HYDROGEOCHEMISTRY OF OXIDISED WASTE ROCK FROM STRATMAT SITE, N.B.

MEND Report 2.36.2a

This work was done on behalf of MEND and sponsored by
Noranda Inc. as well as
The Probince of New Brunswich, and
The Canada Centre for Mineral and Energy Technology (CANMET)
Through the Canada/New Brunswich Mineral Development Agreement (MDA)

March 1999

FINAL REPORT

HYDROGEOCHEMISTRY OF OXIDISED WASTE ROCK FROM STRATMAT SITE, N.B.

Prepared for

CANMET - MMSL Division
Natural Resources Canada
555 Booth Street, Ottawa, Ontario K1A 0G1
PWGSC Contract No. 23440-4-1316/01-SQ

by

M. Li
Noranda Inc., Technology Centre
240 Hymus Blvd., Pointe-Claire, Québec H9R 1G5

March 1999

noranda

EXECUTIVE SUMMARY

This report documents the results of the first part of a research project jointly funded by Noranda Inc. and the Mine Environment Neutral Drainage (MEND) program. The second part is covered in a separate report entitled *Hydrology and Solute Transport in Oxidised Waste Rock from Stratmat Site, N.B.*, published concurrently with this report. The overall objective of the project was to understand the geochemical and hydrological interactions between the partially oxidised waste rock and water and to improve our capabilities and techniques in the prediction of acidic drainage from waste rock piles.

Partially oxidised waste rock was sampled from the Stratmat pile at Heath Steele Division of Noranda Inc. by grabbing, trenching, and bulk excavation techniques. The samples were physically and geochemically characterised in the laboratory whereas the bulk density was measured in the field. The trenched samples were used in column dissolution tests in which 25-kg composite sub-samples were subjected to repeated washing with water to observe the water quality evolution over time. The resulting data were used to predict water quality for a hypothetical scenario where the waste rock were backfilled in the Stratmat pit. In addition, water quality profiles were measured in the Stratmat pit.

Results of the column dissolution tests suggest the following mass balance for the Stratmat pile: Approximately 7% of the original sulphide sulphur has been oxidised since deposition, releasing a total acidity of 11 800 t $CaCO_3$ equivalent, of which 56% has been neutralised in situ. Currently, the acidity inventory is approximately 5200 t $CaCO_3$ equivalent whereas the inventory of soluble zinc is about 1660 t. The mass balance appears to support preferential oxidation of sphalerite over pyrite.

The column dissolution experiments further indicate that dumping the waste rock into the flooded Stratmat pit will cause significant release of stored metals and sulphate. The long-term pore water quality in the absence of ground water movement is predicted as follows: pH 3.32, acidity 12 500 mg $CaCO_3$/L, SO_4^{2-} 19 500 mg/L, Zn 4500 mg/L, Cu 180 mg/L and Pb 2.4 mg/L. In the presence of uncontaminated ground water movement, the water quality would gradually improve as the initial pore water is displaced or diluted. It would take nine pore volumes of flushing to reduce the concentrations of most metals (except Pb) to below 0.1 mg/L. For Pb, this would take many more pore volumes.

Geochemical modelling suggests various concentration control mechanisms. Concentrations of Pb and Fe in the pore water are likely controlled by equilibria of the leachate solution with anglesite and ferric hydroxide, respectively. On the other hand, concentra-

tions of SO_4, Zn, Ca, Mg, Mn, and Al in the pore water seem to be limited in the short term by dissolution/diffusion rate controls. The presence of gypsum is found to inhibit the dissolution of anglesite. As a result the anglesite stored in the waste rock would not dissolve appreciably until gypsum storage is exhausted by dissolution. This implies that decommissioning of the waste rock by a backfilling-flushing-treatment process would last a long time before the pore water in the backfilled waste rock becomes acceptable for discharge to the receiving groundwater.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

1.0 INTRODUCTION

Acid mine drainage (AMD) is the largest environmental problem facing the base metal, coal, and uranium mining industry in North America, with financial liabilities measured in billions of dollars (Feasby et al., 1997). Various degrees of AMD prediction (probability of occurrence, lag time, as well as concentration and loading variation over time) are required for development of new mines as well as management of existing waste facilities in operating and decommissioned mines.

AMD prediction for sulphidic waste rock piles and dumps is particularly difficult, despite progresses made in the last two decades in the battery of prediction techniques. Some progresses have been reviewed under the auspices of the Canadian Mine Environment Neutral Drainage (MEND) program by Norecol, Dames and Moore (1996), Smith et al. (1995), Perkins et al. (1995), and Morin et al. (1991). MEND has also completed a number of case studies on AMD from waste rock (e.g., Geocon et al., 1996; Gélinas et al., 1997; Lefebvre et al., 1997; Isabel et al., 1997; Payant and Yanful, 1997; Noranda Technology Centre, 1997; Norecol, Dames and Moore, 1994; Nolan Davis and ANSTO, 1994; Nolan Davis, 1990).

This report documents the results of a study of the hydrogeochemistry of partially oxidised waste rock from the Stratmat waste rock pile at Heath Steele Division, Noranda Inc., located near Miramichi, New Brunswick. The main intention of this work was to contribute, by means of a case study, to our knowledge of the influence of oxidised waste rock on the quality of water coming into contact with the rock. Accumulation of such case studies should help improve our ability and confidence in the prediction of water quality under a variety of environmental conditions.

1.1 OBJECTIVES AND TASKS

The objective of this work was to study the present status of the partially oxidised Stratmat waste rock and its hydrogeochemical interactions with water under simulated submergence. The specific objectives were as follows:

1. to characterise waste rock samples physically and geochemically,
2. to reveal the hydrogeochemical interactions between the waste rock and water,
3. to estimate the inventory of oxidation products stored in the Stratmat waste rock pile,
4. to predict the future water chemistry of the flooded Stratmat pit for a hypothetical scenario where the oxidised waste rock were placed in the pit for disposal.

To fulfil the above objectives, five tasks were carried out:

1. field sampling of waste rock,
2. pit water sampling and profiling,
3. physicochemical characterisation of solid samples,
4. column dissolution tests and interpretation, and
5. reporting.

1.2 SITE DESCRIPTION

The Stratmat/N5 lead-zinc-copper-silver massive sulphide deposits were located within the mining lease of the Heath Steele Division, Noranda Inc., about 50 km north-west of Miramichi, New Brunswick (Figure 1-1). The deposits were discovered in late 50s and early 60s. Open pit and underground mining commenced at Stratmat in fall 1989. The Stratmat pit was depleted in summer 1991. The N5 pit mining began in winter 1991 and was completed by winter 1992, when a pressure bulkhead was installed between the N5 and the Stratmat underground workings to allow flooding of the N5 pit. Underground mining continued at Stratmat until June 1993. Installation of another bulkhead in the Stratmat decline facilitated flooding of the Stratmat pit. A plan and a section of the Stratmat/N5 area are shown in Figure 1-2 and Figure 1-3, respectively. Figure 1-4 is a photograph of the Stratmat pile. The pink stripes on the dump face are crushed limestone layers placed during construction of the pile.

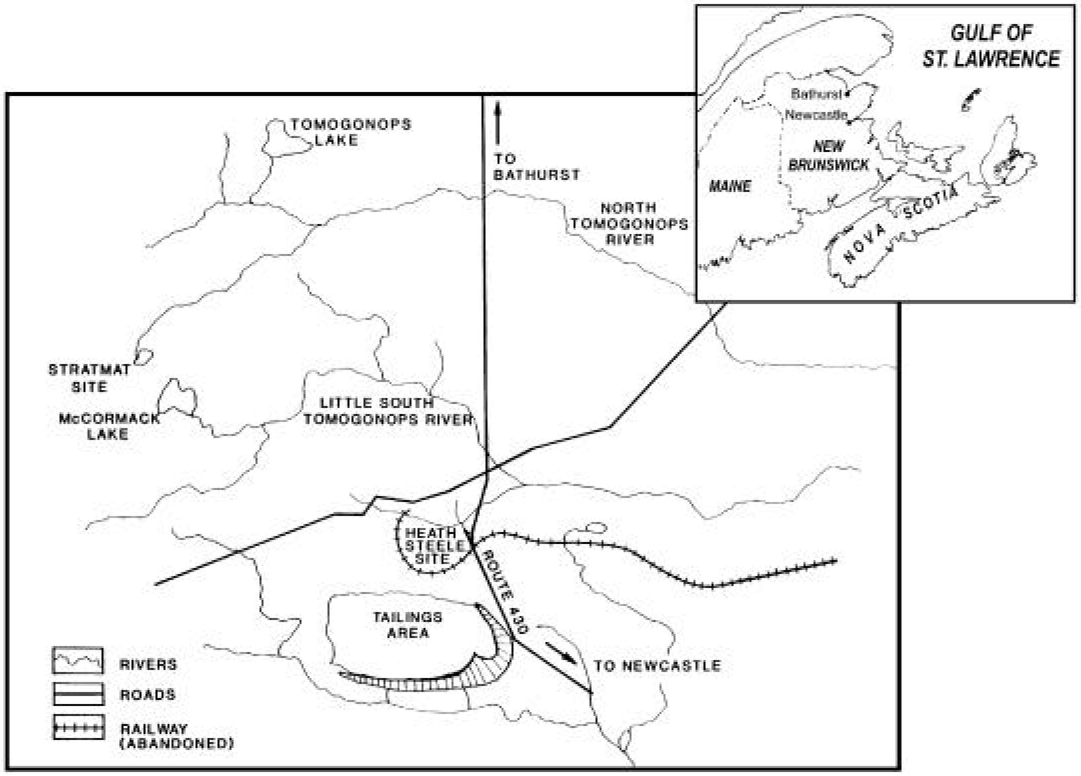


Figure 1-1 Location of Heath Steele Division

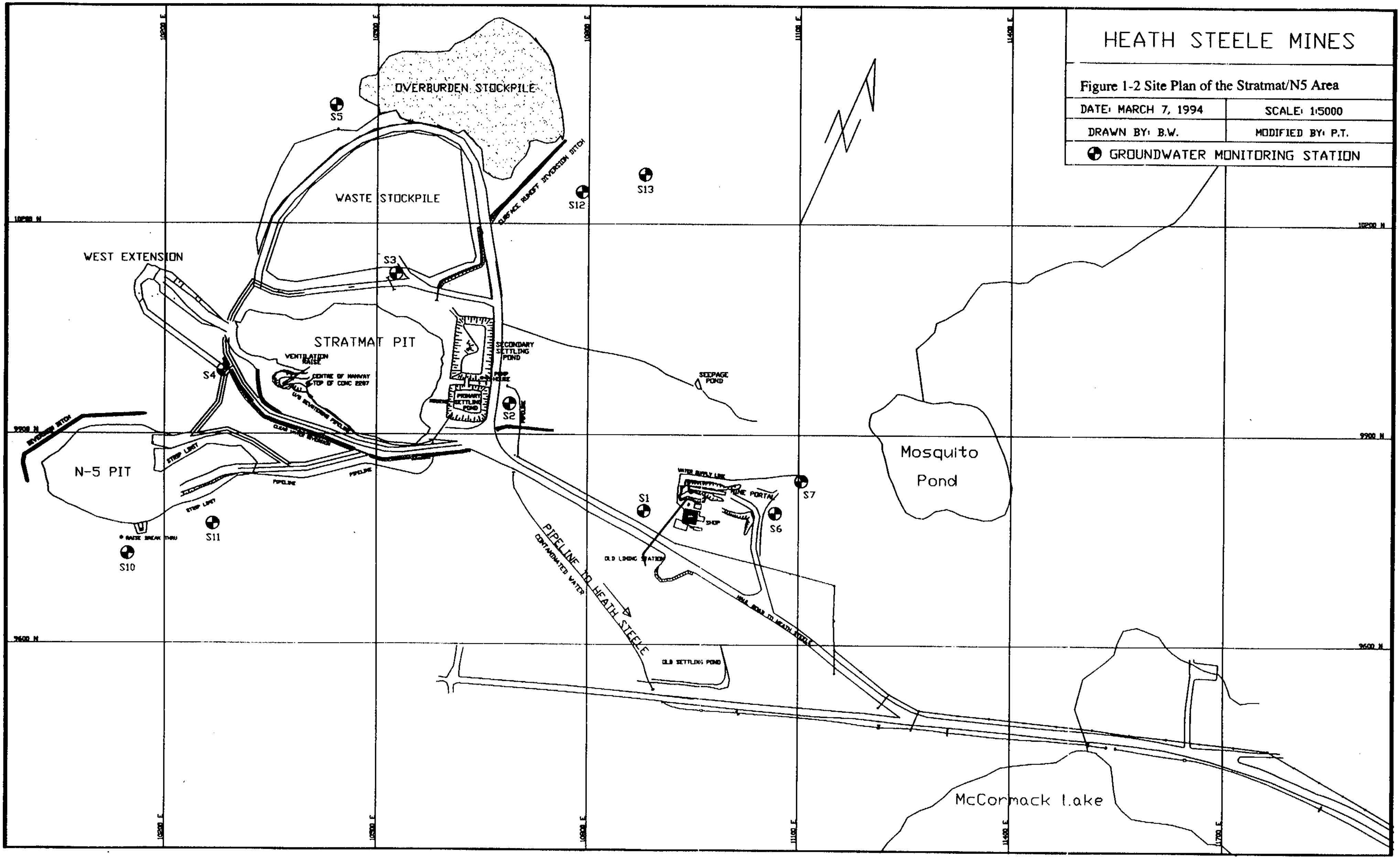
Mining in the Stratmat/N5 area resulted in a waste rock pile of approximately 1.84 million t next to the Stratmat pit and an overburden pile of about two million t north of the waste rock pile. The waste rock pile overall is estimated to contain roughly 3% sulphide sulphur whereas the overburden pile is considered to contain little sulphide sulphur. The waste rock itself possesses small amounts of neutralisation potential (NP), with measured NPs approximately varying from zero to 40 kg $CaCO_3$ equivalent/t of rock (Table 3-1, p. 16). This combination makes the Stratmat waste rock pile amenable to acid generation.

The Stratmat/N5 closure plan (Heath Steele Mines Ltd., 1989) included a provision of blending limestone with the Stratmat/N5 waste rock to prevent or delay acid generation before the waste rock was eventually returned to the mined-out pits. This was partially based on bench scale studies reported by Sheremata et al. (1991), which suggested that approximately 10 kg/t of limestone addition would be sufficient to prevent acid generation. These bench tests were later followed by laboratory column tests and outdoor lysimeter tests, in which 10 kg/t limestone mixed with the Stratmat rock was sufficient to retard acid generation (Yanful and Payant, 1993).

Consequently, at Stratmat, crushed limestone was layered in at about 10 kg/t of waste rock at approximately three-meter intervals. This measure later proved to be unsuccessful, and acidic seepage with elevated zinc concentrations was detected at the toe of the Stratmat waste rock pile during the spring of 1991. Limestone addition was halted at that time. The lack of successful neutralisation was attributed to coating of limestone surfaces by iron and manganese oxide or hydroxide precipitates resulting from initial neutralisation of acidic infiltration.

Since the Stratmat waste rock has become acid-generating, it is no longer considered feasible to backfill the waste rock into the mined-out pits. Presently, contaminated water is collected in the Stratmat pit and pumped to the newly commissioned water treatment plant, constructed next to the Heath Steele mill complex in 1997. The local water table position is known from a groundwater monitoring network installed in 1989 (St-Arnaud, 1990) and the pit water level is maintained below the level of the original water table to prevent outflow of contaminated ground water.

Figure 1-2 Site Plan of the Stratmat/N5 Area



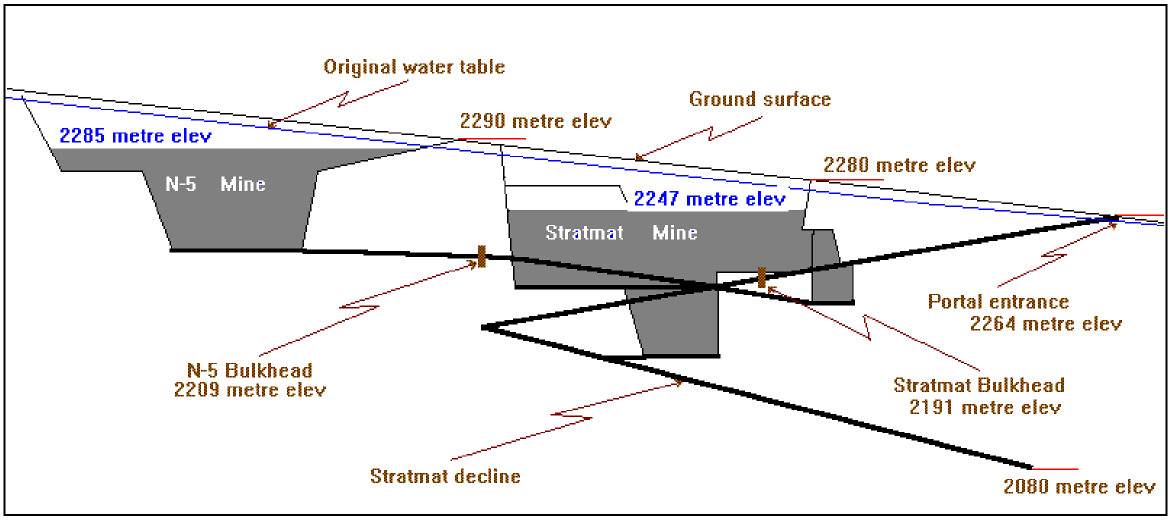


Figure 1-3 Site Section of the Stratmat/N5 Area

Figure 1-4 Photograph of the Stratmat Waste Rock Pile Viewing from South

1.3 SITE GEOLOGICAL SETTING

The Stratmat/N5 ore deposits occur in a poly-deformed volcano-sedimentary sequence that is part of the Ordovician Tetagouche Group. The mineral assemblages are typical of the greenschists facies of regional metamorphism (Hamilton, 1992). Mineable reserves for the Stratmat and N5 deposits were 3.65 million t averaging 2.28% Pb, 6.64% Zn, 0.68% Cu and 64 g/t Ag.

The host rocks of the area have been divided into three informal units: (1) *the Southwall Frag-*

mentals, which form the footwall of the deposit; (2) the *Stratmat Sequence*, which contains the ore zone; (3) the *Northwall Sequence*, which forms the hanging wall of the deposit.

The Southwall Fragmentals (coarse fragmentals, lapilli tuffs, bedded or siliceous tuffs) are the oldest rocks of the mine sequence. They are composed of fine-grained siliceous fragments within a matrix of phyllosilicates (muscovite > chlorite > biotite). These rocks contain an average of 2 to 4% disseminated pyrite, minor sphalerite, galena and chalcopyrite. They grade upward into the ore-bearing sediments (chert and phyllites) of the Stratmat Sequence.

The Stratmat Sequence consists of disseminated and massive sphalerite-galena-pyrite and chalcopyrite lenses. The sulphides are fine- to medium-grained. The deposits have a relatively low iron content, averaging 15% to 20% pyrite. Talc and chlorite are abundant and associated with the ore. Gangue minerals include muscovite, chlorite, talc, quartz and carbonates (calcite> ferroan dolomite and siderite). A sedimentary layer containing 1% to 2% disseminated pyrite is overlying the ore.

The Northwall Sequence rocks are dominated by feldspar-rich crystal tuff associated with other tuff facies. Pyrite is the predominant sulphide, but occurs only in trace amounts.

1.4 PROJECT HISTORY

In December 1994, Supply and Services Canada and Noranda Technology Centre (NTC) signed a contract (DSS Contract No. 23440-4-1316/01-SQ) to share the cost of a research project entitled *Hydrogeochemistry of oxidised waste rock and AMD prediction techniques for Stratmat/N5 waste rock at Heath Steele Mines, New Brunswick*. The study was to be carried out under the auspices of the Mine Environment Neutral Drainage (MEND) program. The government funding was made available under the Canada-New Brunswick Mineral Development Agreement (MDA).

The field work was completed in 1994-95 and the column rinsing (dissolution) tests were finished in 1995-96. Progress reports have been issued (Noranda Technology Centre, 1996 and 1995). A part of the column dissolution tests has been published in a paper (Li et al., 1997). This report updates the results presented in that paper.

This report is one of two concurrent reports resulting from the present research project. The other report, entitled *Hydrology and Solute Transport in Oxidise Waste Rock from Stratmat Site, N.B.* (Li, 1999), describes the large column experimental results.

A related study under the auspices of the MEND program, also carried out by Noranda Inc., Technology Centre, entitled *Evaluation of Techniques for Preventing Acidic Rock Drainage*, has been recently reported (Payant and Yanful, 1997). This four-year long research project started in 1991 and looked at various techniques of acid rock drainage prevention using the South Wall type waste rock from the Stratmat pit. As a result of the study, a wealth of information has been generated on this rock, including detailed geochemical and mineralogical characterisation. A part of the result of this study was also described by Aubé et al. (1995).

1.5 ORGANIZATION OF REPORT

Chapter 1.0 sets out the background information. Chapters 2.0 to 4.0 each report a coherent aspect of the project, giving the objectives, the methods used, the results acquired, and interpretations. Chapter 5.0 gives acknowledgements and Chapter 6.0 provides references. Field work on physicochemical profiling of the Stratmat and N5 pit water is presented and discussed in APPENDIX I. This is because the pit water profiling work is not directly relevant to and is largely independent of the study of the Stratmat waste rock. APPENDIX II provides detailed experimental data for the column dissolution tests discussed in Chapter 4.0 .

2.0 FIELD SOLID SAMPLING AND MEASUREMENT

2.1 OBJECTIVES AND METHODS

The objectives of field solid sampling were to provide samples for laboratory tests including physical and chemical characterisation, column dissolution tests, and large column tests.

Solids for chemical analyses were taken by grab sampling from the Stratmat waste rock pile and by discretion sampling from archived drill cores. Solids needed for the column dissolution tests were obtained by trench sampling on the waste rock pile. Solids used for large column tests were acquired by bulk sampling with a backhoe.

2.2 GRAB SAMPLING

Eleven grab samples were taken by inspection on the top surface, the slopes, and the north excavation area on the Stratmat waste pile. The main consideration was to select materials representing the three major rock types (refer to section 1.3), with sulphide contents varying from low to high within each rock type. In addition, six samples were retrieved from drill cores stored at the mine site. The grab samples are listed in Table 2-1.

Table 2-1 Grab Samples from Stratmat Waste Rock

Sample I.D.	Location	Description
ST1	south slope of waste pile	north wall rock, low sulphide
ST2	south slope of waste pile	weathered sediments, low sulphide
ST3	south slope of waste pile	limestone bed, dump face cemented with brwn ppt.
ST4	south toe of waste pile	white ppt. Accumulated on rock surfaces
ST5	west of waste pile	pink, crushed limestone from limestone stockpile
ST6	waste pile	white ppt. on rock pieces
ST7	north excavation area	internal limestone bed in pile exposed by excavat'n
ST8	top of waste pile	north wall rock, high sulphide
ST9	top of waste pile	sediments, unknown sulphide content
ST10	top of waste pile	sediments, low sulphide
ST11	top of waste pile	sediments, high sulphide
North Wall R&S	drill core file	typical rock, grab
South Wall R&S	drill core file	typical rock, grab
Bedded Pkg 20	drill core file	typical rock, grab
Seds 10 - Low S^{2-}	drill core file	typical rock, grab, low sulphide
Seds 10 - Med S^{2-}	drill core file	typical rock, grab, medium sulphide
Seds 10 - High S^{2-}	drill core file	typical rock, grab, high sulphide

Note: The "high" or "low" sulphide content assessment was based on visual observation only.

2.3 TRENCH SAMPLING

Sixteen trenches were dug with a hydraulic backhoe. Twelve of these were excavated on the top of the rock pile along two straight lines perpendicular to each other, four in the east-west and eight in the south north directions (see upper photograph in Figure 2-1). Each trench was excavated longitudinally, about six meters long, one meter deep, and six meters from its nearest trench. The remaining four trenches were excavated on the lower lift exposed by borrow-pitting on the waste pile for the construction of the internal tailings dam. These four trenches were along an east-west direction and excavated according to the same specifications as those on the upper lift. These trenches were excavated shortly after a rainfall and intercepted perched water tables, presumably formed due to localised low permeability strata.

One waste rock sample was taken from each of the sixteen trenches. This was done by shovelling continuously along the entire length of the two side walls of the trench at about 0.5 meter below the surface (see lower photograph in Figure 2-1 for a view of the trench wall). Only materials smaller than two inches were taken, and the sample from each trench weighted approximately five kilograms. The total sample weight was approximately 70 kg.

