CN 040

1978 DNR/AMAX FIELD LEACHING AND RECLAMATION PROGRAM

Progress Report on the Leaching Study

January 29, 1979

Minnesota Department of Natural Resources
Division of Minerals
St. Paul, Minnesota

LAPAKKO

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FOREWORD

This progress report describes the leaching portion of the joint DNR/Amax leaching and reclamation study. It contains the raw water quality data collected during 1978. Some analysis of the data is presented, but more is needed and planned. Additional literature work is also planned. Supporting references will be cited in future reports and the discussion section will be expanded. Analysis plans are discussed in this report and additional results will be presented as they are completed.

This document is preliminary but it does serve as a starting point for continued discussion of the leaching program. Comments would be appreciated.

ABSTRACT

Runoff from lean ore and waste rock Duluth gabbro stockpiles may pose significant environmental problems. Water quality samples collected from gabbro stockpiles have contained elevated concentrations of trace metals (copper, nickel, cobalt and zinc.) Observed metal concentrations in leachate samples range from 10 to 10,000 times the natural background concentrations of streams in the area.

In 1978, a joint DNR/Amax program was established to study the leaching and reclamation of stockpiled gabbro. Six test piles (FL 1-6) were constructed in 1977. In 1978, two were covered with glacial till (piles 3,5) and one with topsoil (pile 2). These were then fertilized and planted.

Intensive sampling was conducted on FL-4 during two rain events, to determine the fluctuation in runoff concentration over the storm. Copper concentration remained essentially constant while nickel and sulfate concentration varied considerably. Mass release followed the runoff hydrograph, with the maximum release occuring at peak discharge.

Preliminary results indicate that there is a difference in the amount of runoff from each pile. Piles 5 and 6 yield about 65% runoff; piles 1,3 and 4, 50-55%; and pile 2, 35%. It appears that the glacial till treatment did little to control runoff, while the topsoil treatment reduced flow. Vegetation was sparse on the till pile but good growth was observed on the topsoil pile.

Both flow and concentration data indicate that pile 5 and 6 are different from piles 1 - 4. Pile 5 has produced acid leachate and the pH in pile 6 began to decline at the end of the field season. Metal concentrations in samples from piles 5 and 6 are one to two orders of magnitude higher than in samples from piles 1 - 4; the maximum nickel concentration observed was at pile 5, 83 mg/l. The median concentration values for pH, nickel sulfate are comparable for piles 1 - 4. Copper concentrations in samples collected from piles 2 and 3 increased in 1978. This increase appears to

be the result of increased copper mobility, rather than increased sulfide dissolution. Organic compounds removed from the overlying soil cover could produce a increase in copper mobility.

OVERVIEW

In 1974, Amax Exploration Inc. reached an agreement with Bear Creek Mining Company, and assumed Bear Creek's leases for properties located in T 60N R 12W, about 4 miles S.E. of Babbitt, Minnesota. As a significant proportion of the leases involved state land and state minerals, Amax requested permission from the State to construct an exploratory shaft.

In 1974, very little information existed on the potential environmental problems that might be associated with developing Minnesota's copper-nickel resources. The state and Amax agreed that the Amax project could serve as a pilot study. A comprehensive monitoring network was developed and an agreement was reached to conduct leaching tests on stockpiled materials.

In 1977, Amax constructed six (6) test piles containing lean ore material. The mass, grade, and completion date of each pile is given in Table I. Each pile was placed on an impervious liner (30 mil reinforced Hypalon) and all runoff is collected via a six (6) inch perforated drain line. The details of pile construction and pile layout are shown in Figures 1 and 2.

In 1977, Water quality data was collected periodically from each pile and has been present in a report "Field Leaching Summary Report 1977", prepared by Amax Environmental Services, Inc. May, 1978.

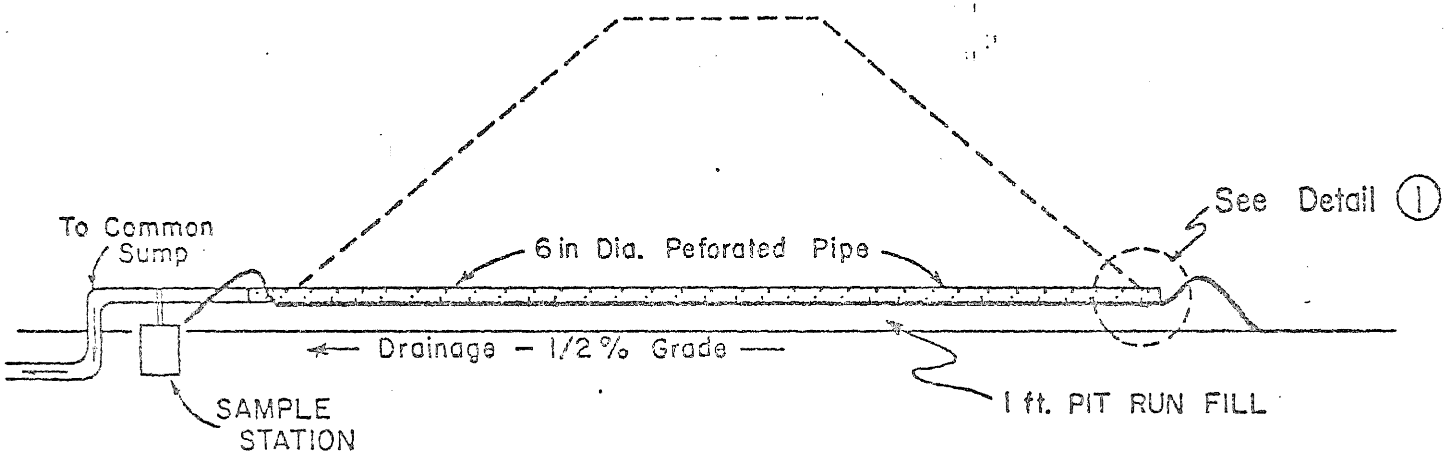
In 1978, a joint DNR/Amax program was initiated to study the leaching and revegetation of the lean ore test piles. This is a unique project not only from a scientific viewpoint but also from the stand point of industry-government cooperation. A concerted effort is being made by both the state and the company to identify significant environmental problems and to study methods of mitigation. In the joint program, Amax is responsible for the revegetation program and the DNR is responsible for the leaching aspects of the study. This is a preliminary progress

TABLE 1. COMPONENTS OF FIELD LEACHING PILES

	Pile No.	Size (Tons)	Completion Date	Average Mineral Content % Cu	% Ni	% S	
	1	1766	April 20, 1977	.33-.35	.075	0.6	NONE
	2	1766	April 20, 1977	.33-.35	.075	0.6	TILL & GRAVEL
	3	1766	April 20, 1977	.33-.35	.075	0.6	TILL & GRAVEL
	4	1765	April 20, 1977	.33-.35	.075	0.6	NONE
	5	1951	Sept. 10, 1977	0.29	0.09	1.45	TILL & GRAVEL
	6	1672	Sept. 30, 1977	0.38	0.09	0.83	NONE
otal	Piles 1-6	10,686		0.33	0.08	0.79	

(ton is short ton = 2000 lbs)

Fi e I T Pi
Con uction



SECTION B-B
1" = 10'

DETAIL 1
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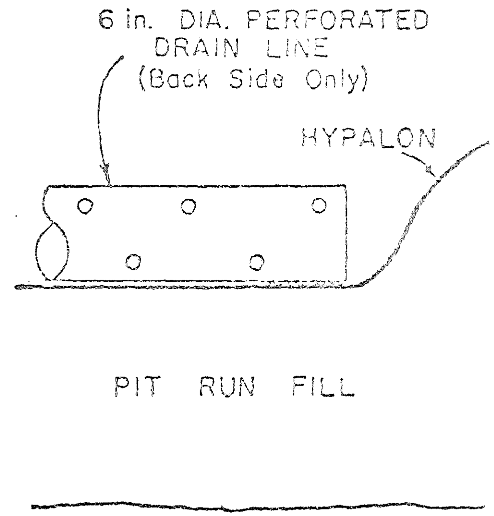

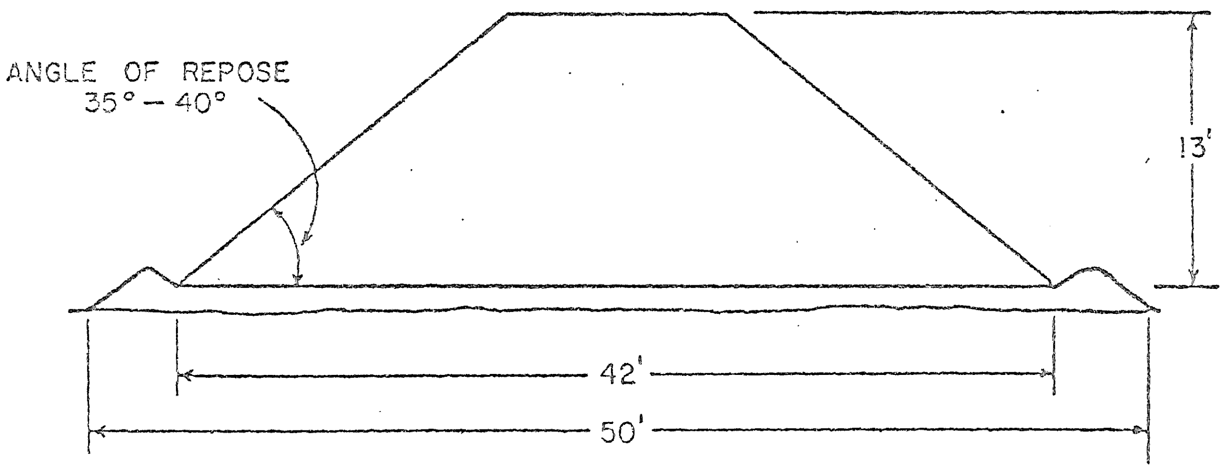

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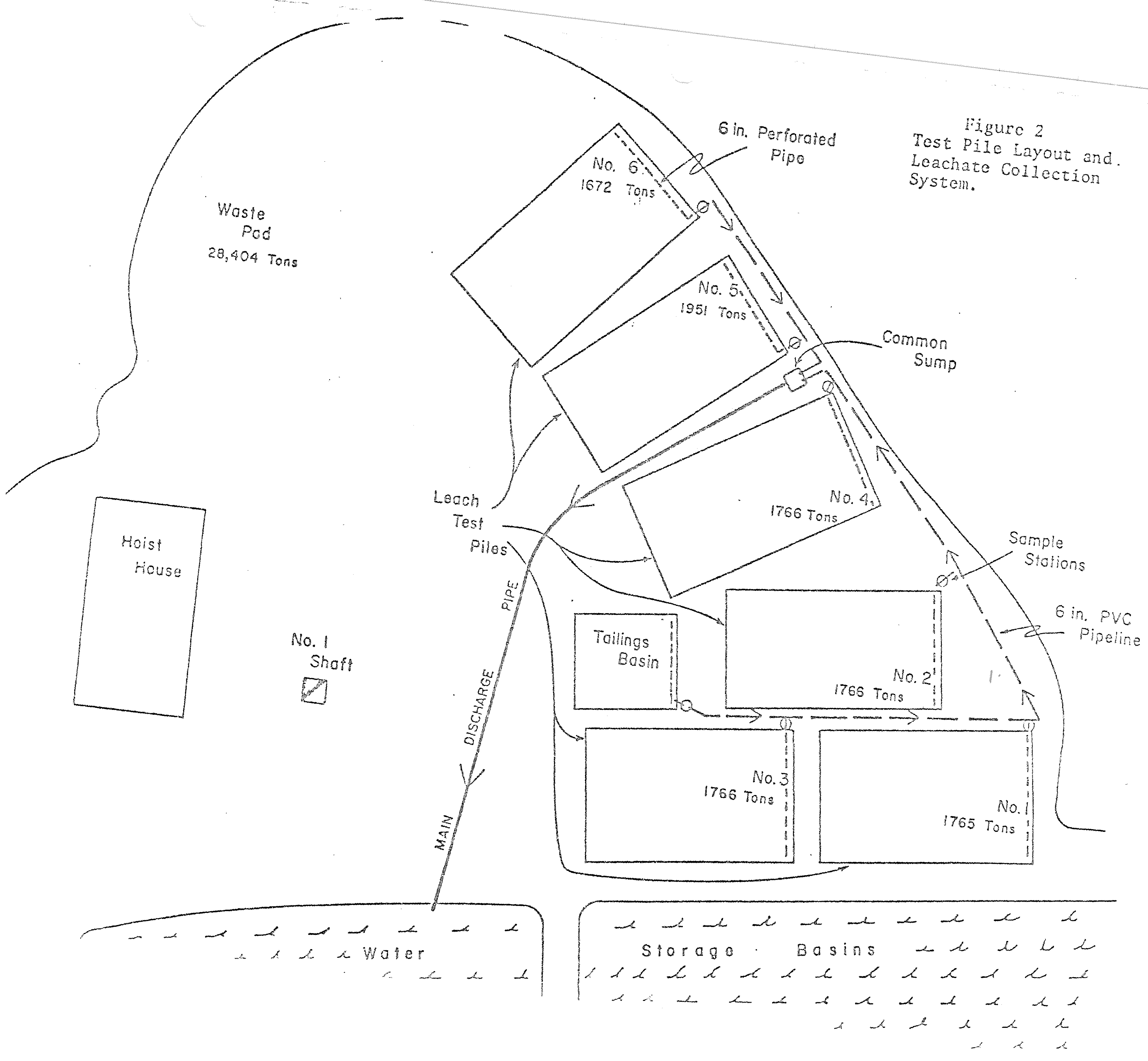


Figure 2
Test Pile Layout and Leachate Collection System.

report on the leaching program. Water quality data, flow data and rainfall data that have been collected are presented. Some preliminary discussion of the results is provided. Data analysis is continuing and additional results will be included in future reports.

