39	55.95	32.25	0.19	0.09	0.11
	T1-15	–	–	–	–	–	–	–	–	–	–	–	
105	T1-14	7120	2260	1880	2410	3070	3010	851.03649	269.65	164.11	71.96	33.90	28.81
110	T1-13	8110	3520	4400	3930	7050	5930	–	425.15	218.06	113.03	64.92	46.68
115	T1-12	9840	7710	4910	4150	5460	8430	2205	649.10	340.74	–	114.93	
120	T1-11	3520	3830	4520	3910	4250	6720	–	–	610.44	249.62	143.57	66.39
125	T1-10	1750	6320	5640	5030	4620	6170	3838	1000.00	–	–	–	
130	T1-9	2213.9	5690	4640	4960	4680	8650	–	–	823.18	262.41	169.76	69.51
135	T1-8	2200	7710	5120	4570	4530	8630	5008	1530.00	–	–	–	
140	T1-7	4460	6540	5320	4590	4550	7680	–	–	827.62	322.63	190.78	70.46
145	T1-6	5980	6290	6310	5990	5540	6100	5864	2430.00	–	–	–	
150	T1-5	6260	4710	5130	5510	5320	7990	–	–	1136.01	368.91	189.58	74.04
160	T1-4	5580	6870	5690	5470	5080	7420	8832	3980.00	–	–	284.40	
170	T1-3	5720	5310	6140	6160	5460	5790	–	–	1467.00	554.83	265.02	88.12
180	T1-2	5520	5470	6040	6000	5610	5980	6273	5120.00	–	–	359.72	
190	T1-1	3110	4530	6460	6100	5630	5900	7307	7330.00	3119.00	990.99	422.81	119.56

Ferric concentration profile data for column MTWC-1

		SPECIES Fe+3 (mg/L)											
		Static profile #1	Static profile #2	Static profile #3	Static profile #4	Static profile #5	Static Kinetic profile	Kinetic profile #1	Kinetic profile #2	Kinetic profile #3	Kinetic profile #3	Kinetic profile #5	Kinetic profile #6
		DATE											
		11/09/92	18/09/92	22/10/92	01/12/92	10/02/93	08/24/93	15/10/93	20/12/93	24/02/94	24/05/94	12/08/94	12/04/95
	Sampling	Time elapsed (days)											
Depth	port	0	7	41	51	152	347	399	465	531	620	701	944
0	W1-15	–	–	–	–	–	–	–	–	–	–	–	–
5	W1-14	–	–	–	–	–	–	–	–	–	–	–	–
15	W1-13	–	–	–	–	1.62	5.45	2.90	2.38	1.98	< 0.10	< 0.05	< 0.05
25	W1-12	–	–	–	–	1.49	5.55	–	–	–	–	–	–
35	W1-11	–	–	–	–	1.47	5.45	5.70	2.49	1.86	< 0.10	< 0.05	< 0.05
45	W1-10	–	–	–	–	1.51	5.55	–	–	–	–	–	–
50	W1-9	–	–	–	–	2.08	5.05	6.20	4.00	1.94	< 0.10	< 0.05	< 0.05
55	W1-8	–	–	–	–	2.33	5.30	–	–	–	–	–	–
60	W1-7	–	–	–	–	2.25	5.15	5.70	5.95	1.86	< 0.10	< 0.05	< 0.05
65	W1-6	–	–	–	–	2.32	5.45	–	–	–	–	–	–
70	W1-5	–	–	–	–	1.99	5.30	5.50	5.73	1.92	< 0.10	< 0.05	< 0.05
75	W1-4	–	–	–	–	2.32	5.35	–	–	–	–	< 0.05	< 0.05
80	W1-3	–	–	–	–	2.23	10.40	7.50	5.87	2.49	< 0.10	< 0.05	< 0.05
85	W1-2	–	–	–	–	–	15.10		5.80	2.55	< 0.10	< 0.05	< 0.05
90	W1-1	–	–	–	–	–	19.10	10.30	5.66	2.60	< 0.10	< 0.05	< 0.05
	T1-15	–	–	–	–	–	–	–	–	–	–	–	
105	T1-14	–	–	–	–	41.6	55.5	7.75	3.37	0.68	7.79	0.26	0.82
110	T1-13	–	–	–	–	186	178	–	5.53	0.93	15.90	0.24	0.69
115	T1-12	–	–	–	–	153	330	22	7.23	1.67	–	0.65	
120	T1-11	–	–	–	–	91.3	245	–	–	3.82	17.10	0.32	0.86
125	T1-10	–	–	–	–	119	228	77	6.86	–	–	–	
130	T1-9	–	–	–	–	111	348	–	–	3.11	15.80	0.40	0.91
135	T1-8	–	–	–	–	108	348	117	11.30	–	–	–	
140	T1-7	–	–	–	–	116	283	–	–	2.68	18.80	0.38	0.85
145	T1-6	–	–	–	–	169	180	201	30.30	–	–	–	
150	T1-5	–	–	–	–	148	293	–	–	4.45	19.20	0.39	0.99
160	T1-4	–	–	–	–	157	275	463	77.60	–	–	0.63	
170	T1-3	–	–	–	–	181	175	–	–	6.58	22.70	0.60	0.67
180	T1-2	–	–	–	–	173	185	229	148.00	–	–	0.54	
190	T1-1	–	–	–	–	177	185	296	323.00	23.30	26.40	1.00	0.74

Sulphate concentration profile data for column MTWC-1

		SPECIES SO4 (mg/L) CALCULATED											
		Static profile #1	Static profile #2	Static profile #3	Static profile #4	Static profile #5	Static Kinetic profile	Kinetic profile #1	Kinetic profile #2	Kinetic profile #3	Kinetic profile #3	Kinetic profile #5	Kinetic profile #6
		DATE											
		11/09/92	18/09/92	22/10/92	01/12/92	10/02/93	08/24/93	15/10/93	20/12/93	20/12/93	24/05/94	12/08/94	12/04/95
		Time elapsed (days)											
	Sampling port	0	7	41	51	152	347	399	465	531	620	701	944
Depth		–	–	–	–	–	–	–	–	–	–	–	–
0	W1-15	90.68826	0	0	0	0	0	–	–	–	–	–	–
5	W1-14	90.1194	126.4366	148.5922	167.0053	259.2804	519.9887584	260.118	220.9318	255.0657	223.2273	166.9152	147.8391
15	W1-13	87.84396	124.9097	145.1192	162.7838	255.987	508.2569789	–	–	–	–	–	–
25	W1-12	89.82	125.6881	147.9036	168.5023	262.5738	500.6995241	472.3035	218.826	251.6692	223.2686	209.2293	147.9382
35	W1-11	87.30504	128.0534	150.9275	162.4245	261.8253	502.843797	–	–	–	–	–	–
45	W1-10	86.40684	120.1792	148.712	163.2928	308.0527	500.0514429	476.5977	316.8481	254.7426	225.3125	204.2764	148.4079
50	W1-9	86.61642	118.5325	152.1551	165.3586	318.7412	512.7743261	–	–	–	–	–	–
55	W1-8	90.2691	118.2929	147.3347	165.4185	318.0526	508.5047624	480.7555	461.7682	256.1028	225.4707	209.9831	146.1694
60	W1-7	104.9098	133.6522	148.712	168.7119	317.6335	526.7075339	–	–	–	–	–	–
65	W1-6	113.293	141.9156	147.1551	188.6519	314.849	547.9931673	475.0451	445.008	253.3299	223.3512	207.9067	146.5694
70	W1-5	94.4607	151.6461	179.4005	259.7594	314.1005	540.1253844	–	–	–	–	209.7715	0
75	W1-4	97.39482	179.3406	223.8314	266.7953	314.37	1153.81766	525.0355	445.0153	380.5284	222.9521	208.9251	147.9896
80	W1-3	107.5145	230.8673	189.3705	310.1784	523.1416	2335.527574	0	445.6066	377.8156	241.4021	204.5145	147.3489
85	W1-2	135.239	384.1003	712.3025	1117.66	1823.765	3383.22	938.8817	425.1668	366.7115	239.3058	210.1616	147.9882
90	W1-1	–	–	–	–	–	–	–	–	–	–	–	–
	T1-15	22604.7	15119.7	11047.86	10239.48	8682.6	7634.7	2958.072	1778.393	1390.559	749.2611	277.2597	191.2609
105	T1-14	25089.72	17814.3	17005.92	14730.48	14311.32	13443.06	–	2256.962	1863.088	1739.641	1188.733	311.8391
110	T1-13	27904.08	31137.6	19640.64	16736.46	16257.42	18143.64	5416.146	2693.557	2006.658	–	1682.443	0
115	T1-12	18742.44	19700.52	19790.34	17395.14	16167.6	18862.2	–	–	2704.139	2107.541	1703.888	1640.196
120	T1-11	16856.22	18233.46	18413.1	17005.92	15987.96	19101.72	8233.5	3323.34	–	–	–	–
125	T1-10	11407.14	19820.28	17365.2	17544.84	16437.06	20299.32	–	–	3109.626	2051.339	1747.735	1643.959
130	T1-9	18682.56	30598.68	20628.66	18532.86	17245.44	20748.42	10419.12	4221.54	–	–	–	–
135	T1-8	20389.14	22634.64	20868.18	18922.08	17425.08	20568.78	–	–	3110.693	2237.778	1833.383	1671.8
140	T1-7	18652.62	29311.26	19071.78	18143.64	17035.86	19401.12	16467	5688.6	–	–	–	–
145	T1-6	20598.72	17904.12	18263.4	18562.8	17305.32	19969.98	–	–	3618.659	2272.936	617.5297	617.5297
150	T1-5	18952.02	24910.08	21317.28	19760.4	17964	19640.64	19880.16	8682.6	–	–	676.2965	676.2965
160	T1-4	19999.92	18562.8	19640.64	19790.34	17964	19610.7	–	–	4559.034	2582.498	662.4719	662.4719
170	T1-3	19940.04	19341.24	19580.76	19850.22	18323.28	20449.02	19610.7	13712.52	–	–	731.7143	731.7143
180	T1-2	15808.32	18143.64	21946.02	21407.1	19610.7	21017.88	20508.9	18892.14	6889.675	3295.565	767.1586	767.1586
190	T1-1												

Zinc concentration profile data for column MTWC-1

		SPECIES Zn (mg/L)											
		Static profile #1	Static profile #2	Static profile #3	Static profile #4	Static profile #5	Static Kinetic profile	Kinetic profile #1	Kinetic profile #2	Kinetic profile #3	Kinetic profile #4	Kinetic profile #5	Kinetic profile #6
		DATE											
		11/09/92	18/09/92	22/10/92	01/12/92	10/02/93	08/24/93	15/10/93	20/12/93	24/02/94	24/05/94	12/08/94	12/04/95
		Time elapsed (days)											
Depth	Sampling port	0	7	41	51	152	347	399	465	531	620	701	944
0	W1-15	–	–	–	–	–	–	–	–	–	–	–	
5	W1-14	10.99	15.07	–	–	–	–	–	–	–	–	–	
15	W1-13	10.97	14.74	18.46	18.37	23.64	22.13179	9.82865	8.64417	9.3206	10.47829	8.34204	7.1168
25	W1-12	11	14.67	18.34	18.18	23.34	21.88696	–	–	–	–	–	
35	W1-11	11.07	14.68	18.28	18.64	24.4	21.62373	18.37169	8.54449	9.16579	10.39712	10.74751	7.07049
45	W1-10	11.04	14.87	18.36	18.11	23.96	21.53062	–	–	–	–	–	
50	W1-9	11.01	14.57	18.61	18.4	24.43	21.44671	18.54361	13.07206	9.40334	10.52325	10.4897	7.14874
55	W1-8	11.06	14.27	18.63	18.38	24.64	21.90995	–	–	–	–	–	
60	W1-7	11.32	14.47	18.28	18.25	24.29	21.695	18.79644	19.17178	9.51678	10.63314	10.71989	7.1168
65	W1-6	11.34	15.68	18.2	18.56	23.86	23.79162	–	–	–	–	–	
70	W1-5	11.99	16.63	18.44	19.73	23.9	21.36857	18.44501	18.49325	9.49676	10.49827	10.6186	7.0689
75	W1-4	10.36	17.37	24.72	26.46	23.96	21.17191	–	–	–	–	10.76823	
80	W1-3	10.57	20.3	24.14	24.18	24	18.3674	19.91306	18.54921	14.93377	10.57695	10.66925	7.30043
85	W1-2	12.31	25.24	20.08	26.02	23.99	14.63526	–	18.62441	15.09125	12.9358	10.52883	7.27646
90	W1-1	15.17	41.41	53.8	59.84	22.63	10.4609	18.65545	16.94954	16.31568	12.90943	10.77743	7.36606
	T1-15	–	–	–	–	–	–	–	–	–	–	–	
105	T1-14	2320	1480	1170	710	239.93	75.78871	6.9847	2.35095	1.55838	2.52518	1.67117	2.35166
110	T1-13	2390	1560	1740	1250	46.94	8.37713	–	0.9298	< 0.025	0.6725	0.13266	0.025
115	T1-12	2400	3910	2260	1770	1120	35.42634	8.60238	0.67791	< 0.025	–	0.20004	
120	T1-11	2990	2340	2200	1840	1600	906.59863	–	–	42.73571	1.73136	0.21899	0.025
125	T1-10	2510	2530	2400	2100	1940	1730	86.20514	10.43156	–	–	–	
130	T1-9	881.71	2350	2140	2130	1950	79.17293	–	–	2.8205	1.06941	0.22952	0.025
135	T1-8	2850	3670	2550	2190	1990	94.95814	7.40999	1.14282	–	–	–	
140	T1-7	2680	2530	2670	2210	2050	688.97009	–	–	29.46718	3.29131	0.57065	0.14877
145	T1-6	2160	2410	2450	2310	2150	1890	1200	78.81749	–	–	–	
150	T1-5	2570	2130	2230	2270	2150	448.00833	–	–	26.90443	4.32644	1.51192	0.39729
160	T1-4	2360	2840	2600	2390	2190	712.16113	91.73915	25.96308	–	–	1.75197	
170	T1-3	2520	2300	2490	2480	2250	1990	–	–	101.3397	11.0251	3.55238	0.55621
180	T1-2	2350	2260	2370	2430	2270	2100	1830	726.2184	–	–	18.82954	
190	T1-1	2060	2050	2730	2650	2450	2220	1210	626.1288	110.2175	23.75652	6.83313	0.79797

Iron concentration profile data for column MTWC-2

		SPECIES Fe (mg/L)											
		Static profile #1	Static profile #2	Static profile #3	Static profile #4	Static profile #5	Static Kinetic profile	Kinetic profile #1	Kinetic profile #2	Kinetic profile #3	Kinetic profile #4	Kinetic profile #5	Kinetic profile #6
		DATE											
		11/09/92	18/09/92	22/10/92	01/12/92	10/02/93	08/24/93	15/10/93	20/12/93	24/02/94	24/05/94	12/08/94	12/04/95
	Sampling port	Time elapsed (days)											
Depth		0	7	41	51	152	347	399	465	531	620	701	944
0	W2-15												
5	W2-14	1.74	0.87	0.21									
15	W2-13	1.91	0.78	0.24	< 0.02	1.49	38.10	18.60	20.45	17.10	0.30	0.08	< 0.03
25	W2-12	1.85	0.56	0.26	< 0.02	1.61	38.66						
35	W2-11	1.84	0.71	0.26	< 0.02	1.36	37.80	45.93	23.98	17.20	0.30	0.07	0.05
45	W2-10	1.94	0.85	< 0.2	< 0.02	1.46	37.21						
50	W2-9	1.9	0.69	0.28	< 0.02	1.43	38.00	49.13	33.89	16.96	0.35	0.06	< 0.03
55	W2-8	1.85	0.49	0.28	< 0.02	1.63	37.55						
60	W2-7	1.95	0.67	0.29	< 0.02	1.48	37.79	49.71	40.98	16.70	0.42	0.07	0.26
65	W2-6	1.95	0.44	0.33	0.07	1.61	37.01	–	–	–	–	–	
70	W2-5	1.77	0.02	0.26	< 0.02	1.69	36.45	48.75	39.44	11.08	0.27	0.07	0.04
75	W2-4	1.82	0.02	0.26	< 0.02	3.77	37.35	–	–	–	–	0.07	
80	W2-3	1.88	0.08	2.05	5.16	35.96	103.96	48.27	40.25	11.08	0.25	0.06	0.12
85	W2-2	2.87	1.77	2.11	5.53	36.23	300.75	–	35.90	11.41	0.28	0.08	0.06
90	W2-1	5.1	21.19	33.79	65.52	155.18	639.52	48.12	35.37	11.42	0.32	0.08	0.17
100	T2-15	–	–	–	–	–	–	–	–	–	–	–	17.80
105	T2-14	1740	1060	1190	940	1260	2130	399.97885	65.65	50.20	25.17	16.54	
110	T2-13	701.07	2020	2280	1950	1460	3810	–	137.74	38.60	18.85	11.48	6.10
115	T2-12	4970	8410	3330	2670	2080	5500	893.79718	125.92	98.05	–	25.04	
120	T2-11	7990	8600	4840	4760	4560	6200	–	–	552.10	185.78	124.37	42.43
125	T2-10	7180	7210	4900	4890	5430	6680	2800	532.64	–	–	–	
130	T2-9	6080	6440	5940	5390	5580	6780	–	–	616.38	187.64	122.81	37.29
135	T2-8	6520	5840	7030	5320	5530	7000	5250	1880.00	–	–	–	
140	T2-7	7520	6570	5770	5480	5790	6550	–	–	1142.50	500.13	319.18	91.57
145	T2-6	6450	5250	5790	5450	5830	6450	5410	2850.00	–	–	–	
150	T2-5	6320	5710	7400	6150	6170	6320	–	–	1214.47	524.53	257.13	65.82
160	T2-4	6150	5540	6730	6150	6320	6450	6670	3780.00	–	–	–	
170	T2-3	5310	2950	6430	6200	6400	6470	–	–	1794.00	808.37	413.78	96.52
180	T2-2	3090	2140	6960	6370	6630	6890	6680	5150.00	–	–	–	
190	T2-1	2080	3210	7610	6780	7020	7250	6650	5340.00	2985.00	1181.40	640.21	119.08

Ferric concentration profile data for column MTWC-2

		SPECIES Fe+3 (mg/L)											
		Static profile #1	Static profile #2	Static profile #3	Static profile #4	Static profile #5	Static Kinetic profile	Kinetic profile #1	Kinetic profile #2	Kinetic profile #3	Kinetic profile #4	Kinetic profile #5	Kinetic profile #6
		DATE											
		11/09/92	18/09/92	22/10/92	01/12/92	10/02/93	08/24/93	15/10/93	20/12/93	24/02/94	24/05/94	12/08/94	12/04/95
	Sampling port	Time elapsed (days)											
Depth	port	0	7	41	51	152	347	399	465	531	620	701	944
0	W2-15	–	–	–	–	–	–	–	–	–	–	–	
5	W2-14	–	–	–	–	–	–	–	–	–	–	–	
15	W2-13	–	–	–	–	0.15	1.55	0.65	0.74	1.98	< 0.10	< 0.05	
25	W2-12	–	–	–	–	0.12	1.60	–	–	–	–	–	
35	W2-11	–	–	–	–	0.16	1.50	1.40	0.91	1.86	< 0.10	< 0.05	< 0.05
45	W2-10	–	–	–	–	0.16	1.60	–	–	–	–	–	
50	W2-9	–	–	–	–	0.14	1.50	1.45	1.16	1.94	< 0.10	< 0.05	
55	W2-8	–	–	–	–	0.16	1.65	–	–	–	–	–	
60	W2-7	–	–	–	–	0.16	1.50	1.55	1.45	1.86	< 0.10	< 0.05	< 0.05
65	W2-6	–	–	–	–	0.14	1.60	–	–	–	–	–	
70	W2-5	–	–	–	–	0.15	1.50	1.70	1.48	1.92	< 0.10	< 0.05	< 0.05
75	W2-4	–	–	–	–	0.26	1.55	–	–	–	–	< 0.05	
80	W2-3	–	–	–	–	1.06	2.50	1.70	1.41	2.49	< 0.10	< 0.05	< 0.05
85	W2-2	–	–	–	–	0.9	3.75	–	1.43	2.55	< 0.10	< 0.05	< 0.05
90	W2-1	–	–	–	–	1.81	4.75	1.70	1.48	2.60	< 0.10	< 0.05	< 0.05
100	T2-15	–	–	–	–	–	–	–	–	–	–	–	
105	T2-14	–	–	–	–	7.28	18.5	2.25	0.71	0.68	0.37	< 0.05	0.52
110	T2-13	–	–	–	–	9.64	63.5	–	1.03	0.93	0.69	< 0.05	0.49
115	T2-12	–	–	–	–	22.7	161	4.9	0.53	1.67	–	< 0.05	
120	T2-11	–	–	–	–	96.7	231	–	–	3.82	1.50	0.12	0.68
125	T2-10	–	–	–	–	157	255	31.3	2.53	–	–	–	
130	T2-9	–	–	–	–	169	277	–	–	3.11	2.90	0.20	0.89
135	T2-8		–	–	–	152	298	125	16.00	–	–	–	
140	T2-7	–	–	–	–	177	260	–	–	2.68	5.94	0.34	1.55
145	T2-6	–	–	–	–	149	247	138	34.00	–	–	–	
150	T2-5	–	–	–	–	173	254	–	–	4.45	4.00	0.25	1.02
160	T2-4	–	–	–	–	212	257	243	63.00	–	–	–	
170	T2-3	–	–	–	–	215	267	–	–	6.58	3.85	0.40	1.18
180	T2-2	–	–	–	–	227	310	258	116.00	–	–	–	
190	T2-1	–	–	–	–	254	328	258	145.00	23.30	6.70	0.85	0.82

Sulphate concentration profile data for column MTWC-2

		SPECIES SO_4 (mg/L)											
		Static profile #1	Static profile #2	Static profile #3	Static profile #4	Static profile #5	Static Kinetic profile	Kinetic profile #1	Kinetic profile #2	Kinetic profile #3	Kinetic profile #4	Kinetic profile #5	Kinetic profile #6
		DATE											
		11/09/92	18/09/92	22/10/92	01/12/92	10/02/93	08/24/93	15/10/93	20/12/93	24/02/94	24/05/94	12/08/94	12/04/95
Depth	Sampling port	Time elapsed (days)											
		0	7	41	51	152	347	399	465	531	620	701	944
0	W2-15	–	–	–	–	–	–	–	–	–	–	–	–
5	W2-14	54.28122	76.7961	94.13136	0	0	0	–	–	–	–	–	–
15	W2-13	59.52072	73.8021	96.8559	122.87376	176.37654	366.1421282	164.6017	172.55629	212.42828	166.05194	170.77698	122.66532
25	W2-12	60.3291	82.39488	91.28706	154.31076	175.35858	366.1230565	–	–	–	–	–	–
35	W2-11	54.76026	78.47274	90.08946	117.78396	176.46636	369.6587609	361.6467	197.88574	212.52601	189.31161	170.38025	121.82131
45	W2-10	57.09558	75.11946	92.69424	123.44262	176.88552	368.9535242	–	–	–	–	–	–
50	W2-9	56.85606	76.88592	90.4188	120.17916	176.91546	373.4613505	384.5272	277.47724	213.17226	187.38132	171.94081	122.68735
55	W2-8	58.29318	80.35896	91.9158	119.52048	175.47834	366.7234732	–	–	–	–	–	–
60	W2-7	53.86206	74.16138	89.58048	121.34682	173.44242	372.4892585	386.2568	349.91216	209.96353	189.52493	170.01654	123.20843
65	W2-6	53.77224	74.16138	92.6643	123.71208	198.26268	369.258493	–	–	–	–	–	–
70	W2-5	57.06564	90.29904	90.95772	114.31092	196.43634	369.9542088	379.044	336.7027	278.42095	180.13506	167.33182	123.16073
75	W2-4	57.30516	114.99954	91.67628	113.20314	216.6159	374.7764949	–	–	–	–	168.81965	121.77361
80	W2-3	56.67642	124.37076	181.82562	253.41216	479.69868	571.318553	380.2676	344.84913	279.17239	177.95016	172.00033	0
85	W2-2	62.96382	170.2089	185.05914	260.29836	480.74658	1173.105338	–	311.04941	280.25448	182.56424	171.25309	119.55713
90	W2-1	123.772	395.77686	623.59032	860.53548	1128.7979	2116.093542	374.1952	308.32784	276.32437	183.69624	169.7851	123.99373
100	T2-15	–	–	–	–	–	–	–	–	–	–	–	–
105	T2-14	19191.54	16526.88	9221.52	7005.96	4730.52	6137.7	2236.599	1127.4604	1343.2753	391.33346	249.16936	157.0059
110	T2-13	16287.36	17514.9	15598.74	12514.92	7993.98	9520.92	–	1766.3344	1714.4931	1494.2164	1306.0745	244.38759
115	T2-12	23023.86	29281.32	19281.36	16646.64	11976	13682.58	3233.52	1571.1916	1772.2199	–	1663.5582	0
120	T2-11	28113.66	29730.42	18472.98	18323.28	19760.4	17484.96	–	–	2782.789	1930.6894	1778.2273	1563.2335
125	T2-10	29760.36	26766.36	18233.46	18353.22	18652.62	18413.1	6377.22	2184.3289	–	–	–	–
130	T2-9	28233.42	26137.62	20059.8	19401.12	18712.5	19969.98	–	–	2871.4304	1949.4004	1732.607	1520.416
135	T2-8	25718.46	21646.62	22634.64	20419.08	19640.64	20688.54	11167.62	3892.2	–	–	–	–
140	T2-7	26646.6	25059.78	20538.84	19910.1	19670.58	19820.28	–	–	3851.9191	2364.3755	2023.8588	1679.1283
145	T2-6	19640.64	19161.6	19790.34	19880.16	19520.88	19940.04	12724.5	5568.84	–	–	–	–
150	T2-5	19910.1	20838.24	22754.4	20628.66	19850.22	19880.16	–	–	3990.3445	2418.055	1944.6797	1622.8324
160	T2-4	19969.98	19461	21736.44	20928.06	20538.84	20059.8	18952.02	7964.04	–	–	–	–
170	T2-3	18173.58	15508.92	22245.42	21526.86	21257.4	20508.9	–	–	4455.072	2845.2828	2203.8736	1666.6186
180	T2-2	14640.66	14730.48	23293.32	22544.82	21886.14	21975.96	20808.3	11167.62	–	–	–	–
190	T2-1	14251.44	16377.18	24011.88	23113.68	22425.06	22904.1	21287.34	13383.18	6365.244	3478.9088	2568.8827	1737.2336