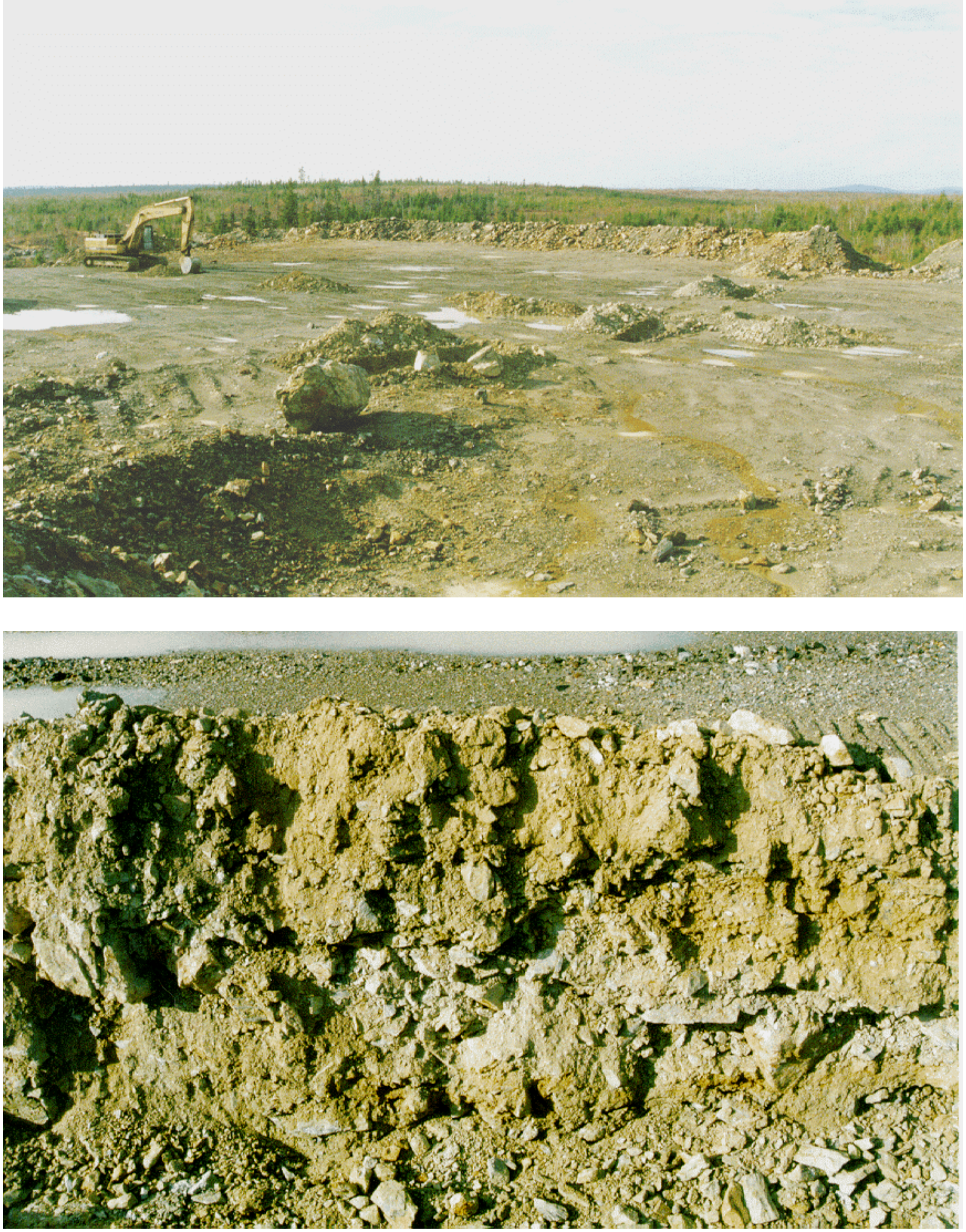


Figure 2-1 Trench Sampling on Stratmat Waste Rock Pile

2.4 BULK SAMPLING

Bulk sampling was conducted with a hydraulic backhoe at four locations: trench no. 6, trench no. 8, the summit of the north end of the waste pile, and the east wall of the excavation area. At each location, the backhoe shovelled indiscriminantly to load the bucket, which was then unloaded slowly into a reinforced nylon bag with dimensions of 1 m x 1 m x 1 m (see photograph in Figure 2-1). Boulders (> ~0.4 m) were removed. Fifteen bags were loaded with approximately 14 t of moist waste rock. These bags were then trucked to NTC.

Figure 2-2 Bulk Sampling of Waste Rock on Stratmat Pile

2.5 IN-SITU BULK DENSITY MEASUREMENT

Bulk density was measured *in situ* at two locations: near the top centre of the waste pile and on the east wall of the borrow pit on the northern part of the waste rock pile. At each location, a cavity in a regular geometric shape was excavated and measured (Figure 2-1). All of the material resulting from the excavation was loaded on to a truck, which was then weighed on a truck scale. All the dimensions of the cavity were measured. The moist bulk density was calculated by dividing the total net weight of the material by the volume of the cavity. The moist bulk densities measured at the top and on the wall of the borrow pit were 2291 and 2589 kg/m^3, respectively. Assuming a moisture content of 7% on the basis of later laboratory gravimetric measurement, the corresponding dry bulk densities were 2131 and 2408 kg/m^3, respectively. The average dry bulk density is then 2270 kg/m^3. The accuracy of these bulk density figures is estimated at ±10%.

Figure 2-3 Cavity for In Situ Bulk Density Measurement

3.0 WASTE ROCK CHARACTERIZATION

3.1 OBJECTIVES AND METHODS

The objectives of waste rock characterisation are:

- to estimate the variations in chemical characteristics of different rock materials in the Stratmat waste rock pile,
- to measure some physical characteristics of the materials contained in the pile,
- to estimate the inventory of potentially acid-generating waste rock and neutralisation materials, and
- to generate chemical and physical data to be used in the interpretation of later tests and mathematical modelling exercises.

Methods used for material characterisation are conventional. Whole rock chemistry was carried out by ICP or AAS analysis following acid digestion of pulverised rock samples. Acid base accounting was achieved by one of the three procedures: Sobek Standard ABA, extended Sobek ABA, or B.C. Research Initial Tests. For a discussion of the ABA procedures refer to Sobek et al. (1978) and the following MEND reports: Wang and Lawrence (1996), Sherlock and Lawrence (1995), Kwong (1993), Norecol (1991), Coastech (1991, 1989). Size distribution, moisture, and density were measured using gravimetric means. Specific details of analyses are given under their respective headings below.

3.2 RESULTS AND DISCUSSION

3.2.1 Whole-Rock Analysis

Whole rock chemistry is available on selected elements for samples of selected rock types. The total sulphur content (S_T) was determined on a Leco furnace. The data are presented in Table 3-1. Note that the samples are representative only of a part, not all, of the South Wall and the North Wall materials. Nevertheless, it can be seen that the South Wall material contains much more sulphur than the North Wall material, and that neither material contains significant amount of ore minerals, e.g., sphalerite, chalcopyrite, and galena. The sulphide-sulphur, thus, is mainly associated with iron, in pyrite.

Welcome Screen | Search | Report List

Table 3-1 Whole Rock Chemical Analysis Results for Selected Samples

Sample I.D	Rock Type	Year of Sample	Elemental Concentrations (in % by weight except where specified)								
			As (ppm)	Ca	Cu	Fe	Mg	Ni	Pb	Zn	S_T
ST163-103m	SWF[1]	1987	143	0.07	<0.01	6.16	0.27	<0.01	<0.01	<0.01	6.62
ST163-105m	SWF	1987	123	0.09	<0.01	8.65	0.16	<0.01	<0.01	<0.01	9.32
ST163-111m	SWF	1987	100	0.05	<0.01	3.55	0.52	<0.01	<0.01	<0.01	3.48
ST164-107m	SWF	1987	<100	0.06	<0.01	12.75	1.53	<0.01	<0.01	0.02	9.21
ST164-112m	SWF	1987	<100	0.19	<0.01	4.36	0.49	<0.01	<0.01	0.04	3.64
ST164-114m	SWF	1987	120	1.26	<0.01	5.53	1.91	<0.01	<0.01	0.02	2.25
ST165-79m	SWF	1987	322	0.02	<0.01	3.33	0.69	<0.01	0.08	0.22	2.13
ST165-83m	SWF	1987	<100	0.05	<0.01	2.43	0.42	<0.01	0.01	<0.01	1.80
ST165-88m	SWF	1987	<100	0.04	<0.01	3.37	0.38	<0.01	0.03	0.04	2.71
ST165-90m	SWF	1987	<100	0.04	<0.01	5.10	0.52	<0.01	0.04	0.04	3.30
ST166-92m	SWF	1987	<100	0.06	<0.01	2.07	0.97	<0.01	<0.01	<0.01	0.68
ST166-94m	SWF	1987	116	0.14	<0.01	4.48	0.28	<0.01	<0.01	<0.01	4.73
ST166-104m	SWF	1987	149	0.22	<0.01	5.66	4.27	<0.01	0.01	0.08	0.78
ST166-108m	SWF	1987	169	0.04	<0.01	2.85	0.60	<0.01	0.01	<0.01	1.63
ST169-42m	SWF	1987	<100	0.04	<0.01	8.45	0.45	<0.01	0.01	<0.01	8.13
ST169-127m	SWF	1987	<100	0.46	<0.01	5.46	1.74	<0.01	<0.01	0.02	1.64
ST169-139m	SWF	1987	116	0.39	<0.01	9.33	1.44	<0.01	0.01	0.01	6.45
ST169-145m	SWF	1987	110	0.04	<0.01	14.38	0.50	<0.01	0.01	<0.01	15.34
RPC6885	NWCT[2]	1988	<100	0.28	<0.01	-	1.53	<0.01	<0.01	<0.01	<0.01
RPC6886	NWCT	1988	<100	0.16	0.02	-	1.22	<0.01	<0.01	0.03	0.07
RPC6887	NWCT	1988	<100	0.21	<0.01	-	1.04	0.01	<0.01	0.01	0.08
RPC6888	NWCT	1988	<100	0.16	0.01	-	1.32	<0.01	<0.01	0.02	0.12

[1] South Wall Fragmentals [2] North Wall Crystal Tuff

All analyses conducted by Research and Productivity Council (RPC) in New Brunswick

3.2.2 Acid-Base Accounting

Prior to this study, there were 42 ABA analyses done from 1987 to 1988 on various samples acquired from development or mining. These samples, however, were only representative of specific parts of the Stratmat/N5 pit and underground workings. A relationship between these samples and the materials in the Stratmat waste rock pile is undetermined.

In September 1994, the Stratmat rock pile was walked and 11 grab samples were taken by inspection, with an attempt to represent the wide variety of rock materials and the wide range of sulphide contents in these materials. In addition, six grab samples were taken from drill core files stored in a shed on the site. These 17 samples have been described in Table 2-1. Twelve of the 17 samples were subjected to ABA analyses and the results are given in Table 3-1 along with those for two South Wall samples used by NTC in 1989 for column tests. The term “extended Sobek ABA” simply refers to the conventional Sobek ABA plus sulphur speciation (into sulphate-sulphur and sulphide-sulphur as a minimum) and CO_2 analysis. For a description of rock types and their geology, refer to Section 1.3 .

From Table 3-1, the following statements can be made:

- With the exception of sample ST8 (which is uncertain with respect to acid generation), all waste rock samples tested are potentially acid-generating. The sulphide-sulphur content varies from a minimum of 0.25% to a maximum of 10%. The degree of AP variation is large and follows the following order: *North Wall Crystal Tuff > South Wall Fragmentals » Stratmat Sequence Sediments.*

- Generally speaking, the order of acid-generating potential is *South Wall Fragmentals » Stratmat Sequence Sediments >> North Wall Crystal Tuff.*

- The degree of NP variation is small, normally within the range of -10 to +15 kg $CaCO_3$ equivalent/t.

- The major sulphide mineral is clearly pyrite for all three rock types.

- Little oxidation had occurred in the samples, as indicated by the near-neutral to alkaline paste pHs and small sulphate contents.

Welcome Screen | Search | Report List

Table 3-1 ABA Results of Stratmat Waste Rock Samples

Sample I.D.	Rock Type	Analytical Procedure	Acid-Base Accounting (ABA)					Sulphur Speciation[5]				
			Paste pH	AP	NP	NNP	NP/AP	S_T	S_{SO4}	S_{Po}	S_{Py}	S_{Res}
				Kg/t[1]	kg/t[1]	Kg/t[1]		%	%	%	%	%
S-1	SWF[2]	B.C.R. Initial Test	6.15	203	6.9	-195	0.034	6.99	0.51	-	6.48	-
S-2	SWF	B.C.R. Initial Test	7.35	213	15.2	-198	0.077	7.33	0.53	-	6.80	-
Core SW R&S	SWF	Extended Sobek	8.9	71.3	6.90	-64.4	0.097	2.28	<0.01	0.02	2.26	<0.01
ST2	SSS[3]	Extended Sobek	4.10	24.1	-6.4	-30.5	-0.266	0.97	0.20	0.07	0.70	<0.01
ST10	SSS	Extended Sobek	5.00	65.3	-1.99	-67.2	-0.030	2.14	0.10	<0.01	2.09	0.01
ST11	SSS	Extended Sobek	6.2	137	5.03	-132	0.037	4.40	0.07	<0.01	4.38	<0.01
Core Seds 10 Low S	SSS	Extended Sobek	7.10	111	12.0	-99.0	0.108	3.57	0.02	0.03	3.52	<0.01
Core Seds 10 Med S	SSS	Extended Sobek	7.90	316	6.20	-310	0.020	10.1	<0.01	0.38	9.72	<0.01
Core Seds 10 High S	SSS	Extended Sobek	7.50	719	5.96	-713	0.008	23.0	<0.01	1.80	21.2	<0.01
Core Bed Pkg 20	SSS	Extended Sobek	8.9	32.5	6.43	-26.1	0.198	1.04	0.01	<0.01	1.03	<0.01
ST1	NWCT[4]	Extended Sobek	9.4	7.81	5.03	-2.78	0.644	0.25	<0.01	0.02	0.23	<0.01
ST8	NWCT	Extended Sobek	8.8	20.0	34.1	14.1	1.705	0.64	0.01	<0.01	0.61	0.02
Core NW R&S	NWCT	Extended Sobek	7.8	83.8	5.96	-77.8	0.071	2.69	0.01	0.08	2.60	<0.01
ST7	Limestone	Extended Sobek	7.9	56.9	547	490	9.613	3.38	1.56	0.06	1.76	<0.01

[1] kg $CaCO_3$ equivalent/t of material. [2] South Wall Fragmentals. [3] Stratmat Sequence Sediments. [4] North Wall Crystal Tuff. [5] The sulphur speciation was carried out by the following methods. Total sulphur S_T was measured on one sub-sample using a Leco induction furnace. Using a second sub-sample, the following sequential analyses were performed: (1) The solids were leached with Na_2CO_3 solution at boiling temperature and filtered; the filtrate was used to measure sulphate sulphur S_{SO4} gravimetrically. (2) The filter cake from the previous step was leached with concentrated HCl to expel H_2S resulting from the reaction between HCl and pyrrhotite. The mixture was filtered and the filtrate discarded. (3) The filter cake from the last step was leached with a mixture of HNO_3 and Br_2 at boiling temperature. The mixture was filtered and the leachate was used to determine pyrite sulphur S_{Py} by gravimetry. (4) The filter cake from the previous step was dried and analysed for total sulphur using the Leco furnace. This was the residual sulphur S_{Res}. (5) The pyrrhotite sulphur S_{Po} was obtained by difference: $S_{Po} = S_T - S_{Res} - S_{SO4} - S_{Py}$

3.2.3 Size Distribution Analysis

Size distribution data of the waste rock are important for estimating the surface area of exposed sulphide minerals, for assessing the hydraulic parameters of the material, for calculating the oxidation product inventories, and for modelling the hydrologic and transport processes in the waste rock.

A size distribution analysis was carried out on the bulk-sampled rock from the Stratmat pile. Approximately 350 kg (moist weight) of the -12 inch material was used. The procedure employed is briefly outlined below:

1. Dump all the rocks from the bags (about 13 t) onto one large pile in a cleaned pavement area. Mix the rocks thoroughly by coning and quartering back and forth three times using a combined hydraulic backhoe/front loader.

2. Take a representative sample, about 500 kg (record exact weight), for size analysis.

3. Hand-pick all large rocks greater than 8 inches in the longest dimension and record the total weight. Screen the -8 inch rocks through a 4-inch and then a 2-inch mesh. Weigh and the +4 inch and the +2 inch fractions, and record the weights.

4. Mix the -2 inch fraction thoroughly and representatively sub-sample a 150-kg (moist weight) portion; record the exact moist weight. Air-dry this sub-sample and weigh again. Record the exact weight. Use a vibrating screen to separate and weigh the following fractions: -2 inch +1 inch, -1 inch +2 mesh, -2 mesh +4 mesh, -4 mesh +8 mesh, and -8 mesh.

5. Thoroughly mix the -8 mesh fraction and take a 5-kg (record exact weight) sub-sample. Oven-dry this sample at 80 °C and record the exact dried weight. Perform a standard sieve analysis on a Rotap machine down to a screen size of 325 mesh.

The cumulative size distribution curve determined is shown in Figure 3-1. The figure shows that Stratmat bulk sample contains 20% sand, 70% gravel, and 10% cobble by weight. Please note that the size distribution of the field material is expected to be slightly coarser than that shown in Figure 3-1, since boulders were deliberately avoided during bulk sampling.

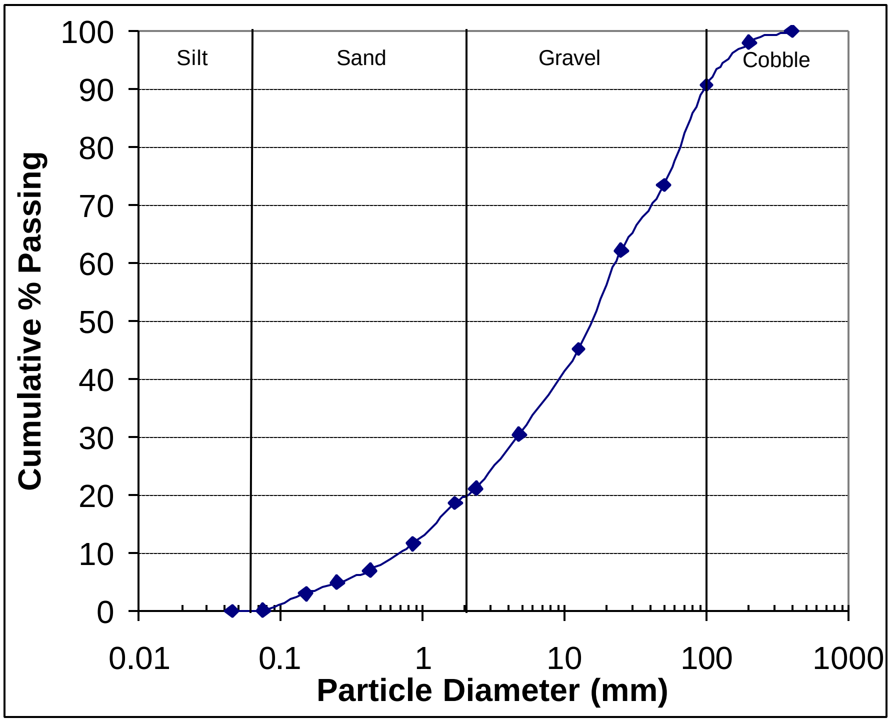


Figure 3-1 Size Distribution of the Stratmat Waste Rock Bulk Sample

3.2.4 Moisture Content

Moisture content was determined on the same bulk rock sample as that used for the size analysis. The overall moisture content was 5.7%; the moisture was 6.0% in the -2 inch fraction and 6.1% in the -8 mesh fraction. Therefore we can conclude that the bulk sample is fairly dry.

3.2.5 Density and Porosity

The in-situ bulk density of the Stratmat waste rock in the traffic-compacted surface strata was measured to be 2270 kg/m^3 (see Section 2.5). RPC (New Brunswick) measured the density of the South Wall waste rock from the Stratmat pit and found it to vary within the range of 2.64 to 3.25 g/cm^3, with an overall average of 2.87 g/cm^3. Using the average bulk density of 2270 kg/m^3, the average rock density of 2870 kg/m^3, and a 7% moisture content, the average porosity of the traffic-compacted surface strata is calculated at 26.4%. This figure is quite low when compared with typical porosity values of waste rock in the range of 30-40%. This could have been produced by compaction due to haul traffic and/or generation of fines due to weathering.

4.0 COLUMN DISSOLUTION TESTS

4.1 OBJECTIVES

A part of the results presented in this chapter has been published in a conference paper (Li et al., 1997). The content of this chapter updates and augments the results already contributed. The objectives of the column dissolution experiment were to:

- investigate the water quality change upon dumping oxidised rock into fresh water;
- estimate the acidity inventory in the oxidised waste rock;
- evaluate the dissolution rates of different oxidation products;
- assess factors controlling the release of contaminants; and
- determine the effects of the rinsed waste rock on a water cover.

4.2 METHODOLOGY

The column dissolution experiment commenced in March 1995 and lasted for over 250 days. The experiment was conducted in three stages to:

- monitor the water quality upon dumping the oxidised rock into fresh water in the column;
- monitor the water quality evolution while rinsing the oxidised rock with fresh water; and
- monitor the water quality of a water cover installed after rinsing ceases.

4.2.1 Test Sample

The oxidised waste rock sample used in this test was a composite of sixteen trenched samples in roughly equal proportions, and therefore is regarded as being representative of the surface strata of the Stratmat waste rock dump (refer to Section 2.3 for the trenching sampling).

4.2.2 Experimental Set-up

The experiment was conducted in duplicate using two plexiglass cylinders measuring 1.3 m tall and 20 cm inside diameter. The cylinders were sealed at the bottom with a central drain hole to allow the water to circulate or drain. Ports with septa were installed on the sides of the cylinders for profile sampling. A geotextile membrane was placed on the bottom of each cylinder and overlaid by a 10-cm-thick layer of polyethylene beads, which was in turn covered by a second geotextile membrane. A peristaltic pump was used to circulate the water in each cylinder from the bottom to the top in the second stage. The purpose of water circulation was to create a well-mixed water body and to induce turbulence to accelerate the dissolution of stored salts or secondary minerals. Large-diameter tubing was used to achieve the required flow rate.

The experimental set-up is shown photographically in Figure 4-1. The test began by pouring 20 L of de-ionised water into each cylinder while the bottom valve was closed. Then 25 kg of the waste rock sample was dumped into the water from the top of each cylinder.

Figure 4-1 Photograph of Experimental Set-Up for Column Dissolution Test

4.2.3 Experimental Procedure

The test procedure is illustrated in Figure 4-1. The experiment consisted of three stages:

- Stage I, or the rock-dumping stage, included only Cycle 0 in which the oxidised rock sample was dumped into de-ionised water in each cylinder. Two hours were allowed for suspended solids to settle before a water quality sample was taken. Stage I was designed to measure the immediate impact of dumping oxidised waste rock into fresh water.

- Stage II, or the rinsing stage, included Cycles 1 through 18. In each cycle, the water in the cylinder was continuously circulated from the bottom to the top, creating a well-mixed water body and some turbulence around rock particles. The cycle length was determined as either two days or the time required for the conductivity of the water (monitored regularly) to stabilise, whichever was longer. Cycle lengths ranged from 2 to 11 days during the experiment. At the end of each cycle, the water in each cylinder was drained; the volume measured; and a water quality sample taken. Stage II was designed to estimate the acidity inventory, and to investigate the controls on dissolution rates of secondary minerals.

- Stage III, or the static stage, included Cycles 19-23. This stage began following Cycle 18 by flooding the washed rock with de-ionised water and maintaining a 60-cm water cover. The water was not circulated (hence static). Water quality was monitored monthly for three consecutive months and bimonthly thereafter, at two depths: the water surface and the water-waste rock interface. Stage III was designed to estimate the water quality and contaminant release rates in a water cover.

All water samples were filtered and analysed for acidity, pH, and concentrations of fourteen elements (including S), and Fe^{3+}.

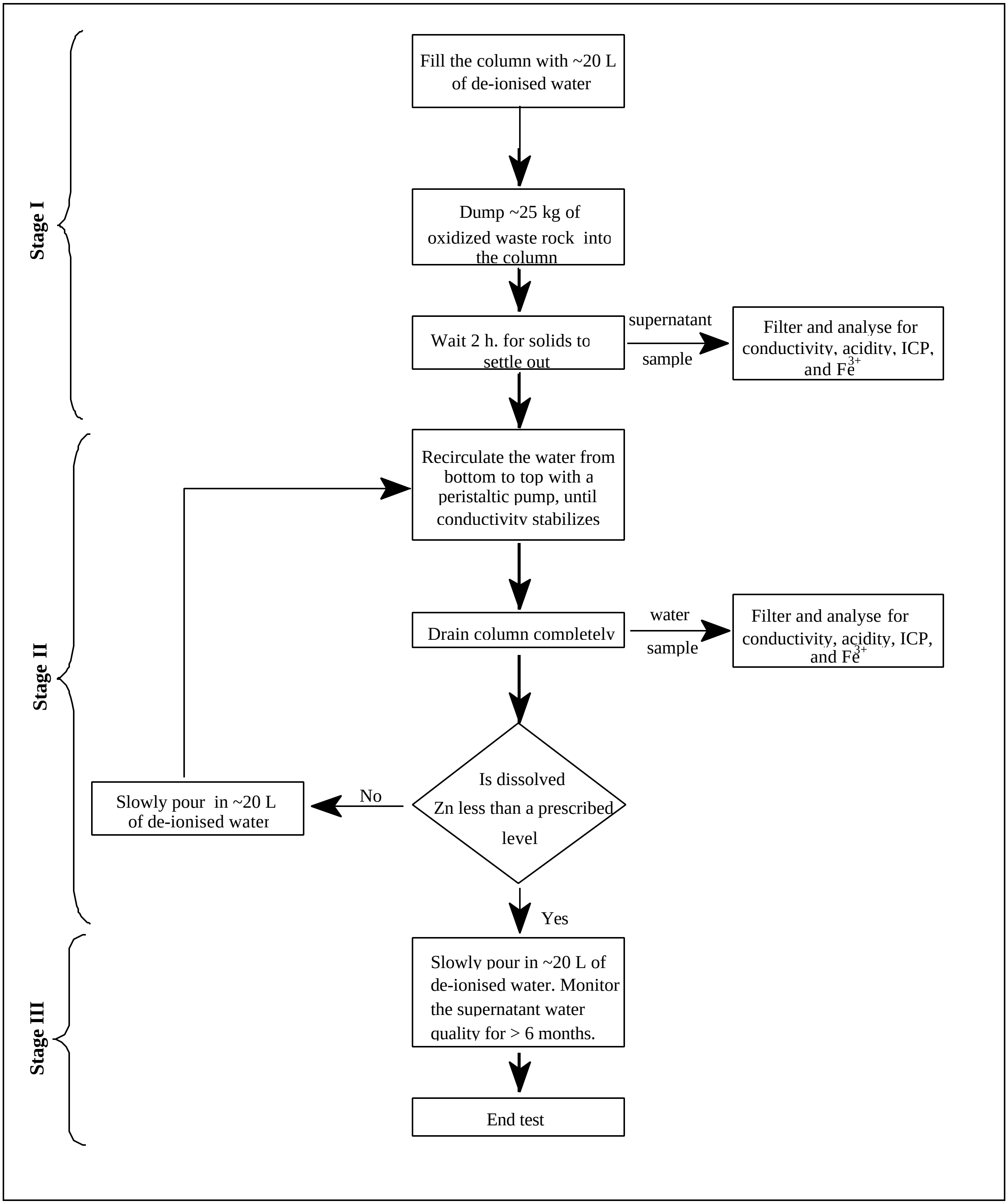


Figure 4-2 Column Dissolution Experiment Procedure

4.3 RESULTS

Water quality results for the three stages of the duplicate column tests are given in APPENDIX II and are plotted against cycle numbers in Figure 4-1. In these graphs, Cycle 0 represents the rock-dumping stage, Cycles 1-18 the rinsing stage, and Cycle 19-23 the static stage. Data from the water quality monitoring during the static stage are also plotted against time in Figure 4-2.