INTRODUCTION

Historically one of the major problems associated with the mining of metal sulfide deposits has been the release of toxic trace metals through the leaching of mining wastes (Hawley, 1972, Eisenreich et al, 1976). In most documented cases of leaching problems, the leachate is acidic, often with pH values as low as 2 to 3.

Most of the field studies reported in the literature involved materials that contained a high concentration of sulfide minerals. Hawley reports that acid leachate has been associated with materials that contain 2.5 to 70 percent sulfide. The Duluth gabbro is a low grade disseminated deposit. "Model" lean ore and waste rock concentrations developed by the Regional Copper Nickel Study (R. Stevenson, personal communication) range from .655 percent sulfur for lean ore to .207 for waste rock. Even though the gabbro is in general a low grade deposit, early water quality samples (1974) collected near stockpiled gabbro at Erie Mining Company's Dunka Pit, near Babbit, MN, indicated elevated levels of trace metals. Studies conducted by the Regional Copper Nickel Study (Level II leaching report, soon to be released) have confirmed the findings of the early samples. Metal concentrations in leachate samples are 10 to 10,000 times the natural background concentrations.

Lean ore and waste rock stockpiles, unless controlled, may pose significant environmental problems. Not only is there evidence that stockpile runoff will contain elevated metal concentrations, but the mass of material that will be stockpiled is extremely large. For its open pit prospect, Amax has projected a stockpile area of 3400 acres, 500-600 feet high.

The Duluth gabbro complex contains a large percentage of silicate minerals. As part of the Regional Copper-Nickel Study, samples of the gabbro were collected across the contact from Hoyt Lakes to Ely (more detail will be given in the Regional Copper Nickel report on geology and mineralogy). The mineralogy of these samples was determined and a complete chemical analysis was made on each sample. Five samples from the Amax area were analyzed, one of which was selected from leach pile FL-1. The mineralogical composition is shown in Table II and the chemical composition in Table III. A description of the mineral forms is given in Table IV. Over ninety percent of the rock is composed of silicate minerals, the three major groups being plagioclase, olivine, and pyroxene. The sulfides make up a very small percentage of the rock, approximately 0.655 percent.

Generally, most of the sulfides found in mining wastes are unwanted iron sulfides, either in the form of pyrite or pyrrhotite. The percent of iron sulfide in the test pile material is quite low (Table II) and this is generally true for the disseminated material across the region (R. Stevenson, personal communication). Only in pockets of massive or semi-massive ore are high concentrations of iron sulfides found. Tables V and VI include the analysis of a semi-massive sample collected from the Amax test shaft. This sample contained 10.5 percent sulfur, most of which was associated with the pyrrhotite which comprised 12.8% of the sample.

Table II MINERALOGICAL COMPOSITION OF FL-1 (volume %)

Plagioclase	59.112
Sericite	2.176
Olivine	10.510
Clinopyroxene	11.185
Orthopyroxene	3.716
Monocrystalline amphibole	3.567
Fibrous amphibole	0.288
Chlorite	1.136
Serpentine	0.257
Iddingsite	0.075
Talc	-
Biotite	1.738
Smectite	0.021
Celadonite	-
Opaques*	5.098
Chalcopyrite-cubanite	0.769
Pentlandite	0.037
Pyrrhotite	0.844
Ilmenite-magnetite	3.447
Graphite	-
Spinel	-
Myrmekite	-
Apatite	0.085
Epidote	0.953
Allanite	-
Calcite	0.056
Quartz	-
Cordierite	0.027

* The value shown for opaques is the sum of the five following values

Table III CHEMICAL COMPOSITION OF FL-1

Element			Units
Si (SiO_2)	22.80	(48.81)	Pct
Al (Al_2O_3)	8.98	(16.96)	Pct
Fe (Fe(O))	9.22	(11.86)	Pct
Mg (MgO)	4.31	(7.15)	Pct
Ca (CaO)	5.55	(7.76)	Pct
Na (Na_2O)	2.00	(2.70)	Pct
K (K_2O)	.32	(.39)	Pct
Ti (TiO_2)	1.41	(2.35)	Pct
P (P_2O_5)	.02	(.05)	Pct
Mn (MnO)	.12	(.16)	Pct
~~Cr (Cr_2O_3)~~	.03	(.05)	Pct
B	662.00		PPM
Ba	1173.00		PPM
Be	1.00		PPM
Sr	279.00		PPM
V	276.50		PPM
Th	6.40		PPM
Zr	80.00		PPM
S	.655		Pct
Cu	.306		Pct
Ni	.073		Pct
Fe (S)	.696		Pct
Co	.009		Pct
Zn	157.00		PPM
Pb	0		PPM
Ag	1.35		PPM
As	0		PPM
Hg	<1.00		PPB

Table III (cont'd) CHEMICAL COMPOSITION OF FL-1

Element		Units
Mo	.50	PPM
Cd	0	PPM

Pct = Weight percent
PPM = parts per million by weight
PPB = parts per billion by weight

Table IV. Mineral Names, Abbreviations and Formulas

AG	Plagioclase	$Na\ Al\ Si_3\ O_8 - Ca\ Al_2\ Si_2\ O_8$	a feldspar
RCT	Sericite	$K_2\ Al_4\ Si_6\ Al_2\ O_{22}\ (OH, F)_4$	a mica, alters from feldspar
OL	Olivine	$(Fe, Mg)\ SiO_4$	Fe-Mg silicate
CPX	Clinopyroxene	$Ca\ (Fe, Mg)\ Si_2\ O_6$	a pyroxene, Fe-Mg silicate
[illegible]	Orthopyroxene	$(Fe, Mg)_2\ Si_2\ O_6$	a pyroxene, Fe-Mg silicate
MP	Monocrystalline amphibole	$(Na,K)_{0-1}\ (Ca, Mg, Fe^{+2}, Fe^{+3}, Al)_7\ (Si_{6-8}\ Al_{2-0})\ O_{22}\ (OH, F, Cl)_2$	amphibole with non-acicular morphology
BAMP	Fibrous Amphibole	$(Na,K)_{0-1}\ (Ca, Mg, Fe^{+2}, Fe^{+3}, Al)_7\ (Si_{6-8}\ Al_{2-0})O_{22}\ (OH, F, Cl)_2$	amphibole with fibrous or acicular morphology
HLRT	Chlorite	$(Mg, Fe, Al)_{12}\ (Si, Al)_8\ O_{22}\ (OH)_{16}$	alters from Fe-Mg silicates
ERPN	Serpentine	$Mg_3\ Si_2\ O_5\ (OH)_4$	alters from Fe-Mg silicates
DNGT	Iddingsite	Serpentine + iron oxide phase	alters from olivine
TALC	Talc	$Mg_6\ Si_8\ O_{20}\ (OH)_4$	alters from Fe-Mg silicates
IOT	Biotite	$K_2\ (Mg, Fe^{+2})_{6-4}\ (Fe^{+3}, Al, Ti)_{0-2}\ (Si_{6-5}\ Al_{-3})\ O_{20}(OH, F)_4$	a mica
MCTT	Smectite	$(\frac{1}{2}\ Ca, Na)_{0.7}\ (Al, Mg, Fe)_4\ (Si, Al)_8\ O_{20}\ (OH)_4 \cdot nH_2O$	a clay, alters from feldspar
LDNT	Celadonite	$K\ Mg\ Fe^{+3}\ Si_4\ O_{10}\ (OH)_2$	a mica, similar to glauconite
PQ	Opaque minerals, sum of following seven minerals*		
P-CB	*Chalcopyrite *Cubanite	$Cu\ Fe\ S$ $Cu\ Fe_2\ S_3$	undifferentiated
N	*Pentlandite	$(Fe, Ni)_9\ S_8$	
	*Pyrrhotite	$Fe_7\ S_8 - Fe\ S$	
ETIO	*Ilmenite	$Fe\ Ti\ O_3$	

	*Magnetite	$Fe_3\ O_4$	contains appreciable titanium (20 wt%)
.RPHT	*Graphite	C	present as flakes
?NL	Spinel	$Mg\ Al_2\ O_4$	
MYRM	Myrmekitic intergrowths, generally between plagioclase and olivine		
APAT	Apatite	$Ca_5\ (PO_4)_3\ (OH, F, Cl)$	
.?I	Epidote	$Ca\ Fe^{+3}\ Al_2\ Si_3\ O_{12}\ (OH)$	(includes zeolites and prehnite ($Ca_2\ Al\ Al\ Si_3\ O_{10}\ (OH)$
ALNT	Allanite	$(Ca, Ce)_2\ (Fe^{+2}\ Fe^{+3}\ Al_2\ Si_3\ O_{12}\ :OH$	borders radiating epidote
CAL	Calcite	$Ca\ CO_3$	
TZ	Quartz	$Si\ O_2$	
CORD	Cordierite	$Al_3\ (Mg, Fe^{+2})_2\ Si_5\ Al\ O_{18}$	associated with hornfels

rom R. Stevenson, Regional Copper-Nickel Study

Table V MINERALOGICAL COMPOSITION OF SEMI-MASSIVE, MINERALIZED ROCK SAMPLE (volume %)

Plagioclase	47.885
Sericite	0.091
Olivine	1.513
Clinopyroxene	2.656
Orthopyroxene	18.472
Monocrystalline amphipole	0.025
Fibrous amphibole	0.024
Chlorite	0.145
Serpentine	-
Iddingsite	-
Talc	-
Biotite	4.475
Smectite	-
Celadonite	-
Opaques*	19.239
Chalcopyrite-cubanite	3.231
Pentlandite	0.161
Pyrrhotite	12.816
Ilemnite-magnetite	2.564
Graphite	0.467
Spinel	-
Myrmekite	-
Apatite	0.118
Epidote	-
Allanite	-
Calcite	-
Quartz	0.037
Cordierite	5.350

* The value shown for opaques is the sum of the five following values

Table VI CHEMICAL COMPOSITION OF SEMI-MASSIVE, MINERALIZED ROCK SAMPLE

Element			Units
Si (SiO_2)	18.15	(38.85)	Pct
Al (Al_2O_3)	6.43	(12.15)	Pct
Fe (Fe(O))	7.71	(9.92)	Pct
Mg (MgO)	2.69	(4.46)	Pct
Ca (CaO)	3.44	(4.81)	Pct
Na (Na_2O)	1.18	(1.59)	Pct
K (K_2O)	.73	(.88)	Pct
Ti (TiO_2)	.65	(1.08)	Pct
P (P_2O_5)	.03	(.07)	Pct
Mn (MnO)	.11	(.14)	Pct
Cr (Cr_2O_3)	.04	(.06)	Pct
B	428.00		PPM
Ba	310.00		PPM
Be	1.20		PPM
Sr	151.50		PPM
V	213.00		PPM
Th	0		PPM
Zr	59.50		PPM
S	10.500		Pct
Cu	1.155		Pct
Ni	.418		Pct
Fe (S)	13.885		Pct
Co	.036		Pct
Zn	185.00		PPM
Pb	0		PPM
Ag	0		PPM
As	0		PPM
Hg	<1.00		PPB

Table VI (cont'd) CHEMICAL COMPOSITION OF SEMI-MASSIVE, MINERALIZED ROCK SAMPLE

Element		Units
Mo	5.50	PPM
Cd	0	PPM

Pct = Weight percent
PPM = parts per million by weight
PPB = parts per billion by weight

1978 FIELD PROGRAM

The overall goals of the joint leaching/reclamation program are measurement of the release of trace metals, sulfate, nutrients and chloride from the lean ore test piles and evaluation of the effect of various reclamation procedures on that release. To accomplish these goals the field program was separated into two phases.

The first phase was a characterization phase. Data was collected on the rock characteristics, top dressing characteristics (soil and fertilizer) and rainfall. In addition, the variability of leachate composition during a storm event was determined.

Phase II was a monitoring phase, in which data were collected to determine the total mass released from each pile. The total mass release will be used to evaluate the effectiveness of different reclamation procedures.

METHODS

As this was the first year of the program, a large effort was required to initiate the program, develop methodology, and provide instrumentation for the leach piles. The details of the problems encountered and the attempts to overcome them are given in Appendix I.

The critical parameters that had to be measured were 1-rainfall; the amount, duration, time of the event, and pH, 2-the discharge from individual piles and 3-a concentration representative of the runoff.

Rainfall

Rainfall is recorded by a standard rain gauge (Science Associates, Inc., NWS Spec. 450.230) and a recording rain gauge (Science Associates, Inc., NWS Spec. 450.220). The standard gauge is more accurate (± 0.01 inches) and is used to determine the amount of rainfall while the recording gauge gives the duration and time of the rain event.

To collect samples for rainfall pH, a polyethylene funnel was attached to the outside of the weather instrument shelter. This funnel was connected by tygon tubing to a teflon bottle inside the shelter. The pH was recorded as soon as possible after rainfall ceased.