Zinc concentration profile data for column MTWC-2

Depth	Sampling port	Static profile #1	Static profile #2	Static profile #3	Static profile #4	Static profile #5	Static Kinetic profile	Kinetic profile #1	Kinetic profile #2	Kinetic profile #3	Kinetic profile #4	Kinetic profile #5	Kinetic profile #6
		SPECIES Zn (mg/L)											
		DATE											
		11/09/92	18/09/92	22/10/92	01/12/92	10/02/93	08/24/93	15/10/93	20/12/93	24/02/94	24/05/94	12/08/94	12/04/95
		Time elapsed (days)											
		0	7	41	51	152	347	399	465	531	620	701	944
0	W2-15	–	–	–	–	–	–	–	–	–	–	–	
5	W2-14	3.97	6.58	10.26	–	–	–	–	–	–	–	–	
15	W2-13	4.22	6.31	10.17	11.16	15.43	16.28216	6.05818	7.07441	7.09321	6.62589	8.45253	6.02621
25	W2-12	4.32	6.95	9.95	11.18	15.34	16.15917	–	–	–	–	–	
35	W2-11	4.13	6.55	9.74	11.35	15.45	16.35343	14.07966	8.11435	7.11056	7.761	8.43411	6.02301
45	W2-10	3.96	6.4	10.01	11.22	15.47	16.22239	–	–	–	–	–	
50	W2-9	4.3	6.39	9.92	11.02	15.43	16.5385	14.97893	11.28503	7.12791	7.59492	8.46404	6.11882
55	W2-8	4.23	6.93	9.96	11.18	15.36	16.11549	–	–	–	–	–	
60	W2-7	3.97	6.38	9.88	11.09	15.22	16.24883	14.97642	13.92259	7.06785	7.76225	8.43641	6.14117
65	W2-6	3.96	6.26	10.13	11.35	17.08	16.07066	–	–	–	–	–	
70	W2-5	4.34	8.33	9.89	10.37	16.81	16.05917	14.80936	13.45611	9.66892	7.24901	8.296	6.05814
75	W2-4	4.11	11.32	9.89	10.33	17.96	16.1086	–	–	–	–	8.32362	
80	W2-3	4.08	12.42	19.08	20.96	29.76	14.94879	14.81815	13.69812	9.70361	7.12414	8.46864	5.95435
85	W2-2	5.37	17.82	19.1	21.53	29.63	12.91423	–	12.32267	9.75833	7.47004	8.43872	5.91763
90	W2-1	15.3	45.9	56.87	58.6	46.76	9.26238	14.38228	12.22127	9.63822	7.45006	8.44792	5.98629
	T2-15	–	–	–	–	–	–	–	–	–	–	–	
105	T2-14	3190	2240	1210	740	87.99	3.40931	< 0.02499	0.07812	< 0.02499	< 0.025	0.23709	0.25228
110	T2-13	2240	2060	2030	1480	779.71	27.47106	–	2.05627	< 0.02499	< 0.025	0.1289	< 0.025
115	T2-12	2480	2410	2600	2070	1410	66.08963	2.53856	0.39895	< 0.02499	–	0.09898	
120	T2-11	2870	2630	2480	2310	1960	882.24993	–	–	37.15027	6.0602	0.33147	< 0.025
125	T2-10	3930	2940	2580	2400	2320	1220	51.44086	2.61646	–	–	–	
130	T2-9	3970	2960	2450	2110	2130	1660	–	–	47.30498	2.09041	0.15883	< 0.025
135	T2-8	4020	2750	2660	2180	2130	1650	131.478	3.34622	–	–	–	
140	T2-7	3860	3240	2820	2490	2490	1910	–	–	71.49929	0.55819	0.42584	< 0.025
145	T2-6	2340	2340	2790	2610	2520	2050	402.4997	25.33354	–	–	–	
150	T2-5	2490	2640	2580	2290	2360	2090	–	–	73.88283	4.81519	1.57679	0.23312
160	T2-4	2580	2460	2970	2600	2560	2160	1150	74.70568	–	–	–	
170	T2-3	2470	2250	3000	2650	2690	2220	–	–	101.3375	3.88986	2.66558	0.57803
180	T2-2	2200	2230	3260	2890	2820	2400	1890	284.51638	–	–	–	
190	T2-1	2330	2240	2780	2600	2680	2540	2100	586.34735	88.09194	9.36565	1.42486	0.15488

Iron concentration profile data for column MTWC-3

		SPECIES Fe (mg/L)						
		Static profile #1	Static profile #2	Static Kinetic profile	Kinetic profile #1	Kinetic profile #2	Kinetic profile #3	Kinetic profile #4
		DATE						
		10/07/93	15/10/93	20/12/93	24/02/94	24/05/94	12/08/94	12/04/95
		Time elapsed (days)						
Depth	Sampling port	0	97	163	229	317	399	642
0	W3-15	0.20135	< 0.02499	< 0.02499	< 0.02499	0.0614	–	
5	W3-14	–	–	–	–	–	0.10743	
15	W3-13	–	< 0.02499	< 0.02499	< 0.02499	0.07622	< 0.03	< 0.03
25	W3-12	–	–	–	–	–	–	
35	W3-11	–	< 0.02499	< 0.02499	< 0.02499	0.07956	< 0.03	< 0.03
45	W3-10	–	–	–	–	–	–	
50	W3-9	–	< 0.02499	< 0.02499	< 0.02499	0.09916	< 0.03	0.07
55	W3-8	–	–	–	–	–	–	
60	W3-7	0.1704	< 0.02499	< 0.02499	< 0.02499	0.07789	< 0.03	0.04
65	W3-6	–	–	–	–	–	–	
70	W3-5	–	< 0.02499	< 0.02499	< 0.02499	0.08291	< 0.03	< 0.03
75	W3-4	–	–	–	–	–	–	
80	W3-3	–	< 0.02499	< 0.02499	21.27097	0.12544	< 0.03	< 0.03
85	W3-2	–	–	< 0.02499	< 0.02499	0.06069	0.19	< 0.025
90	W3-1	2.78948	0.02499	0.34321	< 0.02499	0.06618	0.06	0.04
100	T3-15	1.00439	439.44024	829.55273	< 0.02499	0.081	–	0.03906
105	T3-14	1650	–	4910	23.40469	3.23867	2.10399	0.63218
110	T3-13	6750	7250	6890	39.37664	3.78634	2.37855	0.77086
115	T3-12	8940	–	–	–	–	39.07969	
120	T3-11	9240	14120	13400	406.07748	79.43046	84.12339	25.18504
125	T3-10	8690	–	–	–	–	–	
130	T3-9	10000	15840	15100	2206	785.99938	626.10241	237.60441
135	T3-8	8820	–	–	–	–		
140	T3-7	8840	14520	14400	6001	1400	946.14611	450.87573
145	T3-6	8330	–	–	–	–	–	
150	T3-5	8490	14810	14300	10420	1784	1063.17651	537.9057
160	T3-4	8660	–	–	–	–	–	
170	T3-3	8260	14710	14500	12930	4160	1247.39794	773.99407
180	T3-2	4180	–	–	–	–	–	
190	T3-1	3000	14180	14000	12970	10200	1508	789.77142

Ferric concentration profile data for column MTWC-3

		SPECIES Fe+3 (mg/L)											
		Static profile #1	Static profile #2	Static Kinetic profile	Kinetic profile #1	Kinetic profile #2	Kinetic profile #3	Kinetic profile #4					
		DATE											
		10/07/93	15/10/93	20/12/93	24/02/94	24/05/94	12/08/94	12/04/95					
Depth	Sampling port	Time elapsed (days)											
		0	97	163	229	317	399	642					
0	W3-15	< 0.1	< 0.05	< 0.05	< 0.05	< 0.1	–						
5	W3-14	–	–	–	–	–	< 0.05						
15	W3-13	–	< 0.05	< 0.05	< 0.05	< 0.1	< 0.05						
25	W3-12	–	–	–	–	–	–						
35	W3-11	–	< 0.05	< 0.05	< 0.05	< 0.1	< 0.05						
45	W3-10	–	–	–	–	–	–						
50	W3-9	–	< 0.05	< 0.05	< 0.05	< 0.1	< 0.05	< 0.05					
55	W3-8	–	–	–	–	–	–						
60	W3-7	< 0.1	< 0.05	< 0.05	< 0.05	< 0.1	< 0.05	< 0.05					
65	W3-6	–	–	–	–	–	–						
70	W3-5	–	< 0.05	< 0.05	< 0.05	< 0.1	< 0.05						
75	W3-4	–	–	–	–	–	–						
80	W3-3	–	< 0.05	< 0.05	0.49	< 0.1	< 0.05						
85	W3-2	–	–	–	< 0.05	< 0.1	0.07						
90	W3-1	< 0.1	< 0.05	< 0.05	< 0.05	< 0.1	< 0.05	< 0.05					
100	T3-15	< 0.1	2.3	5.1	< 0.05	< 0.1	–	< 0.05					
105	T3-14	400	–	117	0.34	< 0.1	< 0.05	0.23					
110	T3-13	2150	199	243	1.22	< 0.1	< 0.05	0.4					
115	T3-12	2370	–	–	–	–	0.13						
120	T3-11	3760	716	920	10.1	0.4	0.0785	0.55					
125	T3-10	2330	–	–	–	–	–						
130	T3-9	2850	920	1110	24.7	8.79	1.37	0.95					
135	T3-8	2250	–	–	–	–	–						
140	T3-7	2440	790	1050	181	9.6	1.38	1.99					
145	T3-6	2280	–	–	–	–	–						
150	T3-5	2400	960	1020	546	62.2	2.28	3.35					
160	T3-4	2490	–	–	–	–	–						
170	T3-3	2220	914	1090	739	254	4.03	3.92					
180	T3-2	780	–	–	–	–	–						
190	T3-1	670	926	1120	694	545	5.04	4.55					

Sulphate concentration profile data for column MTWC-3

		SPECIES SO4 (mg/L)											
		Static profile #1	Static profile #2	Static Kinetic profile	Kinetic profile #1	Kinetic profile #2	Kinetic profile #3	Kinetic profile #4					
		DATE											
		10/07/93	15/10/93	20/12/93	24/02/94	24/05/94	12/08/94	12/04/95					
		Time elapsed (days)											
Depth	Sampling port	0	97	163	229	317	399	642					
0	W3-15	1.976369	25.01952	47.3749602	51.54578	26.528397	–						
5	W3-14			–	–	–	36.151053						
15	W3-13		24.87108	47.77193466	50.29806	39.534513	35.807222	19.669293					
25	W3-12			–	–	–	–						
35	W3-11		25.33869	47.29283478	52.10033	39.235172	36.435423	20.344529					
45	W3-10			–	–	–	–						
50	W3-9		24.86367	45.78029592	50.13303	38.863587	36.078329	19.838094					
55	W3-8			–	–	–	–						
60	W3-7	5.950425	25.52424	46.57418496	50.87902	39.345292	36.270094	19.907825					
65	W3-6			–	–	–	–						
70	W3-5		25.36095	47.9087904	50.8856	38.846372	36.805721	20.113333					
75	W3-4			–	–	–	–						
80	W3-3		26.66721	46.05403734	111.433	39.107868	36.21719	20.41423					
85	W3-2			46.70424432	58.77114	37.748771	37.29506	20.671115					
90	W3-1	13.57971	24.89337	49.031241	58.75611	38.76724	36.984253	20.010579					
100	T3-15	194.6214	2523.8757	2940.30773	67.04464	39.723763	–	20.696803					
105	T3-14	6167.64		9970.02	1282.731	70.31918	52.411467	27.537016					
110	T3-13	18652.62	13772.4	13203.54	1717.957	93.114328	64.783633	29.4159					
115	T3-12	20688.54		–	–	–	–						
120	T3-11	21017.88	24670.56	23832.24	2459.935	540.52901	315.73841	117.0104					
125	T3-10	19490.94		–	–	–	–						
130	T3-9	24431.04	27544.8	26257.38	4670.64	2493.2809	1325.3832	519.65154					
135	T3-8	22754.4		–	–	–	–						
140	T3-7	24101.7	26736.42	26077.74	11296.36	3547.89	2093.7674	913.54057					
145	T3-6	22784.34		–	–	–	–						
150	T3-5	22844.22	27754.38	26556.78	18826.27	4233.516	2368.7127	1069.6328					
160	T3-4	23832.24		–	–	–	–						
170	T3-3	22425.06	28233.42	27335.22	23511.88	8371.224	3113.3708	1511.0915					
180	T3-2	11736.48		–	–	–	–						
190	T3-1	8383.2		27634.62	27335.22	24050.802	19032.858	3605.0373					

Zinc concentration profile data for column MTWC-3

		SPECIES Zn (mg/L)											
		Static profile #1	Static profile #2	Static Kinetic profile	Kinetic profile #1	Kinetic profile #2	Kinetic profile #3	Kinetic profile #4					
		DATE											
		10/07/93	15/10/93	20/12/93	24/02/94	24/05/94	12/08/94	12/04/95					
	Sampling	Time elapsed (days)											
Depth	port	0	97	163	229	317	399	642					
0	W3-15	< 0.02499	< 0.02499	< 0.02499	< 0.02499	< 0.025	–						
5	W3-14	–	–	–	–	–	0.08286						
15	W3-13	–	< 0.02499	< 0.02499	< 0.02499	< 0.025	0.05984	< 0.025					
25	W3-12	–	–	–	–	–	–						
35	W3-11	–	< 0.02499	< 0.02499	< 0.02499	< 0.025	0.05294	< 0.025					
45	W3-10	–	–	–	–	–	–						
50	W3-9	–	< 0.02499	< 0.02499	< 0.02499	< 0.025	0.05294	< 0.025					
55	W3-8	–	–	–	–	–	–						
60	W3-7	< 0.02499	< 0.02499	< 0.02499	< 0.02499	< 0.025	0.05984	< 0.025					
65	W3-6	–	–	–	–	–	–						
70	W3-5	–	< 0.02499	< 0.02499	< 0.02499	< 0.025	0.06905	< 0.025					
75	W3-4	–	–	–	–	–	–						
80	W3-3	–	< 0.02499	< 0.02499	< 0.02499	< 0.025	0.05754	< 0.025					
85	W3-2	–	–	–	< 0.02499	< 0.025	0.08056	< 0.025					
90	W3-1	< 0.02499	< 0.02499	< 0.02499	< 0.02499	< 0.025	0.07366	< 0.025					
100	T3-15	< 0.02499	0.84263	2.88609	< 0.02499	< 0.025	–	< 0.025					
105	T3-14	49.44693	–	31.47862	< 0.02499	< 0.025	0.06905	< 0.025					
110	T3-13	161.2308	77.11743	66.79475	0.19618	< 0.025	0.13811	< 0.025					
115	T3-12	155.6901	–	–	–	–	0.79645						
120	T3-11	152.8966	176.17138	168.59689	6.50066	< 0.025	1.27754	0.10858					
125	T3-10	141.6418	–	–	–	–	–						
130	T3-9	165.0002	187.58293	179.95838	34.66798	10.54448	9.59196	2.01672					
135	T3-8	101.5201	–	–	–	–	–						
140	T3-7	77.01435	144.58909	151.81724	87.96382	22.42513	19.21616	7.05293					
145	T3-6	74.80955	–	–	–	–	–						
150	T3-5	78.20898	137.58096	138.88401	144.2438	33.01082	26.37273	11.99015					
160	T3-4	74.32868	–	–	–	–	–						
170	T3-3	59.29035	121.9709	133.88423	152.9211	65.14002	34.8782	26.77943					
180	T3-2	33.90151	–	–	–	–	–						
190	T3-1	24.29904	113.39823	124.18102	138.2809	129.70687	37.73254	28.34587					

Iron concentration profile data for column MTWC-4

		SPECIES Fe (mg/L)											
		Static profile #1	Static profile #2	Static Kinetic profile	Kinetic profile #1	Kinetic profile #2	Kinetic profile #3	Kinetic profile #4	Kinetic profile #2	Kinetic profile #3	Kinetic profile #4	Kinetic profile #5	Kinetic profile #6
		DATE											
		10/07/93	15/10/93	20/12/93	24/02/94	24/05/94	12/08/94	12/04/95	20/12/93	24/02/94	24/05/94	12/08/94	12/04/95
	Sampling	Time elapsed (days)											
Depth	port	0	97	163	229	317	399	642	465	531	620	701	944
0	W4-15	0.05952	< 0.02499	< 0.02499									
5	W4-14	–	–	–		0.05439	0.27	0.04059					
15	W4-13	–	0.59963	< 0.02499	< 0.02499	0.03641	0.07	< 0.03	20.45	17.10	0.30	0.08	< 0.03
25	W4-12	–	–	–									
35	W4-11	–	0.23886	< 0.02499	< 0.02499	0.03689	0.08	0.05	23.98	17.20	0.30	0.07	0.05
45	W4-10	–	–	–									
50	W4-9	–	0.81146	< 0.02499	0.11597	< 0.025	0.10	< 0.03	33.89	16.96	0.35	0.06	< 0.03
55	W4-8	–	–	–									
60	W4-7	0.19211	0.47322	< 0.02499	< 0.02499	5.01619	0.03	< 0.03	40.98	16.70	0.42	0.07	0.26
65	W4-6	–	–	–					–	–	–	–	
70	W4-5	–	0.38916	0.14827	< 0.02499	0.14023	< 0.03	< 0.03	39.44	11.08	0.27	0.07	0.04
75	W4-4	–	–	–					–	–	–	0.07	
80	W4-3	–	1.16412	< 0.02499	0.36859	0.1504	< 0.03	< 0.03	40.25	11.08	0.25	0.06	0.12
85	W4-2	–	–	–	< 0.02499	0.10003	0.05	< 0.025	35.90	11.41	0.28	0.08	0.06
90	W4-1	0.16589	0.7745	0.28661	< 0.02499	0.04374	0.04	< 0.03	35.37	11.42	0.32	0.08	0.17
100	T4-15	0.46265	154.63145	463.93261	< 0.02499	0.04398	0.04685	< 0.025	–	–	–	–	17.80
105	T4-14	360.17547	–	4300	27.55409	3.05318	2.06	0.758	65.65	50.20	25.17	16.54	
110	T4-13	6170	6380	6920	65.99099	6.00373	5.01	1.94986	137.74	38.60	18.85	11.48	6.10
115	T4-12	7930	–	–			16.67		125.92	98.05	–	25.04	
120	T4-11	9260	13580	13200	622	71.61082	49.67	17.6017	–	552.10	185.78	124.37	42.43
125	T4-10	9480	–	–					532.64	–	–	–	
130	T4-9	9920	14450	14300	3328	549.88934	433.72	202.16174	–	616.38	187.64	122.81	37.29
135	T4-8	9290	–	–					1880.00	–	–	–	
140	T4-7	9500	15130	15100	7452	697.63397	584.77	264.06948	–	1142.50	500.13	319.18	91.57
145	T4-6	9160	–	–					2850.00	–	–	–	
150	T4-5	7880	14500	14300	11990	1117.26184	760.65	422.23641	–	1214.47	524.53	257.13	65.82
160	T4-4	7590	–	–					3780.00	–	–	–	
170	T4-3	6860	13690	14200	14780	2614	616.13	474.70135	–	1794.00	808.37	413.78	96.52
180	T4-2	6170	13330	14100			817.95		5150.00	–	–	–	
190	T4-1	4320	–	–	12390	4841		623.86395	5340.00	2985.00	1181.40	640.21	119.08

Ferric concentration profile data for column MTWC-4

SPECIES
Fe+3 (mg/L)

Sampling port	Static profile #1	Static profile #2	Static Kinetic profile	Kinetic profile #1	Kinetic profile #2	Kinetic profile #3	Kinetic profile #4	Kinetic profile #2	Kinetic profile #3	Kinetic profile #4	Kinetic profile #5	Kinetic profile #6
DATE	10/07/93	15/10/93	20/12/93	24/02/94	24/05/94	12/08/94	12/04/95	20/12/93	24/02/94	24/05/94	12/08/94	12/04/95
Time elapsed (days)	0	97	163	229	317	399	642	465	531	620	701	944
W4-15	< 0.1	< 0.05	< 0.05	< 0.05				—	—	—	—	
W4-14	—	—	—	—	< 0.1	< 0.05	< 0.05	—	—	—	—	
W4-13	—	< 0.05	< 0.05	< 0.05	< 0.1	< 0.05		0.74	1.98	< 0.10	< 0.05	
W4-12	—	—	—	—				—	—	—	—	
W4-11	—	< 0.05	< 0.05	< 0.05	< 0.1	< 0.05	< 0.05	0.91	1.86	< 0.10	< 0.05	< 0.05
W4-10	—	—	—	—				—	—	—	—	
W4-9	—	< 0.05	< 0.05	0.17	< 0.1	< 0.05		1.16	1.94	< 0.10	< 0.05	
W4-8	—	—	—	—				—	—	—	—	
W4-7	< 0.1	< 0.05	< 0.05	< 0.05	< 0.1	< 0.05		1.45	1.86	< 0.10	< 0.05	< 0.05
W4-6	—	—	—	—				—	—	—	—	
W4-5	—	< 0.05	< 0.05	< 0.05	< 0.1	< 0.05		1.48	1.92	< 0.10	< 0.05	< 0.05
W4-4	—	—	—	—				—	—	—	< 0.05	
W4-3	—	< 0.05	< 0.05	0.25	< 0.1	< 0.05		1.41	2.49	< 0.10	< 0.05	< 0.05
W4-2	—	—	—	< 0.05	< 0.1	< 0.05		1.43	2.55	< 0.10	< 0.05	< 0.05
W4-1	< 0.1	< 0.05	< 0.05	< 0.05	< 0.1	< 0.05		1.48	2.60	< 0.10	< 0.05	< 0.05
T4-15	< 0.1	1.05	3.01	< 0.05	< 0.1	< 0.05		—	—	—	—	
T4-14	90	—	94.3	0.42	< 0.1	< 0.05	0.27	0.71	0.68	0.37	< 0.05	0.52
T4-13	2160	156	265	1.7	0.12	< 0.05	0.8	1.03	0.93	0.69	< 0.05	0.49
T4-12	6830	—	—			< 0.05		0.53	1.67	—	< 0.05	
T4-11	2330	668	954	24.8	0.46	5.04	0.61	—	3.82	1.50	0.12	0.68
T4-10	2310	—	—					2.53	—	—	—	
T4-9	2740	740	1110	115	5.85	0.403	0.73	—	3.11	2.90	0.20	0.89
T4-8	2660	—	—					16.00	—	—	—	
T4-7	2730	852	1200	241	2.91	0.757	1.24	—	2.68	5.94	0.34	1.55
T4-6	2670	—	—					34.00	—	—	—	
T4-5	2060	838	1100	589	9.23	1.7	3.45	—	4.45	4.00	0.25	1.02
T4-4	2130	—	—					63.00	—	—	—	
T4-3	1770	736	1120	819	23.8	0.971	3.98	—	6.58	3.85	0.40	1.18
T4-2	1480	732	1050			2.38		116.00	—	—	—	
T4-1	1520	—	—	693	165		3.48	145.00	23.30	6.70	0.85	0.82