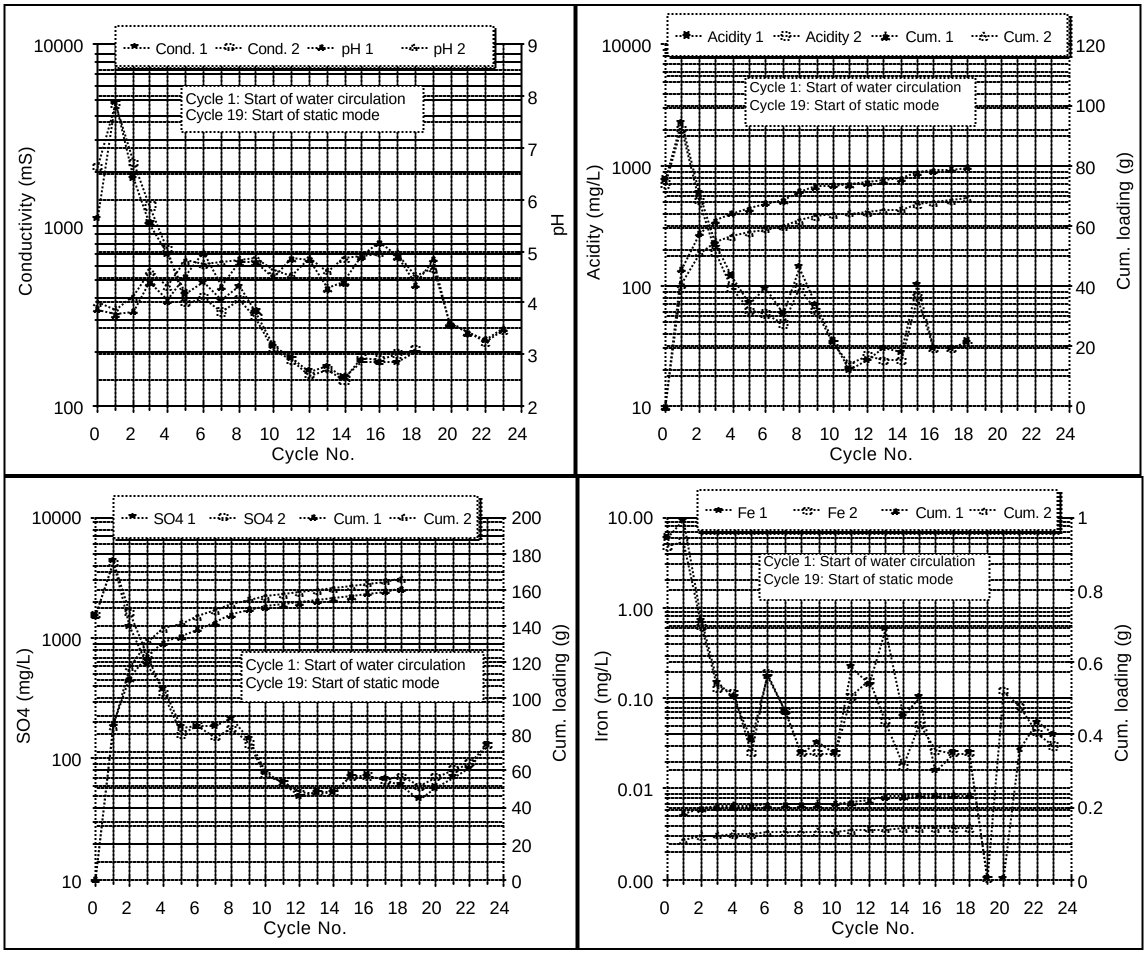


Figure 4-3 Results for Duplicate Column Dissolution Tests

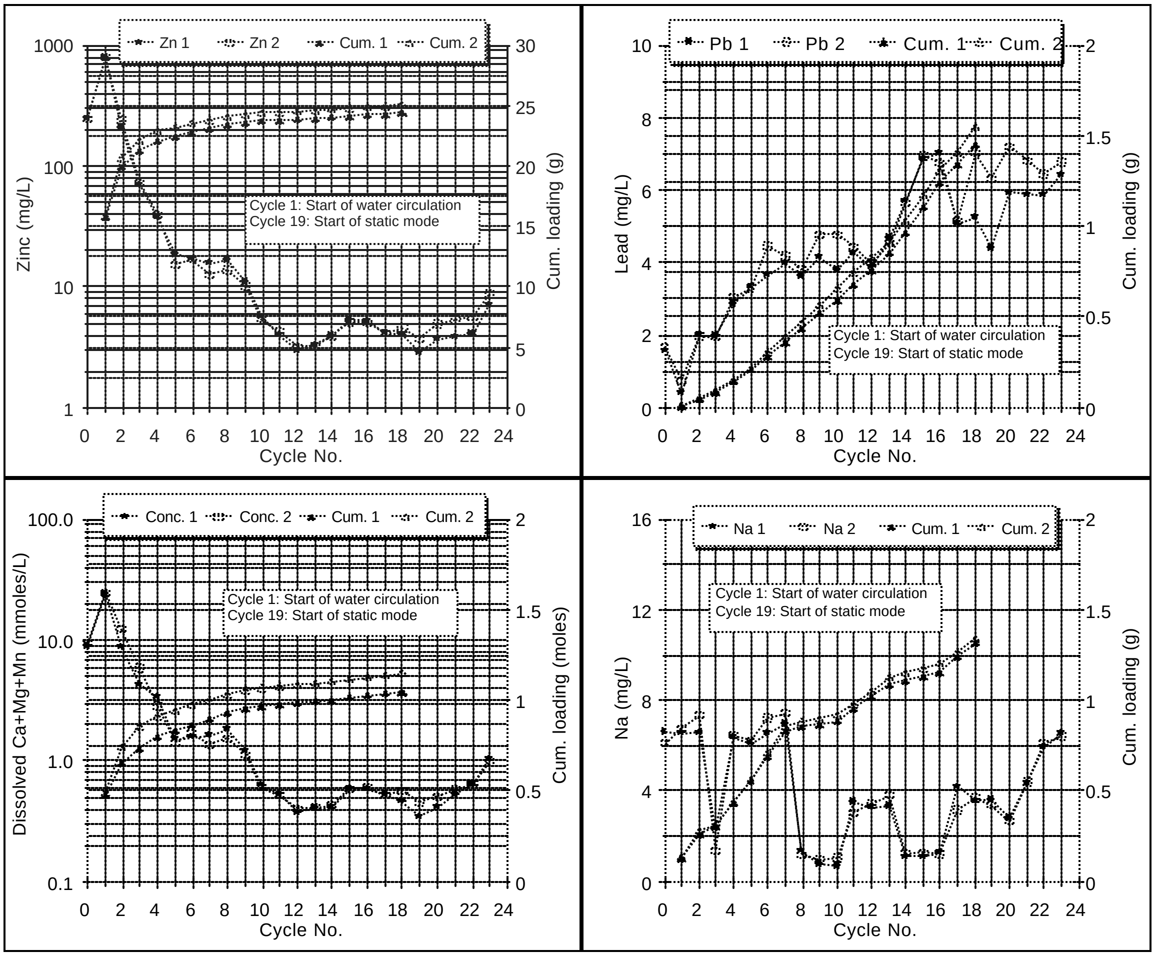


Figure 4-3 Results for Duplicate Column Dissolution Tests (continued)

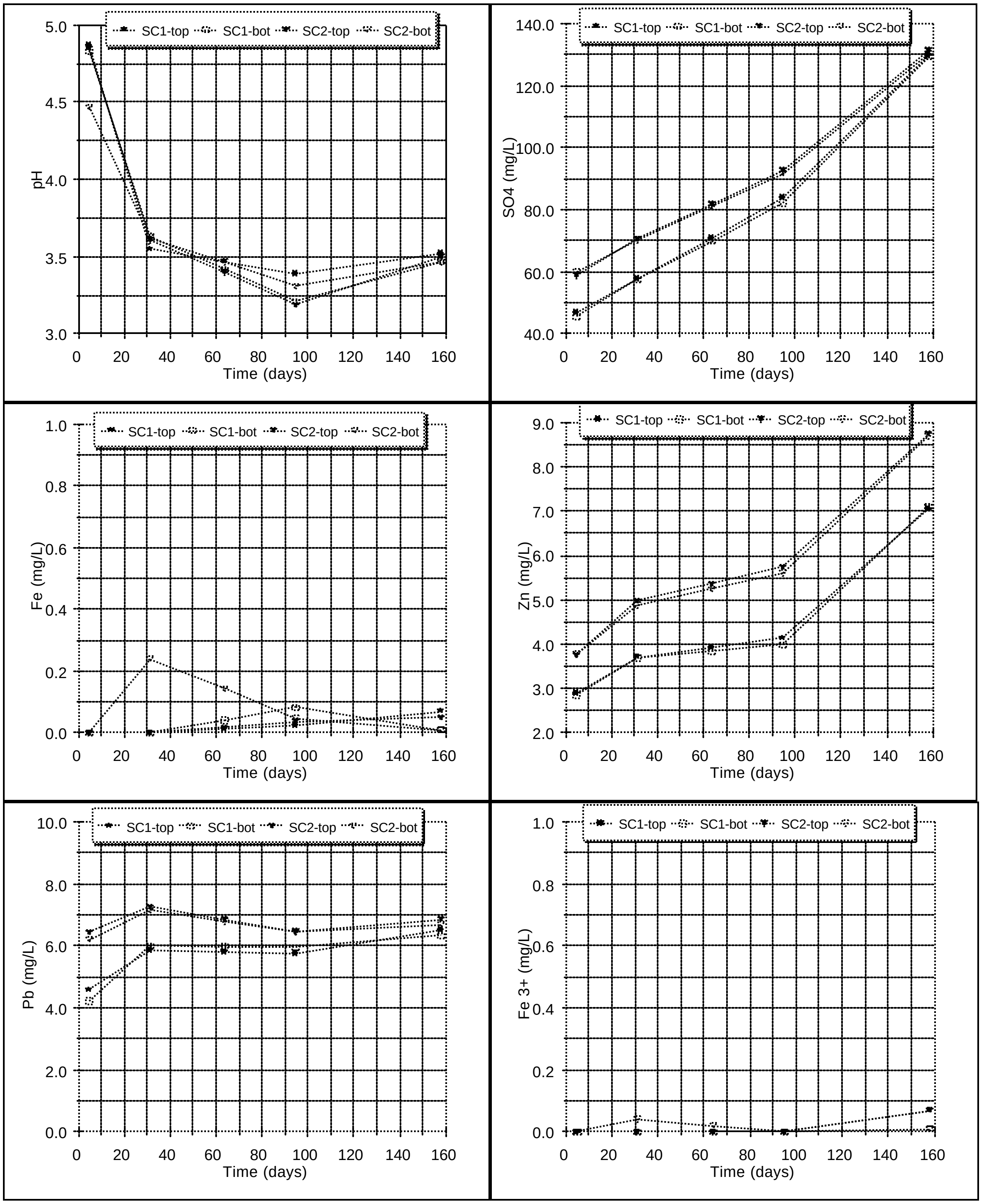


Figure 4-4 Results for Duplicate Column Dissolution Tests in the Static Mode

Welcome Screen Search Report List

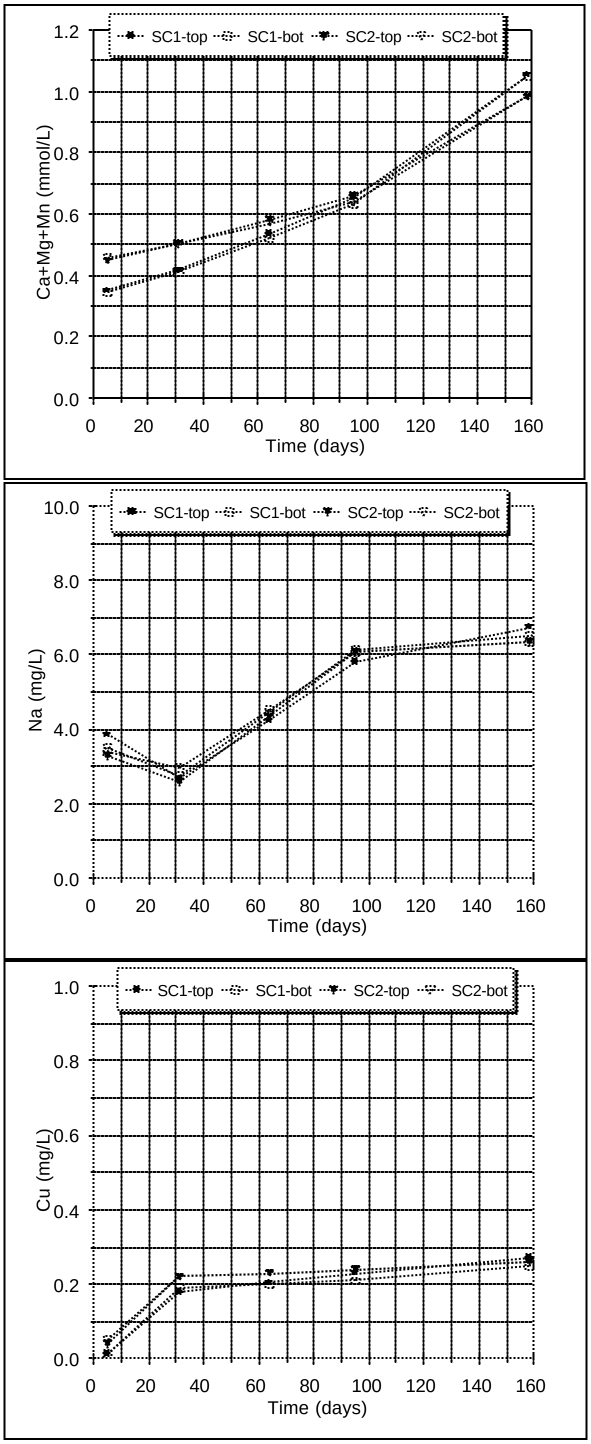


Figure 4-4 Results for Duplicate Column Dissolution Tests in the Static Mode (continued)

4.4 INTERPRETATION

4.4.1 Rock Dumping Stage

Simply dumping the oxidised waste rock into standing de-ionised water caused significant quantities of soluble minerals to dissolve (Figure 4-1). Conductivity reached 1000-2000 µS/cm; the difference in conductivity between the two columns shows that the quantity of salts dissolved probably depends on the manner in which the rock was dumped into the column. Acidity reached about 700 mg $CaCO_3$ equiv./L, SO_4^{2-} 1500 mg/L, Zn 250 mg/L, Ca+Mg+Mn 9 mmol/L (equivalent of 360 mg/L Ca), Fe 5 mg/L, Pb 1.5 mg/L, and Na 6 mg/L.

The collective molar concentration of Ca+Mg+Mn is taken as a measure of the amount of acid, originally produced by sulphide oxidation, which was later neutralised by carbonate minerals. This statement has two underlying assumptions: (1) the sole sources of dissolved Ca, Mg, and Mn are carbonate minerals; (2) no secondary minerals containing Ca, Mg, and Mn precipitate. When secondary minerals such as gypsum ($CaSO_4 \cdot 2H_2O$) do precipitate, the metals Ca, Mg, and Mn reporting to secondary minerals must be accounted for when calculating the total acidity neutralised by carbonates. The chemical reactions taking place under the conditions prevailing in the test columns are as follows:

$$2H^+ + CaCO_3 \text{ (calcite)} \Rightarrow Ca^{2+} + CO_2 \text{ (g)} + H_2O$$
$$4H^+ + CaMg(CO_3)_2 \text{ (dolomite)} \Rightarrow Ca^{2+} + Mg^{2+} + 2CO_2 \text{ (g)} + 2H_2O$$
$$2H^+ + MgCO_3 \text{ (magnesite)} \Rightarrow Mg^{2+} + CO_2 \text{ (g)} + H_2O$$
$$2H^+ + MnCO_3 \text{ (rhodochrosite)} \Rightarrow Mn^{2+} + CO_2 \text{ (g)} + H_2O$$

The pH upon dumping the oxidised waste rock into fresh water was about 4.0, suggesting that there is not a great deal of free acid (H^+) in the oxidised waste rock. This indicates that the acid originally produced by the oxidation of pyrite has already been neutralised within the rock itself, presumably by carbonates of Ca, Mg, Mn and, to a lesser degree, silicates. It is also possible that some of the acid generated by oxidation has been lost to drainage over time.

By comparing Cycle 0 (rock dumping, no water circulation) with Cycle 1 (rock settled, water circulated), one finds that, from Cycle 0 to Cycle 1, conductivity, acidity, and concentrations of SO_4^{2-}, Zn, and Ca+Mg+Mn all increased by an approximate factor of 3. In other words, in Cycle 0 these parameters did not reach their maximum potential values (taken as those in Cycle 1) because of short contact time and lack of mixing, both of which restrict the mass transfer from the solid phase (the rock) to the liquid phase (the solution).

Dissolved Pb, Fe and Na behaved differently. In Cycles 0 and 1, Pb dissolution appears controlled by the solubility of anglesite ($PbSO_4$). As the SO_4^{2-} increased by a factor of 3, the dissolved Pb decreased proportionally by a factor of about 3. Saturation index (SI) calculations (discussed later) support this point. The concentrations of Fe are restricted by the solubility of its hydroxide: as the pH did not change much from Cycle 0 to Cycle 1, the dissolve Fe remained nearly constant. Na concentrations tend to remain at the same level from Cycle 0 to Cycle 1, probably suggesting its ease of dissolution and a low inventory of soluble Na in the waste rock.

4.4.2 Rinsing Stage

There are three ways to index the progress of rinsing: the cycle number, the length (in days) of test, and the number of pore volumes flushed. Cycle numbers cannot be converted linearly to the length of testing and thus the length of testing will be provided when needed. However, the conversion from cycle numbers to pore volumes flushed is linear: number of pore volumes = 4 x cycle number, where cycle number = 1 to 18 inclusive.

The saturation indices (SIs), calculated using MINTEQA2 (Allison et al., 1991) from the solution compositions, are plotted in Figure 4-1. The individual and cumulative amounts of sulphate salts dissolved in each cycle and the proportions of different minerals dissolved in each cycle are graphed in Figure 4-2.

Note that Figure 4-2 is not meant to indicate that the dissolved constituents are present in the solution as molecular metal sulphate species. No speciation information is suggested by the graphs. In reality, the dissolved constituents exist as hydrated metal cations, sulphate anions, charged or neutral complex ions or ion pairs. Rather, Figure 4-2 is presented to show the following points:

- The total dissolved solids initially decrease quickly with the number of washing cycles and then stabilise starting from Cycle 10.
- The only significant anion in the leachate is SO_4^{2-}.
- The major cations in the leachate are Ca^{2+}, Mg^{2+}, Zn^{2+}, Al^{3+}, and Mn^{2+}.
- After Cycle 3, the relative proportions among the major cations remain roughly constant.
- As the number of washing increases indefinitely, the total amount of dissolved matter washed tends asymptotically to a value probably between 60 and 70 mmol/kg.

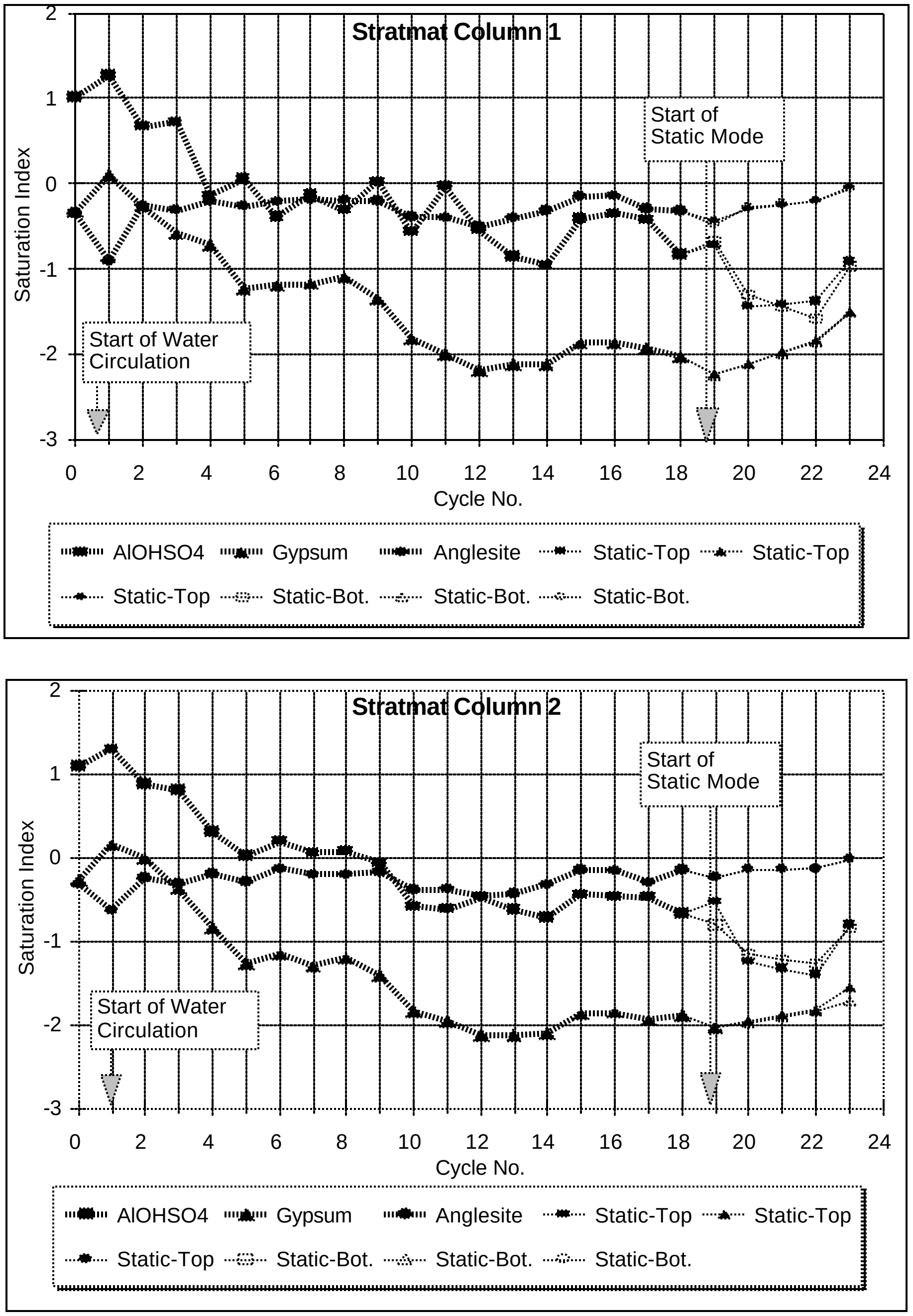


Figure 4-5 Saturation Indices of Solutions in Duplicate Column Rinsing Tests

Welcome Screen | Search | Report List

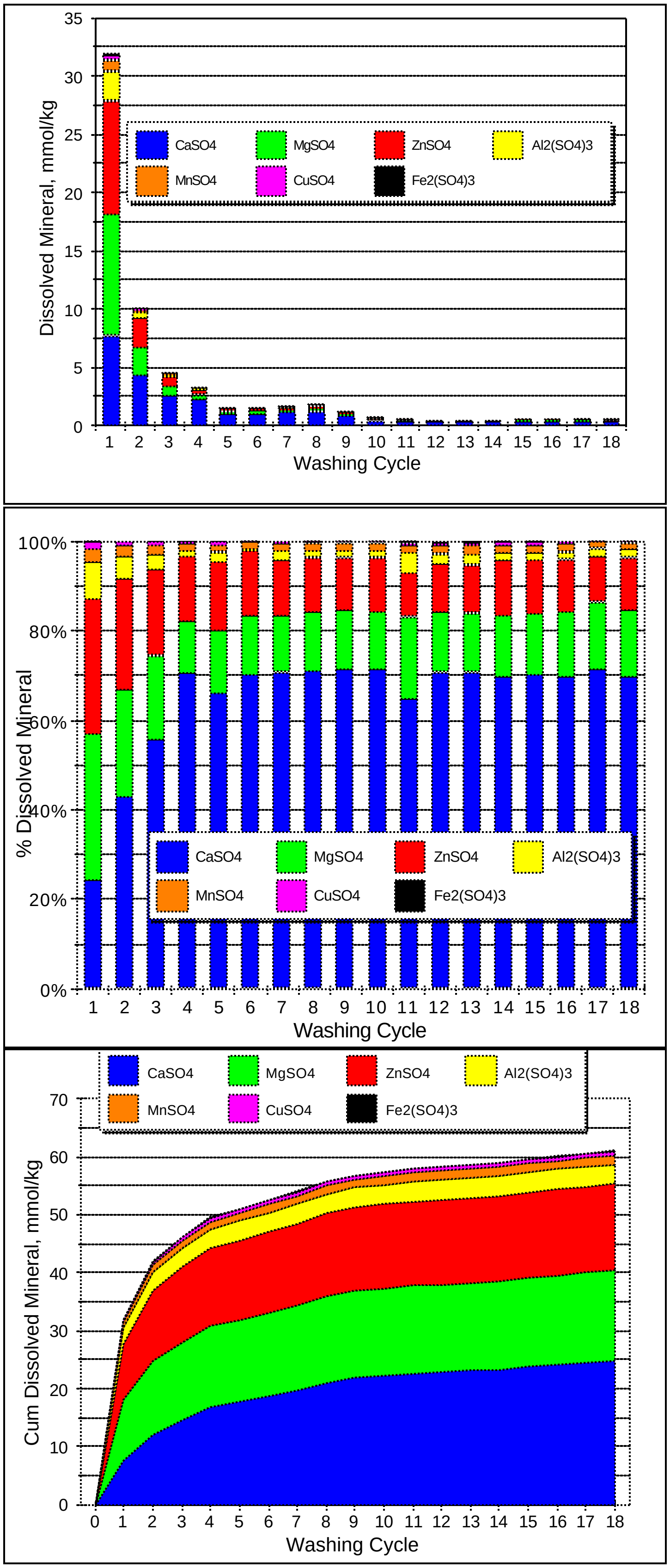


Figure 4-6 Dissolved Constituents in Duplicate Column Rinsing Tests

The rinsing curves in Figure 4-1 can be classified into three groups according to their distinct patterns. Group I includes the rinsing curves for conductivity, acidity, SO_4^{2-}, Zn, and Ca+Mg+Mn. Group II includes the rising curves for pH and total dissolved Fe. Group III includes the rinsing curve of Pb.