Flow

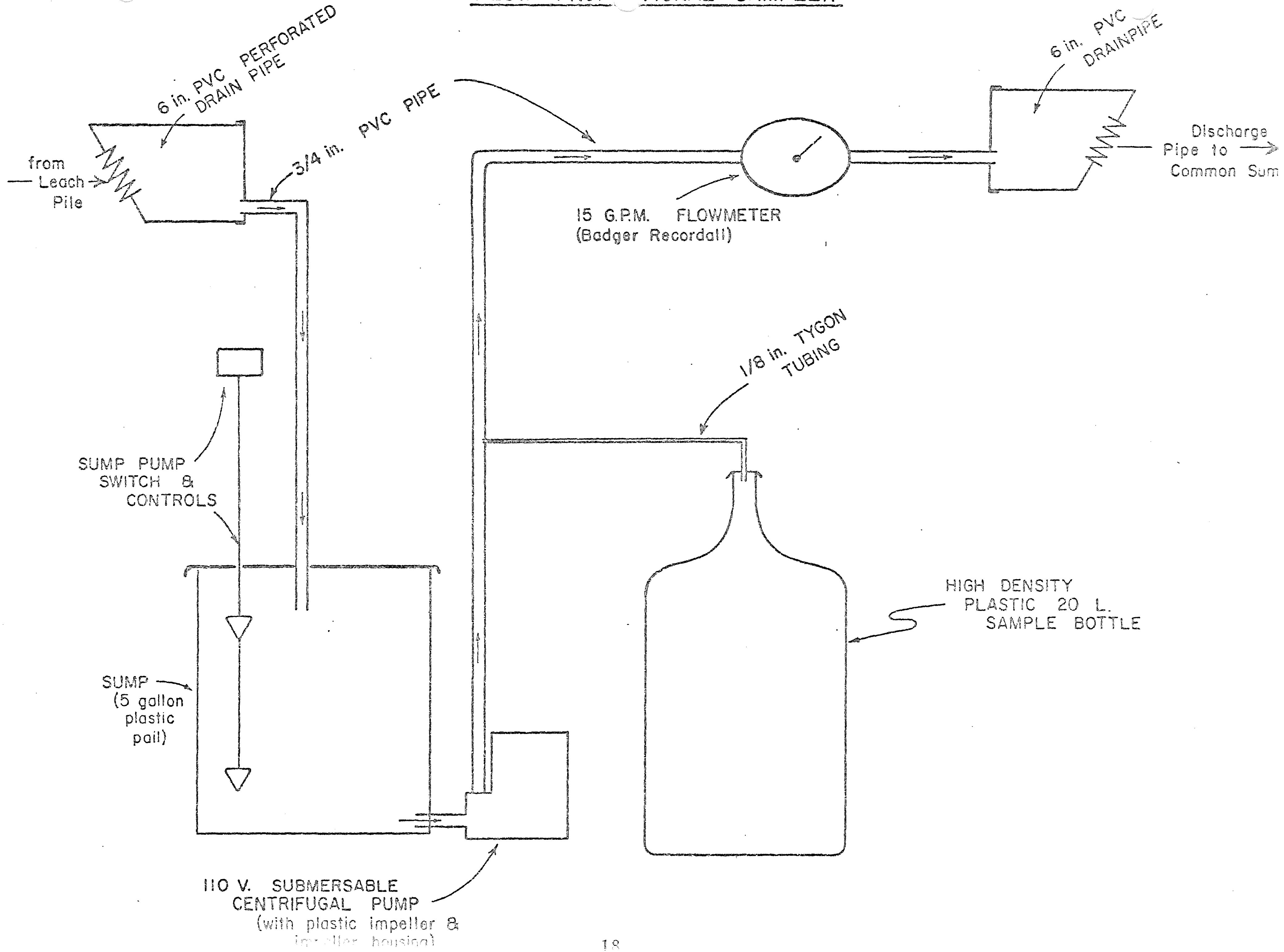
Daily volumetric flow measurements were made on each pile. Each pile is equipped with a flow meter (Badger Recordall Model 15). In July, fine mesh screens were installed upstream of the meters; and the slope was adjusted to increase the pressure drop through the meter. After these changes were made the meters worked satisfactorily at high flow, but failed to operate at low flow. Daily discharge from each pile was estimated using a combination of meter readings and volumetric measurements. Details and sample calculations are shown in Appendix II.

Water Quality Samples

The development of a satisfactory sampling device required a substantial amount of trial and error. As a result, the samples collected in 1978 are a mixture of composite and grab samples. A flow proportional sampler (Figure 3) was developed and tested on pile FL 4 and worked satisfactorily. This system provides a sample over an event that is weighted by flow. Concentrations have been shown to vary over a storm event (see Results-Phase I). In order to get an accurate measure of the total mass released from a pile, either a series of samples must be collected during each event or one flow weighted sample must be collected. The basic concept is that if 50% of the flow occurs in a 4 hour period then 50% of the volume of the sample should be collected in this period.

FIGURE

FLOW PROPORTIONAL SAMPLER



In our system, each time the pump discharges an aliquot of constant volume is placed in the sampling container. The higher the flow, the more often the pump discharges and the greater the volume of sample collected. This system has now been installed on all piles. (For more details refer to Appendix I).

RESULTS - PHASE I

Characterization

The objective of the characterization work is to provide information on all the test materials. Characterization data for the stockpiles are given in Table VII. Particle size distribution and surface area are estimates based on work done by the Regional Copper Nickel Study (Details of the calculation will be presented in the Level II Leaching Report). Piles 5 and 6 contain rock from the drifts which contain a higher degree of mineralization than the rock in the other four piles.

Additional mineralogical, chemical, and surface area information may be needed to clarify the differences between piles 1,2,3,4, and 5,6.

Top Dressing Characteristics

On May 11, test piles FL 3 & FL 5 were covered with glacial till and FL 2 with top soil. The volume and depth of soil cover for each pile is given in Table VIII. Composite samples of each soil type were collected. Each sample will be thoroughly mixed and split to obtain a representative sample. Particle size and total and extractable metal analysis will be performed by the Department of Natural Resources Laboratory in Hibbing. Soil classification, pH, and macro and micro nutrient analyses will be performed by the University of Minnesota Research Analytical Laboratory in St. Paul.

Fertilizer

Fertilizer was applied to test piles 2,3, and 5 on June 22. Sixteen kilograms (35.2 lbs) of a fertilizer with a guaranteed analysis of 10% NH_4NO_3, 20% P_2O_5, and 20% K_2O were applied to each pile. A composite sample of fertilizer was collected and will be analyzed for trace metal content.

TABLE VII. CHARACTERIZATION DATA FOR STOCKPILES

Pile	1	2	3	4	5	6
omposition						
%S	.6	.6	.6	.6	1.45	.83
%Cu	.33-.35	.33-.35	.33-.35	.33-.35	.29	.38
%Ni	.075	.075	.075	.075	.09	.09
ass (tons)	1766	1766	1766	1765	1951	1672
ollecting Ar (ft.^{2})	3173	3678	3178	3524	3648	3444
Surface rea stimate) m^2/ton	90-820	90-820	90-820	90-820	90-820	90-820
ate onstructed	(- - April 20 1977 - - - - - - - - - - - - -)				September 10 1977	September 3 1977
ock source	shaft	shaft	shaft	shaft	drift	drift
reatment	none	covered with topsoil and revegetated	covered with glacial till & revegetated	none	covered with glacial till & revegetated	none

* estimate based on an assumed particle size distribution (Detail of the calculation will be found in the Regional Copper Nickel Study Level II leaching report. This will be available soon.)

TABLE VIII. SOIL DEPTH AND FERTILIZER ADDITION

[illegible]	Mean depth of soil cover (inches)	Mean width of pile (ft)	Length of pile (ft)	Volume of soil cover (ft^3)	(yds^3)	(m^3)	NH_4 added (g)	NO_3 added (g)	P added (g)	K added (g)
2	7.14	56	92	3065	114	87	360	1239	1397	1582
[illegible]	11.3	51	88	4219	156	119	360	1239	1397	1582
5	10.9	56	90	4578	170	130	360	1239	1397	1582

Rainfall

During 1977-78 monthly bulk precipatation samples were collected by the Regional Copper Nickel Study. Bulk samples collect both wet and dry fall, so concentrations may tend to be slightly higher than if only rainfall was sampled. Table IX gives the regional average which was based on data collected at four sites across the copper-nickel study area. More information will be available in the Regional Copper Nickel Study Technical Report on air/water interactions. Concentrations of all constituents are generally quite low.

In 1978, rainfall samples were collected at Amax and pH was analyzed from fourteen separate events. The data is given in Table X and summarized in Figure 4. In general, the rain tends to be acidic. Recent studies conducted in the area have indicated that there is already a trend for increasing rainfall acidity (D. Thingvold, personal communication). The exact effect this increasing acidity will have on the release from stockpiled materials is not known, but if the pH in the pile is lowered more metals may be released.

Variability of Runoff Concentration Over a Storm Event

Intensive sampling was conducted on FL4 for two storm events (0.35 inches on June 23 and 1.53 inches on July 7). The complete set of data for these events is in Appendix III. Figure 5 and 6 illustrate the variation in concentrations of copper, nickel, and sulfate during the runoff. On June 23, there was no flow prior to the storm. Nickel and sulfate concentrations rose rapidly, and then leveled off, while copper concentrations remained essentially constant throughout the runoff period. On July 7, there was a small base flow prior to the rain event. Nickel and sulfate concentrations were high in the base flow, decreased rapidly with the initial rise in flow, increased slightly during the peak runoff, decreased on falling limb of the hydrograph, and then rose gradually as flow diminished.

TABLE IX. REGIONAL RAINFALL AVERAGES

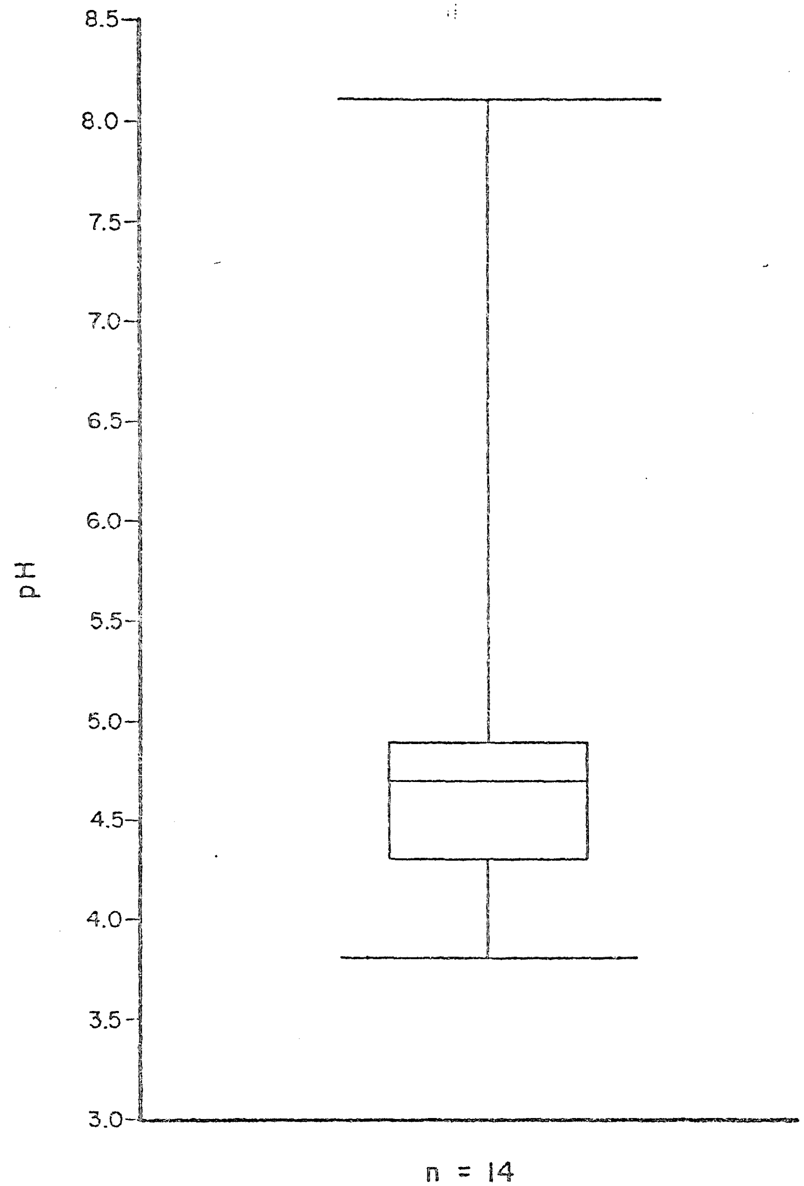
Parameter	
Specific Conductance, 25°C (umhos)	27
Suspended solids	12
Total dissolved solids, 180°C	10
NO_2,NO_3	.27
Total Phosphorus	.04
Total organic Carbon	4.1
Alkalinity, $CaCO_3$	< 10
Cl	<1.9
Ca	1.6
Mg	<1.6
Na	<.5
K (mg/l)	<.5
F (mg/l)	<.1
Ni (ug/l)	2
Cd (ug/l)	.45
Zn (ug/l)	8.1
Pb (ug/l)	10.9
Al (ug/l)	120
Fe (ug/l)	(~154)
As (ug/l)	<1.6
Cu (ug/l)	1.5

All concentrations in mg/l except as noted.