Sulphate concentration profile data for column MTWC-4

		SPECIES SO4 (mg/L) Calculated											
		Static profile #1	Static profile #2	Static Kinetic profile	Kinetic profile #1	Kinetic profile #2	Kinetic profile #3	Kinetic profile #4	Kinetic profile #2	Kinetic profile #3	Kinetic profile #4	Kinetic profile #5	Kinetic profile #6
		DATE											
		10/07/93	15/10/93	20/12/93	24/02/94	24/05/94	12/08/94	12/04/95	20/12/93	24/02/94	24/05/94	12/08/94	12/04/95
	Sampling port	Time elapsed (days)											
Depth		0	97	163	229	317	399	642	465	531	620	701	944
0	W4-15	2.890198	21.545812	40.72247184					–	–	–	–	–
5	W4-14	–	–	–	46.96829	34.509982	31.04778	16.838106	–	–	–	–	–
15	W4-13	–	21.760152	40.414509	47.84322	35.181985	32.42502	16.389934	172.55629	212.42828	166.05194	170.77698	122.66532
25	W4-12	–	–	–	–				–	–	–	–	–
35	W4-11	–	22.46024	40.510317	46.88646	35.516385	31.5867	17.163734	197.88574	212.52601	189.31161	170.38025	121.82131
45	W4-10	–	–	–	–				–	–	–	–	–
50	W4-9	–	21.845871	40.76354952	46.76688	34.94501	32.84418	16.589514	277.47724	213.17226	187.38132	171.94081	122.68735
55	W4-8	–	–	–	–				–	–	–	–	–
60	W4-7	4.994082	22.267366	41.75594076	47.32077	48.865882	32.81424	16.635023	349.91216	209.96353	189.52493	170.01654	123.20843
65	W4-6	–	–	–	–				–	–	–	–	–
70	W4-5	–	22.010181	42.56354232	47.40259	35.922192	31.34718	16.995681	336.7027	278.42095	180.13506	167.33182	123.16073
75	W4-4	–	–	–	–				–	–	–	168.81965	121.77361
80	W4-3	–	24.853434	40.79777094	48.54202	36.071532	32.75436	16.754065	344.84913	279.17239	177.95016	172.00033	0
85	W4-2	–	–	40.61298126	47.26131	36.694853	32.00586	17.149722	311.04941	280.25448	182.56424	171.25309	119.55713
90	W4-1	4.887825	23.824725	43.07686362	46.52853	35.253422	32.69448	17.195261	308.32784	276.32437	183.69624	169.7851	123.99373
100	T4-15	79.90573	1682.4542	2229.019467	54.70137	37.084433	32.57472	17.895527	–	–	–	–	–
105	T4-14	2454.254	–	8832.3	894.2351	55.115318	43.98186	25.080349	1127.4604	1343.2753	391.33346	249.16936	157.0059
110	T4-13	17784.36	12275.4	13353.24	1633.39	108.57498	79.25118	36.274256	1766.3344	1714.4931	1494.2164	1306.0745	244.38759
115	T4-12	21107.7	–	–	–		133.86174		1571.1916	1772.2199	–	1663.5582	0
120	T4-11	21556.8	23323.26	23502.9	2490.485	483.80217	285.83718	109.15735	–	2782.789	1930.6894	1778.2273	1563.2335
125	T4-10	22784.34	–	–	–				2184.3289	–	–	–	–
130	T4-9	24880.14	25389.12	25928.04	6700.597	1935.7233	1012.0918	489.55675	–	2871.4304	1949.4004	1732.607	1520.416
135	T4-8	24221.46	–	–	–				3892.2	–	–	–	–
140	T4-7	26197.5	27215.46	27305.28	14434.07	2420.1435	1369.6352	617.18711	–	3851.9191	2364.3755	2023.8588	1679.1283
145	T4-6	25568.76	–	–	–				5568.84	–	–	–	–
150	T4-5	21946.02	27095.7	26946	22592.72	3177.9471	1755.1726	897.39054	–	3990.3445	2418.055	1944.6797	1622.8324
160	T4-4	21466.98	–	–	–				7964.04	–	–	–	–
170	T4-3	20119.68	25808.28	26616.66	27805.28	5577.822	1809.2143	1019.6852	–	4455.072	2845.2828	2203.8736	1666.6186
180	T4-2	17964	25059.78	26766.36	–		2341.9966		11167.62	–	–	–	–
190	T4-1	12934.08	–	–	23062.78	9464.034		1283.9842	13383.18	6365.244	3478.9088	2568.8827	1737.2336

Zinc concentration profile data for column MTWC-4

Depth	Sampling port	SPECIES Zn (mg/L)											
		Static profile #1	Static profile #2	Static Kinetic profile	Kinetic profile #1	Kinetic profile #2	Kinetic profile #3	Kinetic profile #4	Kinetic profile #2	Kinetic profile #3	Kinetic profile #4	Kinetic profile #5	Kinetic profile #6
		DATE											
		10/07/93	15/10/93	20/12/93	24/02/94	24/05/94	12/08/94	12/04/95	20/12/93	24/02/94	24/05/94	12/08/94	12/04/95
		Time elapsed (days)											
		0	97	163	229	317	399	642	465	531	620	701	944
0	W4-15	< 0.02499	< 0.02499	< 0.02499	–				–	–	–	–	
5	W4-14	–	–	–	< 0.02499	< 0.02499	0.08286	< 0.025	–	–	–	–	
15	W4-13	–	< 0.02499	< 0.02499	< 0.02499	< 0.02499	0.05984	< 0.025	7.07441	7.09321	6.62589	8.45253	6.02621
25	W4-12	–	–	–	–				–	–	–	–	
35	W4-11	–	< 0.02499	< 0.02499	< 0.02499	< 0.02499	0.05524	< 0.025	8.11435	7.11056	7.761	8.43411	6.02301
45	W4-10	–	–	–	–				–	–	–	–	
50	W4-9	–	< 0.02499	< 0.02499	< 0.02499	< 0.02499	0.05984	< 0.025	11.28503	7.12791	7.59492	8.46404	6.11882
55	W4-8	–	–	–	–				–	–	–	–	
60	W4-7	< 0.02499	< 0.02499	< 0.02499	< 0.02499	< 0.02499	0.06675	< 0.025	13.92259	7.06785	7.76225	8.43641	6.14117
65	W4-6	–	–	–	–				–	–	–	–	
70	W4-5	–	< 0.02499	< 0.02499	< 0.02499	< 0.02499	0.06675	< 0.025	13.45611	9.66892	7.24901	8.296	6.05814
75	W4-4	–	–	–	–				–	–	–	8.32362	
80	W4-3	–	< 0.02499	< 0.02499	< 0.02499	< 0.02499	0.07596	< 0.025	13.69812	9.70361	7.12414	8.46864	5.95435
85	W4-2	–	–	–	< 0.02499	< 0.02499	0.06905	< 0.025	12.32267	9.75833	7.47004	8.43872	5.91763
90	W4-1		< 0.02499	< 0.02499	< 0.02499	< 0.02499	0.06675	< 0.025	12.22127	9.63822	7.45006	8.44792	5.98629
100	T4-15	< 0.02499	< 0.02499	2.69481	< 0.02499	< 0.02499	0.05984	< 0.025	–	–	–	–	
105	T4-14	11.62277	–	24.92617	< 0.02499	< 0.02499	0.06445	< 0.025	0.07812	< 0.02499	< 0.025	0.23709	0.25228
110	T4-13	148.5888	68.30409	72.59379	0.55107	< 0.02499	0.13	< 0.025	2.05627	< 0.02499	< 0.025	0.1289	< 0.025
115	T4-12	162.871	–	–	–		0.36		0.39895	< 0.02499	–	0.09898	
120	T4-11	153.5347	162.08274	166.38533	10.65366	0.16414	1.56	0.05429	–	37.15027	6.0602	0.33147	< 0.025
125	T4-10	157.6509	–	–	–				2.61646	–	–	–	
130	T4-9	162.371	156.86737	156.65817	49.93379	9.15836	7.63	2.36801	–	47.30498	2.09041	0.15883	< 0.025
135	T4-8	118.3448	–	–	–				3.34622	–	–	–	
140	T4-7	95.98237	158.99774	164.23249	102.8945	16.48106	14.14	6.73677	–	71.49929	0.55819	0.42584	< 0.025
145	T4-6	88.37903	–	–	–				25.33354	–	–	–	
150	T4-5	71.11777	127.22306	132.59111	149.9498	22.10045	21.04	13.3969	–	73.88283	4.81519	1.57679	0.23312
160	T4-4	65.04175	–	–	–				74.70568	–	–	–	
170	T4-3	53.18005	106.59307	126.36586	165.0736	42.91719	20.02	17.98602	–	101.3375	3.88986	2.66558	0.57803
180	T4-2	47.11814	101.5539	120.31176	–		26.59		284.51638	–	–	–	
190	T4-1	33.64847	–	–	128.9849	68.92499		25.03417	586.34735	88.09194	9.36565	1.42486	0.15488

Iron concentration profile data for column MTWC-5

Depth	Sampling port	Static profile #1	Static profile #2	Static Kinetic profile	Kinetic profile #1	Kinetic profile #2	Kinetic profile #3	Kinetic profile #4
		SPECIES Fe (mg/L)						
		DATE						
		10/07/93	15/10/93	20/12/93	24/02/94	24/05/94	12/08/94	12/04/95
		Time elapsed (days)						
		0	97	163	229	317	399	642
0	W5-15	1.08841	< 0.02499	< 0.02499	–			
5	W5-14	–	–	–	< 0.02499	0.03854	0.08182	< 0.025
15	W5-13	–	< 0.02499	< 0.02499	< 0.02499	0.06905	0.07	0.16
25	W5-12	–	–	–	–			
35	W5-11	–	1.20417	< 0.02499	0.14209	0.08016	0.10	0.06
45	W5-10	–	–	–	–			
50	W5-9	–	0.04321	< 0.02499	< 0.02499	0.15111	0.08	< 0.03
55	W5-8	–	–	–	–			
60	W5-7	16.09957	< 0.02499	< 0.02499	< 0.02499	0.0428	0.11	0.08
65	W5-6	–	–	–	–			
70	W5-5	–	< 0.02499	< 0.02499	0.84871	0.2036	0.13	< 0.03
75	W5-4	–	–	–	–			
80	W5-3	–	< 0.02499	< 0.02499	< 0.02499	0.07259	0.27	< 0.03
85	W5-2	–	–	–	< 0.02499	0.0655	0.14	0.06264
90	W5-1	0.16525	1.59723	0.11912	1.57427	0.10074	0.19	< 0.03
100	T5-15	3.44675	56.25244	174.01419	11.67919	5.2224	4.3	2.50146
105	T5-14	486.49194	–	1770	203	33.63867	18.56	9.97103
110	T5-13	10100	5400	5320	1448	307.35278	90.49	20.5807
115	T5-12	12800	–	–	–		359.21	
120	T5-11	14400	13800	13100	2569	2536	1080	115.2862
125	T5-10	15300	–	–	–			
130	T5-9	14900	14480	14400	3237	3817	3710	695.66314
135	T5-8	13300	–	–	–			
140	T5-7	10800	13390	14100	6299	4664	5260	1280
145	T5-6	9240	–	–	–			
150	T5-5	9230	15600	15400	10630	3897	4840	1867
160	T5-4	9610	–	–	–			
170	T5-3	8390	14600	14700	14320	4714	4840	2693
180	T5-2	5800	–	–	–			
190	T5-1	3710	13920	14400	14900	9697	4590	3002

Ferric concentration profile data for column MTWC-5

		SPECIES Fe+3 (mg/L)						
		Static profile #1	Static profile #2	Static Kinetic profile	Kinetic profile #1	Kinetic profile #2	Kinetic profile #3	Kinetic profile #4
		DATE						
		10/07/93	15/10/93	20/12/93	24/02/94	24/05/94	12/08/94	12/04/95
	Sampling	Time elapsed (days)						
Depth	port	0	97	163	229	317	399	642
0	W5-15	< 0.1	< 0.05	< 0.05				
5	W5-14	–	–	–	< 0.05	< 0.05	< 0.05	
15	W5-13	–	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
25	W5-12	–	–	–				
35	W5-11	–	< 0.05	< 0.05	0.19	< 0.05	< 0.05	< 0.05
45	W5-10	–	–	–				
50	W5-9	–	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	
55	W5-8	–	–	–				
60	W5-7	< 0.1	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
65	W5-6	–	–	–				
70	W5-5	–	< 0.05	< 0.05	0.42	< 0.05	< 0.05	
75	W5-4	–	–	–				
80	W5-3	–	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	
85	W5-2	–	–	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
90	W5-1	< 0.1	< 0.05	< 0.05	0.35	< 0.1	< 0.05	
100	T5-15	< 0.1	1.95	2.92	0.68	0.24	0.101	< 0.05
105	T5-14	10	–	24.9	2.44	1.08	0.403	0.72
110	T5-13	1400	110	160	7.69	1.83	0.374	1.24
115	T5-12	2100	–	–	–		0.462	0.99
120	T5-11	3700	730	928	33.4	31.9	4.42	
125	T5-10	2750	–	–	–			
130	T5-9	2850	754	1100	43	66.5	21.9	2.66
135	T5-8	2300	–	–	–			
140	T5-7	2220	682	1090	230	146	62.4	6.17
145	T5-6	2360	–	–	–			
150	T5-5	2070	954	1310	455	70.8	36.8	8.89
160	T5-4	2410	–	–	–			
170	T5-3	1800	800	1180	803	106	37.8	25
180	T5-2	5080	–	–	–			
190	T5-1	740	796	1140	712	558	36.5	28.7

Sulphate concentration profile data for column MTWC-5

		SPECIES SO4 (mg/L) Calculated										
		Static profile #1	Static profile #2	Static Kinetic profile	Kinetic profile #1	Kinetic profile #2	Kinetic profile #3	Kinetic profile #4				
		DATE										
		10/07/93	15/10/93	20/12/93	24/02/94	24/05/94	12/08/94	12/04/95				
		Time elapsed (days)										
Depth	Sampling port	0	97	163	229	317	399	642				
0	W5-15	34.00244	88.796531	140.2801275	0							
5	W5-14					105.51679	95.62836	44.276919				
15	W5-13		85.879956	127.81386	147.2937	105.78952	94.22118	45.267514				
25	W5-12											
35	W5-11		86.834473	129.6549305	149.1442	106.21805	94.87986	44.764043				
45	W5-10											
50	W5-9		87.000191	127.8412551	148.905	105.80574	96.22716	45.34925				
55	W5-8											
60	W5-7	72.34019	85.899836	128.8952329	148.4644	108.44187	93.95172	45.725236				
65	W5-6											
70	W5-5		94.527346	128.2039782	149.4778	107.04266	95.29902	41.720282				
75	W5-4											
80	W5-3		97.213443	127.7385908	148.7728	106.27323	94.84992	46.902208				
85	W5-2			130.510436	147.942	108.03933	95.83794	46.313707				
90	W5-1	29.94338	94.67022	157.4283823	150.2898	107.80232	95.41878	47.261847				
100	T5-15	1517.895	1823.7023	2264.903066	166.2899	148.47087	84.19128	37.636826				
105	T5-14	3502.98		5119.74	1118.484	148.47087	48.11358	16.873136				
110	T5-13	20029.86	10868.22	11047.86	4059.737	1018.5383	174.2508	8.4512836				
115	T5-12	24700.5					647.81178					
120	T5-11	27245.4	23742.42	23443.02	5932.396	4898.184	1870.4716	185.30339				
125	T5-10	29401.08										
130	T5-9	28443	24880.14	25299.3	7359.371	7673.622	6137.7	1152.1669				
135	T5-8	26047.8										
140	T5-7	23832.24	24311.28	25838.22	12676.6	9317.328	9041.88	2126.4287				
145	T5-6	23922.06										
150	T5-5	24191.52	27155.58	27454.98	20014.89	8224.518	8742.48	3051.6959				
160	T5-4	24820.26										
170	T5-3	21377.16	27095.7	27365.16	26951.99	9616.728	9251.46	4426.3786				
180	T5-2	16107.72										
190	T5-1	10389.18	26407.08	27454.98	28326.23	18377.172	9131.7	4906.2808				

Zinc concentration profile data for column MTWC-5

		SPECIES Zn (mg/L)											
		Static profile #1	Static profile #2	Static Kinetic profile	Kinetic profile #1	Kinetic profile #2	Kinetic profile #3	Kinetic profile #4					
		DATE											
		10/07/93	15/10/93	20/12/93	24/02/94	24/05/94	12/08/94	12/04/95					
Depth	Sampling port	Time elapsed (days)											
		0	97	163	229	317	399	642					
0	W5-15	< 0.02499	0.19414	1.3402	0.416								
5	W5-14	–	–	–	–	< 0.025	0.83	0.12463					
15	W5-13	–	0.17796	1.10913	0.416	< 0.025	0.81	0.12746					
25	W5-12	–	–	–	–	–							
35	W5-11	–	0.1909	1.16282	0.43397	< 0.025	0.81	0.15862					
45	W5-10	–	–	–	–	–							
50	W5-9	–	0.206	1.09235	0.45709	< 0.025	0.82	0.13596					
55	W5-8	–	–	–	–	–							
60	W5-7	< 0.02499	0.24483	1.1343	0.43397	< 0.025	0.82	0.1303					
65	W5-6	–	–	–	–	–							
70	W5-5	–	0.11745	1.11416	0.45452	< 0.025	0.81	< 0.025					
75	W5-4	–	–	–	–	–							
80	W5-3	–	0.14048	1.12927	0.43911	< 0.025	0.83	0.14446					
85	W5-2	–	–	1.12088	0.41471	< 0.025	0.87	0.15154					
90	W5-1	< 0.02499	0.114	1.36754	0.43141	< 0.025	0.84	0.14163					
100	T5-15	9.234	13.91761	23.37237	1.06055	< 0.025	0.46	< 0.025					
105	T5-14	30.63233	–	47.53675	4.99717	< 0.025	0.33	< 0.025					
110	T5-13	129.1807	79.13555	72.46962	2.06075	< 0.025	0.35	< 0.025					
115	T5-12	136.2711	–	–	–	–	0.37						
120	T5-11	142.9562	129.259	124.29861	17.27569	2.91418	0.78	< 0.025					
125	T5-10	148.9668	–	–	–	–							
130	T5-9	144.7998	127.73665	128.36935	37.47753	19.9616	7.79	0.10715					
135	T5-8	124.7137	–	–	–	–							
140	T5-7	79.91273	85.47597	93.76804	68.92173	32.18098	21.83	1.44129					
145	T5-6	54.94226	–	–	–	–							
150	T5-5	47.13125	132.27375	131.07926	111.5467	37.72269	36.84	3.48476					
160	T5-4	42.79627	–	–	–	–							
170	T5-3	30.26921	83.55289	93.3284	115.3421	49.95991	42.81	24.62126					
180	T5-2	23.82925	–	–	–	–							
190	T5-1	15.83878	62.37246	77.89785	107.8334	101.54702	48.65	45.19633					

Welcome Screen Search Report List

Iron concentration profile data for column MTWC-6

		SPECIES Fe (mg/L)						
		Static profile #1	Static profile #2	Static Kinetic profile	Kinetic profile #1	Kinetic profile #2	Kinetic profile #3	Kinetic profile #4
		DATE						
		10/07/93	15/10/93	20/12/93	24/02/94	24/05/94	12/08/94	12/04/95
		Time elapsed (days)						
Depth	Sampling port	0	97	163	229	317	399	642
0	W6-15	0.08804	< 0.02499	0.0327	–			
5	W6-14			–	< 0.02499	0.17844	0.03	0.04205
15	W6-13		< 0.02499	0.22203	< 0.02499	0.1572	0.25	0.03
25	W6-12			–	–			
35	W6-11		< 0.02499	0.0288	< 0.02499	0.1201	0.67	< 0.03
45	W6-10			–	–			
50	W6-9		< 0.02499	0.0426	< 0.02499	0.08128	0.63	< 0.03
55	W6-8			–	–			
60	W6-7	0.11827	< 0.02499	< 0.02499	< 0.02499	0.09862	0.14	0.10
65	W6-6			–	–			
70	W6-5		< 0.02499	< 0.02499	< 0.02499	0.14817	0.19	0.07
75	W6-4			–	–			
80	W6-3		< 0.02499	< 0.02499	< 0.02499	0.3232	0.13	0.92
85	W6-2			< 0.02499	< 0.02499	0.09227	0.13	< 0.025
90	W6-1	0.12511	< 0.02499	0.19173	0.25295	0.16843	0.74	< 0.03
100	T6-15	8.24728	76.66009	265.57196	14.76173	6.96299	5.55	
105	T6-14	1040		2200	222.19952	29.06054	19.74	9.25496
110	T6-13	12800	6360	6010	1840	151.42575	95.23	22.46528
115	T6-12	14200		–	–		259.42	
120	T6-11	13700	15150	13600	2596	1349	1001	94.07288
125	T6-10	13600		–	–			
130	T6-9	12800	15330	14800	9035	4082	2690	582.8916
135	T6-8	13000		–	–			
140	T6-7	9610	14690	14600	6246	5235	4960	889.50878
145	T6-6	9790		–	–			
150	T6-5	9630	14030	14000	11910	5248	5870	1438
160	T6-4	9370		–	–			
170	T6-3	9280	14840	14600	15040	4213	5450	2206
180	T6-2	7770		–	–			
190	T6-1	3750	13470	13900	14640	5071	5320	3208

Ferric concentration profile data for column MTWC-6

		SPECIES Fe+3 (mg/L)											
		Static profile #1	Static profile #2	Static Kinetic profile	Kinetic profile #1	Kinetic profile #2	Kinetic profile #3	Kinetic profile #4					
		DATE											
		10/07/93	15/10/93	20/12/93	24/02/94	24/05/94	12/08/94	12/04/95					
	Sampling port	Time elapsed (days)											
Depth		0	97	163	229	317	399	642					
0	W6-15	< 0.1	< 0.05	< 0.05	< 0.05	< 0.05							
5	W6-14	–	–	–	–	–	< 0.05	< 0.05					
15	W6-13	–	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05					
25	W6-12	–	–	–	–	–							
35	W6-11	–	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05						
45	W6-10	–	–	–	–	–							
50	W6-9	–	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05						
55	W6-8	–	–	–	–	–							
60	W6-7	< 0.1	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05					
65	W6-6	–	–	–	–	–							
70	W6-5	–	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05					
75	W6-4	–	–	–	–	–							
80	W6-3	–	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	0.29					
85	W6-2	–	–	< 0.05	< 0.05	< 0.05	< 0.05						
90	W6-1	< 0.1	< 0.05	< 0.05	0.23	< 0.05	< 0.05						
100	T6-15	< 100	1.9	2.86	0.79	0.213	0.204						
105	T6-14	90	–	33.6	2.36	0.748	0.352	0.56					
110	T6-13	2180	157	191	13.2	0.875	0.293	1.14					
115	T6-12	2490	–	–	–		0.248						
120	T6-11	2150	876	1030	35.8	9.76	0.912	1.07					
125	T6-10	2300	–	–	–								
130	T6-9	2180	998	1190	396	76.4	68.3	2.87					
135	T6-8	2220	–	–	–								
140	T6-7	2080	824	1230	189	139	44.1	6					
145	T6-6	2130	–	–	–								
150	T6-5	2120	706	1040	628	147	51.8	5.5					
160	T6-4	2120	–	–	–								
170	T6-3	2020	806	1220	898	89.7	50.4	18.4					
180	T6-2	1410	–	–	–								
190	T6-1	450	754	1070	875	143	53.6	20.3					