The common shape of Group I curves is recognised as follows: (1) a linear decrease (on a logarithmic scale) from Cycle 1 to Cycle 5; (2) a plateau of nearly constant values from Cycle 5 to Cycle 8; (3) another linear decrease from Cycle 8 to Cycle 10; and (4) a second plateau of roughly constant values from Cycle 10 to Cycle 18. This common shape is a reflection of the release of relatively soluble components that are not subject to solubility constraints. For Zn, Mg, and Mn(II), the leachate is well under-saturated with respect to all of their possible mineral phases. For SO_4, gypsum ($CaSO_4 \cdot 2H_2O$) is below saturation after Cycle 2 (Figure 4-1). Although anglesite ($PbSO_4$) is at saturation for the duration of the tests (Figure 4-1), it has a strong solubility control only on the concentration of Pb, not on the concentration of SO_4. This is because the concentration of SO_4 is several orders of magnitude greater than that of Pb. The conductivity varies in the Group I pattern because it is primarily determined by the dissolved major ions including SO_4^{2-}, Zn^{2+}, Ca^{2+}, and Mg^{2+}. The acidity follows the Group I pattern because it is primarily determined by dissolved Zn.

Although Group I species are not subject to solubility (equilibrium) control, their rinsing is subject to three other possible rate control mechanisms: (1) flushing of species already dissolved in the pore water; (2) dissolution of secondary minerals whose rate is controlled either by dissolution kinetics or mass transfer rates (an example of mass transfer rate control is the diffusion of ions through static liquid phases within micro fissures and cracks in a rock particle); (3) oxidative dissolution of primary minerals (primarily pyrite, FeS_2, and sphalerite, ZnS). The measurements made in the experiments, however, do not allow the differentiation of these processes.

For Group II, the shape of the rinsing curves is a result of pH buffering. The leachate pH gradually rose from about 3.8 in Cycle 1 to about 5.0 in Cycle 5, then buffered at that level until Cycle 18. Correspondingly, dissolved Fe gradually decreased from about 7 mg/L in Cycle 1 to between 0.03 and 0.1 in Cycle 5, then remained roughly constant at that level from Cycle 5 to Cycle 18. This inverse relation between pH and total dissolved Fe suggests that the concentration of Fe is controlled by the solubility of goethite, FeOOH. MINTEQ modelling shows that the solubility indices for goethite fluctuated between -1 and 0.3 from Cycle 1 to Cycle 18 (not shown in Figure 4-1 because of too few Fe^{3+} analyses).

For Group III, which includes only Pb, the shape of the rinsing curve forms a sharp contrast with those of Group I and Group II. Pb follows an increasing trend from Cycle 1 to Cycle 18 (Figure 4-1). Moreover, the Pb curve exhibits an inverse relationship with the SO_4 curve, suggesting that concentrations of Pb are controlled by the solubility of its sulphate, the mineral anglesite ($PbSO_4$). This is supported by the SI's of anglesite, which are roughly constant and close to zero throughout the rinsing period (Cycles 1-18), indicating saturation of anglesite in the leachate solutions (Figure 4-1).

4.4.3 Static Stage

The pH, SO4, Fe(total), Zn, Pb, Ca+Mg+Mn, and Na during the static phase of the experiment are compared with those during the rinsing stage in Figure 4-1. The same parameters plus Fe3+ and Cu are plotted against time of the static phase in Figure 4-2.

It is interesting to note that, although the 60-cm water cover was "static", it in fact was well-mixed throughout, as indicated by the fact that the parameter values monitored at the top coincided with those at the bottom (rock-water interface).

As in the rinsing stage, SO_4^{2-}, Zn, and Ca+Mg+Mn vary in a similar manner: they all show a quasi-linear increase with time (on a logarithmic scale). Immediately after the installation of the static water cover, these parameters showed a decrease as compared with the last rinsing cycles. With time, they recovered to values comparable to those in the last rinsing cycles and eventually exceeded them. This probably reflects the effect of two processes: the slow dissolution of remaining sulphate minerals (controlled by either slow kinetics or slow mass transfer) and the oxidative dissolution of sulphide minerals.

As discussed for the rinsing stage, the Pb concentration in the static stage is again limited by the solubility of anglesite, whereas the Fe concentration is once again limited by the solubility of goethite.

The pH of the water cover started declining immediately after the installation of the water cover from about 4.5, to eventually stabilise at about 3.5.

The static stage data reveal that even after washing the waste rock with 72 pore volumes or 18 cycles of water, the water cover quality would still not meet the MMLER with respect to pH, Zn, and Pb.

4.4.4 Oxidation State of Dissolved Fe

The leachate chemistry indicates that the Stratmat oxidised waste rock exhibits a lack of soluble ferrous sulphate minerals such as melanterite ($FeSO_4{\cdot}7H_2O$) which are sometimes found accompanying pyrite oxidation. This suggests that the Fe^{2+} initially produced from pyrite oxidation has been oxidised to Fe^{3+}, consistent with the fact that the samples were taken at the waste rock dump surface and supply of oxygen is ample for the oxidation of Fe^{2+} to Fe^{3+}.

4.4.5 Rinsing Sequence

A sequence designating the ease of rinsing for different metals can be derived from Figure 4-1, which shows the changing concentrations of various metals as a percentage of their initial concentrations in Cycle 1. This rinsing sequence is Al > Cu > Mg > Zn > Mn > Ca > Pb. The practical importance of this sequence is that the later an element appears in the sequence, the more difficult it becomes to decrease this element's concentration in the leachate by rinsing.

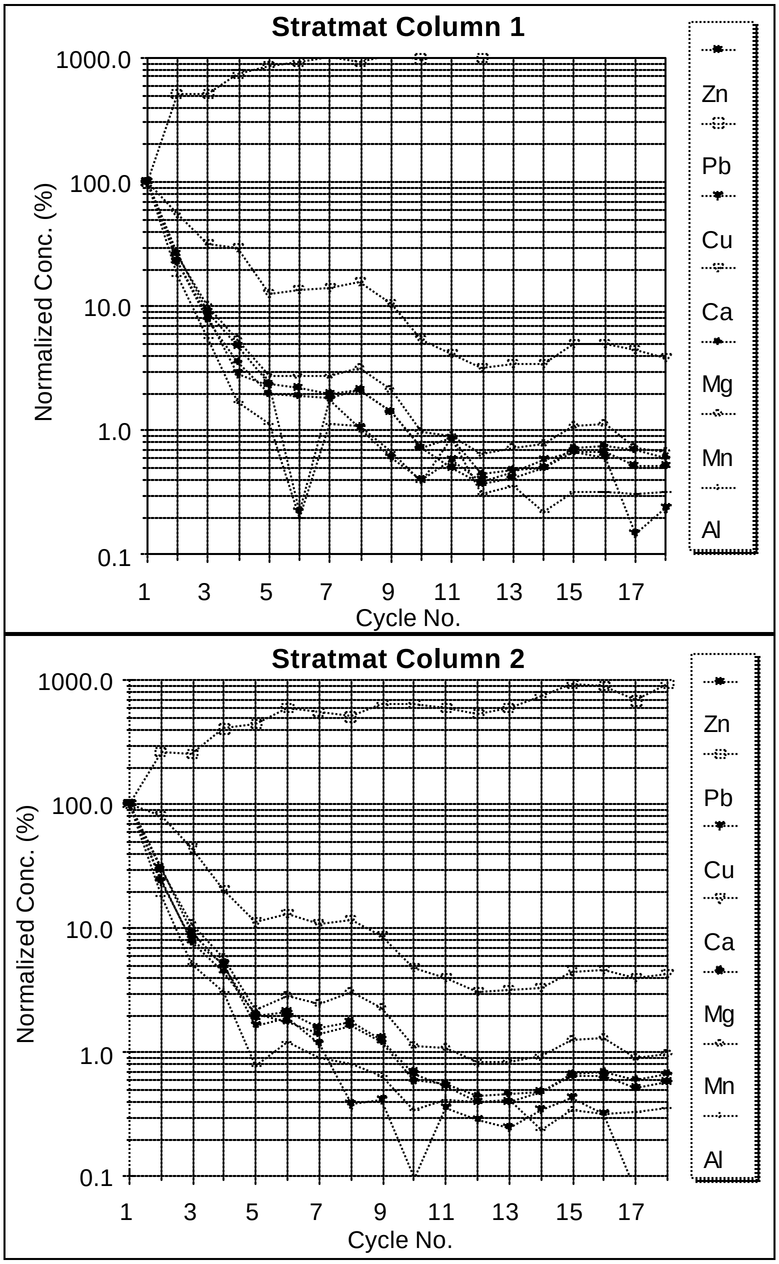


Figure 4-7 Dissolved Metal Concentrations Normalised to Those of Cycle 1

Several processes co-exist to cause the variation in the rinsing behaviour of different species. These processes are therefore responsible for the ordering of the elements in the rinsing sequence: equilibrium solubility control, slow dissolution kinetics, and slow mass transfer processes. Figure 4-1 shows three different patterns of concentration variation: (1) dissolved Pb, which increased during Cycles 1-6 and then remained roughly constant during Cycles 7-18; (2) dissolved Ca, which exhibited a slow decrease over the 18 flushing cycles; and (3) all other dissolved metals shown (Zn, Cu, Mg, Mn, Al), which showed relatively fast concentration decreases, down to about 2% or lower within five flushing cycles.

The Pb concentration in the leachate is dictated by the low solubility of anglesite ($PbSO_4$); as a result it increased as the SO_4 concentration decreased. The dissolution of anglesite will be inhibited until the leachate SO_4 concentration decreases to a very low level, which would only be possible when the stock of gypsum becomes depleted by rinsing. The concentration of Ca in the leachate is controlled by the slow dissolution rate of gypsum, thus decreases slowly due to the large stock of gypsum in the waste rock. The rinsing of Zn, Mg, and Mn is subject to rate control by mass transfer after Cycle 8; before Cycle 8 their concentration decreases rapidly. The concentrations of Cu and Al, besides being controlled by mass transfer processes, are probably also controlled by the solubility of their hydroxides or oxy-hydroxides. This explains why their concentrations decreased more rapidly than those of Zn, Mg, and Mn did when pH increased.

4.4.6 Buffering of Leachate pH

Since the leachate pH likely exerts a solubility control on the concentrations of some dissolved metals, it is advantageous to increase the leachate pH as quickly as possible to prevent the release of these metals. However, the column rinsing experiment shows that the leachate pH is buffered between 4.0 and 5.0 for Cycles 1-18. One possible buffering reaction is the precipitation of dissolved Al^{3+} in the pore water upon dilution by the flushing water, which takes place in the approximate pH range of 4.0 - 5.0:

$$Al^{3+} + 3H_2O = Al(OH)_3 \text{ (amorphous)} + 3H^+$$

The leachate pH may also have been buffered by the following reactions involving solid phases:

$$AlOHSO_4 \text{ (jurbanite)} + xH_2O = Al(OH)_{1+x}^{x-2} \text{ (aq)} + SO_4^{2-} + x\,H^+ \quad \text{where } x = 1{,}2$$

$$AlOHSO_4 \text{ (jurbanite)} + 2\,H_2O = Al(OH)_3 \text{ (gibbsite)} + SO_4^{2-} + 2\,H^+$$

Lower leachate pH would favour the first reaction over the second, giving rise to a higher Al concentration, whereas higher leachate pH would favour the second over the first reaction, resulting in a lower Al concentration. Both reactions release H^+ to buffer the leachate pH, i.e., to resist the rise of the leachate pH. Note that the presence of jurbanite in the oxidised waste rock has not been confirmed by independent means such as XRD (x-ray diffractometry).

4.4.7 Sulphate Modelling

Sulphate was chosen to represent Group I parameters for the modelling exercise. Other parameters in Group I can be determined by their correlation with sulphate once sulphate is known. The purpose of sulphate modelling discussed below is neither to predict leachate sulphate concentrations nor to predict sulphate loadings, but rather to probe the mechanisms controlling sulphate release to flushing water. All calculations were performed based on averages of the two columns.

The SO_4 concentration in the pore water associated with the waste rock used in the column dissolution tests is an important parameter in this modelling exercise. Since it was not measured, it is estimated as follows. The 25-kg waste rock loaded in each column contains 1.5 L (kg) of pore water at the estimated moisture content of 6%. Addition of the 23.5 L of de-ionised water in Cycle 1 dilutes the original pore water by 16.7 folds. Now if we *assume* that the 1533 mg/L SO_4 in the solution phase immediately upon dumping the waste rock into the columns derives entirely from the SO_4 dissolved in the original pore water, reversing the dilution gives a pore water SO_4 concentration of about 25 600 mg/L. This sets the lower limit for the pore water SO_4 concentration. Similarly, if we assume that the 4270 mg/L SO_4 in the solution at the end of Cycle 1 (after two days of circulation) derives entirely from the SO_4 dissolved in the original pore water, reversing the dilution gives a pore water SO_4 concentration of about 71 300 mg/L. This sets the upper limit for the pore water SO_4 concentration. The true pore water SO_4 concentration is bracketed by these two limits. Study of the rinsing data and corroboration from other related studies put the pore water SO_4 concentration at an estimated value of 50 000 mg/L.

Another important parameter for the modelling exercise is the rate of dissolved SO_4 production from sulphide oxidation during the rinsing tests. Analysis of the rinsing data points to a production rate of 5.0 mg SO_4/kg rock/day for the Stratmat oxidised waste rock.

Given the pore water SO_4 concentration, the rate of dissolved SO_4 production, and the rinsing data, the total release of SO_4 to the rinsing solution in each cycle can be partitioned into three parts: that deriving from the original pore water, that deriving from rate-controlled, simple dissolution of secondary mineral solids, and that deriving from aqueous oxidation of sulphide minerals. The result of this partition is presented in Figure 4-1.

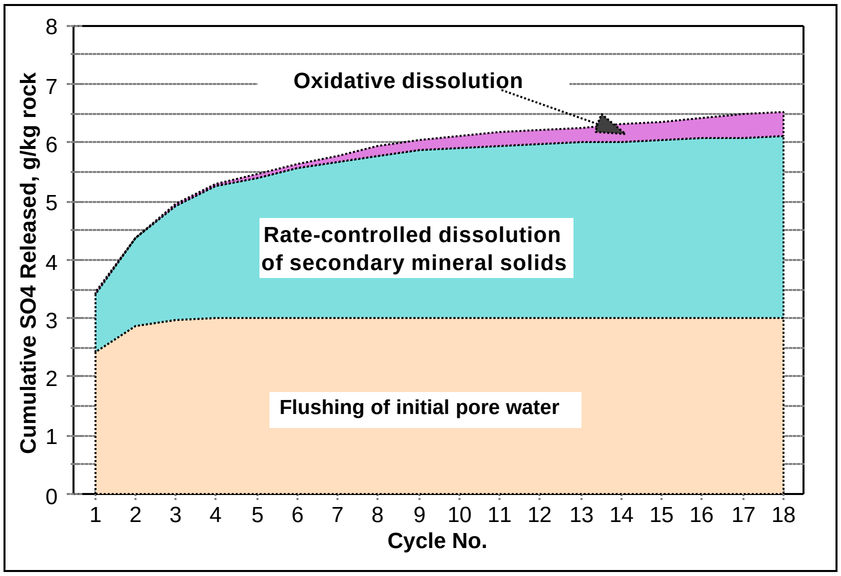


Figure 4-8 Partitioning of Total SO_4 Release among Different Mechanisms

Figure 4-1 shows that flushing of initial pore water is the dominating mechanism for SO_4 release in the first rinsing cycle; however this mechanism attenuates very rapidly and is essentially completed after three cycles. SO_4^{2-} release due to secondary mineral dissolution starts to dominate from Cycle 2; it slows down as dissolvable secondary minerals become gradually depleted. By Cycle 15, the rate of SO_4 release due to secondary mineral dissolution has fallen below that due to oxidative dissolution of sulphides. At the end of Cycle 18, the SO_4 released due to pore water flushing and that due to secondary mineral dissolution are roughly equal, and the sulphate released from aqueous oxidation of sulphides accounts for about 6% of the total SO_4 flushed.

To investigate what controls the rate of the simple (non-redox) dissolution of secondary minerals (i.e., the middle portion of Figure 4-1), the SO_4 concentrations deriving from this release mechanism are fitted to an equation of the following form:

$$C_{n,f} = a\,(C_{n-1,f} - C_{n,i})^b\, t_n^c$$

where

$C_{n,f}$ = final SO_4 concentration in the *n*th rinse cycle, mg/L;
$C_{n,i}$ = initial SO_4 concentration of the *n*th rinse cycle, mg/L;
$C_{n-1,f}$ = final SO_4 concentration of the (*n*-1)th rinse cycle, mg/L;
t_n = duration of nth cycle, days.

The results of fitting are shown in Figure 4-2. The model predictions are in good agreement with the experimental values. Note that only the first seven cycles are modelled; cycles after the seventh cannot be fitted successfully. The least-square best-fit equation representing the multi-segment line in Figure 4-2 is as follows:

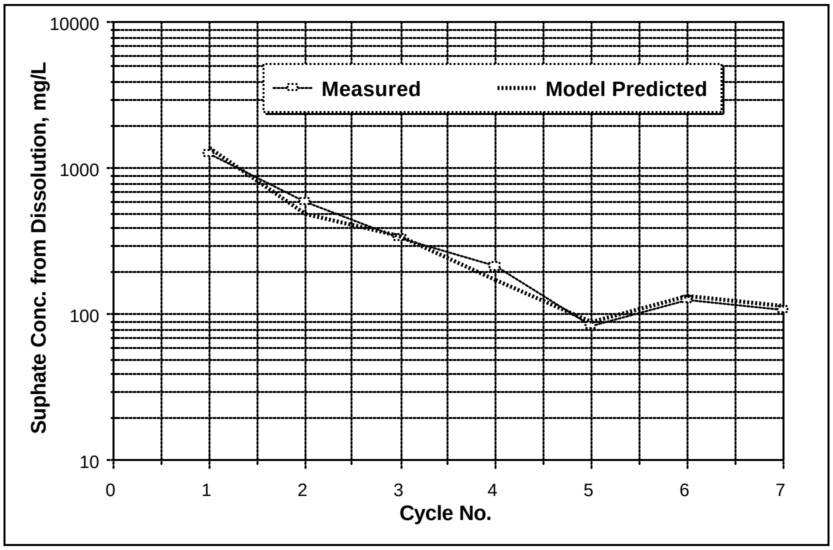


Figure 4-9 Comparisons between Modelled and Measured SO_4 Concentrations

$$C_{n,f} = 2.234\,(C_{n-1,f} - C_{n,i})^{0.539}\ t_n^{0.904}$$

This equation shows that, for the first seven rinsing cycles, the SO_4 concentration at the end of a cycle is almost linearly proportional to the length of the cycle, suggesting surface disintegration rates as an important control on sulphate release. In addition, the SO_4 concentration is approximately proportional to the square root of the difference between the initial SO_4 concentration of the current cycle and the final SO_4 concentration of the last cycle. This difference is a rough representation of the “driving force” for diffusion-controlled mineral dissolution. The exact nature of this “driving force” cannot be identified with existing experimental data. Nevertheless, the fitted equation suggests that the rate of sulphate release from secondary minerals in the early rinsing cycles are controlled primarily by the surface dissolution rates of these minerals and secondarily by some sort of diffusion control mechanism.

4.4.8 Sulphur Balance and Total Acidity Inventory

Assuming 100% efficiency in the removal of sulphate by the 18 washing cycles, the total sulphate inventory in the Stratmat waste rock sample would be 6.15 g SO_4/kg of rock (Figure 4-1, excluding the contribution from oxidative dissolution). If we further assume negligible loss of sulphate to infiltrating water in the field, the sulphate inventory would correspond to an acidity generation of 6.41 g $CaCO_3$ equivalent/kg of waste rock from sulphide oxidation. Part of this acidity has been neutralised, as illustrated by the sulphate balance depicted in Figure 4-1.

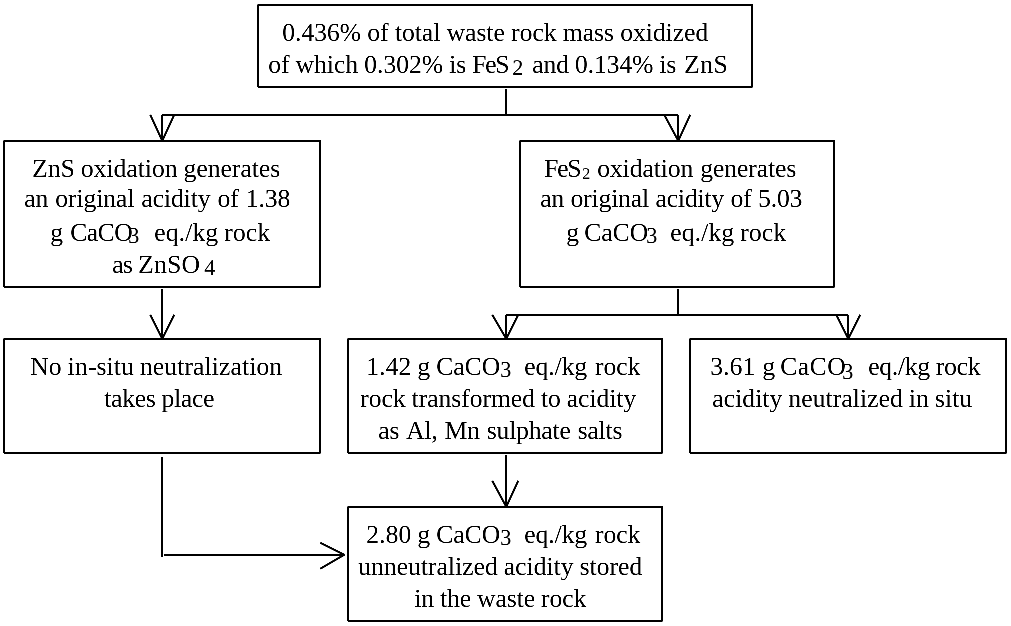


Figure 4-10 Sulphur-Acidity Mass Balance Flow Chart

The column test data show that the acidity in g $CaCO_3$ equivalent/kg of rock presently stored in the oxidised waste rock is 45.5% of the total sulphate storage in g SO_4/kg rock. This gives a total acidity storage of 6.15 x 45.5% = 2.80 g $CaCO_3$ equivalent/kg of waste rock. The acidity exists primarily in the form of Zn, Al, and Mn sulphate salts.

The column experiments reveal the following sulphur balance for the samples examined: since deposition, 1.34 g sphalerite (ZnS)/kg of waste rock (equivalent of 0.134% of the waste rock mass) has been oxidised. The oxidation of sphalerite does not produce acid (H^+) but does produce acidity in the form of $ZnSO_4$. All the acidity produced by sphalerite oxidation (equal to 1.38 g $CaCO_3$ equivalent/kg of waste rock) reports to the present acidity inventory, accounting for 49.3% of the total present-day acidity storage in the waste rock (which is 2.80 g $CaCO_3$ equivalent/kg of waste rock).

Meanwhile, 3.02 g pyrite/kg of waste rock (or 0.302% of waste rock mass) has been oxidised to produce an acidity of 5.03 g $CaCO_3$ equivalent/kg of rock, mainly in the form of acid (H^+). 71.8% of this acidity (or 3.61 g $CaCO_3$ equivalent/kg of rock) has been neutralised in situ by carbonate minerals and, to much a lesser degree, silicate minerals. The 28.2% unneutralized acidity (or 1.42 g $CaCO_3$ equivalent/kg of rock), mainly in the form of Al sulphate (0.88 g $CaCO_3$ equivalent/kg of rock) and Mn sulphate (0.14 g $CaCO_3$ equivalent/kg of rock), reports to the present acidity inventory, accounting for 50.7% of the total acidity storage today.

If one assumes that the samples used in the column tests are representative of the 1.84 million t of waste rock in the Stratmat pile, the total acidity inventory would be 5152 t $CaCO_3$ equivalent. In reality, the acidity inventory may be more or less, depending on a suite of factors.

With an estimated average sulphide sulphur content of 3% in the Stratmat pile, only about 7% of the original sulphide sulphur, or 0.436% (0.134% as ZnS plus 0.302% as FeS_2) of the waste rock mass, has been oxidised. There are about 1660 t of soluble zinc present in the form of $ZnSO_4$ that has resulted from the ZnS oxidation.

On average pyrite is more than three times more abundant than sphalerite in the pile, but the amount of pyrite oxidised is only about twice the amount of sphalerite oxidised. This seems to suggest that sphalerite is preferentially oxidised over pyrite.

4.4.9 Water Quality Predictions for a Hypothetical Flooded Pit

Water quality predictions will now be presented for the flooded Stratmat pit assuming that the oxidised Stratmat waste rock had been back-filled in the pit. As pointed out in Chapter 1.0 , this is a hypothetical scenario, as the current decommissioning plan does not provide for the backfilling of the Stratmat waste rock, but rather calls for the collection and treatment of the drainage from the Stratmat pile. The water quality prediction is primarily conducted on the basis of the column dissolution test data, using mass balance and geochemical equilibrium principles.