TABLE X
Rain pH

Date 1978	pH	Specific Conductance (umhos)	Remarks
			[H+] x 10^6
6/07	5.2		6.31
6/23	6.3		0.501
7/02	4.9		pH taken 7/5, 1030 12.6
7/07	4.7		20.0
7/18	4.7		20.0
7/22	4.6	20	pH taken 7/24, 1100 25.1
7/24	4.9	15	12.6
7/28	8.1	18	7.94x10^-3
8/15	4.3		50.1
8/16	4.2	1.5	63.1
8/18	3.8	14	158
9/11	4.3		50.1
9/12	4.0		100
9/14	4.8		pH taken 9/15, 1610 15.8
n=14			
$\bar{x}$	4.4		38.2

Figure 4
RAINFALL pH, AMAX 1978



LEACH PILE 4

Concentration vs Time

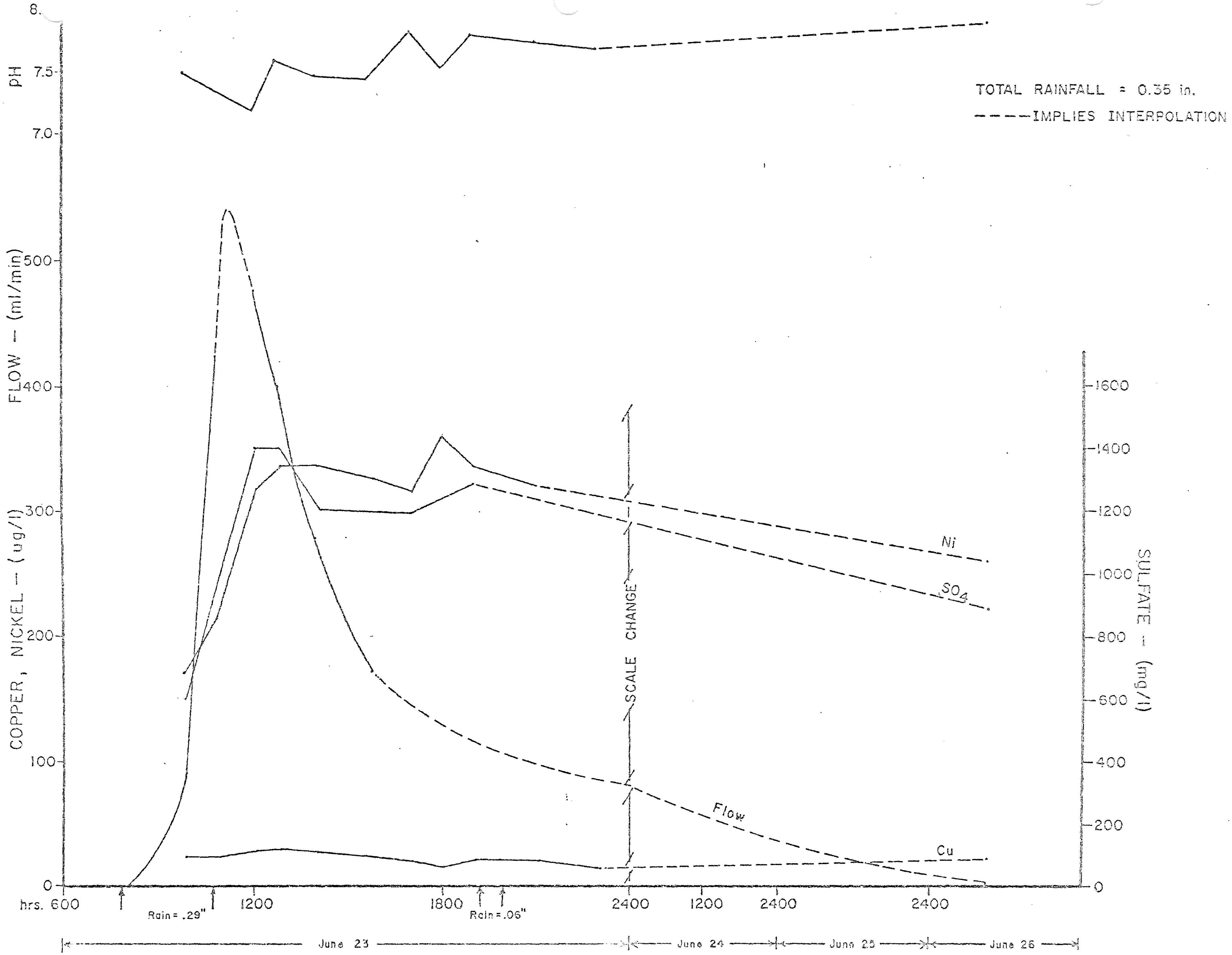
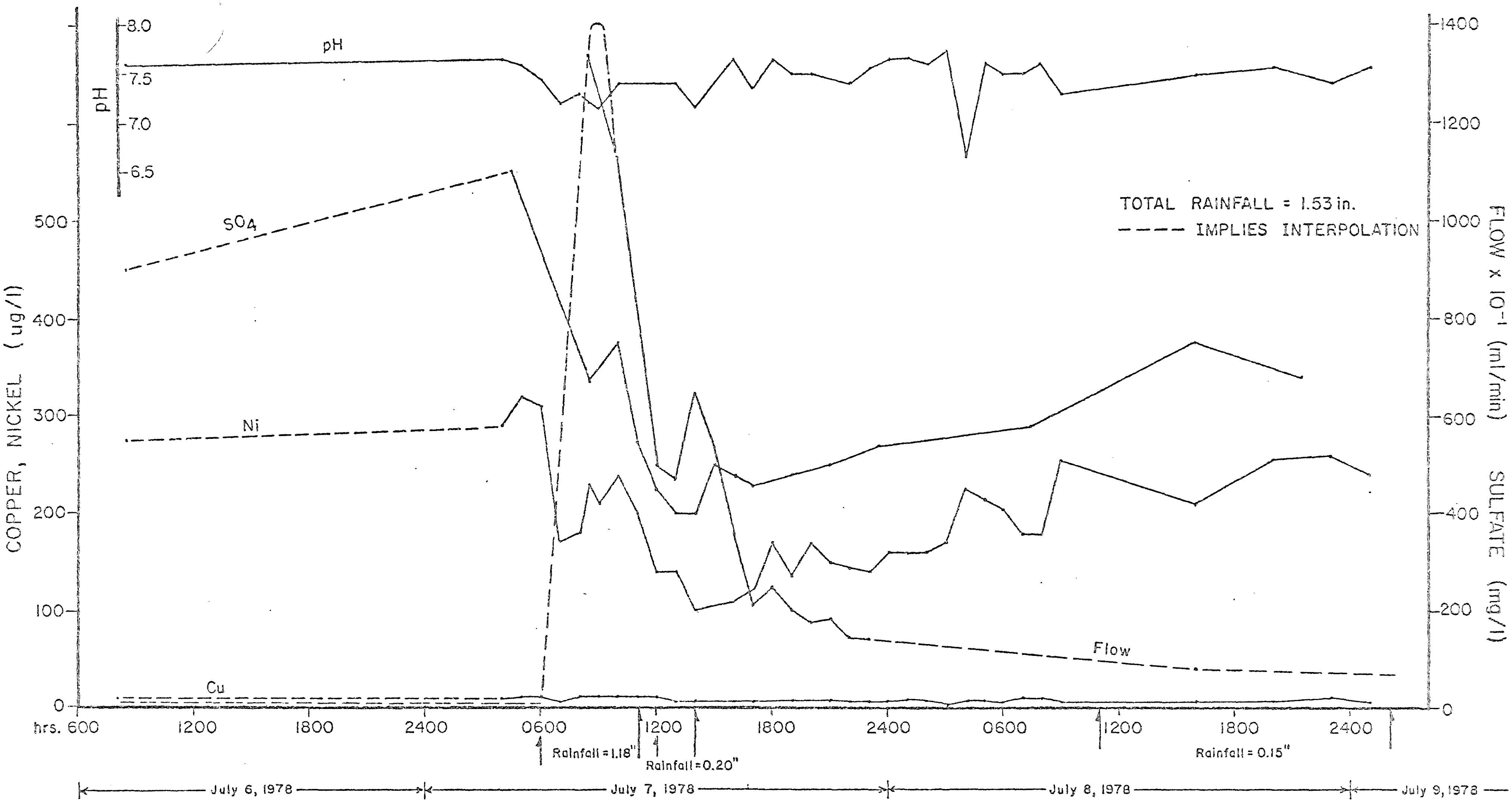


Figure 6

INTENSIVE SAMPLING OF RAIN EVENT OF JULY 7 and JULY 8, 1978

LEACH PILE 4

Concentration vs Time



Copper concentrations essentially remained constant throughout the event.

DISCUSSION - PHASE I

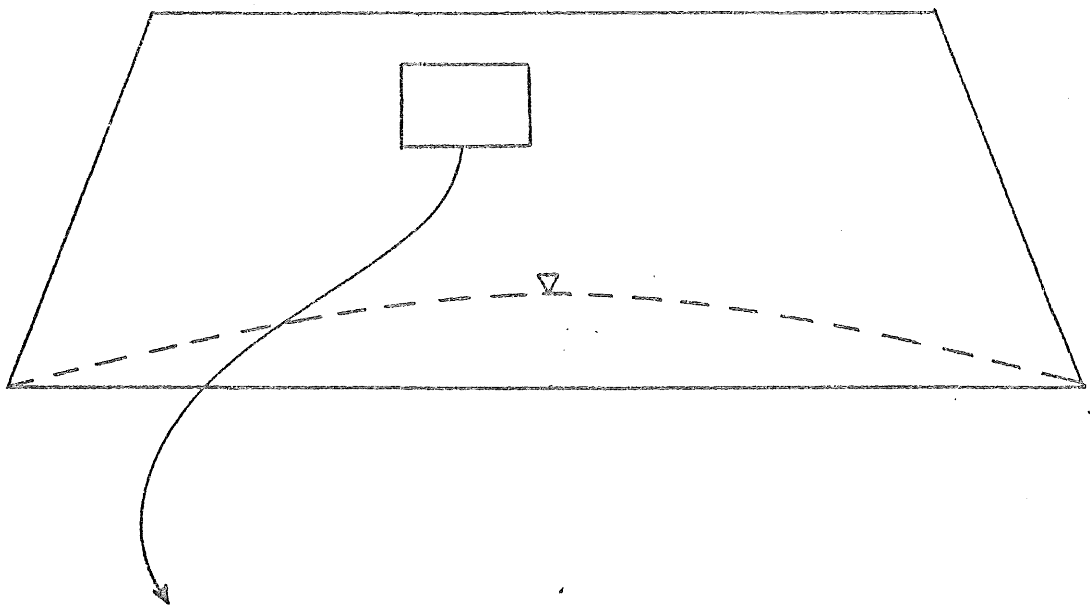
Leaching, as the term is generally used, is the net transfer of material from the solid phase to an environmentally observed aqueous phase. The net transfer is the complex result of a series of chemical and physical reactions that involve mineral dissolution and the transport of the dissolution products out of the stockpile. A schematic of the processes involved in the net transfer of material from the stockpile to an observation point is shown in Figure 7. A detailed discussion of each type of process will not be presented here, but will be provided in later reports as well as in the Regional Copper Nickel level II leaching report, and the technical report on the laboratory leaching experiments conducted at the University of Minnesota. Preliminary discussion can be found in earlier progress reports, (Eisenreich et al, 1977).

The two major considerations in leaching are 1) the reactivity of the specific mineral phase and 2) the mobility of the resulting chemical species; e.g. copper, nickel or sulfate. The reactivity of the mineral phase is a measure of how easily the mineral dissolves. Mobility is a measure of the tendency of an ion to remain in solution. It is the result of many competing reactions, and it is a function of the aqueous environment. Under acid pH conditions, mobility of most trace metals (e.g. copper) will be very high, while at neutral or basic pH, mobility may be low.

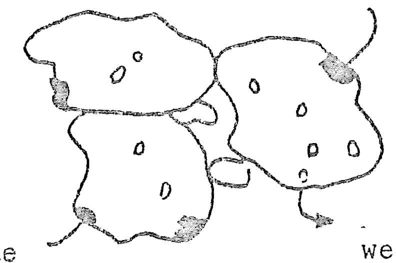
Although sulfate does undergo reactions in solution, under oxidizing conditions it is generally treated as a mobile ion. Therefore, it can be used as an indication of the dissolution of the metal sulfides in the pile. If it is assumed that the only source of the trace metals is the sulfide minerals and that the sulfate release is a measure of the total rate of sulfide mineral dissolution, then the percent of each metal that is transported out of the pile can be calculated. This

Figure 7

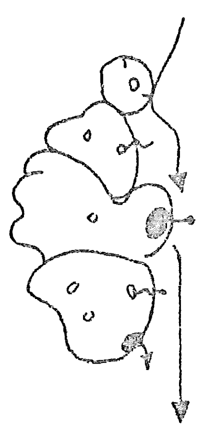
Schematic of Stockpile Leaching Process



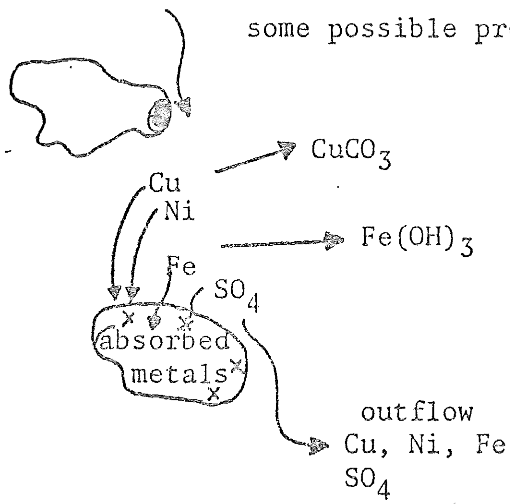
Step 1: Reaction: sulfide minerals oxidize or dissolve on surface



Step 2: Transport: A. reaction products are removed by percolating water



B. Some of the metals are readsorbed onto the silicate mineral surface or form precipitates.



(In saturated zone the processes are essentially the same, although water is always available to transport the reaction products.)