Sulphate concentration profile data for column MTWC-6

		SPECIES SO4 (mg/L) Calculated											
		Static profile #1	Static profile #2	Static Kinetic profile	Kinetic profile #1	Kinetic profile #2	Kinetic profile #3	Kinetic profile #4					
		DATE											
		10/07/93	15/10/93	20/12/93	24/02/94	24/05/94	12/08/94	12/04/95					
Depth	Sampling port					Time elapsed (days)							
		0	97	163	229	317	399	642					
0	W6-15	23.5514	82.90371	133.3954245	123.0829								
5	W6-14	–	–	–	–	108.41669	90.47868	40.739448					
15	W6-13	–	81.220064	132.3430934	121.9354	109.12127	89.58048	41.867377					
25	W6-12	–	–	–	–								
35	W6-11	–	82.260749	134.0144041	120.946	108.08274	88.9218	42.057017					
45	W6-10	–	–	–	–								
50	W6-9	–	81.060963	133.5467113	120.5635	107.10433	91.6164	41.210254					
55	W6-8	–	–	–	–								
60	W6-7	22.1785	81.59126	133.856231	120.2309	106.91736	91.13736	40.850615					
65	W6-6	–	–	–	–								
70	W6-5	–	80.318571	133.7118005	112.923	108.22636	91.0176	40.889866					
75	W6-4	–	–	–	–								
80	W6-3	–	82.214342	137.5771443	115.613	107.72879	90.92778	42.475489					
85	W6-2	–	–	137.94855	113.6834	109.56205	89.84994	41.775851					
90	W6-1	21.51997	81.524973	223.2267119	114.3048	109.2916	90.47868	41.050045					
100	T6-15	1358.672	2036.7992	2720.853937	193.4596	107.23457	69.6105						
105	T6-14	4371.24	–	5958.06	1142.68	122.78565	59.2812	18.847829					
110	T6-13	24221.46	12335.28	11946.06	4491	369.94313	170.23884	15.173083					
115	T6-12	26616.66	–	–	–		469.24962						
120	T6-11	25269.36	26047.8	24161.58	5979.018	2492.2819	1719.0051	133.45848					
125	T6-10	25209.48	–	–	–								
130	T6-9	23922.06	26347.2	26047.8	18035.86	7490.988	4461.06	921.04039					
135	T6-8	24969.96	–	–	–								
140	T6-7	23053.8	26227.44	26496.9	12440.07	9727.506	8712.54	1437.3506					
145	T6-6	25449	–	–	–								
150	T6-5	24910.08	25419.06	25928.04	22703.5	10440.078	10239.48	2136.9836					
160	T6-4	24191.52	–	–	–								
170	T6-3	24131.64	27904.08	27814.26	27901.09	8697.57	10149.66	3259.8673					
180	T6-2	19850.22	–	–	–								
190	T6-1	10299.36	25478.94	26796.3	28419.05	10239.48	10239.48	4941.1321					

Zinc concentration profile data for column MTWC-6

		SPECIES Zn (mg/L)											
		Static profile #1	Static profile #2	Static Kinetic profile	Kinetic profile #1	Kinetic profile #2	Kinetic profile #3	Kinetic profile #4					
		DATE											
		10/07/93	15/10/93	20/12/93	24/02/94	24/05/94	12/08/94	12/04/95					
		Time elapsed (days)											
Depth	Sampling port	0	97	163	229	317	399	642					
0	W6-15	< 0.02499	< 0.02499	0.352									
5	W6-14				< 0.02499	0.27331	0.29	< 0.025					
15	W6-13		< 0.02499	0.35846	< 0.02499	0.28188	0.28	< 0.025					
25	W6-12												
35	W6-11		< 0.02499	0.34877	< 0.02499	0.29414	0.26	< 0.025					
45	W6-10												
50	W6-9		< 0.02499	0.35038	< 0.02499	0.3211	0.3	< 0.025					
55	W6-8												
60	W6-7	< 0.02499	< 0.02499	0.36169	< 0.02499	0.28924	0.28	< 0.025					
65	W6-6												
70	W6-5		< 0.02499	0.34716	< 0.02499	0.34071	0.28	< 0.025					
75	W6-4												
80	W6-3		< 0.02499	0.38106	< 0.02499	0.32723	0.27	< 0.025					
85	W6-2			0.37461	< 0.02499	0.2586	0.29	< 0.025					
90	W6-1	< 0.02499	< 0.02499	0.61035	< 0.02499	0.2635	0.28	< 0.025					
100	T6-15	5.75933	9.32539	17.82467	0.44564	0.55029	0.26						
105	T6-14	48.57784		59.60342	2.29132	0.4694	0.18	< 0.025					
110	T6-13	145.069	87.8675	81.60533	0.26601	0.163	0.14	< 0.025					
115	T6-12	145.8935					0.12						
120	T6-11	135.6284	146.16252	158.55709	27.70289	0.51352	0.41	< 0.025					
125	T6-10	133.2494											
130	T6-9	123.2644	123.25566	127.75668	70.92121	10.66033	1.65	< 0.025					
135	T6-8	120.1374											
140	T6-7	61.81099	98.55729	120.73435	73.80764	31.76038	11.31	0.22944					
145	T6-6	46.96666											
150	T6-5	41.56791	74.60744	89.5884	124.4851	50.93501	26.18	0.70674					
160	T6-4	33.36498											
170	T6-3	30.63729	66.73706	80.58644	130.2065	55.48	43.38	7.00231					
180	T6-2	27.84802											
190	T6-1	16.19725	54.08425	66.79368	90.04801	58.6549	57.36	37.94479					

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Iron concentration profile data for column MTWC-7

Depth	Sampling port	SPECIES Fe (mg/L)											
		Static profile #1	Static profile #2	Static profile #3	Static Kinetic profile	Kinetic profile #1	Kinetic profile #3	Kinetic profile #4					
		DATE											
		10/07/93	15/10/93	20/12/93	24/02/94	24/05/94	12/08/94	12/04/95					
		Time elapsed (days)											
		0	97	163	229	317	399	642					
0	W7-15												
5	W7-14												
15	W7-13												
25	W7-12												
35	W7-11	N	N	N	N	N	N	N					
45	W7-10	o	o	o	o	o	o	o					
50	W7-9												
55	W7-8	W	W	W	W	W	W	W					
60	W7-7	a	a	a	a	a	a	a					
65	W7-6	t	t	t	t	t	t	t					
70	W7-5	e	e	e	e	e	e	e					
75	W7-4	r	r	r	r	r	r	r					
80	W7-3												
85	W7-2												
90	W7-1						2.07						
100	T7-15	15200	1630	16400	16810	479.41589	198.28	61.80825					
105	T7-14	14400	–	–	16920		472.07						
110	T7-13	16200	1820	17100	17400	970.00714	637.84	120.10228					
115	T7-12	17700	–	–	–		1170						
120	T7-11	15900	16290	15800	15670	1843	1400	202.98284					
125	T7-10	15100	–	–	–								
130	T7-9	10100	20230	18200	17460	4832	2510	540.01672					
135	T7-8	7510	–	–	–								
140	T7-7	7990	14020	15100	15910	12900	3450	1264					
145	T7-6	7530	–	–	–								
150	T7-5	7330	15180	16500	17080	16570	4010	1538					
160	T7-4	7530	14940	17200	17620								
170	T7-3	6400	–	–	–		8830	1984					
180	T7-2	1770	–	–	–	18680							
190	T7-1		19910	20200	19410	18450	16060	2038					

Ferric concentration profile data for column MTWC-7

Depth	Sampling port	SPECIES Fe+3 (mg/L)											
		Static profile #1	Static profile #2	Static profile #3	Static Kinetic profile	Kinetic profile #1	Kinetic profile #3	Kinetic profile #4					
		DATE											
		10/07/93	15/10/93	20/12/93	24/02/94	24/05/94	12/08/94	12/04/95					
		Time elapsed (days)											
		0	97	163	229	317	399	642					
0	W7-15												
5	W7-14												
15	W7-13												
25	W7-12												
35	W7-11	N	N	N	N	N	N	N					
45	W7-10	o	o	o	o	o	o	o					
50	W7-9												
55	W7-8	W	W	W	W	W	W	W					
60	W7-7	a	a	a	a	a	a	a					
65	W7-6	t	t	t	t	t	t	t					
70	W7-5	e	e	e	e	e	e	e					
75	W7-4	r	r	r	r	r	r	r					
80	W7-3												
85	W7-2												
90	W7-1						1.02						
100	T7-15	4970	1370	684	946	4.39	0.234	0.76					
105	T7-14	5390	—	—	1070		0.617						
110	T7-13	7330	1650	726	1020	8.19	4.75	0.59					
115	T7-12	8130	—	—	—		1.79						
120	T7-11	6990	1470	777	1040	159	2.42	0.63					
125	T7-10	11900	—	—	—								
130	T7-9	3570	1890	831	1160	189	12.6	2.45					
135	T7-8	2230	—	—	—								
140	T7-7	7100	1210	622	972	852	50.8	4.88					
145	T7-6	2070	—	—	—								
150	T7-5	1860	1470	679	1170	1350	34.9	13.5					
160	T7-4	2350	1390	751	893								
170	T7-3	—	—	—	—		186	12.7					
180	T7-2	1780	—	—	—	1540							
190	T7-1	550	1830	907	970	1580	287	12.6					

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Sulphate concentration profile data for column MTWC-7

		SPECIES SO4 (mg/L) Calculated											
		Static profile #1	Static profile #2	Static profile #3	Static Kinetic profile	Kinetic profile #1	Kinetic profile #3	Kinetic profile #4					
		DATE											
		10/07/93	15/10/93	20/12/93	24/02/94	24/05/94	12/08/94	12/04/95					
	Sampling port	Time elapsed (days)											
Depth		0	97	163	229	317	399	642					
0	W7-15												
5	W7-14												
15	W7-13												
25	W7-12												
35	W7-11	No water	No water	No water	No water	No water	No water	No water					
45	W7-10												
50	W7-9												
55	W7-8												
60	W7-7												
65	W7-6												
70	W7-5												
75	W7-4												
80	W7-3												
85	W7-2												
90	W7-1						83.56254						
100	T7-15	36227.4	31047.78	29730.42	31257.36	862.1563	361.13628	104.59985					
105	T7-14	35329.2	–	–	32065.74		837.4218						
110	T7-13	41317.2	34700.46	30838.2	32604.66	1718.834	1139.3966	207.79716					
115	T7-12	46706.4	–	–	–		2020.0817						
120	T7-11	41916	31287.3	29041.8	29969.94	3412.28	2441.5471	359.35479					
125	T7-10	40119.6	–	–	–								
130	T7-9	25957.98	38383.08	33532.8	33203.46	9071.82	4491	928.53706					
135	T7-8	18772.38	–	–	–								
140	T7-7	19580.76	26646.6	28353.18	30868.14	23946.01	5958.06	2033.7405					
145	T7-6	18652.62	–	–	–								
150	T7-5	18113.7	29191.5	30538.8	32963.94	30748.38	7155.66	2492.922					
160	T7-4	18772.38	28592.7	32634.6	34401.06								
170	T7-3	–	–	–	–		16496.94	3211.8895					
180	T7-2	16167.6	–	–	–	34670.52							
190	T7-1	4820.34	37454.94	38023.8	38682.48	34730.4	29820.24	3287.6934					

Zinc concentration profile data for column MTWC-7

		SPECIES Zn (mg/L)											
		Static profile #1	Static profile #2	Static profile #3	Static Kinetic profile	Kinetic profile #1	Kinetic profile #3	Kinetic profile #4					
		DATE											
		10/07/93	15/10/93	20/12/93	24/02/94	24/05/94	12/08/94	12/04/95					
		Time elapsed (days)											
Depth	Sampling port	0	97	163	229	317	399	642					
0	W7-15												
5	W7-14												
15	W7-13												
25	W7-12												
35	W7-11	No water	No water	No water	No water	No water	No water	No water					
45	W7-10												
50	W7-9												
55	W7-8												
60	W7-7												
65	W7-6												
70	W7-5												
75	W7-4												
80	W7-3												
85	W7-2												
90	W7-1						3.67						
100	T7-15	178.2234	139.86926	155.16784	152.2747	8.56394	3.97	0.80872					
105	T7-14	165.0518	–	–	158.33378		7.81						
110	T7-13	180.808	151.66223	160.29936	158.67048	13.8962	9.64	0.94468					
115	T7-12	186.6012	–	–	–		15.15						
120	T7-11	162.193	103.62769	113.87834	107.30113	24.58064	17.31	1.8653					
125	T7-10	143.5055	–	–	–								
130	T7-9	67.29517	141.83311	150.67251	135.61486	50.22563	30.29	7.24025					
135	T7-8	30.18334	–	–	–								
140	T7-7	26.81794	59.59687	85.28523	93.41793	108.6944	37.93	19.87813					
145	T7-6	23.46644	–	–	–								
150	T7-5	23.11977	65.46434	107.30005	115.24393	131.2775	42.77	27.05183					
160	T7-4	24.71605	67.29253	117.51464	117.15287								
170	T7-3	–	–	–	–		84.56	33.49044					
180	T7-2	22.42146	–	–	–	152.4006							
190	T7-1	9.53696	127.62715	155.9978	144.38531	136.6111	133.24	33.91959					

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Iron concentration profile data for column MTWC-8

		SPECIES Fe (mg/L)											
		Static profile #1	Static profile #2	Static profile #3	Static Kinetic profile	Kinetic profile #1	Kinetic profile #3	Kinetic profile #4					
		DATE											
		10/07/93	15/10/93	20/12/93	24/02/94	24/05/94	12/08/94	12/04/95					
	Sampling port	Time elapsed (days)											
Depth		0	97	163	229	317	399	642					
0	W8-15												
5	W8-14												
15	W8-13												
25	W8-12												
35	W8-11	N	N	N	N	N	N	N					
45	W8-10	o	o	o	o	o	o	o					
50	W8-9												
55	W8-8	W	W	W	W	W	W	W					
60	W8-7	a	a	a	a	a	a	a					
65	W8-6	t	t	t	t	t	t	t					
70	W8-5	e	e	e	e	e	e	e					
75	W8-4	r	r	r	r	r	r	r					
80	W8-3												
85	W8-2												
90	W8-1					77.47915							
100	T8-15	11700	16060	16000	16370	163.53623	48.09	23.37393					
105	T8-14	15500	—	—	16530		269.16						
110	T8-13	12200	19970	17100	17010	1673	762.96	194.26152					
115	T8-12	13400	—	—	—		1170						
120	T8-11	15800	15530	14100	14570	4409	1600	405.49584					
125	T8-10	13900	—	—	—								
130	T8-9	13800	18510	16900	16740	11450	2310	848.82391					
135	T8-8	7940	—	—	—								
140	T8-7	7440	12710	14000	14860	15080	2580	1113.2678					
145	T8-6	7210	—	—	—								
150	T8-5	8790	19250	17600	17340	16980	3210	1305					
160	T8-4	6300	—	—	—		3910						
170	T8-3	6080	13830	16800	17040	16530	5710	1922					
180	T8-2	1790	—	—	—								
190	T8-1	2020	17430	18800	13040	18260		2106					

Ferric concentration profile data for column MTWC-8

		SPECIES Fe+3 (mg/L)											
		Static profile #1	Static profile #2	Static profile #3	Static Kinetic profile	Kinetic profile #1	Kinetic profile #3	Kinetic profile #4					
		DATE											
		10/07/93	15/10/93	20/12/93	24/02/94	24/05/94	12/08/94	12/04/95					
	Sampling	Time elapsed (days)											
Depth	port	0	97	163	229	317	399	642					
0	W8-15												
5	W8-14												
15	W8-13												
25	W8-12												
35	W8-11	No Water	No Water	No Water	No Water	No Water	No Water	No Water					
45	W8-10												
50	W8-9												
55	W8-8												
60	W8-7												
65	W8-6												
70	W8-5												
75	W8-4												
80	W8-3												
85	W8-2												
90	W8-1					24.4							
100	T8-15	3120	1520	711	914	16.5	0.706	0.9					
105	T8-14	5700	–	–	1010		2.1						
110	T8-13	4030	2260	865	1070	11.3	4.01	0.71					
115	T8-12	5280	–	–	–		1.86						
120	T8-11	7950	1270	585	850	96.3	23.6	1.28					
125	T8-10	7360	–	–	–								
130	T8-9	6940	2080	726	889	856	17.2	4.21					
135	T8-8	2590	–	–	–								
140	T8-7	2660	1110	596	914	1280	25.8	4.33					
145	T8-6	2530	–	–	–								
150	T8-5	3270	2060	796	1220	1500	29.8	5.46					
160	T8-4	2520	–	–	–		30.6						
170	T8-3	2270	1590	737	1070	1650	83.6	9.33					
180	T8-2	740	–	–	–								
190	T8-1	690	1490	866	1090	1680		16.4					

Sulphate concentration profile data for column MTWC-8

		SPECIES											
		SO4 (mg/L) Calculated											
		Static profile #1	Static profile #2	Static profile #3	Static Kinetic profile	Kinetic profile #1	Kinetic profile #3	Kinetic profile #4					
		DATE											
		10/07/93	15/10/93	20/12/93	24/02/94	24/05/94	12/08/94	12/04/95					
	Sampling port	Time elapsed (days)											
Depth		0	97	163	229	317	399	642					
0	W8-15												
5	W8-14												
15	W8-13												
25	W8-12												
35	W8-11	No Water	No Water	No Water	No Water	No Water	No Water	No Water					
45	W8-10												
50	W8-9												
55	W8-8												
60	W8-7												
65	W8-6												
70	W8-5												
75	W8-4												
80	W8-3												
85	W8-2												
90	W8-1					297.1934							
100	T8-15	26407.08	30628.62	28592.7	30239.4	416.7708	137.81382	50.540995					
105	T8-14	37724.4	–	–	–	–	491.4651						
110	T8-13	28263.36	37425	30538.8	31586.7	2759.088	1332.9587	334.86731					
115	T8-12	34131.6	–	–	–	–	2034.3032						
120	T8-11	41317.2	30359.16	25359.18	27353.184	7739.49	2815.5277	695.99081					
125	T8-10	37724.4	–	–	–	–							
130	T8-9	36526.8	36047.76	30538.8	31556.76	20493.93	4011.96	1446.616					
135	T8-8	20598.72	–	–	–	–							
140	T8-7	19311.3	25389.12	26586.72	29065.752	27727.43	4431.12	1910.8125					
145	T8-6	18922.08	–	–	–	–							
150	T8-5	22934.04	37694.46	32035.8	33203.46	31137.6	5329.32	2120.3327					
160	T8-4	16766.4					6526.92						
170	T8-3	–	27844.2	31736.4	33442.98	31197.48	10059.84	3031.1041					
180	T8-2	5179.62	–	–	–	–							
190	T8-1	5718.54	34580.7	35029.8	25386.126	33772.32		3346.3746					

Zinc concentration profile data for column MTWC-8

		SPECIES Zn (mg/L)											
		Static profile #1	Static profile #2	Static profile #3	Static Kinetic profile	Kinetic profile #1	Kinetic profile #3	Kinetic profile #4					
		DATE											
		10/07/93	15/10/93	20/12/93	24/02/94	24/05/94	12/08/94	12/04/95					
	Sampling port	Time elapsed (days)											
Depth		0	97	163	229	317	399	642					
0	W8-15												
5	W8-14												
15	W8-13												
25	W8-12												
35	W8-11	N	N	N	N	N	N	N					
45	W8-10	o	o	o	o	o	o	o					
50	W8-9												
55	W8-8	W	W	W	W	W	W	W					
60	W8-7	a	a	a	a	a	a	a					
65	W8-6	t	t	t	t	t	t	t					
70	W8-5	e	e	e	e	e	e	e					
75	W8-4	r	r	r	r	r	r	r					
80	W8-3												
85	W8-2												
90	W8-1					4.48804							
100	T8-15	143.3714	147.88632	163.12509	148.64053	6.1917	0.706	1.23645					
105	T8-14	181.9931	–	–	145.8581		2.1						
110	T8-13	146.1597	194.41261	188.70838	167.48541	20.25886	4.01	1.78315					
115	T8-12	157.7459	–	–	–		1.86						
120	T8-11	169.2884	105.21772	104.40489	104.06794	43.9906	23.6	4.31412					
125	T8-10	139.5659	–	–	–								
130	T8-9	82.7067	138.26541	145.51354	140.69486	113.3264	17.2	10.99352					
135	T8-8	30.15652	–	–	–								
140	T8-7	29.46715	59.75055	86.01345	90.60421	111.076	25.8	17.17861					
145	T8-6	29.52774	–	–	–								
150	T8-5	34.59274	134.50291	153.12847	146.47372	139.8215	29.8	18.97027					
160	T8-4	24.98922	–	–	–		30.6						
170	T8-3	24.31474	63.48952	118.71759	120.84468	115.6963	83.6	32.91683					
180	T8-2	9.52206	–	–	–								
190	T8-1	11.89215	102.98287	145.2019	104.99172	147.5225		35.39398					

Seepage data for column MTWC-1

MTWC 1
Kinetic test started
25/08/93

Pore vol. (L) 34.21

MTWC-1 kinetic test DATE	Time elapsed (days)	Measured in lab Volume Collected (L)	34.21 Cumulative Volume Collected (L)	Number of pore volumes	Measured in lab pH	Measured in lab Acidity (mg/L CaCO3)	Acidity load (g CaCO3)	Reported by lab Fe mg/L	Fe load mg	Reported by lab Fe+3 mg/L	Fe+3 load mg	Reported by lab Zn mg/L	Zn load mg	Reported by lab S mg/L	Calc SO4 mg/L	SO4 load mg
27/08/93	3	0.50	0.50	0.01	3.61	10960	5.48	5870	2935	688.00	344	2280	1140	7150	21407	10704
03/09/93	10	1.36	1.86	0.05	3.84	8650	11.76	5860	7970	464.00	631	2190	2978	7080	21198	28829
10/09/93	17	0.50	2.36	0.07	3.12	11400	5.70	5790	2895	584.00	292	2160	1080	7080	21198	10599
17/09/93	24	0.98	3.34	0.10	3.45	10260	10.05	5940	5821	548.00	537	2140	2097	7190	21527	21096
22/09/93	29	2.29	5.63	0.16	3.36	9700	22.21	6190	14175	378.00	866	1870	4282	7040	21078	48268
01/10/93	38	0.62	6.25	0.18	3.52	10500	6.51	6640	4117	412.00	255	1570	973	6980	20898	12957
08/10/93	45	0.40	6.65	0.19	3.19	8490	3.40	6440	2576	316.00	126	1490	596	6810	20389	8156
15/10/93	52	1.10	7.75	0.23	3.23	11520	12.67	7140	7854	366.00	403	1450	1595	7290	21826	24009
22/10/93	59	4.40	12.15	0.36	3.26	11090	48.80	6190	27236	433.00	1905	1250	5500	6450	19311	84970
29/10/93	66	1.84	13.99	0.41	3.44	9860	18.14	6510	11978	362.00	666	1090	2006	6370	19072	35092
05/11/93	73	0.88	14.87	0.43	3.34	11230	9.88	6720	5914	289.00	254	980	862	6390	19132	16836
12/11/93	80	0.40	15.27	0.45	3.30	8780	3.51	6610	2644	211.00	84	900	360	6250	18713	7485
19/11/93	87	1.62	16.89	0.49	3.35	8520	13.80	6710	10870	102.00	165	820	1328	6340	18982	30751
26/11/93	94	0.34	17.23	0.50	3.31	11100	3.77	7674	2609	1130.00	384	727	247	6928	20742	7052
03/12/93	101	2.50	19.73	0.58	3.62	9180	22.95	7629	19073	1070.00	2675	779	1949	7090	21227	53069
10/12/93	108	0.00	19.73	0.58	–	–	–	–	–	–	0	–	0	–	–	–
17/12/93	115	0.00	19.73	0.58	–	–	–	–	–	–	0	–	0	–	–	–
23/12/93	120	0.00	19.73	0.58	–	–	–	–	–	–	0	–	0	–	–	–
31/12/93	129	0.00	19.73	0.58	–	–	–	–	–	–	0	–	0	–	–	–
07/01/94	136	0.58	20.31	0.59	3.21	9530	5.53	7534	4370	771.00	447	851	494	7346	21994	12756
14/01/94	143	3.05	23.36	0.68	3.37	6820	20.80	6882	20990	493.00	1504	693	2113	6590	19730	60178
21/01/94	150	0.30	23.66	0.69	3.15	8330	2.50	6118	1835	382.00	115	560	168	5790	17335	5201
28/01/94	157	1.24	24.60	0.72	3.50	8010	9.93	5536	6865	313.00	388	461.9658	573	5113	15308	18982
04/02/94	164	1.24	25.84	0.76	3.27	6610	8.20	4795	5946	190.00	236	346	430	4345	13009	16131
11/02/94	171	1.18	27.02	0.79	3.14	6800	8.02	4397	5188	127.00	150	264	312	3783	11326	13365
18/02/94	178	1.16	28.18	0.82	3.30	6100	7.08	4000	4640	108.00	125	202	234	3318	9934	11524
11/03/94	199	3.00	31.18	0.91	3.17	4500	13.50	3365	10095	92.50	278	130.1949	391	2664	7976	23928
01/04/94	220	3.20	34.38	1.00	3.21	3070	9.82	2361	7555	24.70	79	70.89183	227	1902	5695	18223
22/04/94	241	2.10	36.48	1.07	3.45	1960	4.12	1821	3824	45.30	95	46.64151	98	1595	4775	10027
13/05/94	262	3.05	39.53	1.16	3.48	1180	3.60	1430	4362	14.90	45	30.07978	92	1347	4033	12300
03/06/94	283	2.55	42.08	1.23	3.50	780	1.99	1024	2610	5.10	13	20.58933	53	1080	3234	8246
24/06/94	304	2.95	45.03	1.32	3.47	860	2.54	787	2322	24.00	71	14.43	43	990	2966	8748
15/07/94	325	2.85	47.88	1.40	3.47	960	2.74	595	1695	22.90	65	9.55	27	891	2668	7604
26/09/94	398	9.00	56.88	1.66	2.77	650	5.85	297	2669		0	5.08825	46	790	2365	21284
25/11/94	458	7.70	64.58	1.89	3.20	390	3.00	223	1720	6.63	51	2.11	16	670	2006	15447
20/01/95	514	6.88	71.46	2.09	3.77	310	2.13	168	1156	1.30	9	0.8	6	624	1868	12852
17/03/95	570	7.10	78.56	2.30	3.99	270	1.92	109.8911	780	2.32	16	0.025	0	554.9892	1662	11798
21/04/95	605	4.50	83.06	2.43	4.26	160	0.72	86	386	2.06	9	0.025	0	613.9321	1838	8272
Fresh 16/06/95	661							80.32623		1.01		0.33202		573	1717	