4.4.9.1 Water Quality Immediately after Backfill

If the oxidised waste rock of the Stratmat pile were to be dumped into the flooded Stratmat pit and water is just enough to keep all back-filled rock saturated (i.e., 0 m water cover), the sulphate concentration immediately following the dumping can be predicted from the Cycle 0 rinsing data. The porosity of the dumped rock is assumed to be 40% and the bulk dry density is assumed to be 2000 kg/m^3. The acidity and dissolved metals are calculated by applying the proportions of these parameters to sulphate as observed in Cycle 0 of the column test to the field. The pore water quality predicted on the basis of these considerations is as follows:

pH: 3.02
SO_4^{2-}:12950 mg/L
Acidity: 6496 mg $CaCO_3$ equivalent/L (calculated from dissolved metals)
Zn: 2073 mg/L
Cu: 96 mg/L
Pb: 14 mg/L
Ca: 1511 mg/L
Mg: 812 mg/L
Mn: 146 mg/L
Al: 492 mg/L
Fe: 45 mg/L

However, the above water quality represents the maximum possible values (minimum for pH) if no minerals precipitate. Because of the high concentrations, it is likely that precipitation of secondary minerals would occur. This is quantified with the computer equilibrium model MINTEQA2. The (equilibrated) water quality immediately following waste rock dumping is predicted as follows:

pH: 3.43
Acidity: 6429 mg $CaCO_3$ equivalent/L (calculated from dissolved metals)
SO4: 10000 mg/L
Zn: 2070 mg/L
Cu: 96 mg/L
Pb: 2.4 mg/L
Ca: 218 mg/L
Mg: 812 mg/L
Mn: 146 mg/L
Al: 492 mg/L
Fe: 35 mg/L

The MINTEQA2 model precipitated gypsum, anglesite, and ferric hydroxide (synonymously, ferrihydrite) to reduce the concentrations of SO_4^{2-}, Ca, Pb, and Fe. This is in agreement with our experimental observations previously discussed that the concentrations of Fe and Pb are limited by the solubility of ferric hydroxide and anglesite, respectively. Because of the high concentrations of SO_4^{2-} and Ca, the mineral gypsum has also reached saturation and regulates the concentrations of Ca and, to a lesser degree, SO_4^{2-}.

The pore water with the above quality amounts to 368,000 m^3. At an acidity of 6429 mg $CaCO_3$ equivalent/L, it requires 2370 t of limestone ($CaCO_3$) or 1330 t of quick lime (CaO) to neutralise at 100% efficiency.

4.4.9.2 Mid Term Water Quality

In the months following the dumping of waste rock, mineral dissolution continues to alter the water quality presented above. The sulphate salts of Zn, Cu, Al, Mn, and Mg will dissolve whereas anglesite and gypsum will precipitate. In effect, the concentrations of Zn, Cu, Al, Mn, and Mg will rise whereas those of Pb and Ca will decrease. The pH might decrease slightly, and the Fe concentration will increase by a small amount.

Suppose that the pore water has negligible movement on a time scale of years. Within this time frame the pore water quality can be predicted by dissolving the total sulphate inventory determined in the column experiments into the pore water then precipitating over-saturated minerals using the MINTEQA2 model. We also assume that oxygen entry has been excluded either through a soil or a water cover. Dissolution of all stored sulphates before precipitating over-saturated minerals results in the following water quality:

pH: 2.32
SO_4^{2-}:30750 mg/L
Acidity: 12532 mg $CaCO_3$ equivalent/L (calculated from dissolved metals)
Zn: 4477 mg/L
Cu: 181 mg/L
Pb: 30 mg/L
Ca: 4890 mg/L
Mg: 1705 mg/L
Mn: 383 mg/L
Al: 787 mg/L
Fe^{3+}: 29 mg/L
Fe^{2+}: 7 mg/L

By equilibrating the above solution using MINTEQA2, the following water quality is predicted for one year after rock dumping:

pH: 3.32
SO_4^{2-}:19500 mg/L
Acidity: 12500 mg $CaCO_3$ equivalent/L (calculated from dissolved metals)
Zn: 4480 mg/L
Cu: 181 mg/L
Pb: 2.3 mg/L
Ca: 190 mg/L
Mg: 1700 mg/L
Mn: 383 mg/L
Al: 787 mg/L
Fe^{3+}: 107 mg/L
Fe^{2+}: 7.3 mg/L

The pore water with the above quality amounts to 368,000 m^3. At an acidity of 12500 mg $CaCO_3$ equivalent/L, it requires 4600 t of limestone ($CaCO_3$) or 2580 t of quick lime (CaO) to neutralise at 100% efficiency.

4.4.9.3 Long Term Water Quality

In the long term (years, decades, centuries after backfill of the waste rock into the pit), the pore water quality is dependent on the hydrogeological conditions in the pit. We will examine two scenarios below: no ground water flow and a ground water flow at a rate of one pore water volume per year.

In the event of zero ground water flow, as would be the case if the entire pit is lined with an impermeable layer of material, the water quality in years and decades following the waste rock backfill would be the same as that presented above for one year after the dumping of waste rock in the pit, ignoring the neutralising effect of silicates. The neutralising power of silicate minerals comes into effect when longer time spans such as centuries are concerned. In such a case, the acidity of the pore water would be gradually reduced and the pore water pH would slowly rise. As the pH rises, Al, Fe, Mn, Cu, and Zn concentrations will gradually decrease, while K, Na, Mg concentrations would gradually increase.

In the presence of slow ground water movement, the pore water quality will improve over time, as the heavily contaminated pore water is displaced. The pore water quality has been predicted using a dilution-equilibrium model, and the results for major parameters of concern have been plotted in Figure 4-1. Note that the x-axis is expressed as number of pore volumes displaced; as we assume that the ground water flow rate is equal to one pore volume per year, the x-axis can also be read as years after backfill. The assumptions made for this water quality model are as follows:

- The backfilled waste rock has a porosity of 40% and a bulk density of 2000 kg/m^3.
- A water content equal to 10% of the dry rock weight (or 50% of the pore volume) is tightly bound within the solids (such as in fine fissures and cracks) and are not displaceable.
- The pore water is well mixed.
- Oxygen entry is inhibited.
- There is a finite source of gypsum (980 mg Ca/kg of rock) and infinite source of ferric hydroxide and anglesite (This is justifiable from the case-specific conditions). The pore water is in equilibrium with these three mineral phases.

An important feature of the predicted water quality is that, although the concentrations of all the metals except Ca and Pb have dropped to below 0.1 mg/L after 9 pore volumes, the concentration of dissolved Pb remains at about 3 mg/L. Starting from pore volume 15, the Pb concentration slowly increases until it reaches about 25 mg/L at pore volume 20. After that, the dissolved Pb will remain at around 25 mg/L until the stored anglesite is exhausted. This phenomenon is explained by the fact that as long as there is gypsum remaining in the waste rock, the sulphate concentration in the pore water will remain high at above 1000 mg/L, which depresses the dissolution of anglesite. Only after the gypsum has completely been dissolved can the sulphate concentration start to decrease, unleashing the dissolution of anglesite and elevating the dissolved Pb levels in the pore water.

The inhibition of anglesite dissolution by the presence of gypsum creates a potential problem for decommissioning. In an open system, although the water quality is acceptable for most parameters after nine pore volumes are flushed, it is not for dissolved Pb. Therefore, one must continue to flush the rock to dissolve all gypsum, and after that, to dissolve all anglesite stored in the waste rock. This could mean well over 30 pore volumes (could be higher if anglesite storage is greater) of water to be flushed and consequently treated, with the water after nine pore volumes flushed and treated for removal of Pb. At an assumed flushing rate of 0.1 pore volume per year, the treatment requirement is 36,800 m^3 per year for 300 years. A more realistic ground water flow rate can be estimated by considering the local hydrogeology around the Stratmat pit area.

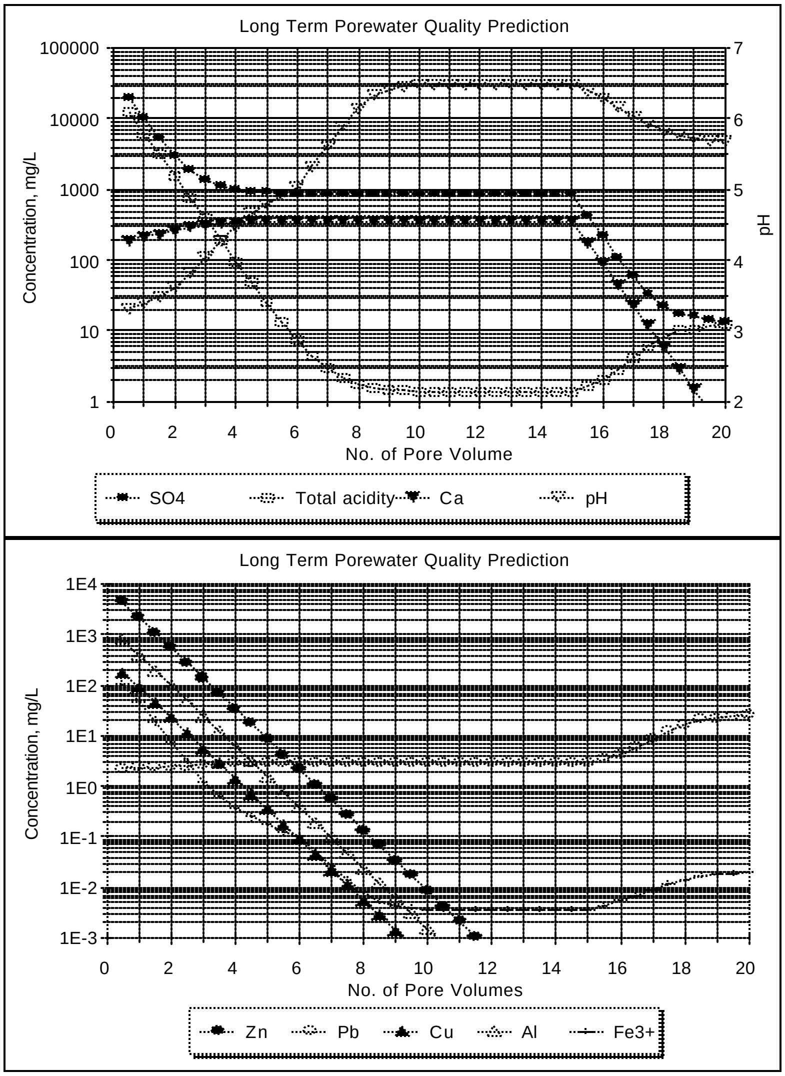


Figure 4-11 Empirical Prediction of Long Term Porewater Quality

4.5 CONCLUSIONS AND IMPLICATIONS

A 25-kg composite sample, taken from trenches excavated across the surface of the Stratmat pile, was used in each of the duplicate laboratory dissolution column tests. The experimental findings are summarised below. In addition, the data were used to derive field implications based on a hypothetical scenario where all the partially-oxidised waste rock in the Stratmat pile were backfilled in the Stratmat pit and kept saturated.

- The total acidity inventory in the Stratmat pile is approximately 5200 t $CaCO_3$ equivalent. About 7% of the original sulphide sulphur has been oxidised, to release a total acidity of 11 800 t $CaCO_3$ equivalent, of which 56% has been neutralised in situ. Sphalerite seems to oxidise preferentially over pyrite. The inventory of soluble zinc is about 1660 t.

- Dumping the oxidised waste rock into the pits would cause significant release of metals and sulphate stored in the rock and result in a water containing elevated acidity and dissolved metals. The pore water quality immediately following backfill is predicted as follows: pH 3.43, acidity 6400 mg $CaCO_3$/L, SO_4^{2-} 10000 mg/L, Zn 2000 mg/L, Cu 100 mg/L and Pb 2.4 mg/L. In the event of backfilling, due to the specific circumstances at the Stratmat pit (underground connections, pit geometry, local hydrogeology, etc.), contamination of adjacent ground water could occur, which may not easily be collected and treated.

- The worst long-term pore water quality is found in the scenario where the backfilled waste rock and its associated pore water remained static (i.e. a hypothetical case of no ground water movement). The water quality in this case is predicted as follows: pH 3.32, acidity 12500 mg $CaCO_3$/L, SO_4^{2-} 19500 mg/L, Zn 4500 mg/L, Cu 180 mg/L and Pb 2.4 mg/L.

- In the presence of ground water movement, the pore water quality would gradually improve as the initial pore water is displaced or diluted, provided that the local ground water is uncontaminated. Such rinsing action by ground water would cause release of acidity and metals into the ground water that leaves the backfilled material. It would take nine pore volumes of flushing to bring the concentrations of most contaminant metals (except Pb) to below 0.1 mg/L. For Pb, however, this would take many more pore volumes. Realistically, the local ground water is likely already contaminated. This means that the quality of the pore water in the backfilled material would not improve beyond that of the local ground water.

- The dissolution of anglesite and the precipitation of ferric hydroxide, hence the concentrations of Pb and Fe in the pore water, are controlled by equilibrium. The concentrations of SO_4, Zn, Ca, Mg, Mn, and Al in the pore water are limited in the short term (days to weeks) by dissolution/diffusion rates. In the long term (years), the concentrations of these metals are dependent on their total amounts of storage in the waste rock.

- The presence of gypsum inhibits the dissolution of anglesite. Anglesite stored in the waste rock would not dissolve appreciably until the gypsum storage in the rock is exhausted by dissolution. This makes the decommissioning of the waste rock by backfilling-flushing-treatment a very long process.

5.0 ACKNOWLEDGMENT

Many individuals at Noranda Inc. have participated in this four-year project. In particular, S. Payant and K. Shikatani conducted most of the lab experimental work. B. Aubé and J-F. Ricard helped with the filed work. L. St-Arnaud provided management and technical advice. M. Patterson was responsible for site management and site support of the project.

The final report benefited greatly from the technical reviews by R. Nicholson, C. Weatherell, and L. St-Arnaud. Valuable comments from M. Patterson, R. Schwenger, and D. Scott of Heath Steele Division, Noranda Inc. are also appreciated. Proof-reading of the final report by M. Itzkovitch is gratefully acknowledged.

6.0 REFERENCES

Allison, J.D., Brown, D.S. and Novo-Gradac, K.J. (1991). *MinteqA2/ProdefA2, A Geochemical Assessment Model for Environmental Systems: Version 3.0 User's Manual*, US Environmental Protection Agency, Athens, Georgia.

Aubé, B.C., St-Arnaud, L.C., Payant, S.C., and Yanful, E. (1995). "Laboratory Evaluation of the Effectiveness of Water Covers for Preventing Acid Generation from Pyritic Rock,", *Proceedings of Sudbury '95 - Mining and Environment*, May 28 - June 1, 1995, Sudbury, Ontario, Canada.

Coastech Research (1991). *Acid Rock Drainage Prediction Manual*, MEND Report 1.16.1b.

Coastech Research (1989). *Investigation of Prediction Techniques for Acid Mine Drainage*, MEND Report 1.16.1a.

Feasby, D.G., Tremblay, G.A., and Weatherell, C.J. (1997). "A Decade of Technology Improvement to the Challenges of Acid Drainage - A Canadian Perspective," *Proceedings of the Fourth International Conference on Acid Rock Drainage*, May 31 - June 6, 1997, Vancouver, B.C.

Gélinas, P., Lefebvre, R., Choquette, M., Isabel, D., Locat, J., and Guay, R. (1997). *Sampling and Monitoring Data from the Mine Doyon South Waste Rock Dump 1990-1995*, MEND Report 1.14.2b.

Geocon, Unité de Recherche et de Service en Technologie Minérale, Noranda Technology Centre, and Senes Consultants Ltd. (1996). *Peer Review of MEND Studies Conducted from 1990 to 1994 on Acid Mine Drainage at Mine Doyon south Waste Rock Dump*, MEND Report 1.14.3e.

Hamilton, A. (1992). "Geology of the Stratmat Boundary and Heath Steele N-5 Zones, Bathurst Camp, Northern New Brunswick," *Exploration and Mining Geology*, Vol. 1, No. 2, pp. 131-135.

Heath Steele Mines Limited (1989). *Heath Steele - Stratmat Closure Plan*.

Isabel, D., Gélinas, P., Bourque, E., Nastev, M., and Précourt, S. (1997). *Water Budget for the Waste Rock Dump at La Mine Doyon, Québec*, MEND Report 1.14.2d.

Kwong, Y.T.J. (1993). *Prediction and Prevention of Acid Rock Drainage from A Geological and Mineralogical Perspective*, MEND Report 1.32.1.

Lawrence, R. and Wang, Y. (1996). *Determination of Neutralisation Potential for Acid Rock Drainage Prediction*, MEND Report 1.16.3.

Lefebvre, R., Gélinas, P., and Isabel, D. (1997). *Heat Transfer during Acid Mine Drainage Production in a Waste Rock Dump, La Mine Doyon, Québec*, MEND Report 1.14.2c.

Li, M. (1999). *Hydrology and Solute Transport in Oxidised Waste Rock from Stratmat Site, N.B.*, Final Report by Noranda Inc., Technology Centre to MEND2000 (Canmet), March.

Li, M., L. St-Arnaud, and M. Patterson (1997). "Hydrogeochemistry of Secondary Mineral Dissolution: Column Leaching Experiment Using Oxidised Waste Rock", *Proceedings of the Fourth International Conference on Acid Rock Drainage*, May 31 - June 6, 1997, Vancouver, B.C.

Morin, K., Gerencher, E., Jones, C.E., and Konasewich, D.E. (1991). *Critical Literature Review of Acid Drainage from Waste Rock*, MEND Report 1.11.1.

Nolan, Davis & Associates (N.S.) Ltd. And ANSTO (Australian Nuclear Science and Technology Organisation) (1994). *Field Procedures Manual: Gas Transfer Measurements, Waste Rock Piles at Heath Steele Mines, New Brunswick*, MEND Report 1.22.1a.

Nolan, Davis & Associates (N.S.) Ltd. (1990). *Heath Steele Waste Rock Study, Phases 1 to 3*, MEND Report 2.31.1.

Noranda Technology Centre, (1997). *Monitoring Report Phase IV - Composite Soil Cover, Acid Waste Rock Study*, Heath Steele Mines. MEND Report.

Noranda Technology Centre, (1996). *Hydrogeochemistry of Oxidised Waste Rock and AMD Prediction Techniques for Stratmat/N-5 Waste Rock at Heath Steele Mine*, Progress Reports No. 2 and 3, Submitted to Canmet on a Joint Noranda-MEND Project under DSS Contract No. 22330-4-1316/01-SQ.

Noranda Technology Centre, (1995). *Hydrogeochemistry of Oxidised Waste Rock and AMD Prediction Techniques for Stratmat/N-5 Waste Rock at Heath Steele Mine*, Progress Reports No. 1, Submitted to Canmet on a Joint Noranda-MEND Project under DSS Contract No. 22330-4-1316/01-SQ.

Norecol Environmental Consultants Ltd. (1991). *New Methods for Determination of Key Mineral Species in Acid Generation Prediction by Acid Base Accounting*, MEND Report 1.16.1c.

Norecol, Dames and Moore, (1996). *Guide for Predicting Water Chemistry from Waste Rock Piles*, MEND Report 1.27.1a.

Norecol, Dames and Moore, (1994). *Long Term Acid Generation Studies: Cinola Project,* *British Columbia*, MEND Report 1.19.1.

Payant, S.C. and Yanful, E.K. (1997). *Evaluation of Techniques for Preventing Acidic Rock Drainage: Final Report*, January, MEND Report 2.35.2b.

Perkins, E.H., H.W. Nesbitt, W.D. Gunter, L.C. St-Arnaud, and J.R. Mycroft, 1995. *Critical Literature Review of Geochemical Processes and Geochemical Models Adaptable for Prediction of Acidic Drainage from Waste Rock,* MEND Report 1.42.1.

Sherlock, E. and Lawrence, R. (1995). *Evaluation of Static and Kinetic Prediction Test Data and Comparison with Field Monitoring Data*, MEND Report 1.16.4.

Sheremata, T.W., E.K. Yanful, L.C. St-Arnaud, and S.C. Payant (1991). "Flooding and Lime Addition for the Control of Acidic Drainage From Mine Waste Rock: A Comparative Laboratory Study", *Proceedings of the First Canadian Conference on Environmental Geotechnics*, sponsored by the Canadian Geotechnical Society, Montreal, May 14 -16, 1991.

Smith, L., Lopez, D.L., Beckie, R., Morin, K., Dawson, R., and Price, W. (1995). *Hydrology of Waste Rock Dumps*, Report to Natural Resources Canada.

Sobek, A.A., Shuller, W.A., Freeman, J.R. and Smith, R.M. (1978). *Field and Laboratory Methods Applicable to Overburderns and Minesoils*, EPA Report EPA-600/2-78-054, USEPA, Cincinnati.

St-Arnaud, L. (1990). *Hydrogeological Investigation of the Stratmat Open Pit Area, Heath Steele Mines Ltd.*, Centre de Technologie Noranda, Internal Report, June.

Stevens, C. and Lawrence G. (1995). "Contaminant Transport in Water-Filled Mine-Pits," *Proceedings of the 19th Annual British Columbia Mine Reclamation Symposium*, Held at Dawson Creek, B.C., Canada, June 19-23.

Stumm, W. and J.J. Morgan (1996). *Aquatic Chemistry - Chemical Equilibria and Rates in Natural Waters*, 3rd edn., John Wiley & Sons, New York.

Yanful, E.K. and S.C. Payant (1993). *Evaluation of Techniques for Preventing Acidic Rock Drainage*, Noranda Technology Centre, First Milestone Research Report submitted to MEND.

APPENDIX I STRATMAT/N5 PIT WATER PHYSICOCHEMICAL PROFILES

OBJECTIVES AND METHODS

The objectives of pit water profiling were to detect chemical and physical stratification, possible turnovers, active volumes, and hydrological patterns. The resulting data would provide inputs to pit water quality prediction for the future. Since pit water quality prediction was deleted from the objectives, the pit water profile data are not used further. The profiles are reported here for qualitative observations of the flooded pits.

Two rounds of chemical profiles of the Stratmat and the N5 pit waters were taken: the first on October 24 and 27, 1994 and the second on June 6 and 7, 1995, using a Hydrolab integrated profiling unit. The unit simultaneously measures pH, redox potential, conductivity, dissolved oxygen, temperature, and depth. All parameter values were logged in a portable computer once every two seconds as the unit was slowly lowered down or lifted up in the pit water. Five locations were selected for profiling in the first round: three located in the Stratmat pit (Stratmat East, Middle and West) and two in the N5 pit (N5 East and West). For the second round the number of stations in the N5 pit was reduced to one (N5 Middle). Water was sampled from the two pits using a messenger-activated Alpha sampler at various depths for chemical analyses (ICP 32-element scan, acidity, alkalinity, sulphate, phosphate, nitrate, nitrite, chloride, Fe^{3+}).

RESULTS AND DISCUSSION

The pit water physicochemical profiles from the first and the second profiling campaigns are presented at the end of this appendix. Note that at each profiling station, a downward profile, measured when the Hydrolab probe was being lowered, and a upward profile, measured when the Hydrolab probe was being lifted, were presented. The differences in the downward and upward profiles reflect the lag in response time of the various probes. Generally speaking, the downward and upward profiles are nearly identical for conductivity, temperature, and pH, indicating the quick responses of these probes. In contrast, the downward and upward profiles for redox potential (Eh) and dissolved oxygen (DO) are significantly apart, indicating that these probes have a longer response time to the changes in water properties. The true profiles are approximated by the average of the downward and upward profiles.

STRATMAT PIT

In the first campaign in October 94, water was sampled at each of the three profiling stations in Stratmat at an interval of about 10 m. In the second campaign of June 95, water was sampled also at each of the three profiling stations, but this time at an interval of 5 m. Station "Stratmat East" was situated above the original open pit floor; stations "Stratmat Middle" and "Stratmat West" were located above the deep depression excavated for under-ground mining access. The locations of the stations were approximate, thus are not at the exact same places for the October 94 campaign and the June 95 campaign. This explains the large differences in water depths between the two campaigns for same-name stations. Reference zero was taken as the water surface at the time of profiling and thus the depth underwater was negative (in meters). All profiles were taken down to the water/pit bottom interface. The following qualitative observations can be made of the profiling results for the Stratmat pit:

- All three profiling stations indicate the presence of a thin epilimnion[1] made of a "fresh water lens" and about 1 to 2 m thick (see DO, conductivity, temperature, and pH profiles). This lens had a conductivity of 1.6 mS/cm (October 94) or 0.8 mS/cm (June 95) (compared with 2.8 mS/cm (October 94) or 2.0 mS/cm (June 95), respectively, in the lower strata), a DO of 11 mg/L (October 94) or 9 mg/L (June 95) (fully aerated), a temperature of 7.5 (October 94) or 13.5 °C (June 95), and a pH of 3.6 (October 94) or 3.3 (June 95). This evidence suggests that the epilimnion was formed from water inputs to the pit from surrounding surface flows. It appears that the water inflows, having a higher temperature and a lower salinity than the pit water, and thus a lower density, did not mix deeply but rather spread laterally to form the "fresh water lens" observed at the surface.

- Below the epilimnion, there exists a well-defined thermocline[1] for both campaigns: all three stations showed a decline in temperature from 7.5 (October 94) or 13.5 (June 95) °C at the surface to about 3.0 °C (both October 94 and June 95) at -7 m. This indicates that the thickness of the thermocline does not vary significantly with time (season) or space (location).

- Below the thermocline, there exists a hypolimnion[1] with relatively uniform physical and chemical properties (e.g., conductivity, dissolved oxygen, some dissolved metals). In particular, a fairly uniform temperature profile, nearly at the temperature of maximum water density, of about 3 to 4 °C, exists in the hypolimnion at places where water depths are greater than 7 m. This isothermal hypolimnion extends down to the pit bottom, which is up to 30 m deep. These observations suggest that there is a lack of fall or spring turnovers[1] in the deep portions of the pit water.

- Stratmat Middle and Stratmat West, which were about 20 m apart and both located above the depressed portion of the pit, demonstrated almost identical profiles for both campaigns, indicating that within the depression in the pit bottom, the water physical and chemical characteristics are quite invariant laterally and with time. This also provides evidence to the hypothesis that water in this "deep hole" in the pit does not turn over, or mix readily with the overlying water, which is subject to diurnal and seasonal warming and cooling and receives inflows from the surrounding areas.