The outflow from the stockpile is composed of the weathering products of 1) the sulfide minerals (the prime source of the trace metals; copper, nickel, zinc, cobalt; and sulfate) 2) the silicate minerals (major contributors of calcium, magnesium) and the residual chemicals that were on the rocks when they were stockpiled (primary source of nitrate).

is illustrated in Table XI using the 1977 data for leach pile FL 1. The details of the calculation are given in Appendix IV. The metals exhibit very low mobility. Under present environmental conditions, only a very small percentage of each metal that is released from the mineral phase is transported from the stockpile.

The mobility factor is important in discussing the different behavior of the release of copper and nickel from the test piles. The pH values of the samples collected during the rain events of 6-23 and 7-7 are shown in Figures 5 and 6. The mean pH was 7.55 on 6-23 and 7.44 on 7-7. At this pH, in the absence of complexing ligands, copper is not very mobile. It can form carbonate and hydroxide precipitates and be adsorbed onto the silicate surface of the gabbro or onto iron hydroxide precipitates. The result is that very little copper is transported from the test pile. The constant concentration over the rain event supports the concept that the copper release is controlled by its mobility.

In general, nickel is a more mobile ion than copper, particularly in the neutral pH range. As can be seen from Figures 5 and 6, the nickel concentration is more than an order of magnitude higher than the copper concentration. The nickel concentrations fluctuate over a factor of two during the storm of 7-7. The final concentration in solution is influenced not only by reaction equilibrium but also by the amount and rate of water moving through the pile. Further analysis of the fluctuations in concentration over the events is being conducted.

Figures 8,9,10, show the rate of mass release (mg/min) for copper, nickel and sulfate for the storms of 6-23 and 7-7. The general trend is that mass release follows the hydrograph with the maximum mass release occuring during the peak runoff. Table XII summarizes the total release from the pile for each storm.

Table XI. PERCENT OF OXIDIZED METAL THAT IS RETAINED IN STOCKPILE

	Concentration (mg/l) predicted from chemical composition[1]	Concentration (mg/l) observed (median)	Percent of metal retained in pile
SO_4	610[1] basis	610[1]	0
Ni	22.7	.288	98.7
Cu	95.2	.03	99.97
Zn	5.0	.013	99.7
Co	2.8	.006	99.8
Fe	217	$<$ .05	$>$ 99.98

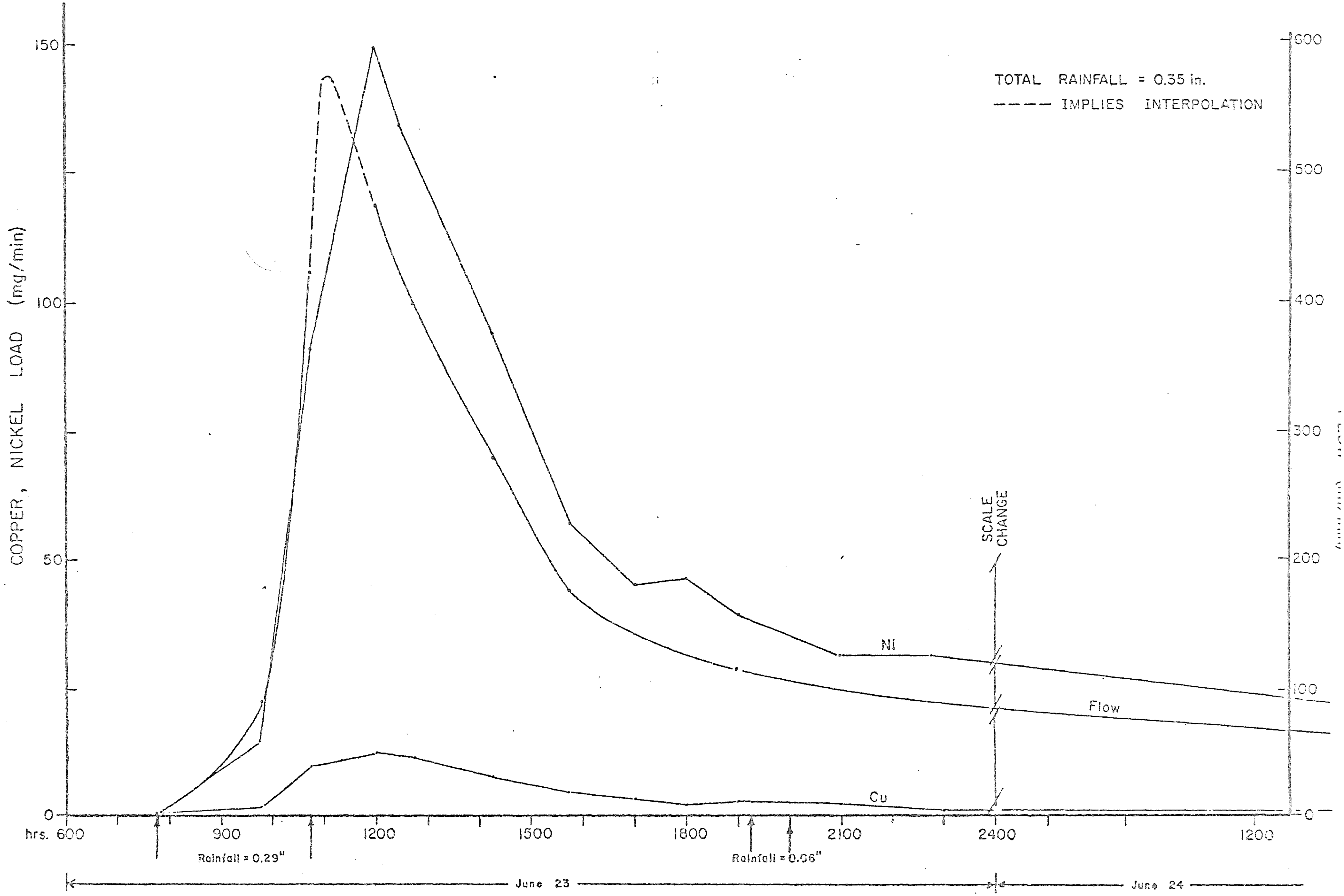
[1] SO_4 is the basis of the calculation, it is assumed that SO_4 indicates total sulfide dissolution and that it is 100% removed from pile