Seepage data for column MTWC-2

MTWC 2		Pore vol. (L)	34.21	445.07													
Kinetic test started 25/08/93 MTCW-2 kinetic test DATE	Time elapsed (days)	Measured in lab Volume Collected (L)	Cumulative Volume Collected (L)	Number of pore volumes	Measured in lab pH	Measured in lab Acidity (mg/L CaCO3)	Acidity load (g CaCO3)	Reported by lab Fe mg/L	Fe load mg	Reported by lab Fe+3 mg/L	Fe+3 load mg	Reported by lab Zn mg/L	Zn load mg	Reported by lab S mg/L	Calc SO4 mg/L	SO4 load mg
27/08/93	3	0.72	0.72	0.02	5.10	13010	9.37	7160	5155	818.00	589	2530	1822	8090	24221	17439
03/09/93	10	1.14	1.86	0.05	3.42	10250	11.69	6960	7934	692.00	789	2440	2782	7900	23653	26964
10/09/93	17	1.44	3.30	0.10	3.28	11400	16.42	6960	10022	694.00	999	2390	3442	7960	23832	34318
17/09/93	24	1.14	4.44	0.13	3.43	10260	11.70	6880	7843	654.00	746	2310	2633	7810	23383	26657
22/09/93	29	1.34	5.78	0.17	3.25	11730	15.72	6730	9018	546.00	732	2260	3028	7780	23293	31213
01/10/93	38	1.14	6.92	0.20	3.64	11930	13.60	6670	7604	444.00	506	2200	2508	7610	22784	25974
08/10/93	45	1.28	8.20	0.24	3.31	9700	12.42	6490	8307	310.00	397	2140	2739	7470	22365	28627
15/10/93	52	2.13	10.33	0.30	3.42	11870	25.28	6610	14079	282.00	601	2170	4622	7590	22724	48403
22/10/93	59	1.40	11.73	0.34	3.58	11860	16.60	5890	8246	400.00	560	1930	2702	6680	20000	28000
29/10/93	66	1.06	12.79	0.37	3.39	10970	11.63	5860	6212	297.00	315	1880	1993	6670	19970	21168
05/11/93	73	1.02	13.81	0.40	4.50	11540	11.77	5820	5936	250.00	255	1820	1856	6630	19850	20247
12/11/93	80	0.98	14.79	0.43	3.51	10460	10.25	5820	5704	172.00	169	1750	1715	6530	19551	19160
19/11/93	87	1.20	15.99	0.47	3.33	9160	10.99	5830	6996	103.00	124	1680	2016	6520	19521	23425
26/11/93	94	0.98	16.97	0.50	3.52	11070	10.85	6490	6360	805.00	789	1774	1739	7126	21335	20909
03/12/93	101	1.18	18.15	0.53	3.37	10360	12.22	6356	7500	771.00	910	1618	1909	7067	21159	24967
10/12/93	108	1.12	19.27	0.56	3.58	8470	9.49	6190	6933	683.00	765	1404	1572	6729	20147	22564
17/12/93	115	1.26	20.53	0.60	3.66	7840	9.88	5923	7463	582.00	733	1177	1483	6232	18659	23510
23/12/93	120	1.26	21.79	0.64	3.50	7520	9.48	5560	7006	520.00	655	859.57	1083.06	5590	16736	21088
31/12/93	129	0.80	22.59	0.66	3.22	6570	5.26	5292	4234	439.00	351	723.87	579.09	5151	15422	12338
07/01/94	136	1.14	23.73	0.69	3.51	7250	8.27	5273	6011	335.00	382	599.50	683.44	4813	14410	16428
14/01/94	143	2.05	25.78	0.75	3.49	4670	9.57	5073	10400	247.00	506	413.31	847.29	4275	12799	26239
21/01/94	150	1.30	27.08	0.79	3.38	6800	8.84	4747	6171	199.00	259	282.37	367.09	3828	11461	14899
28/01/94	157	1.15	28.23	0.83	3.54	6520	7.50	4375	5031	168.00	193	216.15	248.57	3472	10395	11954
04/02/94	164	1.18	29.41	0.86	3.28	6020	7.10	4047	4775	129.00	152	168.49	198.81	3225	9656	11394
11/02/94	171	1.10	30.51	0.89	3.35	5800	6.38	3860	4246	89.80	99	133.37	146.71	2984	8934	9828
18/02/94	178	0.98	31.49	0.92	3.30	5600	5.49	3719	3645	86.40	85	110.18	107.98	2826	8461	8292
11/03/94	199	2.70	34.19	1.00	3.17	4810	12.99	3440	9288	95.90	259	81.82	220.93	2508	7509	20274
01/04/94	220	3.30	37.49	1.10	3.17	3660	12.08	2741	9045	32.10	106	50.11	165.36	1987	5949	19632
22/04/94	241	2.20	39.69	1.16	3.34	2620	5.76	2248	4946	62.70	138	31.70	69.73	1726	5167	11368
13/05/94	262	3.20	42.89	1.25	3.36	1920	6.14	1742	5574	22.70	73	16.83	53.86	1445	4326	13844
03/06/94	283	2.60	45.49	1.33	3.30	1180	3.07	1368	3557	7.99	21	8.94	23.25	1249	3740	9723
24/06/94	304	3.00	48.49	1.42	3.18	1200	3.60	1030	3090	41.00	123	3.28	9.84	1090	3263	9790
15/07/94	325	3.00	51.49	1.51	3.01	1250	3.75	813.03	2439	35.20	106	0.69	2.07	983	2942	8826
26/09/94	398	8.70	60.19	1.76	2.74	1000	8.70	484.3988	4214		0	0.13	1.13	865	2589	22529
25/11/94	458	8.20	68.39	2.00	2.83	540	4.43	246.55	2022	84.10	690	0.30	2.46	707	2117	17356
20/01/95	514	7.46	75.85	2.22	3.05	420	3.13	187.57	1399	16.00	119	0.09	0.67	654	1957	14600
17/03/95	570	7.60	83.45	2.44	2.98	250	1.90	68.09233	518	31	236	0.025	0.19	559.6849	1676	12735
21/04/95	605	5.00	88.45	2.59	3.26	180	0.90	70.28794	351	5.12	26	0.025	0.13	613.2408	1836	9180

Seepage data for column MTWC-3

MTWC 3
Kinetic test started
08/01/94
MTWC-3 kinetic test

Pore vol. (L) 34.21 623.99

DATE	Time elapsed (days)	Measured in lab Volume Collected (L)	Cumulative Volume Collected (L)	Number of pore volumes	Measured in lab pH	Measured in lab Acidity (mg/L CaCO3)	Acidity load (g CaCO3)	Reported by lab Fe mg/L	Fe load mg	Reported by lab Fe+3 mg/L	Fe+3 load mg	Reported by lab Zn mg/L	Zn load mg	Reported by lab S mg/L	Calc SO4 mg/L	SO4 load mg
14/01/94	6	2.35	2.35	0.07	3.36	18240	42.86	14340	33699	1090	2562	124.45	292	10070	30204	70979
21/01/94	13	1.64	3.99	0.12	3.15	20670	33.90	14390	23600	1100	1804	129.58	213	10110	30324	49731
28/01/94	20	0.76	4.75	0.14	3.22	22030	16.74	14050	10678	1560	1186	131.72	100	9910	29724	22590
04/02/94	27	1.19	5.94	0.17	3.01	21880	26.04	13920	16565	1100	1309	129.72	154	9882	29640	35272
11/02/94	34	1.22	7.16	0.21	2.90	22000	26.84	13870	16921	1450	1769	133.47	163	9719	29151	35564
18/02/94	41	0.86	8.02	0.23	2.82	22500	19.35	13700	11782	1940	1668	134.92	116	9527	28575	24575
11/03/94	62	2.35	10.37	0.30	2.69	21100	49.59	13880	32618	2150	5053	141.07	332	9149	27442	64488
01/04/94	83	2.70	13.07	0.38	2.66	20900	56.43	13980	37746	1590	4293	150.81	407	8634	25897	69921
22/04/94	104	1.75	14.82	0.43	2.70	19600	34.30	14420	25235	3310	5793	172.71	302	9354	28056	49099
13/05/94	125	2.40	17.22	0.50	2.59	17520	42.05	14420	34608	2330	5592	164.05	394	9073	27214	65313
03/06/94	146	3.35	20.57	0.60	2.59	15440	51.72	12930	43316	2230	7471	155.08	520	8107	24316	81459
24/06/94	167	3.80	24.37	0.71	2.54	8660	32.91	7350	27930	2205	8379	105.33	400	4890	14667	55735
15/07/94	188	4.10	28.47	0.83	2.59	4810	19.72	3170	12997	604	2476	58.44	240	2280	6839	28038
26/09/94	261	10.50	38.97	1.14	2.48	2600	27.30	1142.558	11997		0	39.60	416	1240.059	3719	39054
25/11/94	321	8.30	47.27	1.38	2.50	1560	12.95	709.5	5889	341	2830	34.23	284	790.57	2371	19681
20/01/95	377	7.88	55.15	1.61	2.57	1560	12.29	710.51	5599	211	1663	33.15	261	646.99	1941	15292
17/03/95	433	8.70	63.85	1.87	2.58	1440	12.53	577.7552	5026	258	2245	28.04543	244	513.0858	1539	13389
21/04/95	468	5.20	69.05	2.02	2.66	1420	7.38	703.9058	3660	103	536	31.46654	164	545.2771	1636	8505

Seepage data for column MTWC-4

		Pore vol. (L)	34.21	619.54													
MTWC 4 Kinetic test started 08/01/94 MTWC-4 kinetic test DATE	Time elapsed (days)	Measured in lab Volume Collected (L)	Cumulative Volume Collected (L)	Number of pore volumes	Measured in lab pH	Measured in lab Acidity (mg/L CaCO3)	Acidity load (g CaCO3)	Reported by lab Fe mg/L	Fe load mg	Reported by lab Fe+3 mg/L	Fe+3 load mg	Reported by lab Zn mg/L	Zn load mg	Reported by lab S mg/L	Calc SO4 mg/L	SO4 load mg
14/01/94	6	1.95	1.95	0.06	3.37	18110	35.31	14130	27554	1090	2126	124.17	242	9799	29391	57313
21/01/94	13	1.44	3.39	0.10	3.17	22400	32.26	14320	20621	1010	1454	129.71	187	9896	29682	42742
28/01/94	20	0.84	4.23	0.12	3.21	22370	18.79	14140	11878	1140	958	134.75	113	9871	29607	24870
04/02/94	27	1.24	5.47	0.16	3.00	22110	27.42	14140	17534	1080	1339	135.74	168	9938	29808	36962
11/02/94	34	1.10	6.57	0.19	3.00	21100	23.21	14320	15752	1270	1397	141.17	155	9793	29373	32310
18/02/94	41	0.84	7.41	0.22	2.83	22800	19.15	14070	11819	1700	1428	143.82	121	9646	28932	24303
11/03/94	62	3.70	11.11	0.32	2.85	22820	84.43	14530	53761	1270	4699	148.91	551	9345	28029	103709
01/04/94	83	3.20	14.31	0.42	2.81	21410	68.51	14510	46432	732	2342	154.52	494	8719	26152	83686
22/04/94	104	1.50	15.81	0.46	2.73	20940	31.41	14400	21600	3150	4725	164.13	246	9248	27738	41608
13/05/94	125	2.75	18.56	0.54	2.65	19270	52.99	14030	38583	1930	5308	158.54	436	8802	26401	72602
03/06/94	146	4.15	22.71	0.66	2.69	12890	53.49	10280	42662	1440	5976	125.63	521	6432	19292	80062
24/06/94	167	4.00	26.71	0.78	2.70	5730	22.92	3920	15680	697	2788	63.12	252	2720	8158	32633
15/07/94	188	3.53	30.24	0.88	2.64	2900	10.24	1700	6001	261	921	37.84	134	1410	4229	14929
26/09/94	261	11.20	41.44	1.21	2.60	1600	17.92	633.0092	7090		0	28.84208	323	898.7261	2696	30191
25/11/94	321	8.20	49.64	1.45	2.50	1040	8.53	376.22	3085	274	2247	22.64	186	539.16	1617	13261
20/01/95	377	7.88	57.52	1.68	2.52	1060	8.35	371.19	2925	268	2112	22.16	175	454.94	1365	10753
17/03/95	433	8.20	65.72	1.92	2.54	970	7.95	327.2656	2684	236	1935	19.14214	157	372.7685	1118	9168
21/04/95	468	5.20	70.92	2.07	2.55	970	5.04	398.4423	2072	172	894	23.11785	120	399.5963	1199	6232

Seepage data for column MTWC-5

MTWC 5
Kinetic test started
08/01/94
MTWC-5 kinetic test

Pore vol. (L) 34.21 623.90

DATE	Time elapsed (days)	Measured in lab Volume Collected (L)	Cumulative Volume Collected (L)	Number of pore volumes	Measured in lab pH	Measured in lab Acidity (mg/L CaCO3)	Acidity load (g CaCO3)	Reported by lab Fe mg/L	Fe load mg	Reported by lab Fe+3 mg/L	Fe+3 load mg	Reported by lab Zn mg/L	Zn load mg	Reported by lab S mg/L	Calc SO4 mg/L	SO4 load mg
14/01/94	6	2.05	2.05	0.06	3.32	18240	37.39	14900	30545	1090	2235	93.00	191	10340	31014	63578.28
21/01/94	13	1.54	3.59	0.10	3.13	20670	31.83	14920	22977	1690	2603	93.00	143	10290	30864	47530.29
28/01/94	20	0.74	4.33	0.13	3.16	22030	16.30	14750	10915	1550	1147	102.00	75	10200	30594	22639.47
04/02/94	27	1.18	5.51	0.16	2.99	21880	25.82	14920	17606	1310	1546	104.00	123	10250	30744	36277.74
11/02/94	34	1.08	6.59	0.19	2.86	22000	23.76	14600	15768	1850	1998	109.00	118	9983	29943	32338.45
18/02/94	41	1.22	7.81	0.23	2.85	22500	27.45	14780	18032	1570	1915	111.00	135	10050	30144	36775.64
11/03/94	62	2.30	10.11	0.30	2.70	21100	48.53	14670	33741	2180	5014	115.87	267	9458	28368	65247.15
01/04/94	83	3.00	13.11	0.38	2.69	21880	65.64	14440	43320	1590	4770	118.16	354	8765	26290	78869.22
22/04/94	104	1.65	14.76	0.43	2.74	21110	34.83	14690	24239	725	1196	124.42	205	9356	28062	46302.94
13/05/94	125	2.75	17.51	0.51	2.66	20030	55.08	14510	39903	2130	5858	123.13	339	9063	27184	74754.80
03/06/94	146	3.50	21.01	0.61	2.60	16210	56.74	11970	41895	2130	7455	115.20	403	7477	22427	78492.80
24/06/94	167	3.50	24.51	0.72	2.55	10280	35.98	6530	22855	2040	7140	78.81	276	4490	13467	47135.57
15/07/94	188	3.53	28.04	0.82	2.54	6930	24.46	4210	14861	1120	3954	54.29	192	3150	9448	33351.83
26/09/94	261	10.00	38.04	1.11	2.45	6800	68.00	3713	37130		0	46.40	464	2929	8785	87852.43
25/11/94	321	5.10	43.14	1.26	2.27	7350	37.49	3590	18309	2650	13515	49.20	251	2890	8668	44208.16
20/01/95	377	10.52	53.66	1.57	2.47	8620	90.68	4990	52495	507	5334	57.32	603	3240	9718	102233.95
17/03/95	433	8.10	61.76	1.81	2.48	7520	60.91	4571	37025	1320	10692	36.87733	299	2875	8623	69848.53
21/04/95	468	5.90	67.66	1.98	2.44	5210	30.74	2845	16786	1240	7316	40.71914	240	1907	5720	33747.15

Seepage data for column MTWC-6

MTWC 6 Kinetic test started 08/01/94 MTWC-6 kinetic test DATE	Time elapsed (days)	Pore vol. (L) Measured in lab Volume Collected (L)	34.2052 Cumulative Volume Collected (L)	619.456 Number of pore volumes	Measured in lab pH	Measured in lab Acidity (mg/L CaCO3)	Acidity load (g CaCO3)	Reported by lab Fe mg/L	Fe load mg	Reported by lab Fe+3 mg/L	Fe+3 load mg	Reported by lab Zn mg/L	Zn load mg	Reported by lab S mg/L	Calc SO4 mg/L	SO4 load mg
14/01/94	6	2.05	2.05	0.05993	3.37	18110	37.1255	14540	29807	1080	2214	70	143.5	10210	30623.874	62778.942
21/01/94	13	2.08	4.13	0.12074	3.27	22400	46.592	14760	30700.8	1170	2433.6	75	156	10380	31133.772	64758.246
28/01/94	20	0.84	4.97	0.1453	3.2	22370	18.7908	14620	12280.8	1290	1083.6	80	67.2	10230	30683.862	25774.444
04/02/94	27	1.16	6.13	0.17921	2.98	22110	25.6476	14630	16970.8	1310	1519.6	83	96.28	10210	30623.874	35523.694
11/02/94	34	1.24	7.37	0.21546	2.88	21100	26.164	14330	17769.2	1830	2269.2	89	110.36	10010	30023.994	37229.753
18/02/94	41	0.8	8.17	0.23885	2.82	22800	18.24	13390	10712	2270	1816	92	73.6	9412	28230.3528	22584.282
11/03/94	62	3.6	11.77	0.3441	2.84	22820	82.152	14720	52992	1650	5940	104.9411	377.788	9407	28215.3558	101575.28
01/04/94	83	3.4	15.17	0.4435	2.82	22560	76.704	14810	50354	735	2499	121.7948	414.1022	8984	26946.6096	91618.473
22/04/94	104	2	17.17	0.50197	2.72	20100	40.2	14780	29560	3200	6400	135.6689	271.3377	9393	28173.3642	56346.728
13/05/94	125	3.35	20.52	0.59991	2.68	17950	60.1325	13090	43851.5	1810	6063.5	126.6051	424.127	8090	24265.146	81288.239
03/06/94	146	3.6	24.12	0.70516	2.66	11710	42.156	7953	28630.8	1340	4824	93.19437	335.4997	5168	15500.8992	55803.237
24/06/94	167	3.6	27.72	0.8104	2.58	6850	24.66	4230	15228	1030	3708	60.91	219.276	3080	9238.152	33257.347
15/07/94	188	3.07	30.79	0.90016	—	6875	21.10625	3720	11420.4	1140	3499.8	56.33	172.9331	2860	8578.284	26335.332
26/09/94	261	9.3	40.09	1.17204	2.54	6900	64.17	4324	40213.2		0	56.20078	522.6673	3219	9655.0686	89792.138
25/11/94	321	8	48.09	1.40593	2.41	7830	62.64	4720	37760	1640	13120	46.07	368.56	3230	9688.062	77504.496
20/01/95	377	4.55	52.64	1.53895	2.38	9050	41.1775	4710	21430.5	1655	7530.25	52.4	238.42	3110	9328.134	42443.01
17/03/95	433	10.4	63.04	1.84299	2.55	7240	75.296	4264	44345.6	737	7664.8	47.99876	499.1871	2594	7780.4436	80916.613
21/04/95	468	5.2	68.24	1.99502	2.46	5340	27.768	3046	15839.2	918	4773.6	37.86935	196.9206	1930	5788.842	30101.978

Estimate value. Acidity and pH were not measured

Seepage data for column MTWC-7

MTWC 7
Kinetic test started
21/02/94
MTWC-7 kinetic test

Pore vol. (L) 34.21 1100.54

DATE	Time elapsed (days)	in lab Volume Collected (L)	Cumulative Volume Collected (L)	Number of pore volumes	Measured in lab pH	Measured in lab Acidity (mg/L CaCO3)	Acidity load (g CaCO3)	Reported by lab Fe mg/L	Fe load mg	Reported by lab Fe+3 mg/L	Fe+3 load mg	Reported by lab Zn mg/L	Zn load mg	Reported by lab S mg/L	Calc SO4 mg/L	SO4 load mg
11/03/94	70	1.70	1.70	0.0497	3.13	32170	54.689	20290	34493	1460	2482	155.85	265	13150	39442	67052
01/04/94	91	3.00	4.70	0.14	2.89	30560	91.68	19900	59700	887	2661	151.36	454	12570	37702	113107
22/04/94	112	1.90	6.60	0.19	2.73	27690	52.611	12730	8303	4370	24187	147.77	281	18050	54139	102864
13/05/94	133	2.55	9.15	0.27	2.68	24400	62.22	19380	49419	2660	6783	140.30	358	19430	58278	148610
03/06/94	154	2.80	11.95	0.35	2.60	25830	72.324	18770	52556	3080	8624	138.80	389	12000	35993	100780
24/06/94	175	2.75	14.70	0.43	2.53	26420	72.655	16050	44138	6630	18233	128.81	354	10760	32274	88752
15/07/94	196	3.05	17.75	0.52	2.57	24290	74.0845	16030	48892	4890	14915	127.53	389	10740	32214	98251
26/09/94	217	12.00	29.75	0.87	2.50	18400	220.8	12270	147240		0	112.95	1355	8209	24622	295465
25/11/94	277	8.50	38.25	1.12	2.37	6030	51.255	3370	28645	1530	13005	45.04	383	2390	7169	60933
20/01/95	333	8.05	46.30	1.35	2.34	4260	34.293	1880	15134	1240	9982	32.90	265	4170	12507	100685
17/03/95	389	7.50	53.80	1.57	2.41	3220	24.15	1546	11595	834	6255	28.75567	216	1154	3461	25960
21/04/95	424	5.20	59.00	1.72	2.43	3050	15.86	1548	8050	969	5039	36.81131	191	1067.821	3203	16655