- A meromictic[1] condition seems to exist in the depression in the pit bottom. The conductivity,

---

[1] Definitions of terms:
Epilimnion - a relatively warm, homogeneous, mixed water stratum at the surface (Hutchinson, 1975a).
Thermocline - a water stratum with a high temperature gradient.
Hypolimnion - a deep, cold, and relatively undisturbed water stratum.
Turnover - a process in which the upper and the lower portions of a water body exchange position.
Meromictic - a non-circulating condition in a water body due to chemically-induced density difference.

dissolved sulphate, zinc, calcium and magnesium are higher in the depression than in the overlying water. The higher salinity, coupled with the near-maximum-density temperature (2.5 to 4.0 °C), results in a higher water density, presumably preventing mixing and turnover of this water. Had mixing occurred during the fall and the spring, the water in the depression would have been warmer than observed for October 94 and June 95.

- For October 94 at all three locations, the pH remains generally constant at about 3.4 for the first 5 m below the surface, then increased steadily deeper in the pit until a pH of 4.5 is reached at the bottom of the depression. This indicates a source of alkalinity in the deeper water. For June 95 this phenomenon was observed only at station Stratmat Middle. The nature of this alkalinity source is uncertain.

- In October 94, all three redox potential profiles have a shape of the letter "U" lying on its side for the top 7 m. The reason for this profile shape is unknown at this time. In June 95, the upper halves of the capsized "U" shape were truncated. The Eh decreased steadily in the depression to about 300 mV (October 94) or 450 mV (June 95) at the bottom, indicating marginally oxidising (or reducing) conditions. These observations, when coupled with the observation that the DO near the pit bottom is generally low, appear to suggest a lack of driving force for reducing reactions, such as decay of organic matter. It can be inferred, therefore, that the organic contents dissolved in the water and settled in the sediments are low, and that sulphate reduction does not take place in the water column.

- The reasons for the sluggish response of the DO probe are suggested as follows: It may be due to the malfunctioning of the stirrer on the Hydrolab probe. The stirrer helps circulate the water in the measuring chamber, the circulation being particularly important for the DO probe. Without a water current at the tip of the DO probe, the water film on the probe may not be able to replenish sufficiently rapidly, thus giving a DO reading only representative of the water it contacted previously. A chance also exists that the water film on the DO probe may not get replaced at all; a water film depleted of oxygen due to the electrical current during measurement may contribute to falsely low (or nearly zero) readings. This may explain the nearly zero readings of DO for the three upward oxygen profiles. For the DO profiles, the downward profiles should be regarded as being more accurate than the upward ones, since the Hydrolab unit is open at the bottom and, in the incident of a malfunctioning stirrer, sufficient agitation may be provided by the turbulence created in the measurement chamber due to the action of lowering the unit. Such agitation is not present when the Hydrolab unit is being lifted.

N5 PIT

In the first campaign of October 94, two locations, N5 East and N5 West, were selected for physicochemical profiling, but only a surface water sample was taken at the northern end of the pit. In the second campaign of June 95, one location, N5 Middle, was used for profiling. This station was also used for sampling the pit water at a depth interval of 5 m. The following qualitative observations can be made of the N5 profiling results:

- The maximum depth in the N5 pit is about 20 m, 10 m less than the Stratmat pit. The maximum horizontal dimension of the N5 pit is also less than that of the Stratmat pit. The differences in pit geometry are probably the main reason for the differences in the limnological observations of the two pits.

- In October 94, the Eh, conductivity, temperature and pH profiles suggest three strata: (1) an upper, well-mixed, uniform layer (epilimnion), approximately 7 m thick; (2) a middle strata with gradually changing properties from -7 m to about -10 m (thermocline), and (3) a lower, thin strata from -12 m to pit bottom (hypolimnion), observed for N5 West only. In June 95, the epilimnion thickness shrank to 2 m, the thermocline was elevated to the depth from -2 to -5 m, and the hypolimnion was thickened.

- For both profiling campaigns, the pH profiles indicate a source of alkalinity in the pit bottom.

- As with the Stratmat case, the downward DO profiles should be taken as more accurate than the upward profiles presumably due to the malfunctioning of the stirrer.

- The epilimnion (7 m and 2 m thick for October 94 and June 95, respectively), with a conductivity of about 0.6 mS/cm, seems "foreign" to the N5 pit. This strata was probably a result of fresh water inflows from surrounding area. The variation in the thickness of this strata can be explained by the fluctuations of water quantity input from surrounding areas. The conductivity of the lower strata, about 2 mS/cm, is comparable to that of the lower strata in the Stratmat pit.

- The October 94 temperature profiles suggest a fall turnover, with the turnover influence running down to about -10 m. The evidence supporting this claim is that the strata from -6 to -10 m showed much higher temperatures than the overlying water (0 to -6 m). The June 95 temperature profile suggests a lack of spring turnover, with the meromictic condition extending from -6 to -20 m (bottom of the pit).

COMPARISON BETWEEN STRATMAT AND N5

The two pit water bodies are similar in the following aspects:

- Both can be classified as *temperate meromictic* (mainly chemically induced) lakes limnologically.

- Both pit lakes are small, with water elevations below those of the surrounding ground. These features limit the influence of the kinetic energy from wind in creating circulation in the water bodies.

- The water in both pits are contaminated with acidity and dissolved metals. The pH and conductivity ranges for the two water bodies are similar.

- Both show a certain degree of stratification and occasional fresh water lenses at the top of the water surface.

- All stations in October 94 and one station in June 95 in the Stratmat pit indicate an alkalinity source at the pit bottom. Similarly, all stations in October 94 and June 95 in the N5 pit suggest a source of alkalinity at the pit bottom.

- Both the Stratmat and the N5 pits seem to lack a spring turnover.

The two pit water bodies are different in the following aspects:

- The Stratmat is bigger in area and deeper than the N5.

- There seems to be a fall turnover in the N5 pit, but not in the Stratmat pit.

CONCLUSIONS AND IMPLICATIONS

CONCLUSIONS

Both the Stratmat and N5 pit lakes are temperate, meromictic lakes. The Stratmat seems to lack significant mixing or turnovers. The N5 seems to be monomictic (one circulation per year), with a fall turnover. Both pit lakes have a meromictic hypolimnion consisting of water containing high dissolved solids. The hypolimnion is stabilised by a high water density deriving predominantly from high dissolved solids (i.e., chemical stratification) and, to a lesser degree, a temperature near 4 °C, the temperature of maximum water density (i.e., thermal stratification). The high dissolved solids are mainly due to dissolved SO_4, Zn, Ca, and Mg, all of which are products of sulphide oxidation or neutralisation of acid generated thereof.

Both pit lakes are also characterised by an epilimnion of seasonally-varying depth. The epilimnion has much less salinity (i.e., dissolved solids) than the hypolimnion. The epilimnion seems to have formed mainly from low-salinity surface water inflows from surrounding areas into the pits. Because of the density contrast, these water inflows do not seem to mix with deeper water in the hypolimnion, but rather spread laterally to form a "fresh water lens" (the epilimnion) with a lower density and warmer temperature. The varying depth of the epilimnion is a result of the balance between the amount of water inflows and the amount of evaporation, both of which fluctuate seasonally.

Within the hypolimnion, dissolved oxygen is nearly depleted. But the redox potential profiles and presence of oxidised species such as Fe^{3+} do not indicate highly reducing conditions, suggesting a low content of degradable organic content in both the water column and the pit bottom sediments. Therefore, there is no significant sulphate reduction in the water column. At some locations in the Stratmat and the N5 pits, there appears to be a source of alkalinity near the pit bottom, as indicated by the pH rise in these regions. The nature of the alkalinity source is probably alkaline original host rock or alkaline rock placed in the pit bottom. The rise in pH is generally not sufficient to cause precipitation of any metals except for Al.

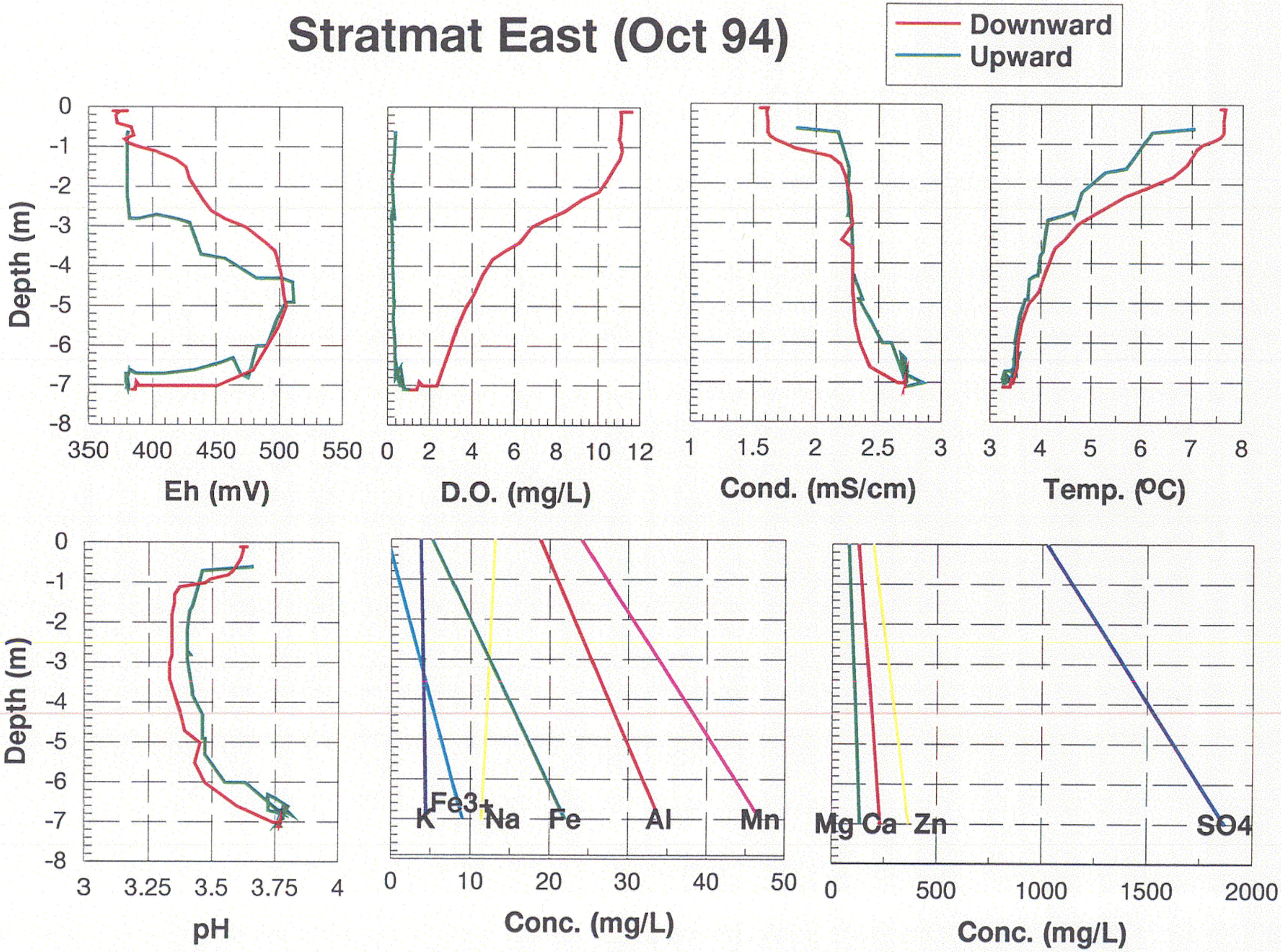
Note that the preliminary conclusions stated above are drawn from the observations of only two physicochemical profiling campaigns. Validation of these conclusions can be achieved through further field measurements.

A recent paper by Stevens and Lawrence (1995) examined the contaminant transport and attempted modelling of a pit lake at Brenda Mines near Peachland, British Columbia. The water column stratification found in the study was similar to that found in this report.

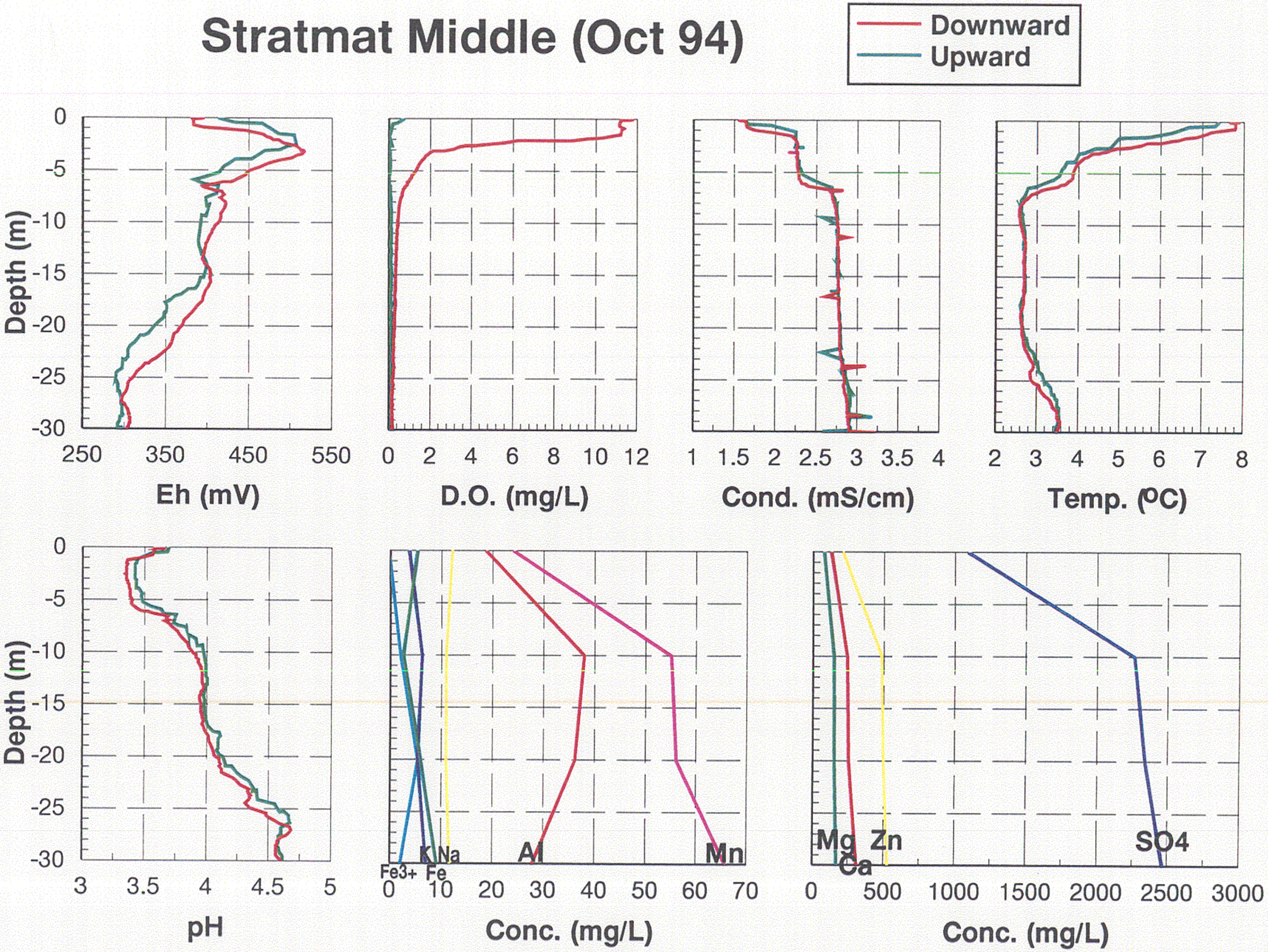
IMPLICATIONS

Since the hypolimnion (lower strata) is more concentrated in dissolved solids than the epilimnion (surface strata) for both pits, it follows that, if this chemical stratification structure persists over an extended period of time, pumping water from the hypolimnion to the water treatment plant is more beneficial than from the epilimnion. This measure would reduce the overall contaminant load in the pits, thereby reducing the environmental risk of an accidental spill or leak. Practically, this measure can be achieved by lowering the pump intake deeply into the hypolimnion, preferably near the pit bottom.

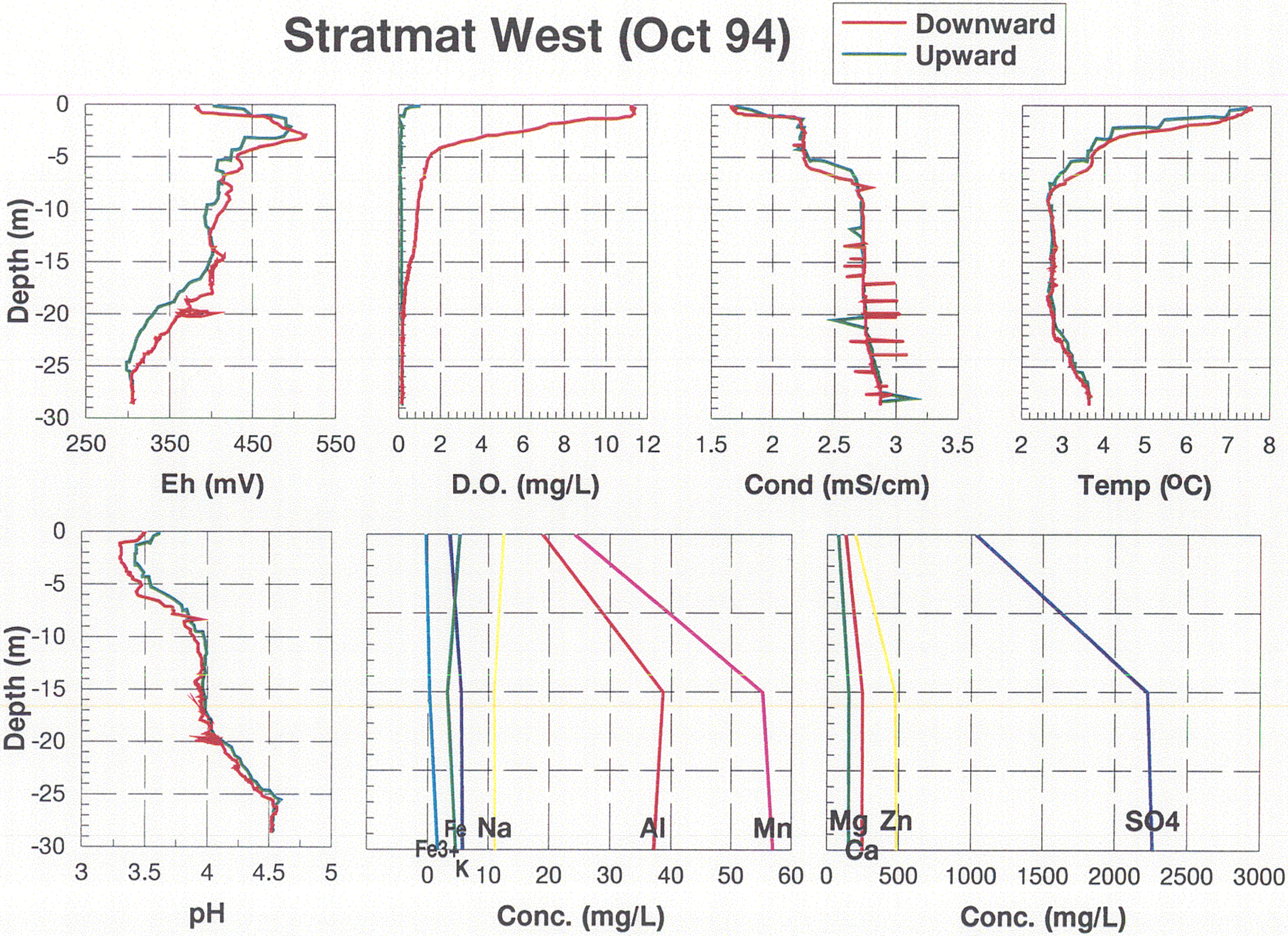
Since the pit water in general and the hypolimnion in particular are contaminated, to protect the environment, the pit water should not be allowed to outflow, either as surface overflow or ground water discharge. The engineering solutions to ensure non-discharge of the pit water are (1) to maintain through proper water management practice the pit water level below the local groundwater table at all times to create a hydraulic gradient towards the pit, (2) to ascertain that there is enough water storage capacity for the design flood, and (3) to treat the water withdrawn from the pit. These engineering solutions are currently practised at the site and have been fully incorporated into the closure plan. A state-of-the-art lime neutralisation water treatment plant was commissioned at the site in 1997 to treat the pit water and other contaminated waters.


Stratmat East (Oct 94)
Downward
Upward
Depth (m)
0
-1
-2
-3
-4
-5
-6
-7
-8
350 400 450 500 550
Eh (mV)
0 2 4 6 8 10 12
D.O. (mg/L)
1 1.5 2 2.5 3
Cond. (mS/cm)
3 4 5 6 7 8
Temp. (ºC)
3 3.25 3.5 3.75 4
pH
K
Fe3+
Na
Fe
Al
Mn
0 10 20 30 40 50
Conc. (mg/L)
Mg
Ca
Zn
SO4
0 500 1000 1500 2000
Conc. (mg/L)

Stratmat Middle (Oct 94)

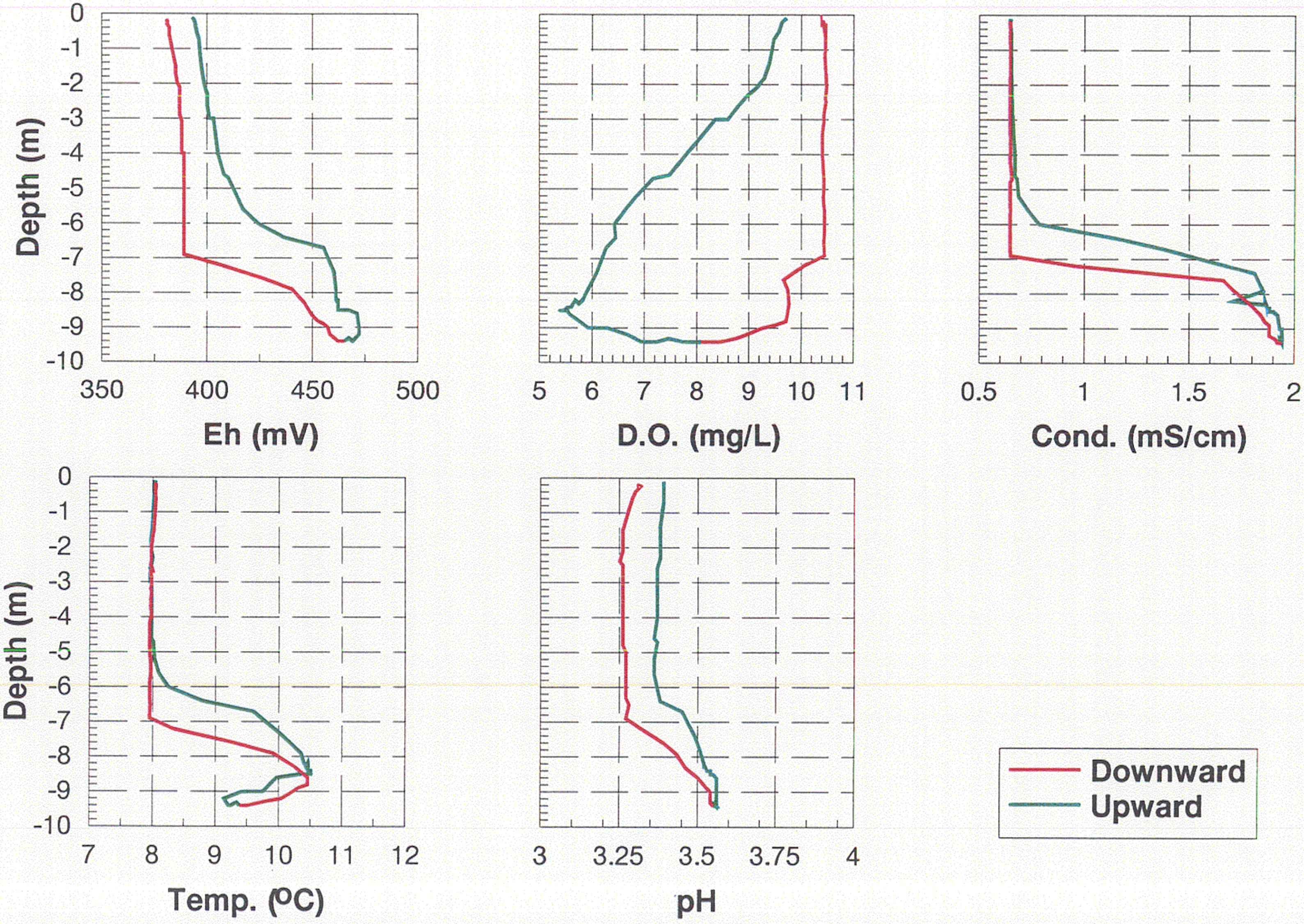


Welcome Screen | Search | Report List

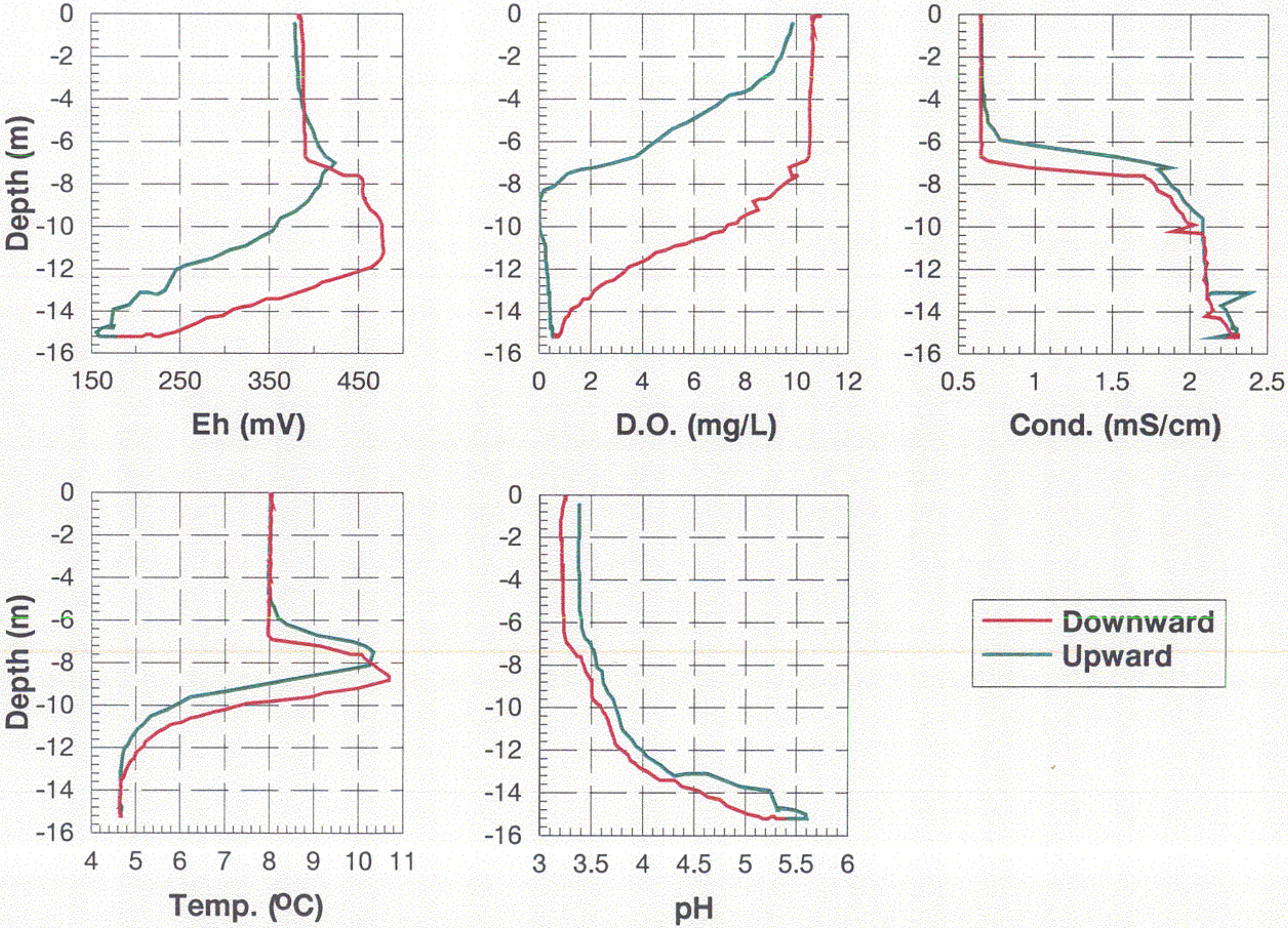


Stratmat West (Oct 94)