Fig 8

INTENSIVE SAMPLING OF RAIN EVENT OF JUNE 23, 1978

LEACH PILE 4

Copper and Nickel Mass Loading vs Time



INTENSIVE SAMPLING OF RAIN EVENT OF JUNE 23, ...8

LEACH PILE 4

Sulfate Mass Loading vs Time

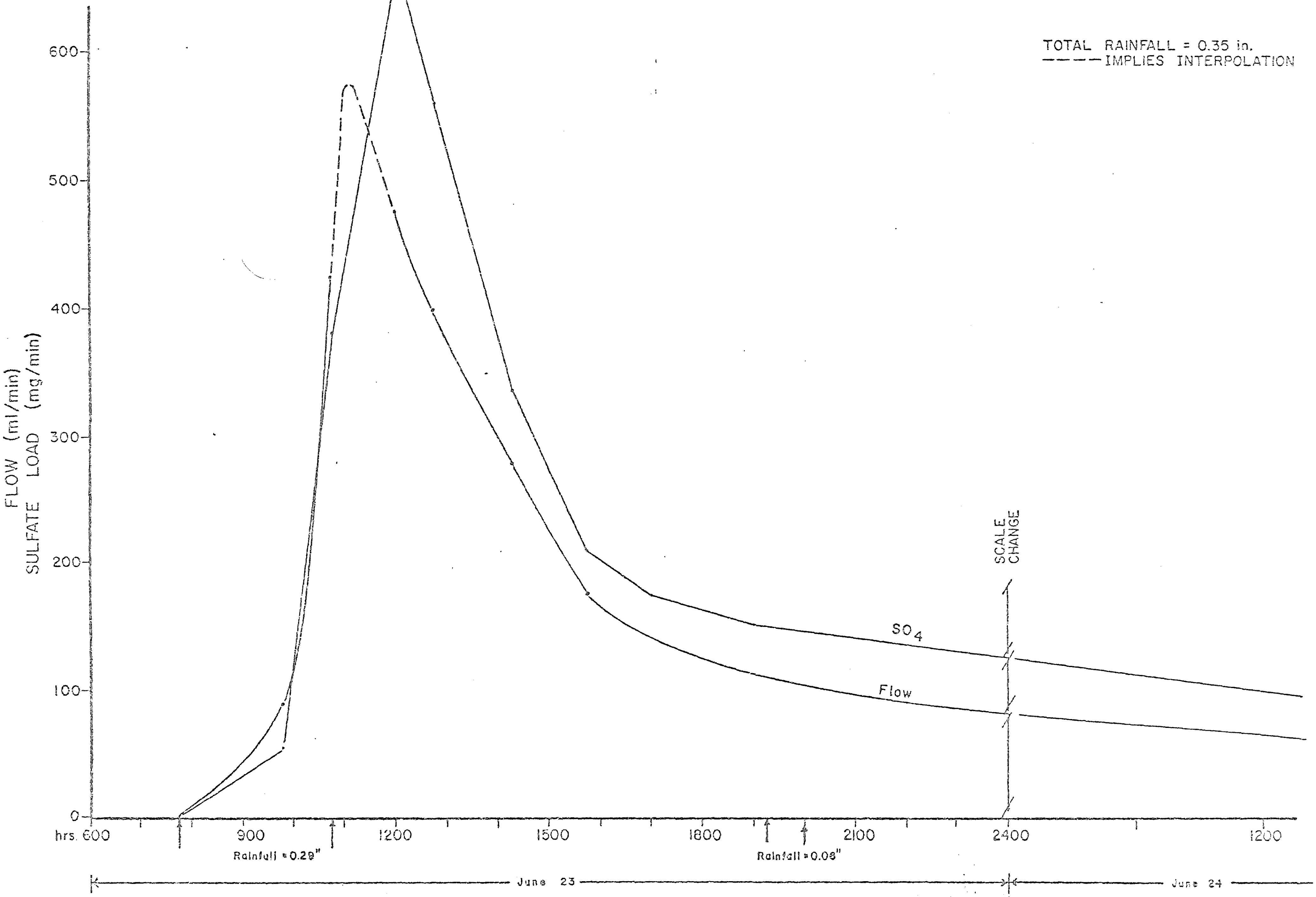


Fig. 10

INTENSIVE SAMPLING OF RAIN EVENT OF JULY 7 and JULY 8, 1978

LEACH PILE 4

Mass Loading vs Time

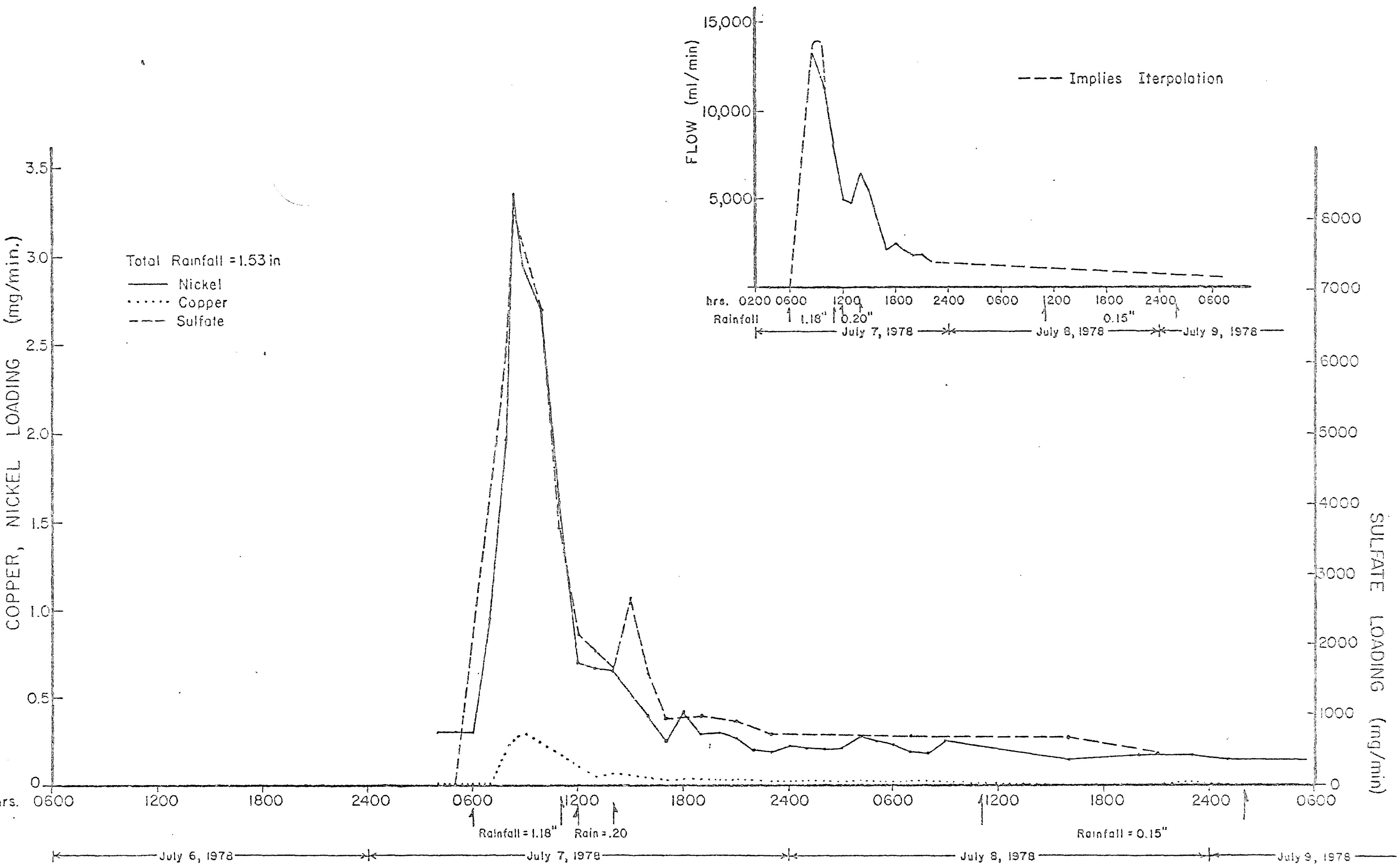


TABLE XII
MASS RELEASE SUMMARY FOR INTENSIVE EVENTS - FL-4

Parameter	6-23-78	7-7-78
Cu released (mg)	6	107
Ni released (mg)	111	1441
SO_4 released (g)	478	3738
Total Volume (l)	341	7599
Time Interval, Δt (min)	4415	4620
Total Rainfall (inches)	.35	1.53

how can rainfall $\frac{1.53}{0.35} \approx 5$

& volume $\frac{7599}{341} \approx 22$?

SUMMARY AND CONCLUSIONS

Copper concentration remains constant during runoff events, while concentrations of sulfate and nickel vary by more than a factor of two. Mass release for all parameters parallel the hydrograph, with the maximum release occurring at peak flow.

The possibilities of large variation in concentrations during storm events makes the collection of a composite sample a necessity. Grab samples will not adequately represent the concentration of all parameters during runoff. For some parameters, the mass calculations made on the basis of grab samples could be in error by more than a factor of two.

RESULTS - PHASE II

It will be recalled that the objective of Phase II is monitoring of the mass release and flow from each pile. The ultimate goal is the use of total mass release to measure the success of different reclamation efforts.

Rainfall

To calculate the total water input to each pile, the total rainfall and the collecting area of each pile must be known. Rainfall data was collected using a standard and a recording rain gauge. Complete rainfall data is given in Appendix V. Table XIII provides a monthly summary of the rainfall. The collecting area of each pile was measured with two sets of measurements taken for each pile and the results averaged. The results are summarized in Table XIV.

Flow Data

The problems encountered with obtaining the flow data have been discussed in Appendix I. Estimates of daily discharge from each pile were made using a combination of flow meter readings and volumetric discharge measurements. (Appendix II.)

The overall comparison between the total of the estimated flow for each pile and the sump flow is given in Table XV. The overall agreement is reasonably good.

The overall runoff relation for each pile is given in Table XVI. Preliminary data suggest that the percent runoff varies as $5 \approx 6 > 4 \approx 3 \approx 1 > 2$. Monthly runoff coefficients were also computed for each pile. The results of these calculations indicated that even though the overall agreement between the estimated flows and the sump flow was good, the individual pile data needed to be re-examined. In the early part of the field season, the flow meters would periodically jam and produce backwater conditions in the pile. Some of the volumetric measurements were influenced by this backwater, and as a result the daily flows were overestimated.

TABLE XIII
Rainfall Events, April through October, 1978

Month	Total # of Events	# of Events ≥ 0.3 in.	Total Rain	Rain provided by events ≥ 0.3 inches in.	%
April	7	2	1.28	0.78	60.9
May	8	2	3.37	2.30	68.2
June	9	3	2.21	1.58	71.5
July	14	4	6.38	4.90	76.8
August	10	5	5.53	4.58	82.8
September	9	3	3.28	2.84	86.6
October	7	2	1.05	0.72	68.6
TOTAL	64	21	23.10	17.70	76.62

Note: Rainfall greater than or equal to 0.01 inches is an event.

Table XIV.
Test Pile Area

Pile	Total Collecting Area (ft^2)
1	3173
2	3678
3	3183
4	3524
5	3648
6	3444

Table XV. FLOW SUMMARY

Month	Rainfall	6 Pile Total	Sump Discharge	% Difference
April				
May	3.37	87,000	79,000	+9.4
June	2.49	82,000	81,000	+1.6
July	6.38	156,000	164,000	-4.6
August	5.53	129,000	123,000	+4.4
September	3.28	89,000	81,000	+9.4
October		12,000	12,000	
May - October		555,000	540,000	+2.8

$$+ \% \text{ difference} = \frac{\text{6 pile} - \text{sump total}}{\text{sump}} \times 100$$

Table XVI. OVERALL RUNOFF CALCULATION

Pile	Total Collecting Area (ft^2)	Area of Exposed Hypalon (ft^2)	% of Area That Is Exposed Hypalon	Input liters/ in Rain	TOTALS Input (l)	outflow (l)	runoff (%)
1	3173	96	3.0	7487	166,137	83,184	50
2	3678	243	6.6	8679	192,587	67,421	35 *
3	3183	36	1.1	7511	166,669	95,265	57 *
4	3524	528	15.0	8315	184,510	92,231	50
5	3648	160	4.4	8608	191,012	120,522	63 *
6	3444	371	10.8	8127	180,338	117,209	65

* Pile has been covered and seeded.

This was a particular problem with FL 3.

All flows will be recomputed. An attempt will be made to correlate flow data between periods of good flow records and then, based on these correlations, make necessary flow estimations. A preliminary examination of the problem time period indicates that the net result may be a reduction in the total flow from FL 3 and possibly FL 2. This would not change the overall relationship in percent runoff that was discussed previously.

Water Quality Data

All the 1978 water quality data are in Appendix III. The sampling procedures are discussed in Appendix I. The data are preliminary. Some of the concentration values appear to be anomalous and will have to be reanalyzed.

Since the major purpose of this report is to serve as a progress report, there is still a large amount of data analysis that remains to be done. The intent of this discussion is illustration of some of the general findings. More detailed analyses, which would include calculation of mass release, will be available in future reports.

Variation In Concentration With Time

To compute the mass release,the total flow for each pile must be computed and representative concentrations must be assigned. These calculations have not been completed. However, general comparisons have been made among the different test piles and between 1977 and 1978.

Figures 11 through 24 present the variation of copper, nickel, sulfate and pH with time for 1977 and 1978. These parameters were selected since they are the key components and products of the leaching reactions. The other parameters will be discussed in future reports. The data presented in these figures are the concentrations in the sample, no attempt has been made to produce a complete set of flow weighted or "representative" concentrations. The concentrations are a mixture of values; some from composite samples and some from grab samples which were collected both at high and low flow.

From the results of Phase I it is clear that concentrations vary during storm runoff. Therefore, the yearly concentration versus time graphs are useful for identifying long term general trends, but may not give an accurate representation of short time fluctuations. The variation between two samples may be the result of the differing flow conditions at which the samples were collected. Comparison of individual concentrations must be done with caution.

The box plot, or schematic diagram, (Figure 25) is a useful tool for summarizing data. In order to produce a meaningful summary of the concentration data, a uniform data set was selected. The objective was to choose a series of sampling dates on which a sample was collected from every pile. (Due to the start-up nature of the program, not all piles were sampled at the same frequency.) The set of samples that was chosen is listed in Table XVII. The concentrations obtained from this set are not necessarily representative of the entire year of of the flow distribution but they do provide a basis for comparing the different test piles.

Since a smaller number of samples was collected in 1977, all the samples were used to provide a reasonable number of data points. There were not enough data to construct a box plot for piles FL 5 and 6 because they were not constructed until September, 1977. The resulting box plots are shown in Figures 26 through 29.

DISCUSSION

The results indicate that the piles tend to separate into two general groups: piles 1 through 4 and piles 5 and 6. Piles 1-4 were constructed from material from the shaft while the material in 5 and 6 came from the drifts. Piles 5 and 6 contain a higher percentage of sulfur (Table VII) and may have a finer particle size distribution (Amax, personal communication). These factors should tend to enhance the reaction rate in these piles. (As mentioned previously, concentration alone is not a good indication of total release. Concentrations must be converted to mass before the total release can be calculated).

Piles 5 and 6 have higher median concentrations of copper, nickel, and sulfate than the other piles. Preliminary analysis of the flow data (Table XVI) indicates that these two piles also yield more water than the rest. It appears that the total mass release is higher in these piles. One of the major factors that affects the release is the pH. Figure 21 indicates the dramatic decline in pH observed for FL 5 and a corresponding increase in metal concentration. The exact cause of the pH decline is still being studied. Figure 30 shows additional pH data for pile 6. The pH dropped considerably in the last two months before freeze up. From Figure 30 it appears that the decline in pH began around the end of August. If this pH trend continues, acidic leachate may be produced. Nickel concentrations tended to increase throughout 1978. Concentration geban to increase sharply about one month prior to the initiation of the decline in pH. This phenomemon can be seen in FL 5.

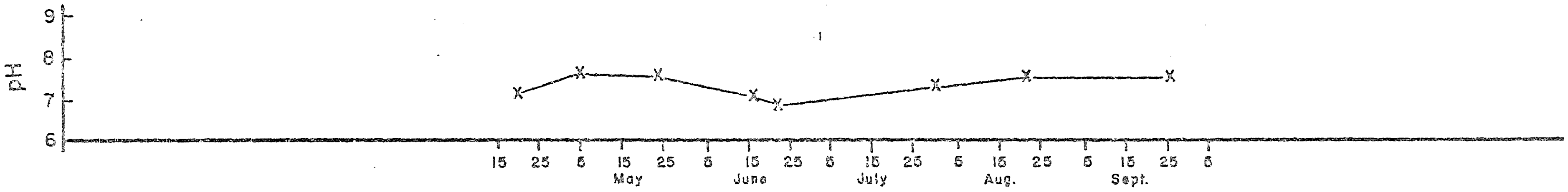
The rise in copper concentrations tend to correspond more closely to the decline in pH. Copper is not very mobile at pH values above 7, but its mobility increases as the pH declines. Preliminary examination of the sulfate data indicate no clear trend in concentration. The concentration is variable and there is no dramatic increase in 1978, as there is for the metals.