Seepage data for column MTWC-8

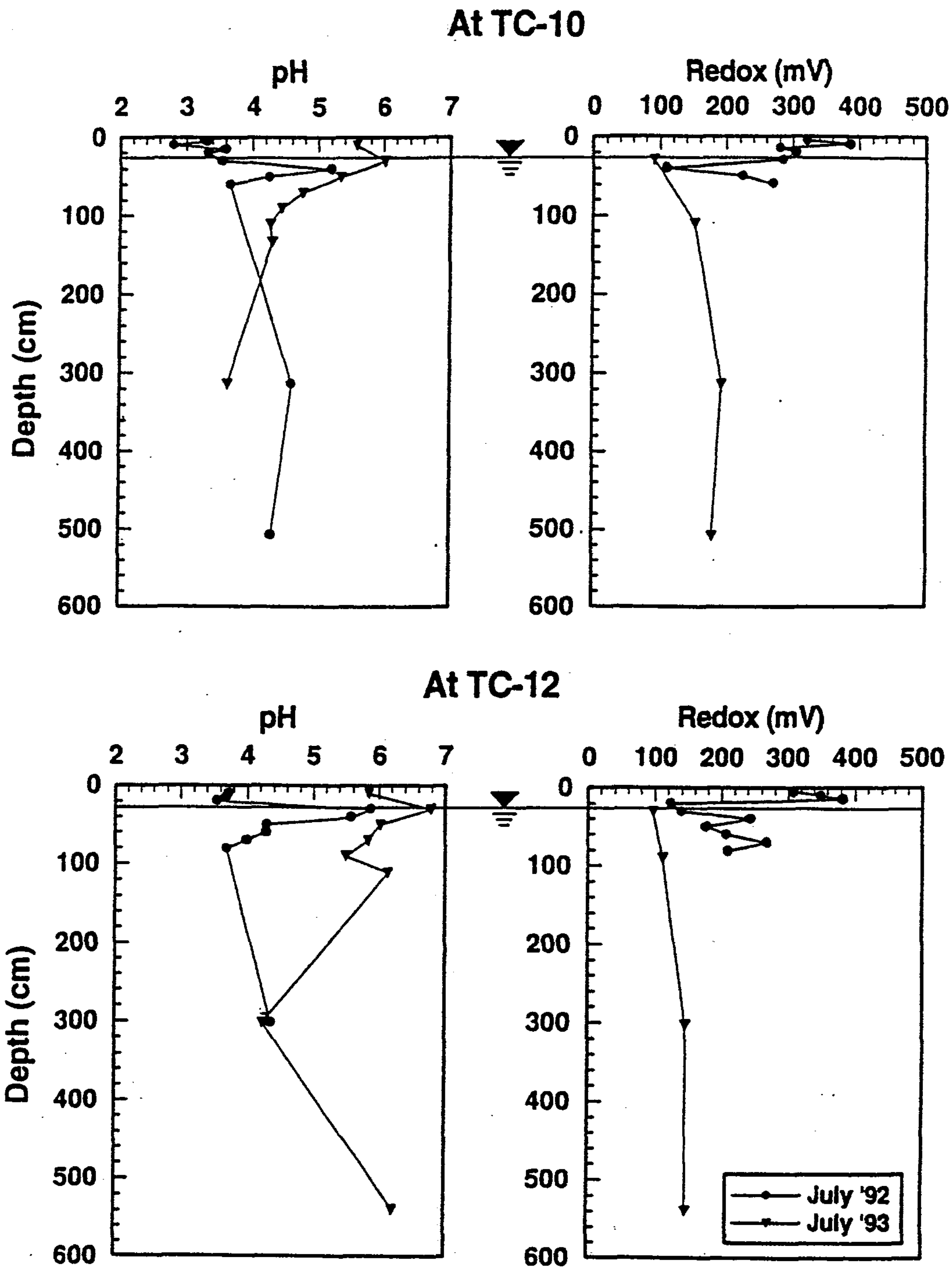
MTWC 8
Kinetic test started
21/02/94
MTWC-8 kinetic test

Pore vol. (L) 34.21 1008.17

DATE	Time elapsed (days)	in lab Volume Collected (L)	Cumulative Volume Collected (L)	Number of pore volumes	Measured in lab pH	Measured in lab Acidity (mg/L CaCO3)	Acidity load (g CaCO3)	Reported by lab Fe mg/L	Fe load mg	Reported by lab Fe+3 mg/L	Fe+3 load mg	Reported by lab Zn mg/L	Zn load mg	Reported by lab S mg/L	Calc SO4 mg/L	SO4 load mg
11/03/94	70	0.75	0.75	0.02	3.04	29470	22.1025	18530	13898	1460	1095	146.80	110	12080	36233	27175
01/04/94	91	2.80	3.55	0.10	2.86	28790	80.612	18370	51436	1010	2828	147.83	414	11660	34973	97924
22/04/94	112	1.40	4.95	0.14	2.77	26510	37.114	18650	26110	3370	4718	145.69	204	12130	36383	50936
13/05/94	133	2.35	7.30	0.21	2.69	26400	62.04	18710	43969	2910	6839	139.28	327	12020	36053	84724
03/06/94	154	3.80	11.10	0.32	2.69	25330	96.254	18050	68590	2790	10602	138.40	526	11500	34493	131074
24/06/94	175	4.00	15.10	0.44	2.73	25570	102.28	15560	62240	5890	23560	127.42	510	10200	30594	122376
15/07/94	196	3.93	19.03	0.56	2.61	22650	89.0145	15280	60050	4500	17685	125.66	494	10030	30084	118230
26/09/94	217	11.70	30.73	0.90	2.59	17700	207.09	12060	141102		0	112.3467	1314	8093	24274	284007
25/11/94	277	7.10	37.83	1.11	2.35	4970	35.287	2630	18673	1430	10153	40.66	289	1840	5519	39184
20/01/95	333	7.40	45.23	1.32	2.30	3740	27.676	1570	11618	1260	9324	35.80	265	1230	3689	27301
17/03/95	389	7.50	52.73	1.54	2.40	3330	24.975	1604	12030	937	7028	33.97111	255	1191	3572	26792
21/04/95	424	5.00	57.73	1.69	2.47	3140	15.7	1666	8330	624	3120	40.3306	202	1091.863	3275	16375

APPENDIX VI

PH, REDOX, AND SOLUTE CONCENTRATION PROFILES FOR FIELD CELL



= depth of water table prior to flooding.