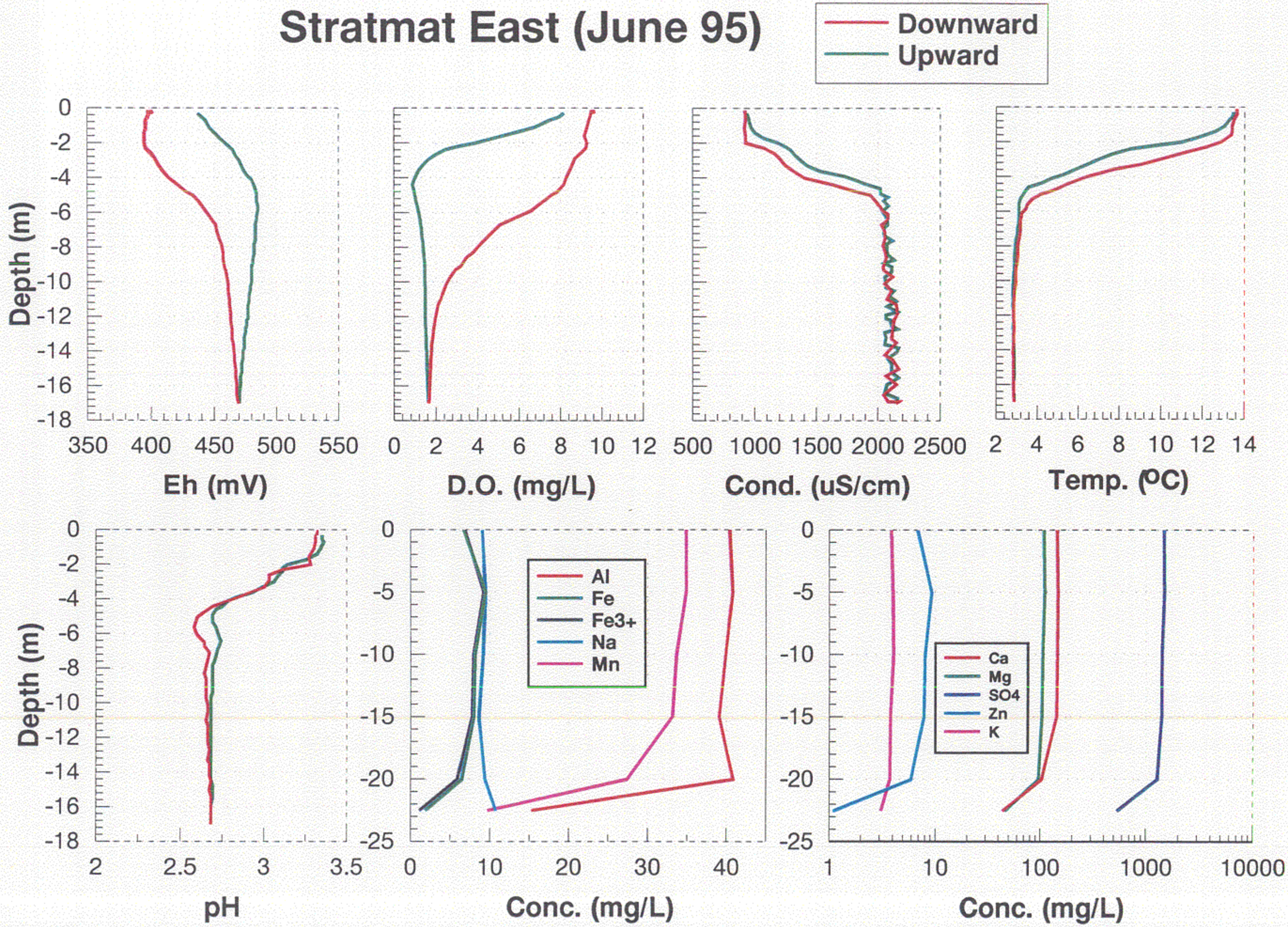
N5 East (Oct 94)

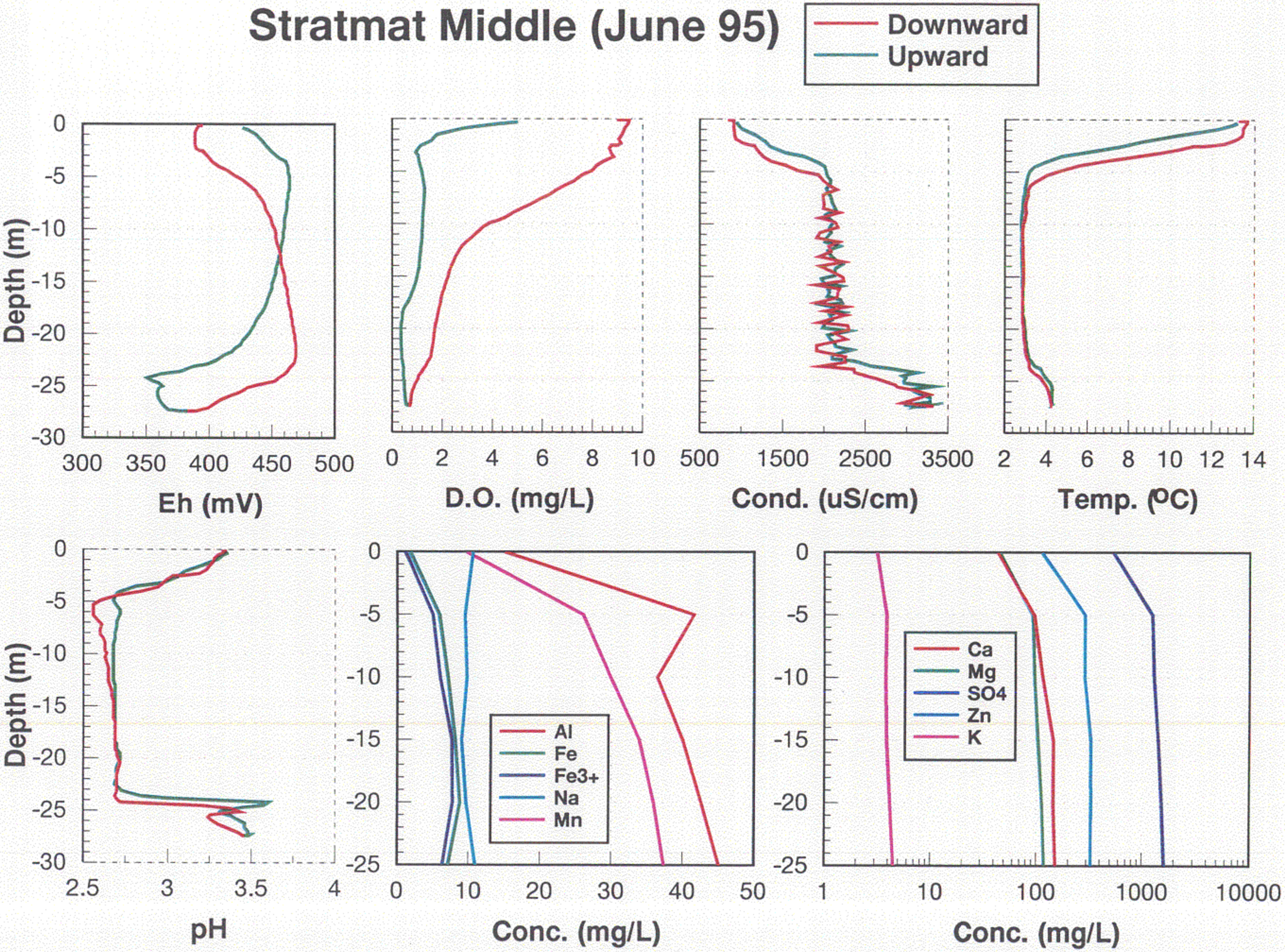


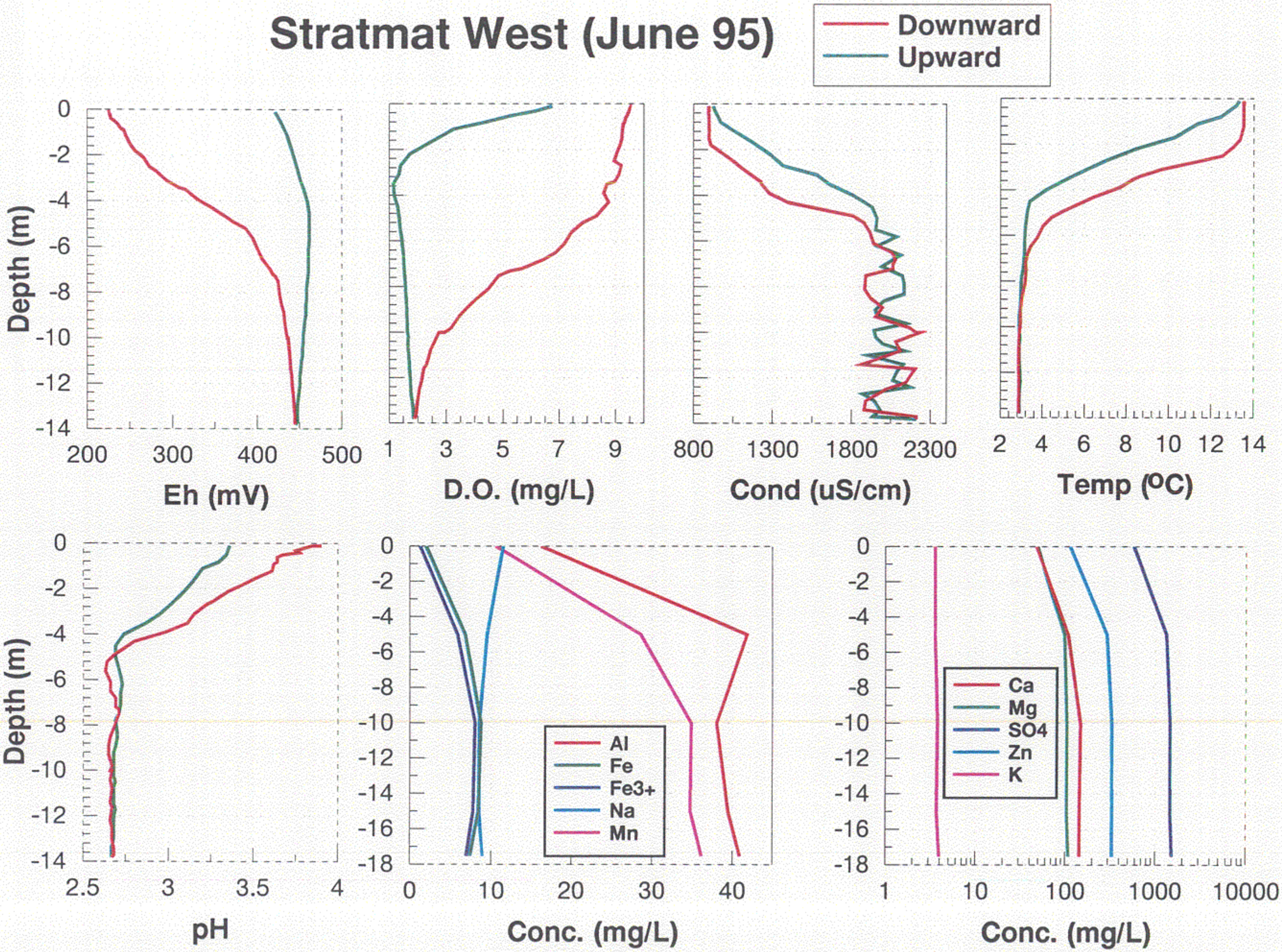
N5 West (Oct 94)



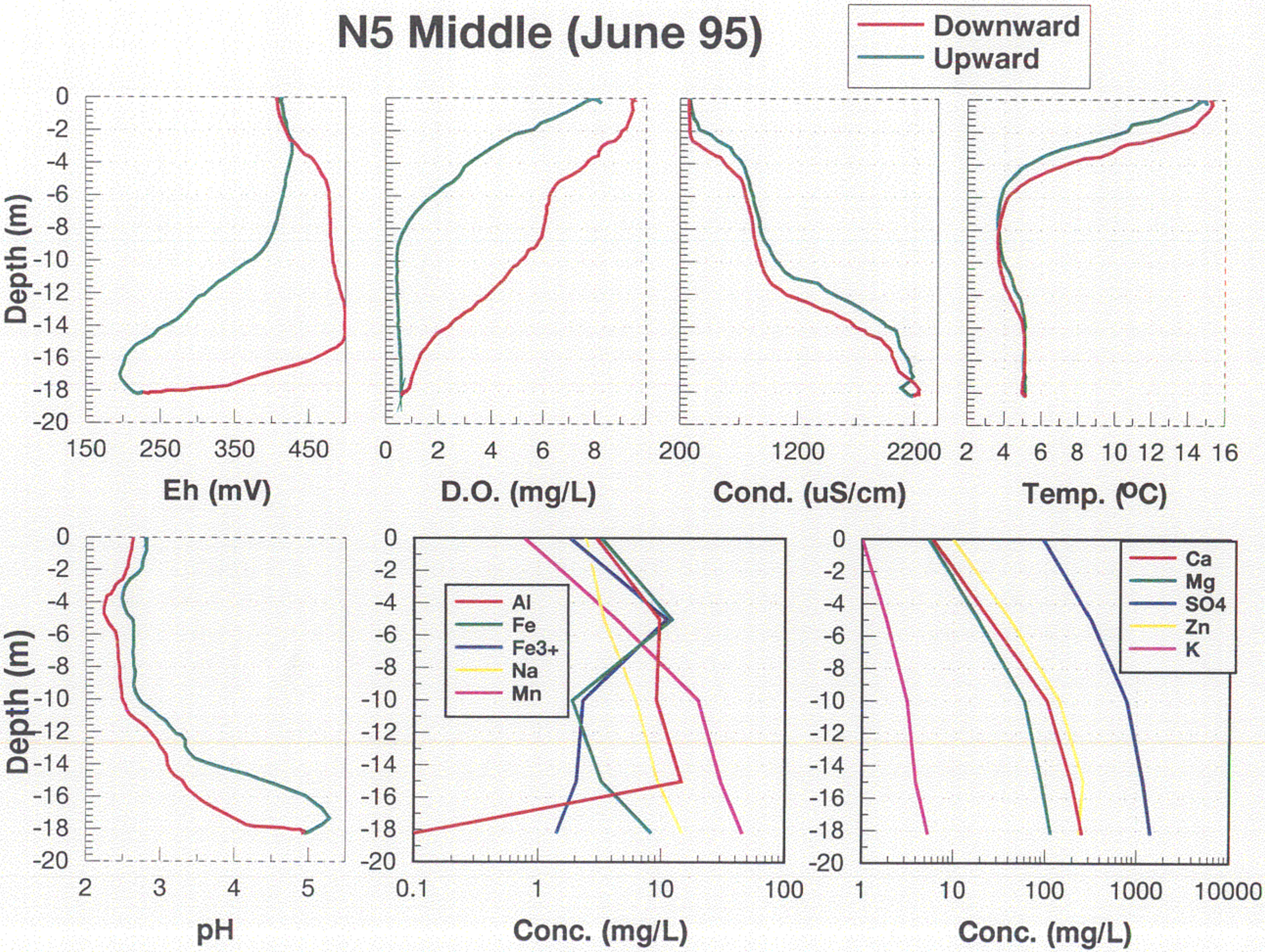
Welcome Screen | Search | Report List




Stratmat Middle (June 95)
Downward
Upward
Depth (m)
0
-5
-10
-15
-20
-25
-30
300 350 400 450 500
Eh (mV)
0 2 4 6 8 10
D.O. (mg/L)
500 1500 2500 3500
Cond. (uS/cm)
2 4 6 8 10 12 14
Temp. (ºC)
2.5 3 3.5 4
pH
Al
Fe
Fe3+
Na
Mn
0 10 20 30 40 50
Conc. (mg/L)
Ca
Mg
SO4
Zn
K
1 10 100 1000 10000
Conc. (mg/L)


Stratmat West (June 95)
Downward
Upward
Depth (m)
0
-2
-4
-6
-8
-10
-12
-14
200
300
400
500
Eh (mV)
1
3
5
7
9
D.O. (mg/L)
800
1300
1800
2300
Cond (uS/cm)
2
4
6
8
10
12
14
Temp (oC)
2.5
3
3.5
4
pH
-16
-18
0
10
20
30
40
Conc. (mg/L)
Al
Fe
Fe3+
Na
Mn
1
100
1000
10000
Conc. (mg/L)
Ca
Mg
SO4
Zn
K

Welcome Screen | Search | Report List



APPENDIX II EXPERIMENTAL DATA FOR COLUMN DISSOLUTION TESTS

Stratmat Column Rinse Test - Physichemical Parameters

Cycle	Item	SC-1	SC-2
Date :	March 29, 1995		
0	Initial mass (kg)	25	25
0	Initial volume water (L)	23	24
0	pH	3.88	4.01
0	Conductivity (uS/cm)	1086	2100
0	Acidity (mg CaCO3/L)	756	700
Date :	March 31, 1995		
1	Initial volume water (L)	23	24
1	Final volume water (L)	19.3	21
1	pH	3.77	3.87
1	Conductivity (uS/cm)	4790	4700
1	Acidity (mg CaCO3/L)	2278	2030
Date :	April 3, 1995		
2	Initial volume water (L)	20	20
2	Final volume water (L)	19.8	19.7
2	pH	3.84	4.12
2	Conductivity (uS/cm)	1840	2240
2	Acidity (mg CaCO3/L)	588	502
Date :	April 7, 1995		*4.61*
3	Initial volume water (L)	20	20
3	Final volume water (L)	19.9	19.6
3	pH	4.4	5.36
3	Conductivity (uS/cm)	1020	1280
3	Acidity (mg CaCO3/L)	218	190
Date :	April 10, 1995		
4	Initial volume water (L)	20	20
4	Final volume water (L)	20	20
4	pH	4.05	4.33
4	Conductivity (uS/cm)	690	740
4	Acidity (mg CaCO3/L)	120	96
Date :	April 12, 1995		
5	Initial volume water (L)	20	20
5	Final volume water (L)	20	20
5	pH	4.53	4.82
5	Conductivity (uS/cm)	420	370
5	Acidity (mg CaCO3/L)	72	62

Cycle	Item	SC-1	SC-2
Date :	April 17, 1995	*4.97*	*4.75*
6	Initial volume water (L)	20	20
6	Final volume water (L)	19.8	19.9
6	pH	5.34	7.89
6	Conductivity (uS/cm)	484	399
6	Acidity (mg CaCO3/L)	94	58
Date :	April 21, 1995		*4.78*
7	Initial volume water (L)	20	20
7	Final volume water (L)	20	20
7	pH	4.32	5.08
7	Conductivity (uS/cm)	382	332
7	Acidity (mg CaCO3/L)	58	48
Date :	May 2, 1995	*4.80*	*4.84*
8	Initial volume water (L)	20	20
8	Final volume water (L)	20	20
8	pH	5.75	6.4
8	Conductivity (uS/cm)	459	390
8	Acidity (mg CaCO3/L)	142	96
Date :	May 9, 1995	*4.82*	*4.87*
9	Initial volume water (L)	20	20
9	Final volume water (L)	20	20
9	pH	4.12	7.38
9	Conductivity (uS/cm)	333	310
9	Acidity (mg CaCO3/L)	70	62
Date :	May 12, 1995		
10	Initial volume water (L)	20	20
10	Final volume water (L)	20	20
10	pH	4.5	4.64
10	Conductivity (uS/cm)	215	207
10	Acidity (mg CaCO3/L)	34	33
Date :	May 15, 1995		
11	Initial volume water (L)	20	20
11	Final volume water (L)	20	20
11	pH	4.87	4.54
11	Conductivity (uS/cm)	183	181
11	Acidity (mg CaCO3/L)	20	22

Note: Bold italic figures are interpolated values. Normal italic figures are pH's calculated by Minteq.

Welcome Screen | Search | Report List

Stratmat Column Rinse Test - Physichemical Parameters

Cycle	Item	SC-1	SC-2
Date :	May 19, 1995	*4.84*	*4.88*
12	Initial volume water (L	20	20
12	Final volume water (L	20	20
12	pH	5.91	5.11
12	Conductivity (uS/cm)	156	148
12	Acidity (mg CaCO3/L)	24	26
Date :	May 23, 1995		
13	Initial volume water (L	20	20
13	Final volume water (L	20	20
13	pH	4.3	4.61
13	Conductivity (uS/cm)	165	160
13	Acidity (mg CaCO3/L)	30	24
Date :	May 26, 1995		
14	Initial volume water (L	20	20
14	Final volume water (L	20	20
14	pH	4.41	4.86
14	Conductivity (uS/cm)	143	139
14	Acidity (mg CaCO3/L)	28	24
Date :	Jun 2, 1995	*4.89*	*4.93*
15	Initial volume water (L	20	20
15	Final volume water (L	20	20
15	pH	5.68	6
15	Conductivity (uS/cm)	177	186
15	Acidity (mg CaCO3/L)	102	80
Date :	June 9, 1995		*4.96*
16	Initial volume water (L	20	20
16	Final volume water (L	20	20
16	pH	5.18	7.35
16	Conductivity (uS/cm)	174	181
16	Acidity (mg CaCO3/L)	30	28
Date :	June 16, 1995	*4.92*	*4.96*
17	Initial volume water (L	20	20
17	Final volume water (L	20	20
17	pH	5.22	5.26
17	Conductivity (uS/cm)	***174***	***194***
17	Acidity (mg CaCO3/L)	30	30
Date :	June 22, 1995		
18	Initial volume water (L	20	20
18	Final volume water (L	20	20
18	pH	4.35	4.52
18	Conductivity (uS/cm)	***197***	***207***
18	Acidity (mg CaCO3/L)	34	32

Note: Bold italic figures are interpolated values. Normal italic figures are pH's calculated by Minteq.