Since the release of sulfate can be used as a measure of the dissolution rate of the metal sulfides, the preliminary indication is that the overall rate of dissolution has not increased dramatically. The increase in metal concentration results from the increased mobility of the metals at the lower pH. From laboratory studies conducted by Lapakko, Eisenreich, and Hoffman (Eisenreich, et al 1977), an increased rate of sulfide dissolution was observed as pH decreased. It is also well

Figure 1

FL – I, 1977

CONCENTRATION VS TIME



X = grab sample
NICKEL
COPPER
SULFATE

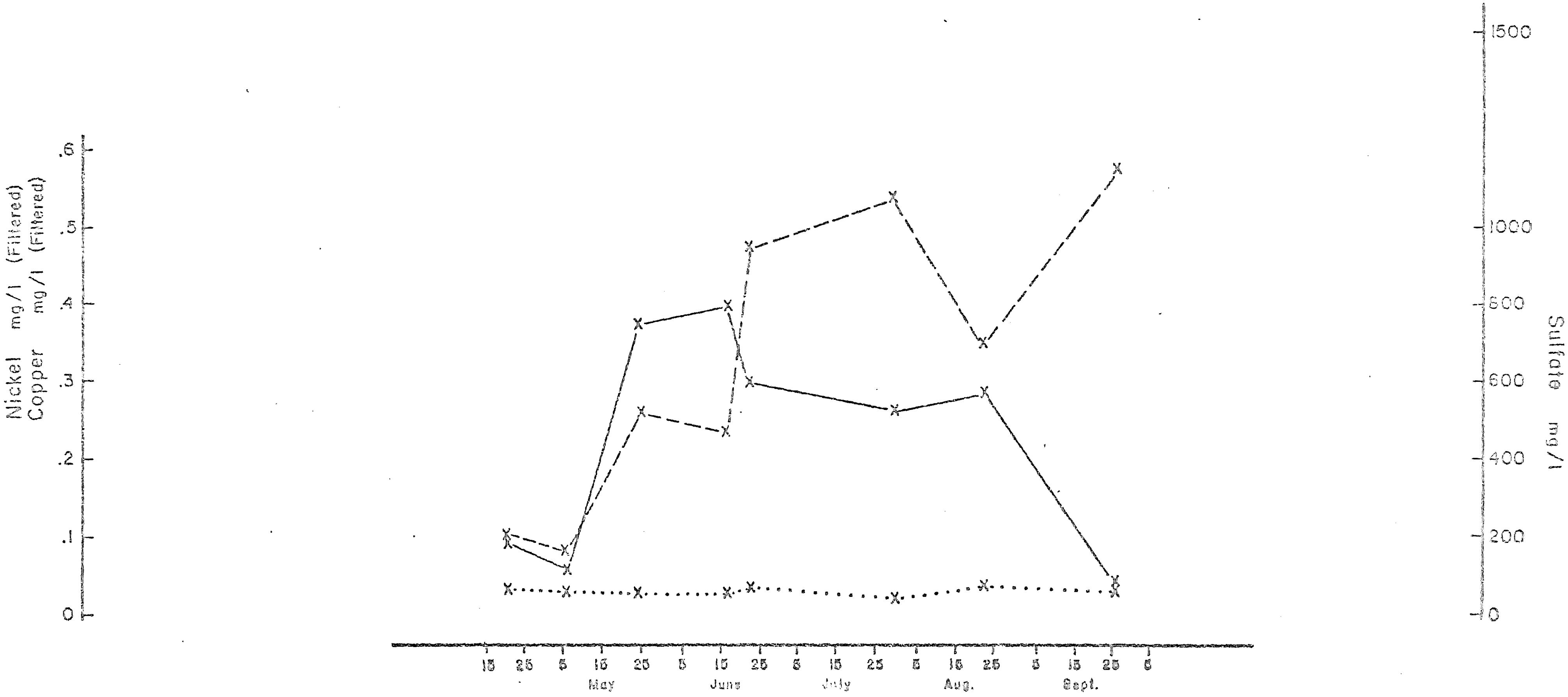
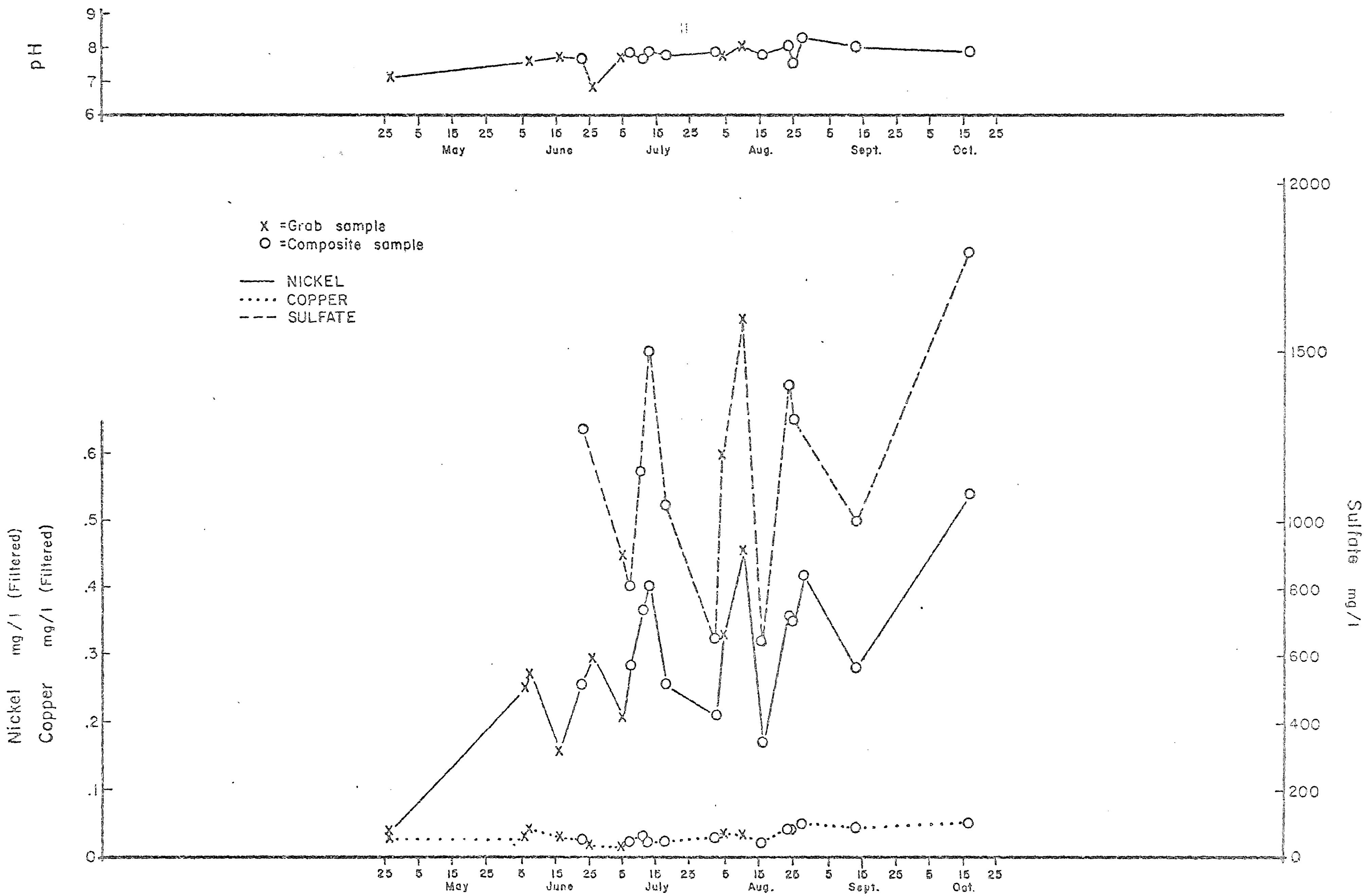


Figure 1.

FL - I, 1978

CONCENTRATION VS TIME



CONCENTRATION VS TIME

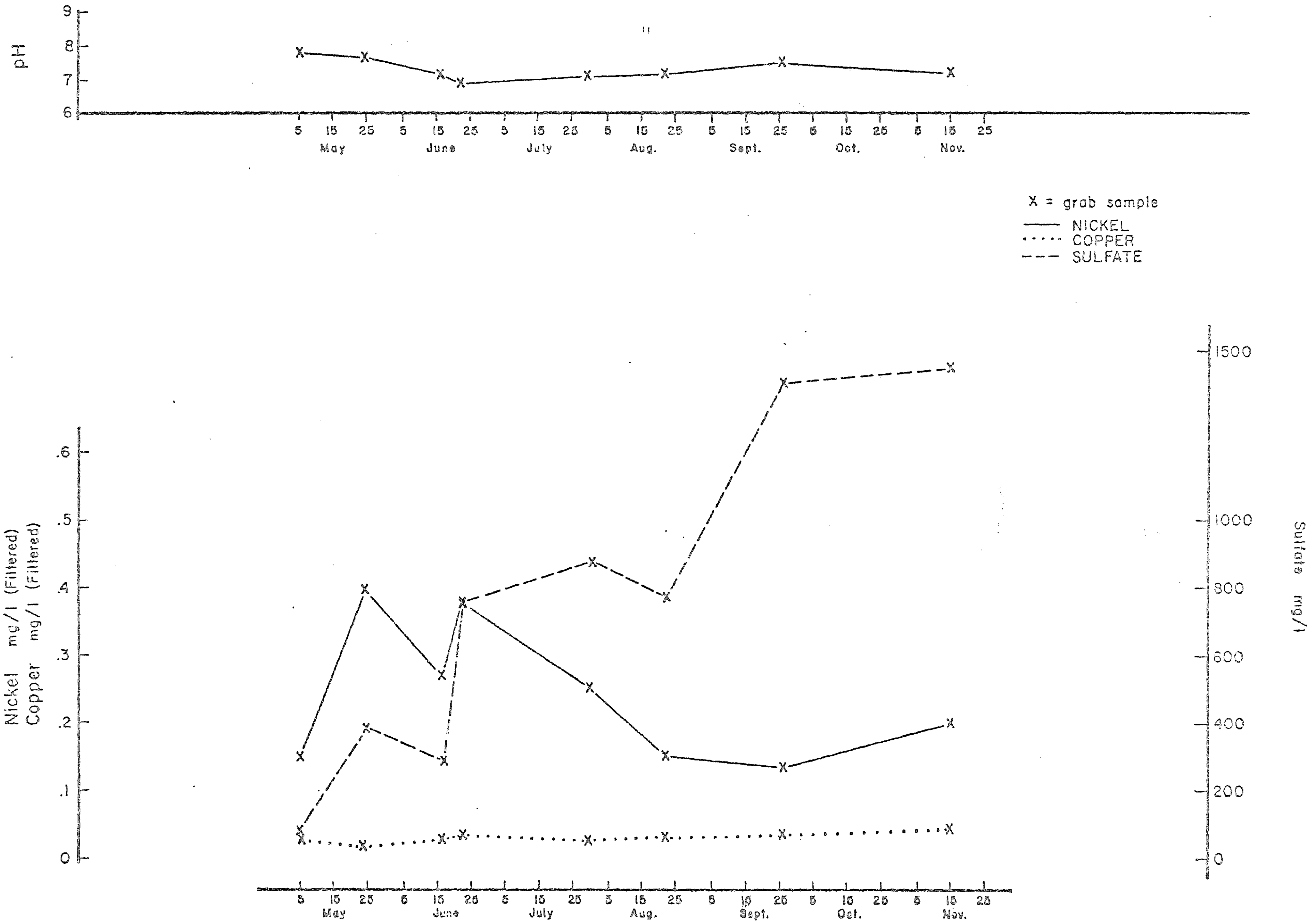
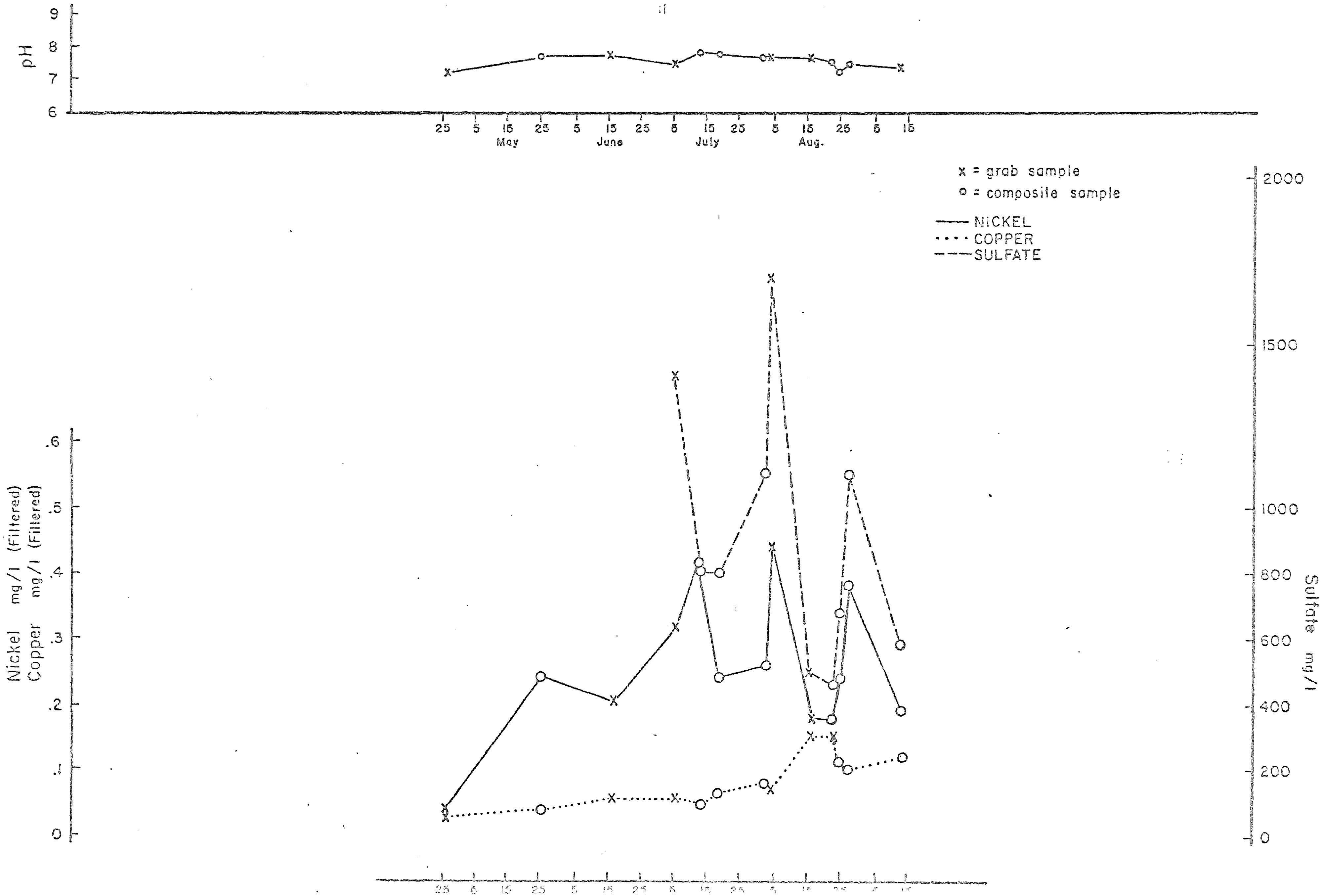