Figure VI-1: pH and redox profiles inside the test cell

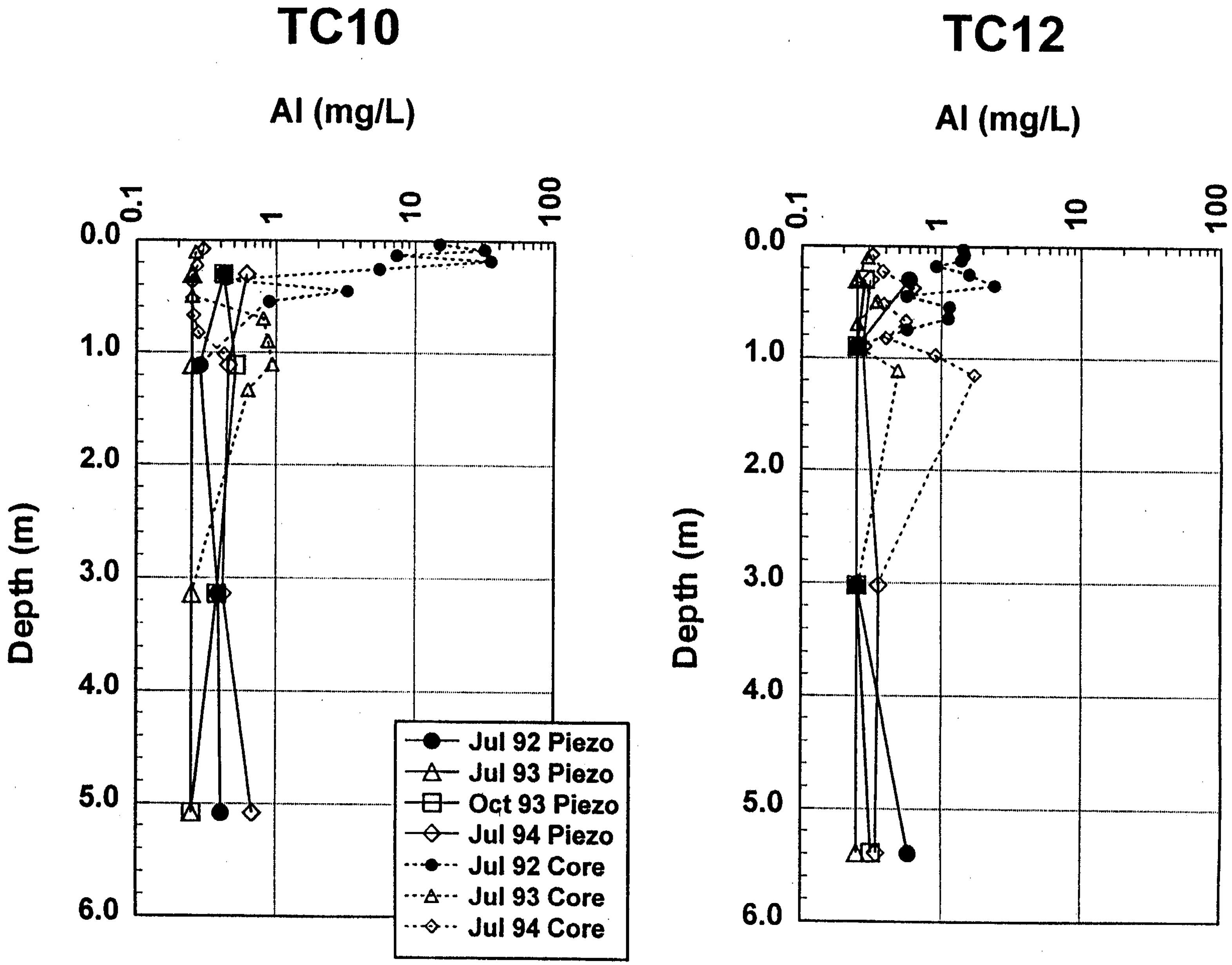


Figure VI-2: Dissolved aluminium concentration profiles inside test cell

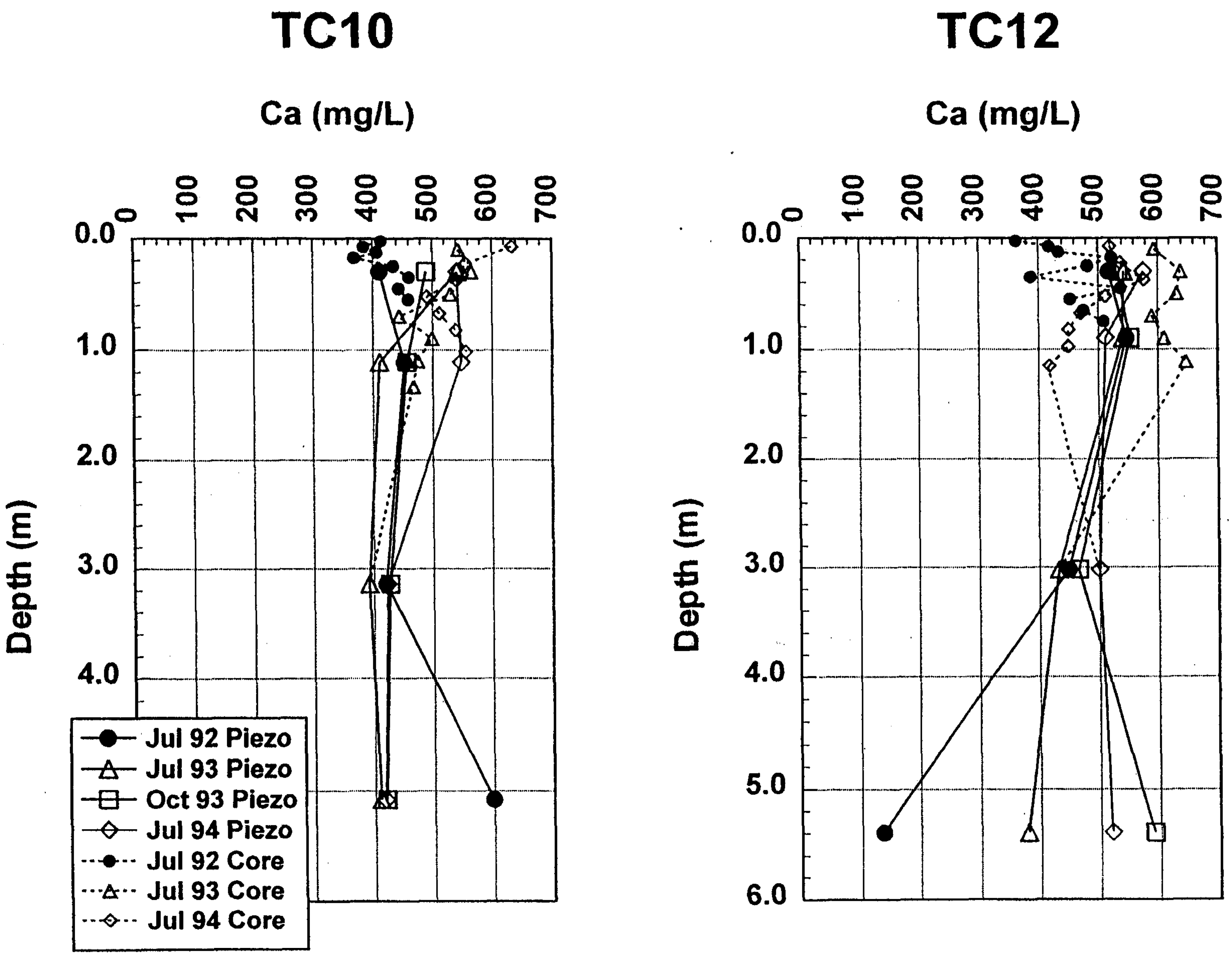


Figure VI-3: Dissolved calcium concentration profiles inside test cell

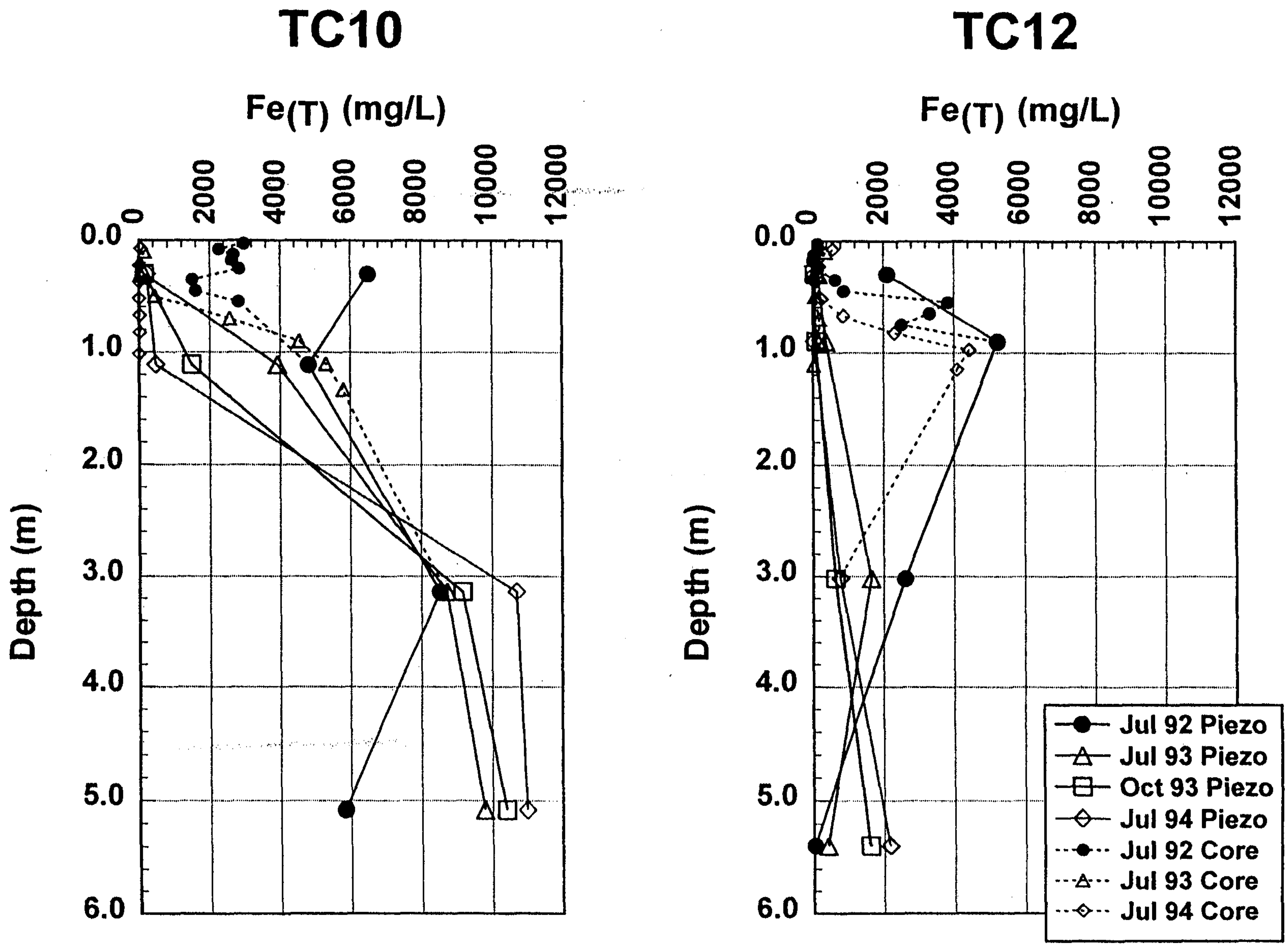


Figure VI-4: Dissolved total iron concentration profiles inside test cell

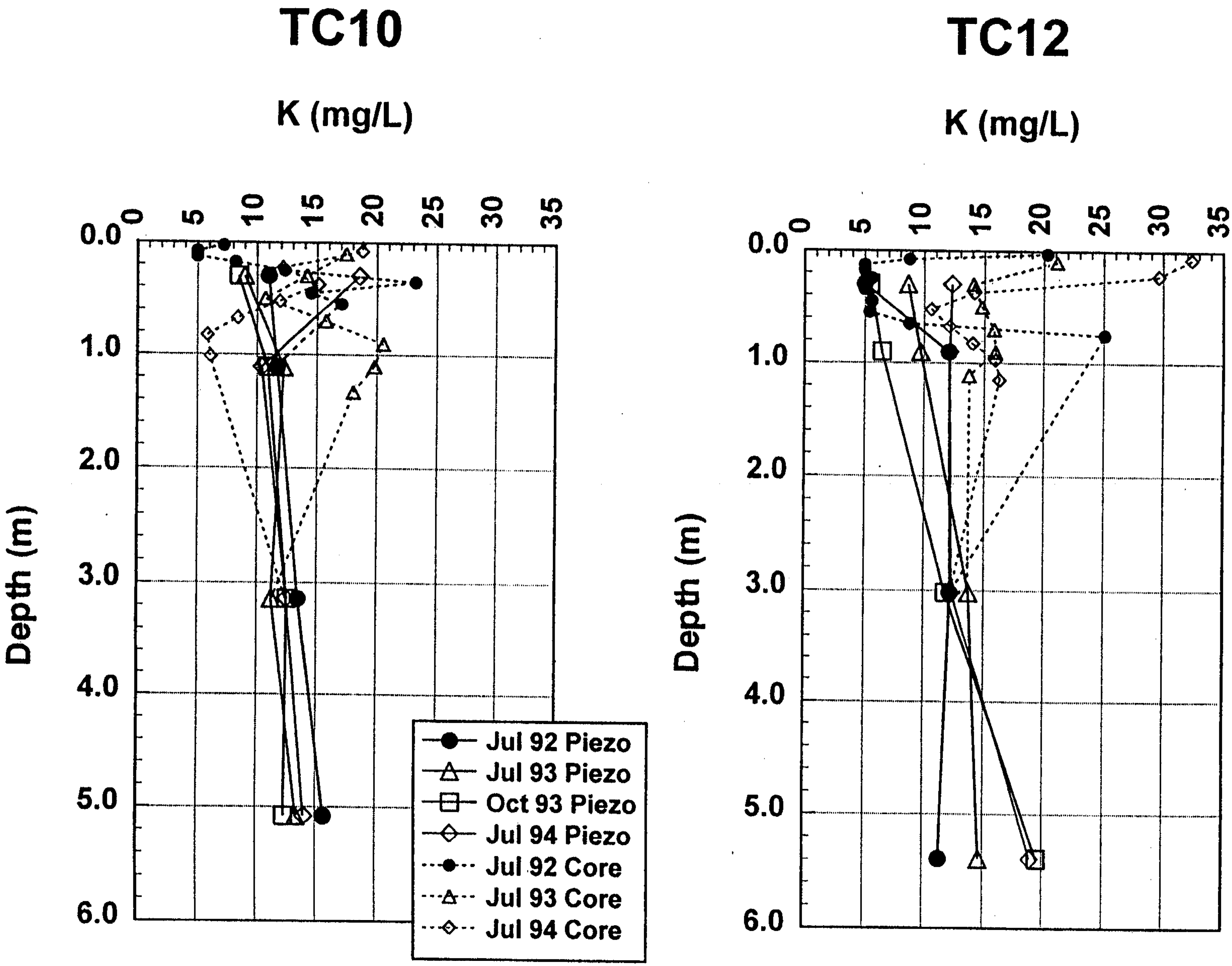


Figure VI-5: Dissolved potassium concentration profiles inside test cell

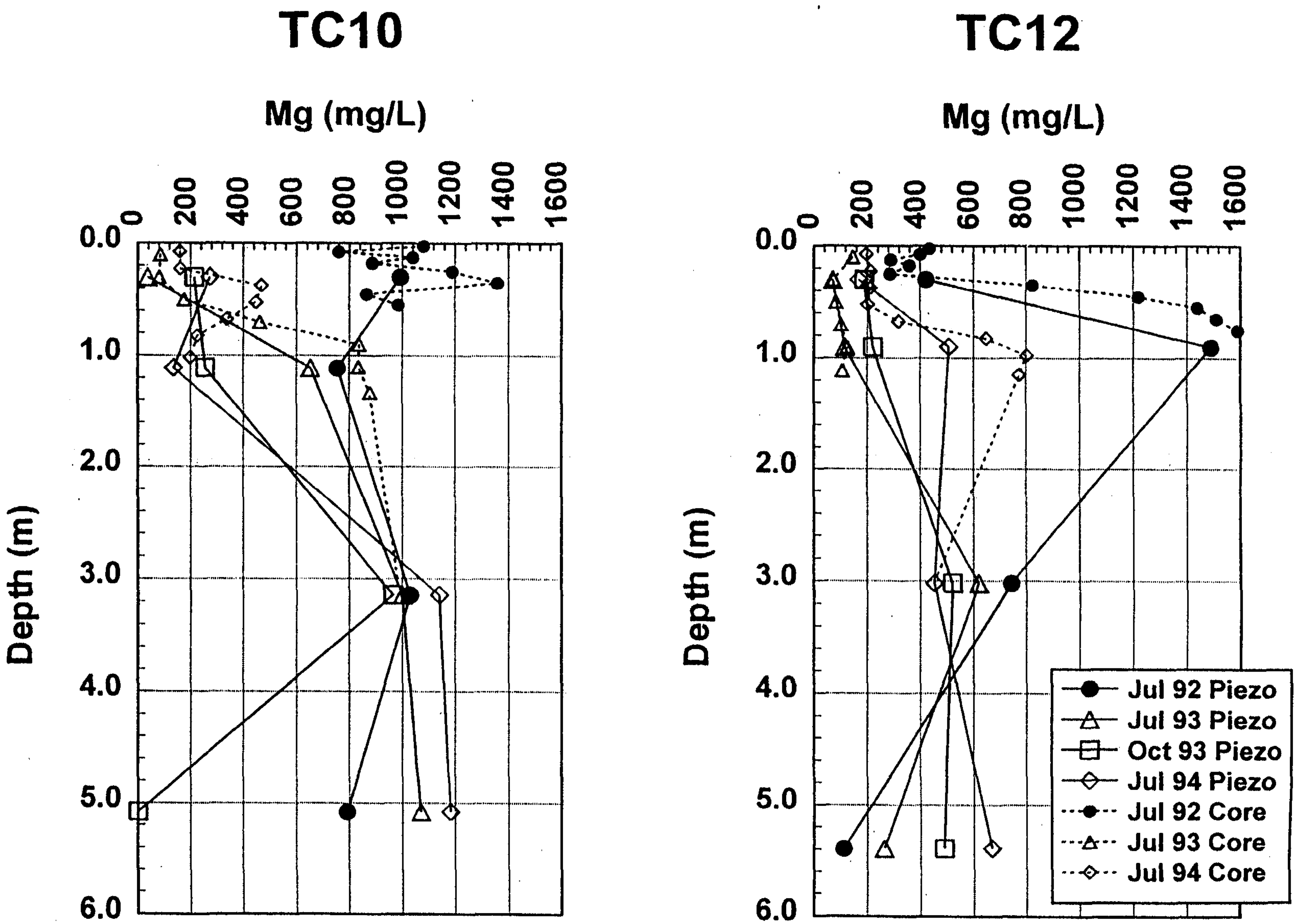


Figure VI-6: Dissolved magnesium concentration profiles inside test cell

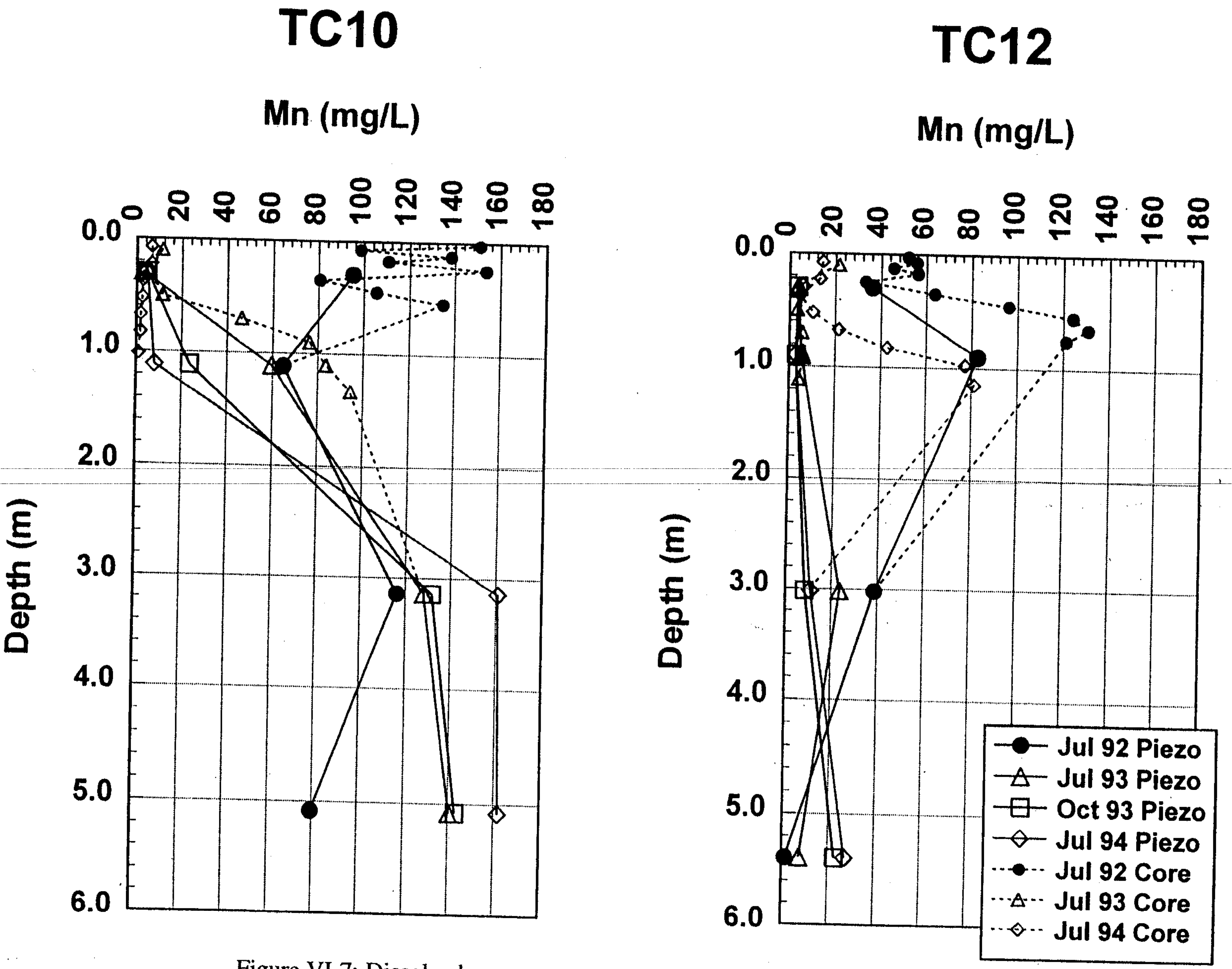


Figure VI-7: Dissolved manganese concentration profiles inside test cell

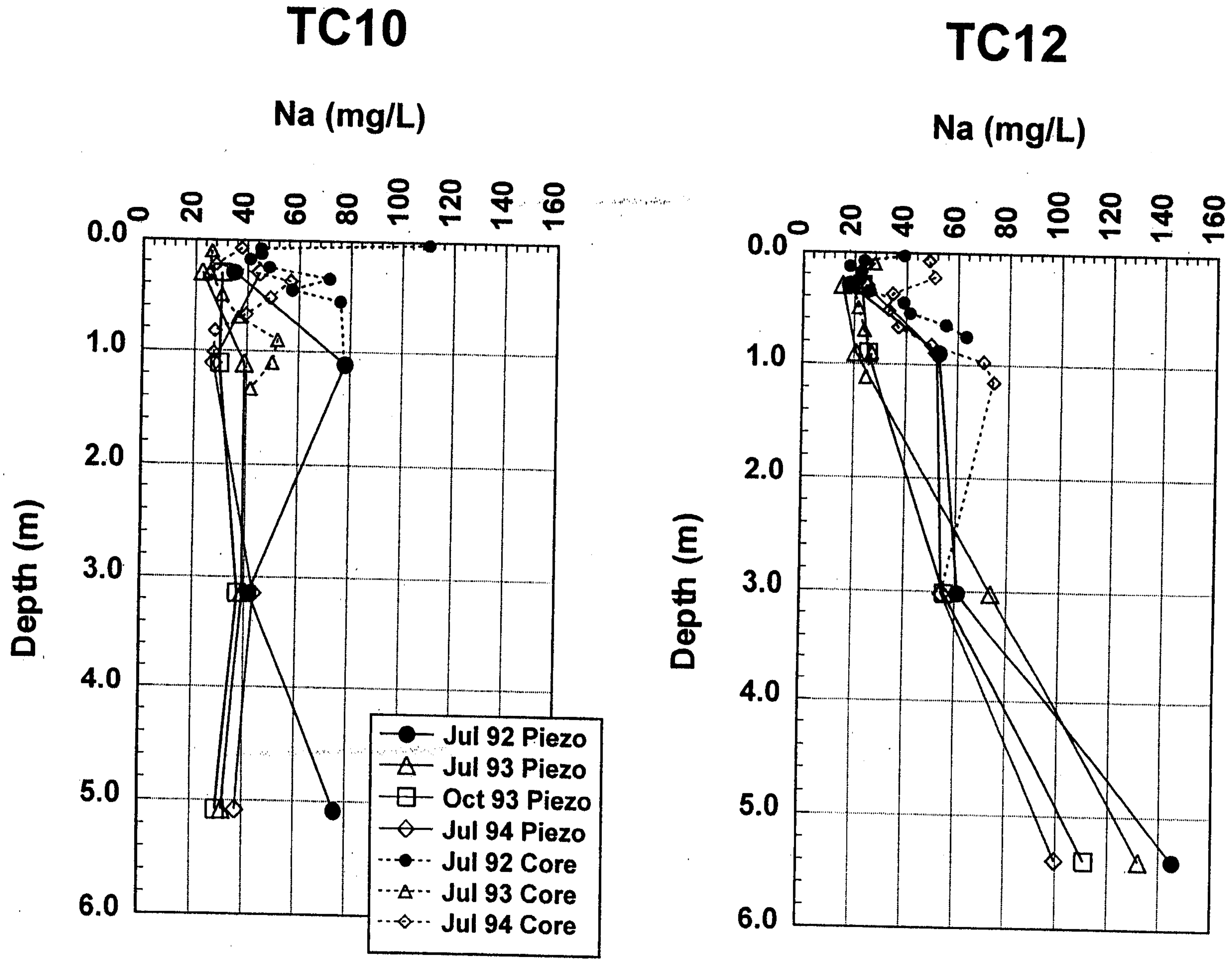


Figure VI-8: Dissolved sodium concentration profiles inside test cell

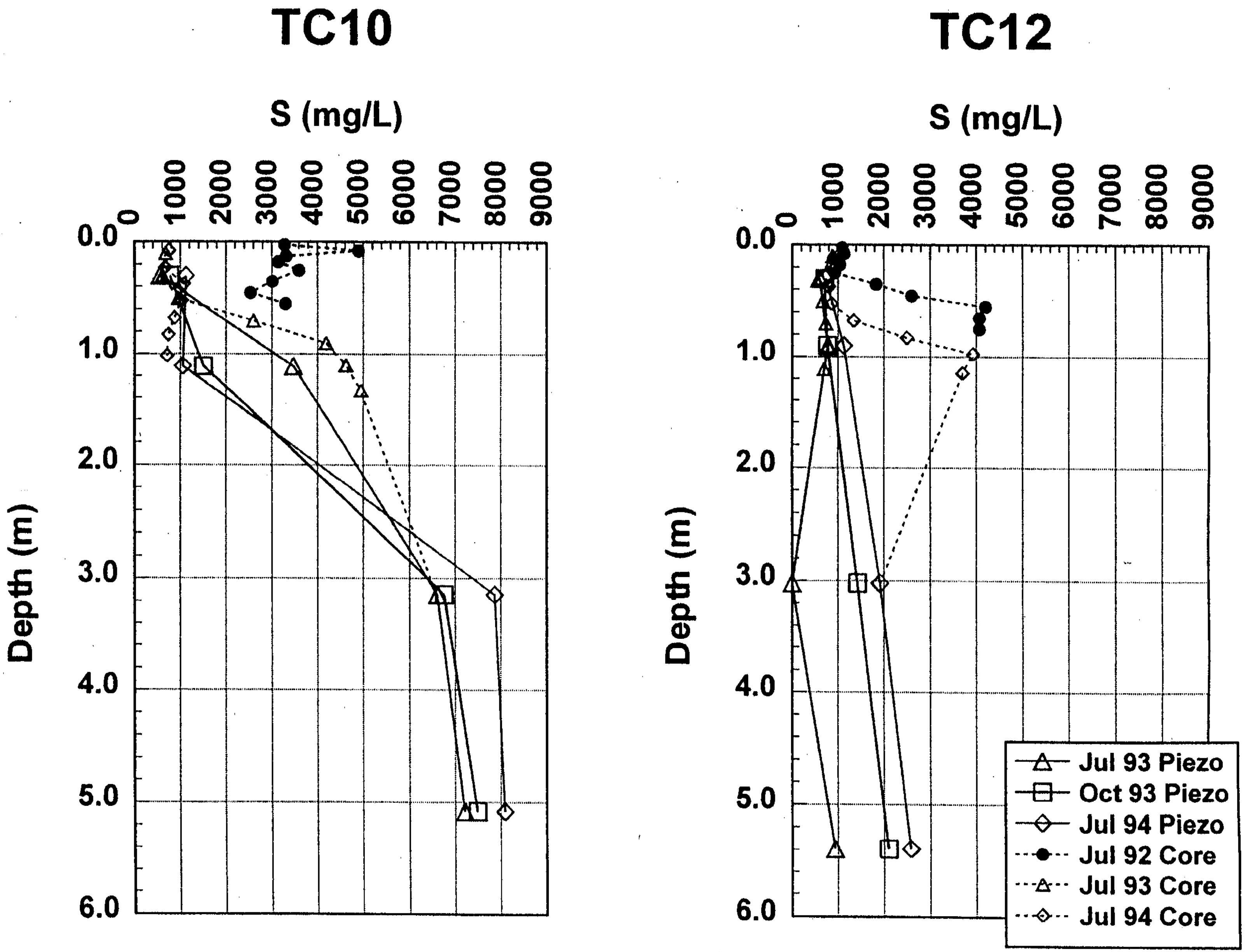


Figure VI-9: Dissolved sulphate concentration profiles inside test cell

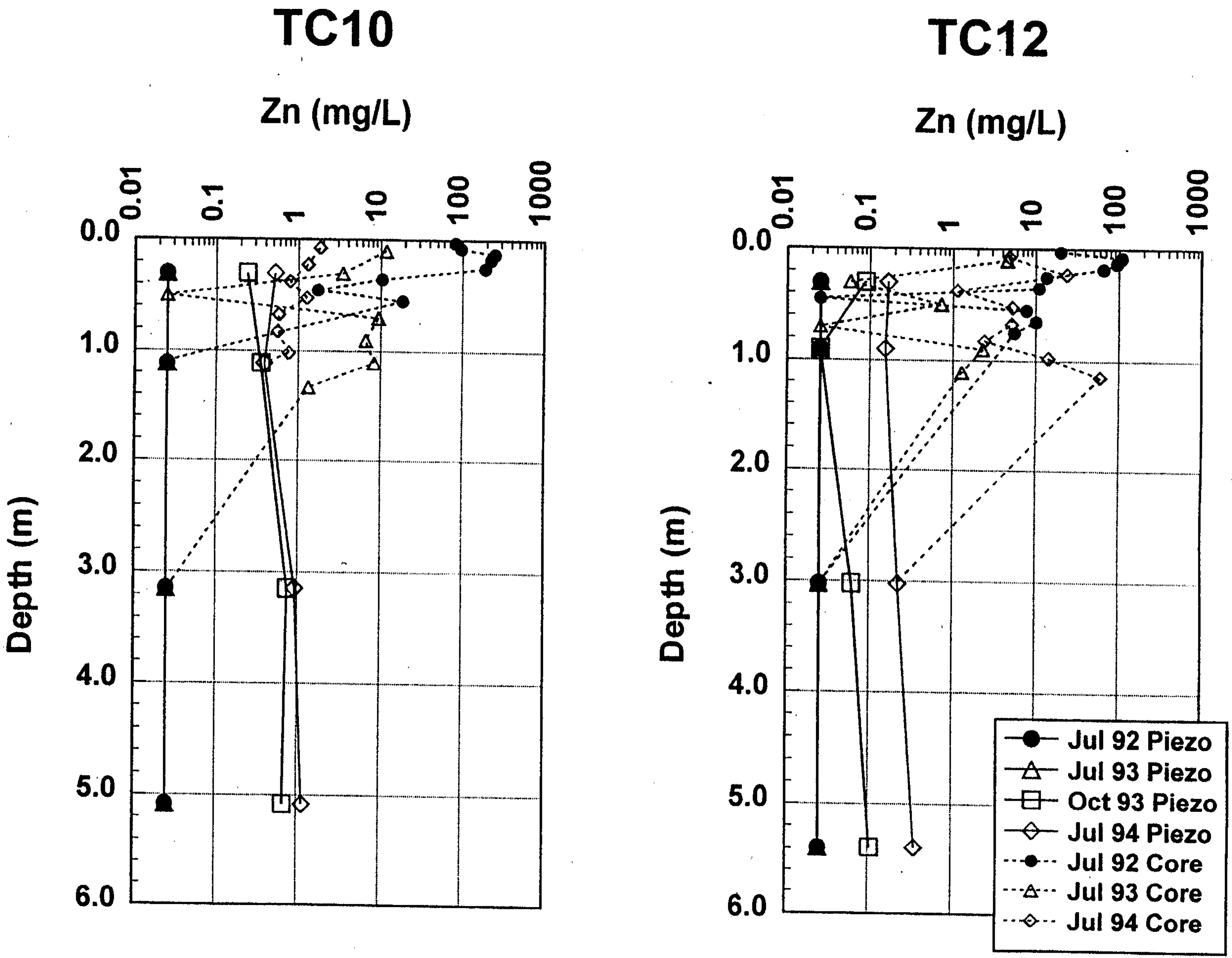
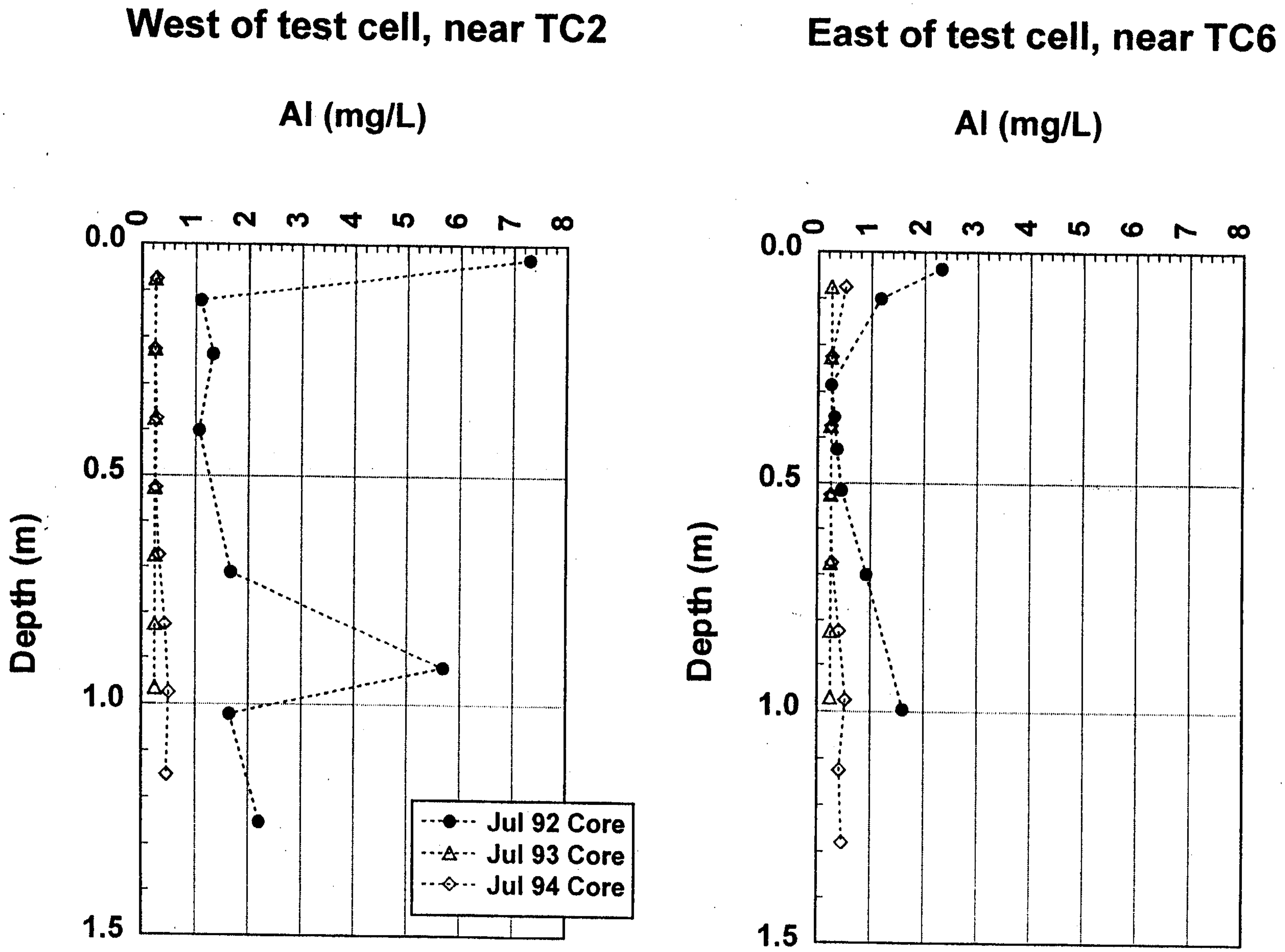