Stratmat Column Rinse Test - Dissolved Elements

March 29, 1995

Cycle	Sample I.D.	Al mg/L	As mg/L	Ca mg/L	Cd mg/L	Cu mg/L	Fe mg/L	K mg/L	Mg mg/L	Mn mg/L	Na mg/L	Pb mg/L	S04 mg/L	Se mg/L	Zn mg/L	Fe+3 mg/L	Fe+2 mg/L
0	SC-1	64.14	0.37	174.69	0.84	12.79	5.87	< 5.00	101.70	18.42	6.60	1.58	1528.64	< 0.50	245.19	4.29	1.58
0	SC-2	57.72	0.35	200.42	0.79	11.19	4.76	< 5.00	100.04	18.11	6.13	1.67	1537.10	< 0.50	245.62	3.61	1.15

March 31, 1995

Cycle	Sample I.D.	Al mg/L	As mg/L	Ca mg/L	Cd mg/L	Cu mg/L	Fe mg/L	K mg/L	Mg mg/L	Mn mg/L	Na mg/L	Pb mg/L	S04 mg/L	Se mg/L	Zn mg/L	Fe+3 mg/L	Fe+2 mg/L
1	SC-1	176.24	1.07	386.37	2.88	37.73	9.19	< 5.00	318.01	64.62	6.55	0.39	4311.37	< 0.50	788.39	7.60	1.59
1	SC-2	149.98	0.89	433.21	2.75	31.70	5.43	< 5.00	310.36	63.41	6.76	0.75	4229.01	< 0.50	793.86	4.84	0.59

April 3, 1995

Cycle	Sample I.D.	Al mg/L	As mg/L	Ca mg/L	Cd mg/L	Cu mg/L	Fe mg/L	K mg/L	Mg mg/L	Mn mg/L	Na mg/L	Pb mg/L	S04 mg/L	Se mg/L	Zn mg/L	Fe+3 mg/L	Fe+2 mg/L
2	SC-1	31.18	< 0.25	215.04	0.74	8.45	0.72	< 5.00	72.36	16.48	6.58	2.00	1250.93	< 0.50	205.63	*0.56*	*0.16*
2	SC-2	27.71	< 0.25	351.97	0.77	7.47	0.63	< 5.00	77.24	18.90	7.35	1.97	1628.22	< 0.50	239.08	*0.49*	*0.14*

April 7, 1995

Cycle	Sample I.D.	Al mg/L	As mg/L	Ca mg/L	Cd mg/L	Cu mg/L	Fe mg/L	K mg/L	Mg mg/L	Mn mg/L	Na mg/L	Pb mg/L	S04 mg/L	Se mg/L	Zn mg/L	Fe+3 mg/L	Fe+2 mg/L
3	SC-1	9.68	0.06	123.86	0.27	3.10	0.15	3.29	25.08	6.53	2.33	1.97	596.19	< 0.05	69.99	*0.12*	*0.03*
3	SC-2	7.74	< 0.05	190.38	0.25	2.53	0.13	3.38	24.55	6.83	1.38	1.93	710.90	< 0.05	72.97	*0.10*	*0.03*

April 10, 1995

Cycle	Sample I.D.	Al mg/L	As mg/L	Ca mg/L	Cd mg/L	Cu mg/L	Fe mg/L	K mg/L	Mg mg/L	Mn mg/L	Na mg/L	Pb mg/L	S04 mg/L	Se mg/L	Zn mg/L	Fe+3 mg/L	Fe+2 mg/L
4	SC-1	2.99	< 0.25	112.50	0.08	1.09	0.10	< 5.00	11.27	3.49	6.38	2.86	383.21	< 0.50	37.66	*0.08*	*0.02*
4	SC-2	4.57	< 0.25	88.61	0.11	1.64	0.12	< 5.00	13.69	3.69	6.46	3.05	348.17	< 0.50	39.38	*0.09*	*0.03*

April 12, 1995

Cycle	Sample I.D.	Al mg/L	As mg/L	Ca mg/L	Cd mg/L	Cu mg/L	Fe mg/L	K mg/L	Mg mg/L	Mn mg/L	Na mg/L	Pb mg/L	S04 mg/L	Se mg/L	Zn mg/L	Fe+3 mg/L	Fe+2 mg/L
5	SC-1	1.97	< 0.25	49.14	< 0.03	0.86	0.03	< 5.00	6.29	1.78	6.12	3.32	182.47	< 0.50	18.74	*0.03*	*0.01*
5	SC-2	1.15	< 0.25	47.86	< 0.03	0.52	< 0.03	< 5.00	4.65	1.41	6.21	3.30	161.44	< 0.50	15.38	*0.02*	*0.01*

April 17, 1995

Cycle	Sample I.D.	Al mg/L	As mg/L	Ca mg/L	Cd mg/L	Cu mg/L	Fe mg/L	K mg/L	Mg mg/L	Mn mg/L	Na mg/L	Pb mg/L	S04 mg/L	Se mg/L	Zn mg/L	Fe+3 mg/L	Fe+2 mg/L
6	SC-1	0.35	< 0.25	51.81	< 0.03	0.08	0.17	5.00	6.06	1.79	6.54	3.65	184.78	< 0.50	17.21	< 0.05	*0.17*
6	SC-2	1.84	< 0.25	57.24	0.06	0.60	0.19	< 5.00	5.42	1.82	7.23	4.46	190.52	< 0.50	16.81	< 0.05	*0.19*

Welcome Screen | Search | Report List

Stratmat Column Rinse Test - Dissolved Elements

April 21, 1995

Cycle	Sample I.D.	Al mg/L	As mg/L	Ca mg/L	Cd mg/L	Cu mg/L	Fe mg/L	K mg/L	Mg mg/L	Mn mg/L	Na mg/L	Pb mg/L	S04 mg/L	Se mg/L	Zn mg/L	Fe+3 mg/L	Fe+2 mg/L
7	SC-1	1.98	< 0.25	54.47	0.06	0.66	0.07	< 5.00	5.83	1.80	6.96	3.99	187.09	< 0.50	15.67	< 0.05	***0.07***
7	SC-2	1.38	< 0.25	46.19	0.04	0.38	0.07	< 5.00	4.44	1.55	7.44	4.18	150.91	< 0.50	12.61	< 0.05	***0.07***

May 2, 1995

Cycle	Sample I.D.	Al mg/L	As mg/L	Ca mg/L	Cd mg/L	Cu mg/L	Fe mg/L	K mg/L	Mg mg/L	Mn mg/L	Na mg/L	Pb mg/L	S04 mg/L	Se mg/L	Zn mg/L	Fe+3 mg/L	Fe+2 mg/L
8	SC-1	1.90	< 0.25	60.18	< 0.03	0.39	< 0.03	< 5.00	6.76	2.05	1.34	3.63	214.44	< 0.50	16.76	< 0.05	***0.03***
8	SC-2	1.20	< 0.25	51.37	< 0.03	0.12	< 0.03	< 5.00	5.06	1.95	1.21	3.83	178.35	< 0.50	13.78	< 0.05	***0.03***

May 9, 1995

Cycle	Sample I.D.	Al mg/L	As mg/L	Ca mg/L	Cd mg/L	Cu mg/L	Fe mg/L	K mg/L	Mg mg/L	Mn mg/L	Na mg/L	Pb mg/L	S04 mg/L	Se mg/L	Zn mg/L	Fe+3 mg/L	Fe+2 mg/L
9	SC-1	1.19	< 0.25	40.39	< 0.03	0.23	0.03	< 5.00	4.46	1.38	0.77	4.15	145.35	< 0.50	10.97	< 0.05	***0.03***
9	SC-2	0.96	< 0.25	38.06	< 0.03	0.13	< 0.03	< 5.00	3.74	1.44	0.96	4.78	133.20	< 0.50	10.21	< 0.05	***0.03***

May 12, 1995

Cycle	Sample I.D.	Al mg/L	As mg/L	Ca mg/L	Cd mg/L	Cu mg/L	Fe mg/L	K mg/L	Mg mg/L	Mn mg/L	Na mg/L	Pb mg/L	S04 mg/L	Se mg/L	Zn mg/L	Fe+3 mg/L	Fe+2 mg/L
10	SC-1	0.68	< 0.25	20.73	< 0.03	0.15	< 0.03	< 5.00	2.32	0.64	0.69	3.80	76.98	< 0.50	5.63	< 0.05	***0.03***
10	SC-2	0.52	< 0.25	20.73	< 0.03	0.03	< 0.03	< 5.00	1.83	0.71	1.04	3.96	73.47	< 0.50	5.42	< 0.05	***0.03***

May 15, 1995

Cycle	Sample I.D.	Al mg/L	As mg/L	Ca mg/L	Cd mg/L	Cu mg/L	Fe mg/L	K mg/L	Mg mg/L	Mn mg/L	Na mg/L	Pb mg/L	S04 mg/L	Se mg/L	Zn mg/L	Fe+3 mg/L	Fe+2 mg/L
11	SC-1	1.52	< 0.25	16.05	< 0.03	0.22	***0.22***	< 5.00	2.72	0.59	3.53	4.29	62.49	< 0.50	3.96	***0.22***	***0.00***
11	SC-2	0.63	< 0.25	17.27	< 0.03	0.11	0.10	< 5.00	1.75	0.69	3.06	4.44	63.38	< 0.50	4.21	< 0.25	***0.00***

May 19, 1995

Cycle	Sample I.D.	Al mg/L	As mg/L	Ca mg/L	Cd mg/L	Cu mg/L	Fe mg/L	K mg/L	Mg mg/L	Mn mg/L	Na mg/L	Pb mg/L	S04 mg/L	Se mg/L	Zn mg/L	Fe+3 mg/L	Fe+2 mg/L
12	SC-1	0.55	< 0.25	12.31	< 0.03	0.15	0.14	< 5.00	1.44	0.42	3.28	3.87	48.91	< 0.50	2.98	< 0.25	***0.00***
12	SC-2	0.60	< 0.25	13.43	< 0.03	0.09	0.16	< 5.00	1.38	0.52	3.44	3.99	52.96	< 0.50	3.21	< 0.25	***0.00***

May 23, 1995

Cycle	Sample I.D.	Al mg/L	As mg/L	Ca mg/L	Cd mg/L	Cu mg/L	Fe mg/L	K mg/L	Mg mg/L	Mn mg/L	Na mg/L	Pb mg/L	S04 mg/L	Se mg/L	Zn mg/L	Fe+3 mg/L	Fe+2 mg/L
13	SC-1	0.62	< 0.25	13.45	< 0.03	0.18	0.58	< 5.00	1.55	0.48	3.34	4.67	53.23	< 0.50	3.31	< 0.25	***0.33***
13	SC-2	0.61	< 0.25	13.76	< 0.03	0.08	0.06	< 5.00	1.45	0.53	3.80	4.53	51.61	< 0.50	3.21	< 0.25	***0.00***

Stratmat Column Rinse Test - Dissolved Elements

May 26, 1995

Cycle	Sample I.D.	Al mg/L	As mg/L	Ca mg/L	Cd mg/L	Cu mg/L	Fe mg/L	K mg/L	Mg mg/L	Mn mg/L	Na mg/L	Pb mg/L	S04 mg/L	Se mg/L	Zn mg/L	Fe+3 mg/L	Fe+2 mg/L
14	SC-1	0.40	< 0.05	13.48	0.01	0.22	0.06	2.43	1.60	0.50	1.13	5.70	52.72	< 0.10	3.92	***0.05***	***0.01***
14	SC-2	0.35	< 0.05	14.28	0.01	0.11	0.02	2.46	1.49	0.58	1.27	5.64	52.77	< 0.10	3.87	***0.01***	***0.00***

June 2, 1995

Cycle	Sample I.D.	Al mg/L	As mg/L	Ca mg/L	Cd mg/L	Cu mg/L	Fe mg/L	K mg/L	Mg mg/L	Mn mg/L	Na mg/L	Pb mg/L	S04 mg/L	Se mg/L	Zn mg/L	Fe+3 mg/L	Fe+2 mg/L
15	SC-1	0.57	< 0.05	19.16	0.02	0.26	0.10	3.36	2.28	0.71	1.41	6.88	72.40	< 0.10	5.34	***0.08***	***0.02***
15	SC-2	0.51	< 0.05	19.64	0.01	0.14	0.05	3.05	2.06	0.80	1.30	6.95	71.09	< 0.10	5.12	***0.04***	***0.01***

June 9, 1995

Cycle	Sample I.D.	Al mg/L	As mg/L	Ca mg/L	Cd mg/L	Cu mg/L	Fe mg/L	K mg/L	Mg mg/L	Mn mg/L	Na mg/L	Pb mg/L	S04 mg/L	Se mg/L	Zn mg/L	Fe+3 mg/L	Fe+2 mg/L
16	SC-1	0.56	< 0.05	19.04	0.01	0.23	0.02	3.26	2.38	0.72	1.25	7.02	72.55	< 0.10	5.26	***0.01***	***0.00***
16	SC-2	0.47	< 0.05	20.06	0.01	0.10	0.03	2.91	2.13	0.82	1.22	6.77	72.65	< 0.10	5.07	***0.02***	***0.01***

June 16, 1995

Cycle	Sample I.D.	Al mg/L	As mg/L	Ca mg/L	Cd mg/L	Cu mg/L	Fe mg/L	K mg/L	Mg mg/L	Mn mg/L	Na mg/L	Pb mg/L	S04 mg/L	Se mg/L	Zn mg/L	Fe+3 mg/L	Fe+2 mg/L
17	SC-1	0.55	< 0.25	17.38	< 0.03	0.06	< 0.03	< 5.00	2.22	0.46	4.20	5.09	67.68	< 0.50	4.11	***0.02***	***0.01***
17	SC-2	0.49	< 0.25	17.37	< 0.03	< 0.03	< 0.03	< 5.00	1.88	0.58	3.17	5.14	65.56	< 0.50	4.10	***0.02***	***0.01***

June 22, 1995

Cycle	Sample I.D.	Al mg/L	As mg/L	Ca mg/L	Cd mg/L	Cu mg/L	Fe mg/L	K mg/L	Mg mg/L	Mn mg/L	Na mg/L	Pb mg/L	S04 mg/L	Se mg/L	Zn mg/L	Fe+3 mg/L	Fe+2 mg/L
18	SC-1	0.56	< 0.25	14.99	< 0.03	0.09	< 0.03	< 5.00	1.93	0.43	3.59	5.24	60.18	< 0.50	4.04	***0.02***	***0.01***
18	SC-2	0.54	< 0.25	18.79	< 0.03	0.03	< 0.03	< 5.00	2.05	0.62	3.68	7.01	71.25	< 0.50	4.58	***0.02***	***0.01***

Stratmat Column Rinse Test - Physichemical Profiles

pH

Cycle		Total #	# of days	Column 1			Column 2		
No.	Date	of days	in static	Top	Bottom	Mean	Top	Bottom	Mean
19	27/6/95	90	5	4.87	4.83	*4.85*	4.85	4.47	*4.66*
20	28/7/95	121	31	3.55	3.63	*3.59*	3.61	3.62	*3.62*
21	29/8/95	154	64	***3.47***	***3.42***	*3.45*	***3.40***	***3.47***	*3.43*
22	29/9/95	185	95	3.39	3.21	*3.30*	3.19	3.31	*3.25*
23	1/12/95	248	158	3.52	3.47	*3.50*	3.50	3.46	*3.48*
Wrap-up	2/2/96	311	221	3.71	3.71	*3.71*	3.68	3.67	*3.68*

Fe+3

Cycle		Total #	# of days	Column 1			Column 2		
No.	Date	of days	in static	Top	Bottom	Mean	Top	Bottom	Mean
19	27/6/95	90	5	0.000	0.000	*0.00*	0.000	0.000	*0.00*
20	28/7/95	121	31	0.000	0.000	*0.00*	0.000	0.040	*0.02*
21	29/8/95	154	64	***0.000***	***0.000***	*0.00*	***0.000***	***0.020***	*0.01*
22	29/9/95	185	95	0.000	0.000	*0.00*	0.000	0.000	*0.00*
23	1/12/95	248	158	0.070	0.010	*0.04*	0.070	0.010	*0.04*
Wrap-up	2/2/96	311	221	n/a	n/a	n/a	n/a	n/a	n/a

SO4

Cycle		Total #	# of days	Column 1			Column 2		
No.	Date	of days	in static	Top	Bottom	Mean	Top	Bottom	Mean
19	27/6/95	90	5	46.88	45.39	*46.14*	58.79	59.92	*59.36*
20	28/7/95	121	31	57.69	57.47	*57.58*	70.61	70.29	*70.45*
21	29/8/95	154	64	***70.79***	***69.84***	*70.31*	***81.61***	***80.94***	*81.27*
22	29/9/95	185	95	83.88	82.20	*83.04*	92.61	91.59	*92.10*
23	1/12/95	248	158	129.66	129.27	*129.47*	131.19	130.14	*130.67*
Wrap-up	2/2/96	311	221	n/a	n/a	n/a	n/a	n/a	n/a

Cu

Cycle		Total #	# of days	Column 1			Column 2		
No.	Date	of days	in static	Top	Bottom	Mean	Top	Bottom	Mean
19	27/6/95	90	5	0.02	0.02	*0.02*	0.04	0.05	*0.05*
20	28/7/95	121	31	0.18	0.19	*0.19*	0.22	0.22	*0.22*
21	29/8/95	154	64	***0.21***	***0.20***	*0.20*	***0.23***	***0.23***	*0.23*
22	29/9/95	185	95	0.23	0.21	*0.22*	0.24	0.24	*0.24*
23	1/12/95	248	158	0.27	0.25	*0.26*	0.26	0.26	*0.26*
Wrap-up	2/2/96	311	221	n/a	n/a	n/a	n/a	n/a	n/a

Ca+Mg+Mn

Cycle		Total #	# of days	Column 1			Column 2		
No.	Date	of days	in static	Top	Bottom	Mean	Top	Bottom	Mean
19	27/6/95	90	5	0.35	0.34	*0.35*	0.45	0.46	*0.45*
20	28/7/95	121	31	0.42	0.41	*0.41*	0.51	0.50	*0.50*
21	29/8/95	154	64	***0.54***	***0.52***	*0.53*	***0.58***	***0.57***	*0.58*
22	29/9/95	185	95	0.66	0.63	*0.64*	0.66	0.64	*0.65*
23	1/12/95	248	158	1.05	1.05	*1.05*	0.98	0.98	*0.98*
Wrap-up	2/2/96	311	221	n/a	n/a	n/a	n/a	n/a	n/a

Welcome Screen Search Report List

Stratmat Column Rinse Test - Physichemical Profiles

Fe(total)

Cycle No.	Date	Total # of days	# of days in static	Column 1			Column 2		
				Top	Bottom	Mean	Top	Bottom	Mean
19	27/6/95	90	5	0.000	0.000	*0.00*	0.000	0.000	*0.00*
20	28/7/95	121	31	0.000	0.000	*0.00*	0.000	0.240	*0.12*
21	29/8/95	154	64	***0.01***	***0.04***	*0.03*	***0.02***	***0.14***	*0.08*
22	29/9/95	185	95	0.025	0.083	*0.05*	0.036	0.047	*0.04*
23	1/12/95	248	158	0.070	0.010	*0.04*	0.050	0.010	*0.03*
Wrap-up	2/2/96	311	221	n/a	n/a	n/a	n/a	n/a	n/a

Pb

Cycle No.	Date	Total # of days	# of days in static	Column 1			Column 2		
				Top	Bottom	Mean	Top	Bottom	Mean
19	27/6/95	90	5	4.58	4.23	*4.41*	6.43	6.2	*6.32*
20	28/7/95	121	31	5.85	5.99	*5.92*	7.26	7.14	*7.20*
21	29/8/95	154	64	***5.80***	***5.97***	*5.89*	***6.86***	***6.79***	*6.82*
22	29/9/95	185	95	5.75	5.95	*5.85*	6.46	6.44	*6.45*
23	1/12/95	248	158	6.52	6.33	*6.43*	6.85	6.70	*6.78*
Wrap-up	2/2/96	311	221	n/a	n/a	n/a	n/a	n/a	n/a

Zn

Cycle No.	Date	Total # of days	# of days in static	Column 1			Column 2		
				Top	Bottom	Mean	Top	Bottom	Mean
19	27/6/95	90	5	2.89	2.86	*2.88*	3.75	3.77	*3.76*
20	28/7/95	121	31	3.71	3.70	*3.70*	4.99	4.88	*4.93*
21	29/8/95	154	64	***3.93***	***3.84***	*3.88*	***5.36***	***5.24***	*5.30*
22	29/9/95	185	95	4.14	3.98	*4.06*	5.74	5.60	*5.67*
23	1/12/95	248	158	7.06	7.10	*7.08*	8.74	8.70	*8.72*
Wrap-up	2/2/96	311	221	n/a	n/a	n/a	n/a	n/a	n/a

Na

Cycle No.	Date	Total # of days	# of days in static	Column 1			Column 2		
				Top	Bottom	Mean	Top	Bottom	Mean
19	27/6/95	90	5	3.85	3.38	*3.62*	3.28	3.50	*3.39*
20	28/7/95	121	31	2.66	2.95	*2.81*	2.59	2.74	*2.67*
21	29/8/95	154	64	***4.23***	***4.51***	*4.37*	***4.34***	***4.44***	*4.39*
22	29/9/95	185	95	5.80	6.06	*5.93*	6.09	6.13	*6.11*
23	1/12/95	248	158	6.75	6.34	*6.55*	6.34	6.52	*6.43*
Wrap-up	2/2/96	311	221	n/a	n/a	n/a	n/a	n/a	n/a

Italic numbers are interpolated.

Stratmat Column Rinse Test - Dissolved Element Profiles - Static Stage

June 27, 1995 **Lab file I.[** 1321_058

Sample I.D.	Al mg/L	As mg/L	Ca mg/L	Cd mg/L	Cu mg/L	Fe mg/L	K mg/L	Mg mg/L	Mn mg/L	Na mg/L	Pb mg/L	S04 mg/L	Se mg/L	Zn mg/L	Fe+3 mg/L	Fe+2 mg/L
SC-1 top	0.37	< 0.25	11.45	< 0.03	< 0.03	< 0.03	< 5.00	1.43	0.27	3.85	4.58	46.88	< 0.50	2.89	< 0.025	< 0.025
SC-1 bot	0.43	< 0.25	11.30	< 0.03	< 0.03	< 0.03	< 5.00	1.40	0.26	3.38	4.23	45.39	< 0.50	2.86	< 0.025	< 0.025
SC-2 top	0.51	< 0.25	15.08	< 0.03	0.04	< 0.03	< 5.00	1.57	0.44	3.28	6.43	58.79	< 0.50	3.75	< 0.025	< 0.025
SC-2 bot	0.48	< 0.25	15.43	< 0.03	0.05	< 0.03	< 5.00	1.59	0.44	3.50	6.20	59.92	< 0.50	3.77	< 0.025	< 0.025

July 28, 1995 **Lab file I.[** 1321_063

Sample I.D.	Al mg/L	As mg/L	Ca mg/L	Cd mg/L	Cu mg/L	Fe mg/L	K mg/L	Mg mg/L	Mn mg/L	Na mg/L	Pb mg/L	S04 mg/L	Se mg/L	Zn mg/L	Fe+3 mg/L	Fe+2 mg/L
SC-1 top	0.81	< 0.25	13.16	< 0.03	0.18	0.04	< 5.00	1.85	0.56	2.66	5.85	57.69	< 0.50	3.71	< 0.025	< 0.025
SC-1 bot	0.93	< 0.25	13.18	< 0.03	0.19	< 0.03	< 5.00	1.80	0.54	2.95	5.99	57.47	< 0.50	3.70	< 0.025	< 0.025
SC-2 top	0.99	< 0.25	16.27	< 0.03	0.22	< 0.03	< 5.00	2.06	0.76	2.59	7.26	70.61	< 0.50	4.99	< 0.025	< 0.025
SC-2 bot	1.20	< 0.25	16.00	< 0.03	0.22	0.24	< 5.00	2.14	0.74	2.74	7.14	70.29	< 0.50	4.88	0.040	0.200

August 29, 1995 **Lab file I.[** 1321_067 (Re-analyzed data)

Sample I.D.	Al mg/L	As mg/L	Ca mg/L	Cd mg/L	Cu mg/L	Fe mg/L	K mg/L	Mg mg/L	Mn mg/L	Na mg/L	Pb mg/L	S04 mg/L	Se mg/L	Zn mg/L	Fe+3 mg/L	Fe+2 mg/L
SC-1 top	5.27	< 0.25	23.61	< 0.03	0.25	0.48	< 5.00	3.96	1.23	12.77	6.94	90.17	< 0.50	5.458	< 0.100	> 0.220
SC-1 bot	0.70	< 0.25	3.38	< 0.03	< 0.02	0.52	> 250.00	0.72	0.05	28.13	0.30	12.25	< 0.50	0.263	0.280	0.130
SC-2 top	6.55	< 0.25	25.14	< 0.03	0.27	0.52	< 5.00	4.34	1.35	15.50	7.10	92.49	< 0.50	5.703	< 0.100	> 0.010
SC-2 bot	1.15	< 0.25	11.88	< 0.03	0.16	0.79	< 5.00	2.61	0.49	6.53	4.68	53.34	< 0.50	2.802	0.540	0.120

Sep 29, 1995 **Lab file I.[** 1321_075

Sample I.D.	Al mg/L	As mg/L	Ca mg/L	Cd mg/L	Cu mg/L	Fe mg/L	K mg/L	Mg mg/L	Mn mg/L	Na mg/L	Pb mg/L	S04 mg/L	Se mg/L	Zn mg/L	Fe+3 mg/L	Fe+2 mg/L
SC-1 top	1.13	< 0.25	20.05	0.04	0.23	0.03	5.00	3.37	0.83	5.80	5.75	83.88	< 0.50	4.14	< 0.100	nd
SC-1 bot	1.11	< 0.25	19.34	0.03	0.21	0.08	5.00	3.25	0.79	6.06	5.95	82.20	< 0.50	3.98	< 0.100	nd
SC-2 top	1.66	< 0.25	19.56	0.03	0.24	0.04	5.43	3.69	1.04	6.09	6.46	92.61	< 0.50	5.74	< 0.100	nd
SC-2 bot	1.71	< 0.25	18.95	0.03	0.24	0.05	5.02	3.59	1.02	6.13	6.44	91.59	< 0.50	5.60	< 0.100	nd

Dec 1, 1995 **Lab file I.[** 1321_087

Sample I.D.	Al mg/L	As mg/L	Ca mg/L	Cd mg/L	Cu mg/L	Fe mg/L	K mg/L	Mg mg/L	Mn mg/L	Na mg/L	Pb mg/L	S04 mg/L	Se mg/L	Zn mg/L	Fe+3 mg/L	Fe+2 mg/L
SC-1 top	2.10	< 0.25	32.01	0.05	0.27	0.07	< 5.00	5.55	1.31	6.75	6.52	129.66	< 0.50	7.06	0.070	nd
SC-1 bot	1.96	< 0.25	31.87	0.04	0.25	< 0.02	< 5.00	5.53	1.27	6.34	6.33	129.27	< 0.50	7.10	< 0.020	nd
SC-2 top	2.82	< 0.25	28.14	< 0.02	0.26	0.05	< 5.00	6.08	1.59	6.34	6.85	131.19	< 0.50	8.74	0.050	nd
SC-2 bot	2.79	< 0.25	28.12	< 0.02	0.26	< 0.02	< 5.00	6.09	1.59	6.52	6.70	130.14	< 0.50	8.70	< 0.020	nd

Decommissioning the column tests, Feb. 2, 1996

Column	Final H2O height (cm)	Drained vol. (L)	pH	Conduct. (us/cm)	Acidity mg/L
SC-1	45	20	4.63	572	114
SC-2	47	20	4.52	520	116