Figure VI-10: Dissolved zinc concentration profiles inside test cell



West of test cell, near TC2

East of test cell, near TC6

Figure VI-11: Dissolved aluminium concentration profiles outside test cell

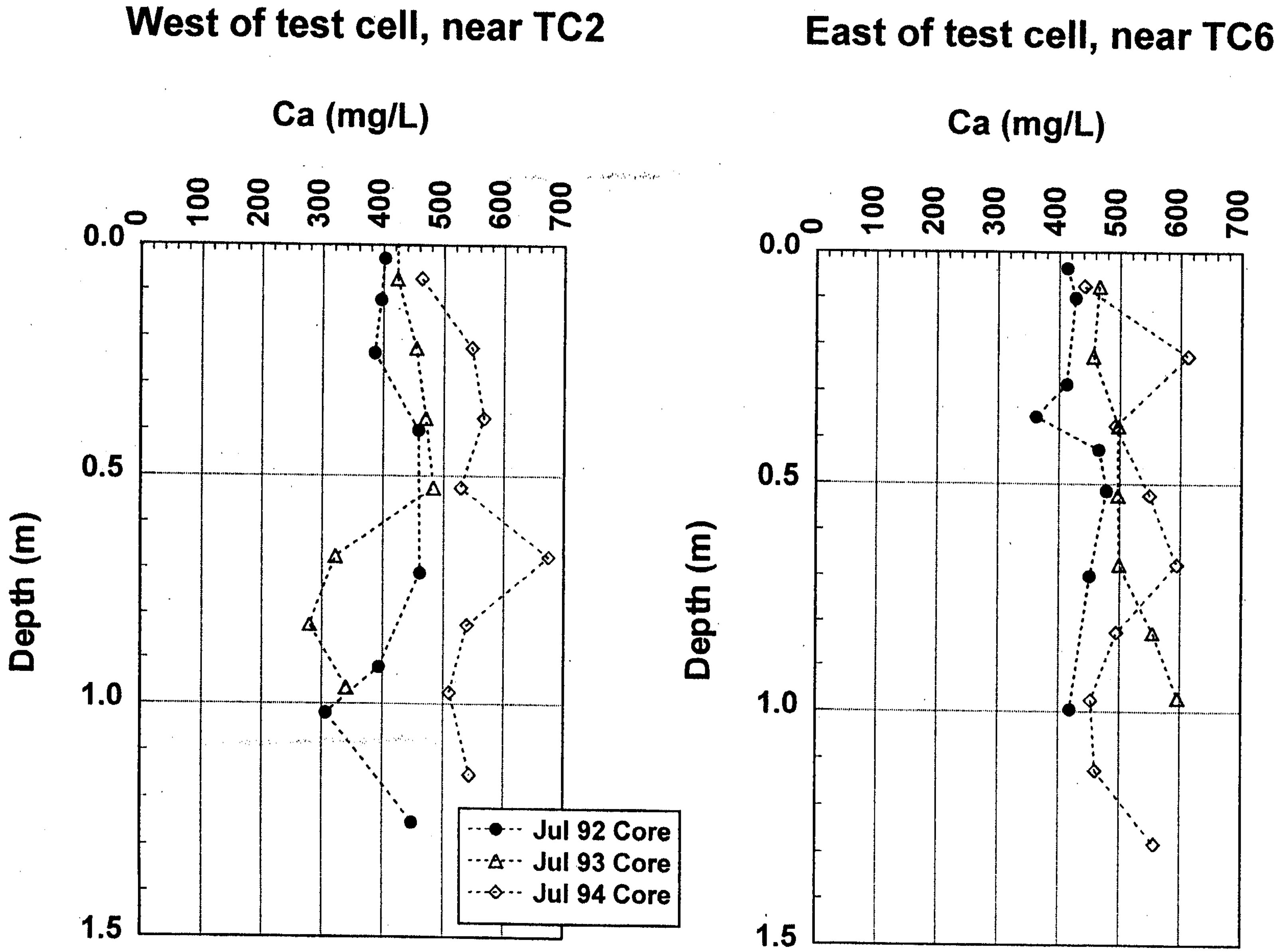


Figure VI-12: Dissolved calcium concentration profiles outside test cell

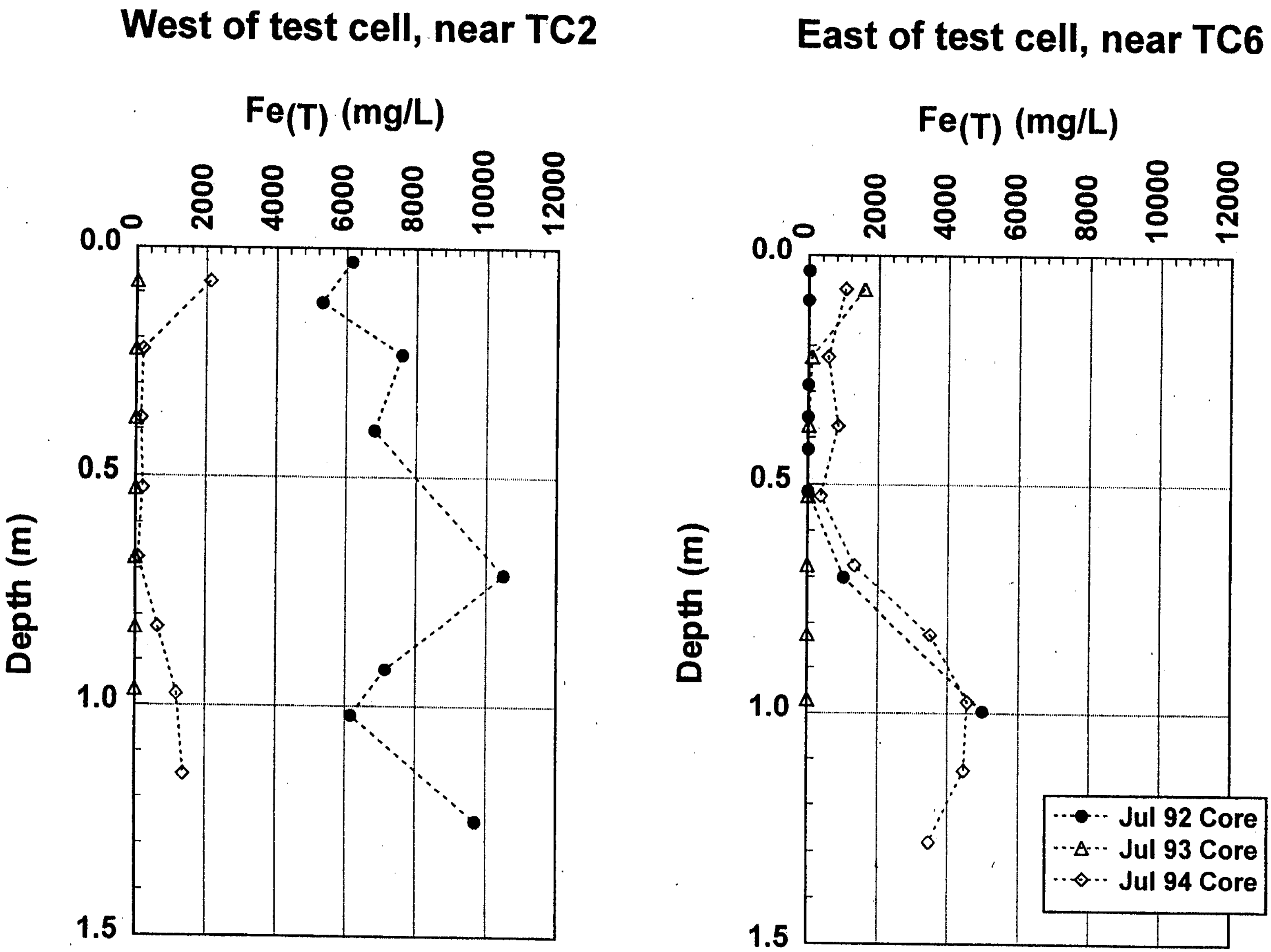


Figure VI-13: Dissolved total iron concentration profiles outside test cell

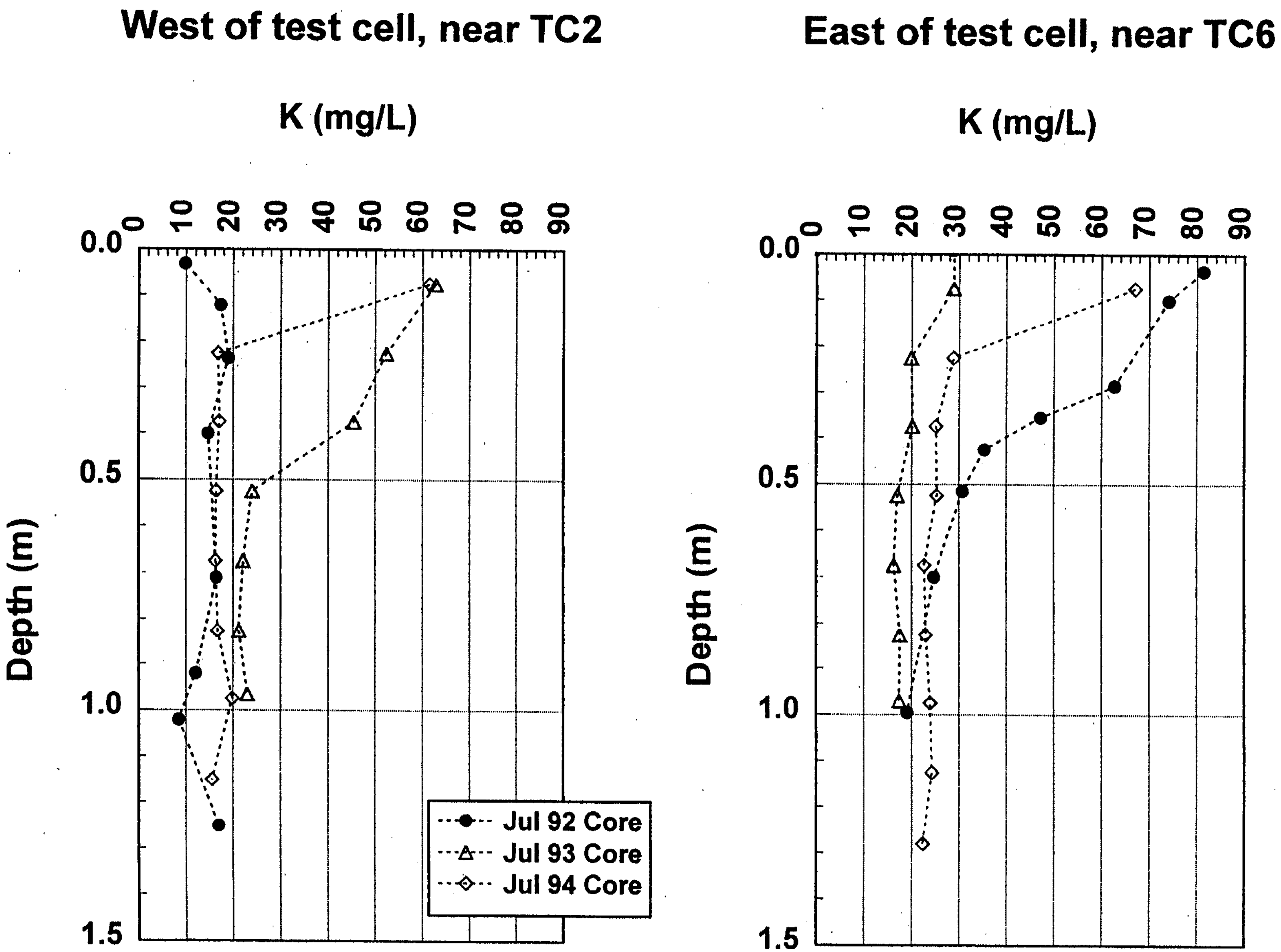


Figure VI-14: Dissolved potassium concentration profiles outside test cell

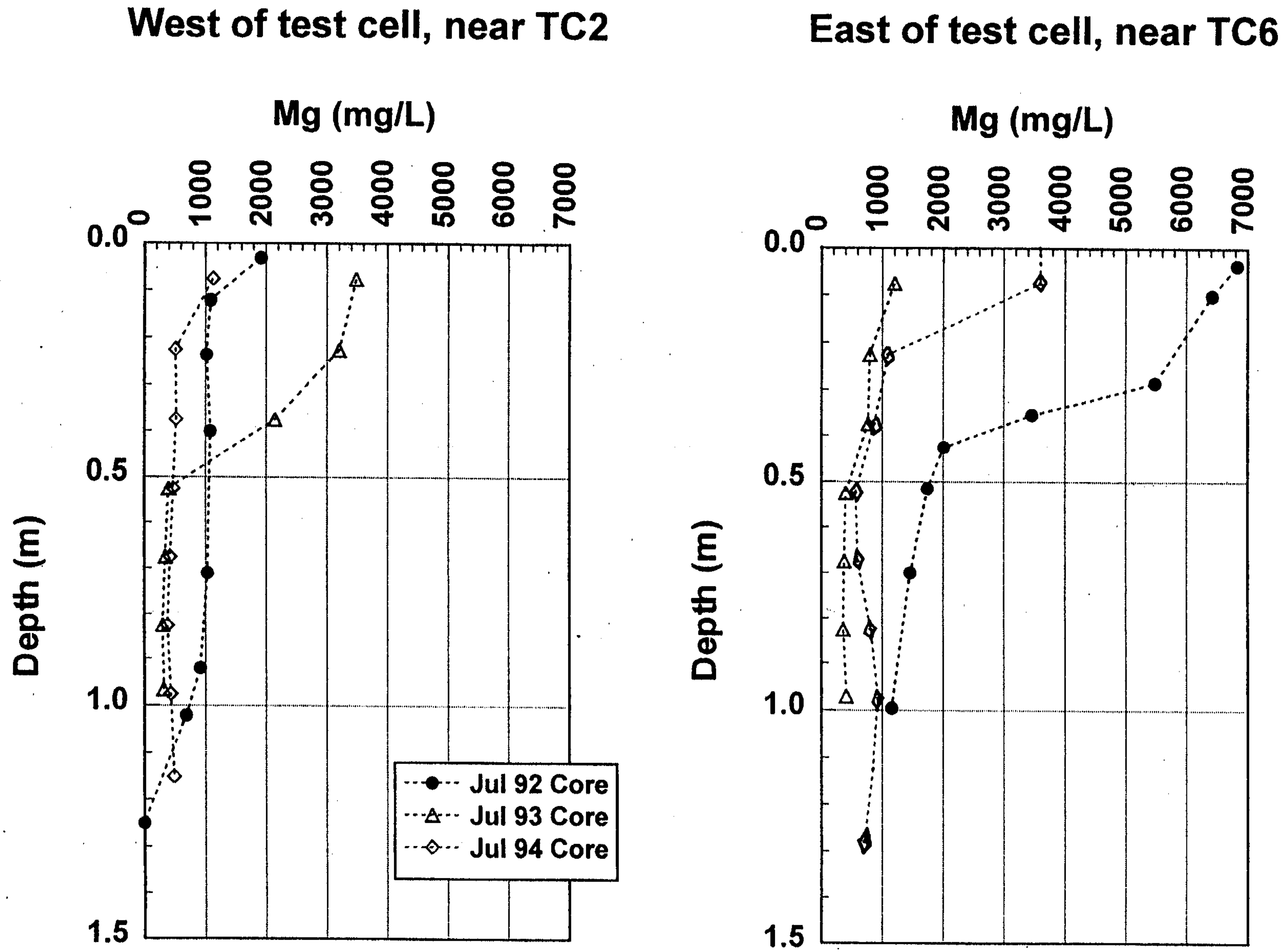


Figure VI-15: Dissolved magnesium concentration profiles outside test cell

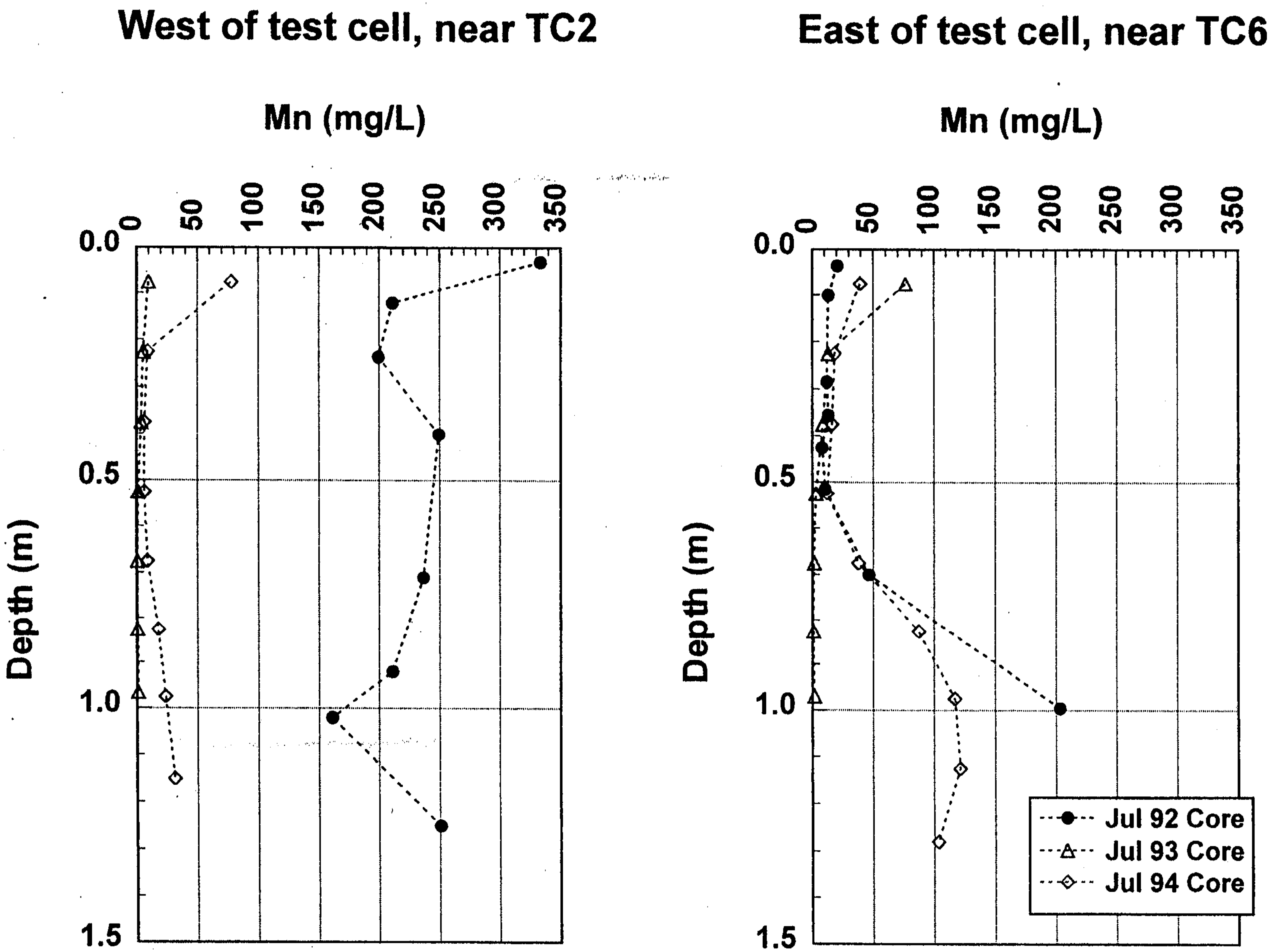


Figure VI-16: Dissolved manganese concentration profiles outside test cell

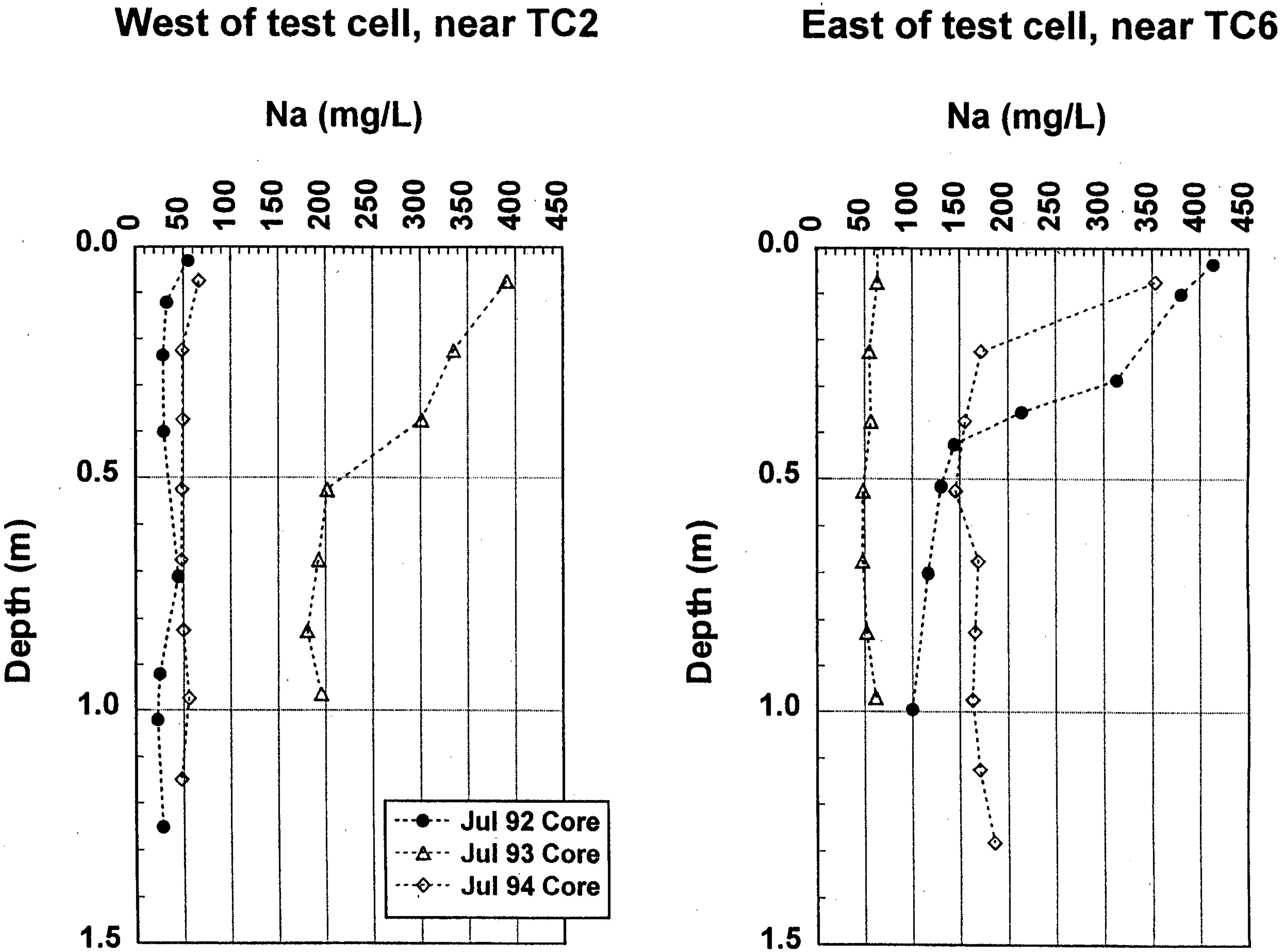
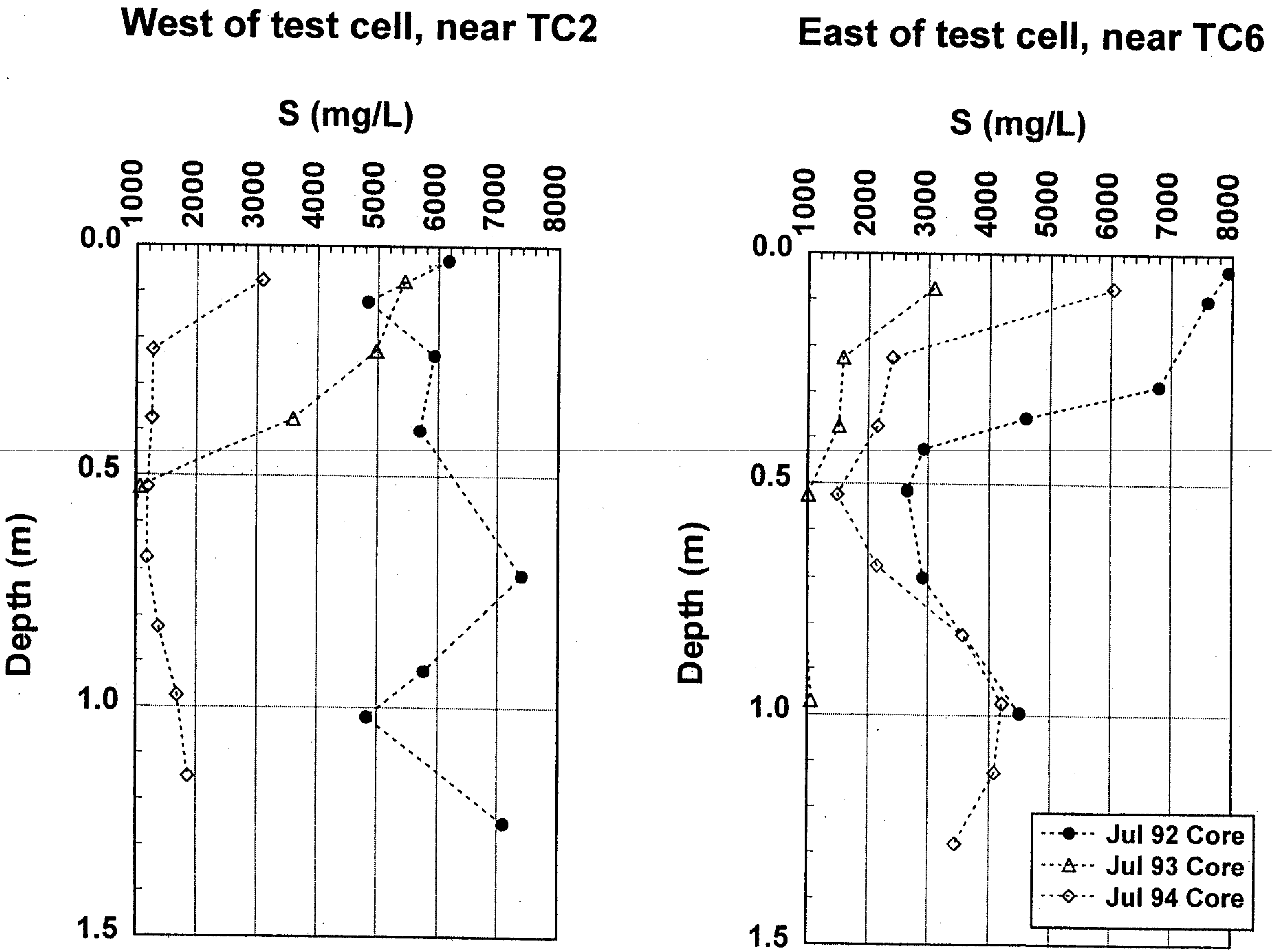


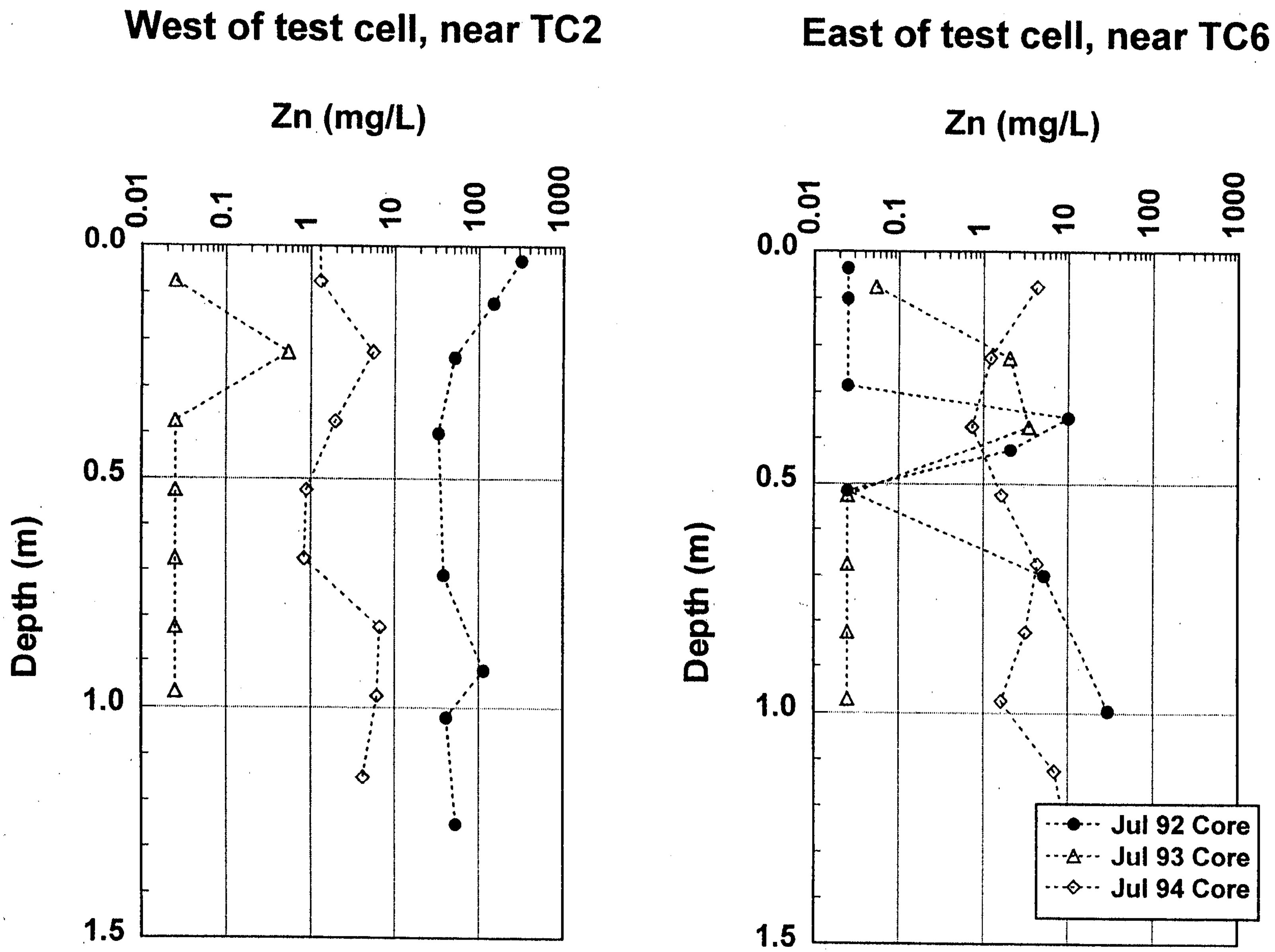
Figure VI-17: Dissolved sodium concentration profiles outside test cell



West of test cell, near TC2

East of test cell, near TC6

Figure VI-18: Dissolved sulphate concentration profiles outside test cell



West of test cell, near TC2

East of test cell, near TC6

Figure VI-19: Dissolved zinc concentration profiles outside test cell