Figure 14

FL - 2, 1978

CONCENTRATION VS TIME



Figur 15

FL – , 1977

CONCENTRATION VS TIME

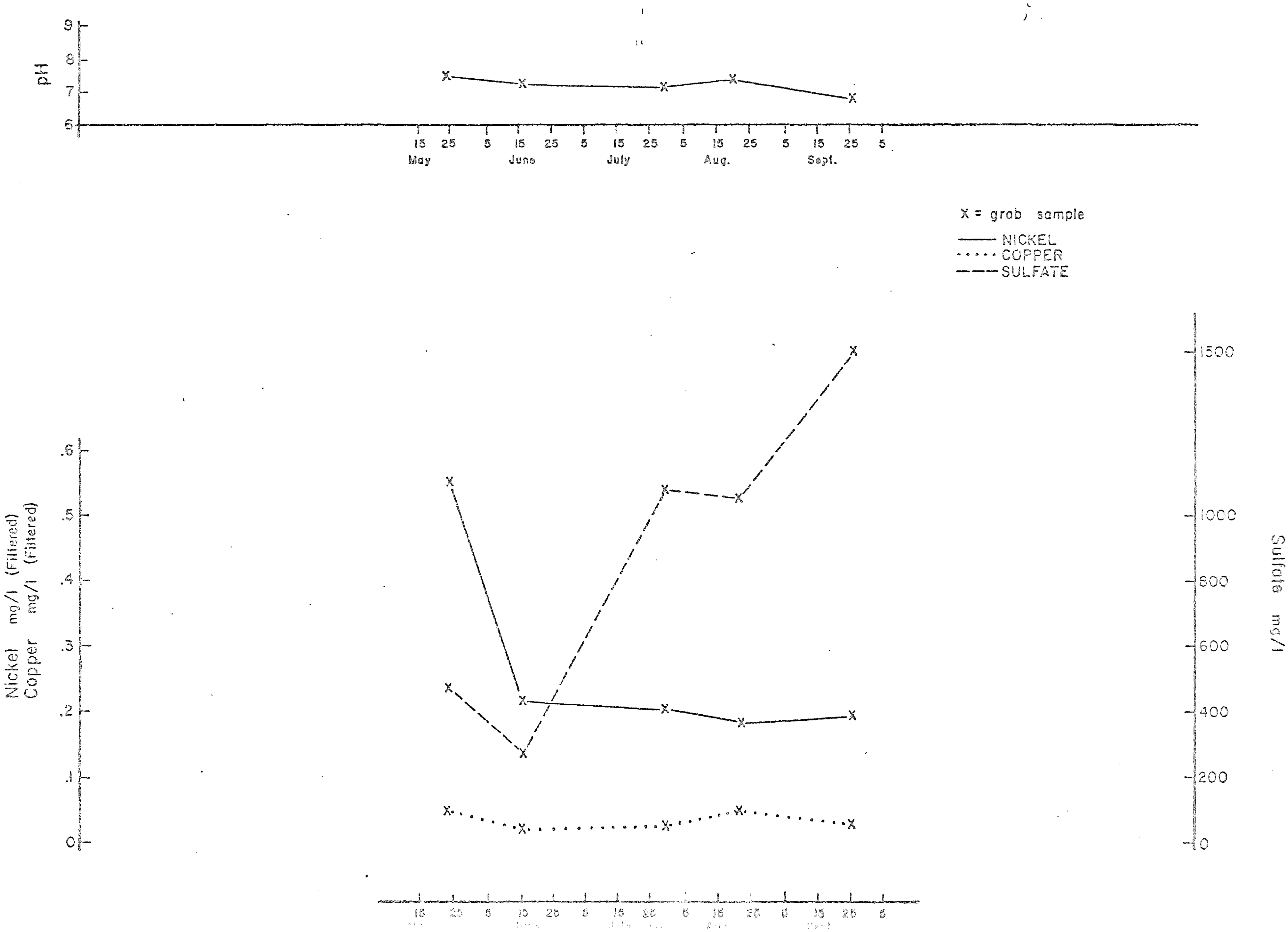


Figure 16
FL-3, 1978

CONCENTRATION VS TIME

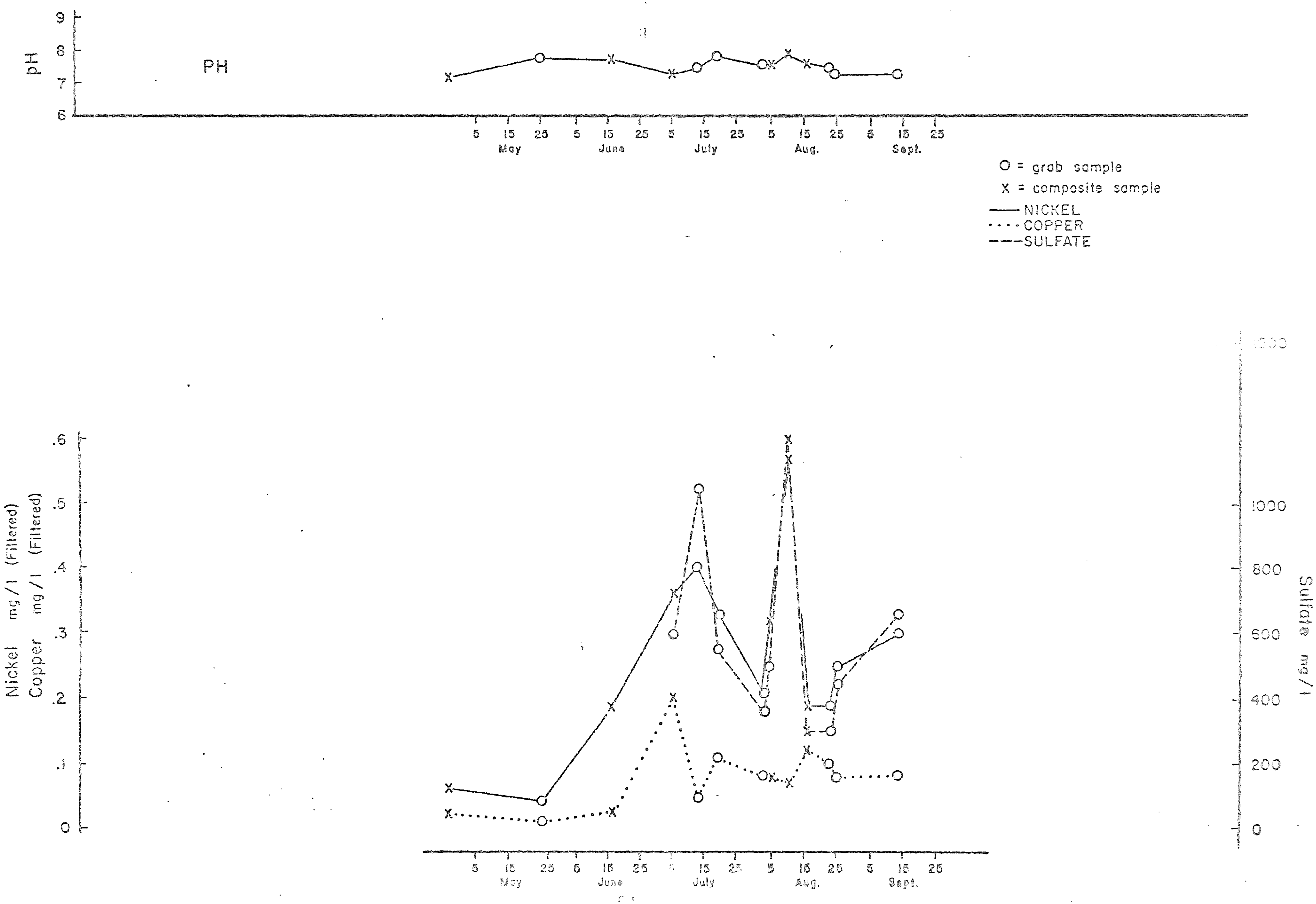
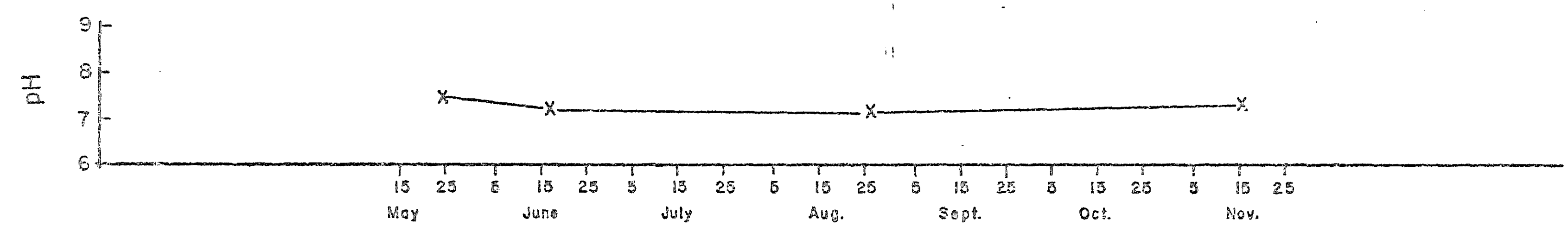


Figure
FL - 4, 1977

CONCENTRATION VS TIME



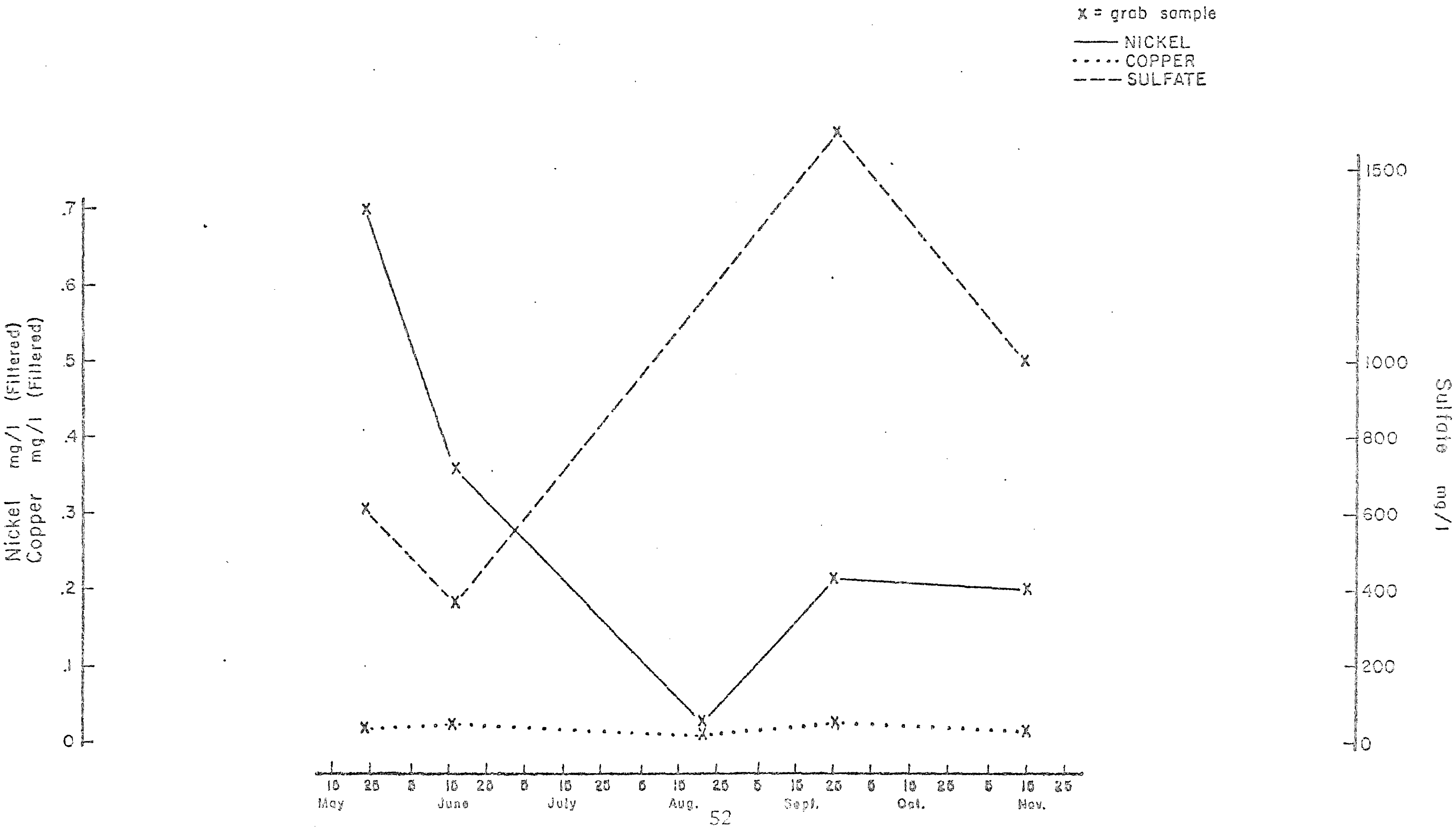


Figure 18
FL-4, 1978

CONCENTRATION VS TIME

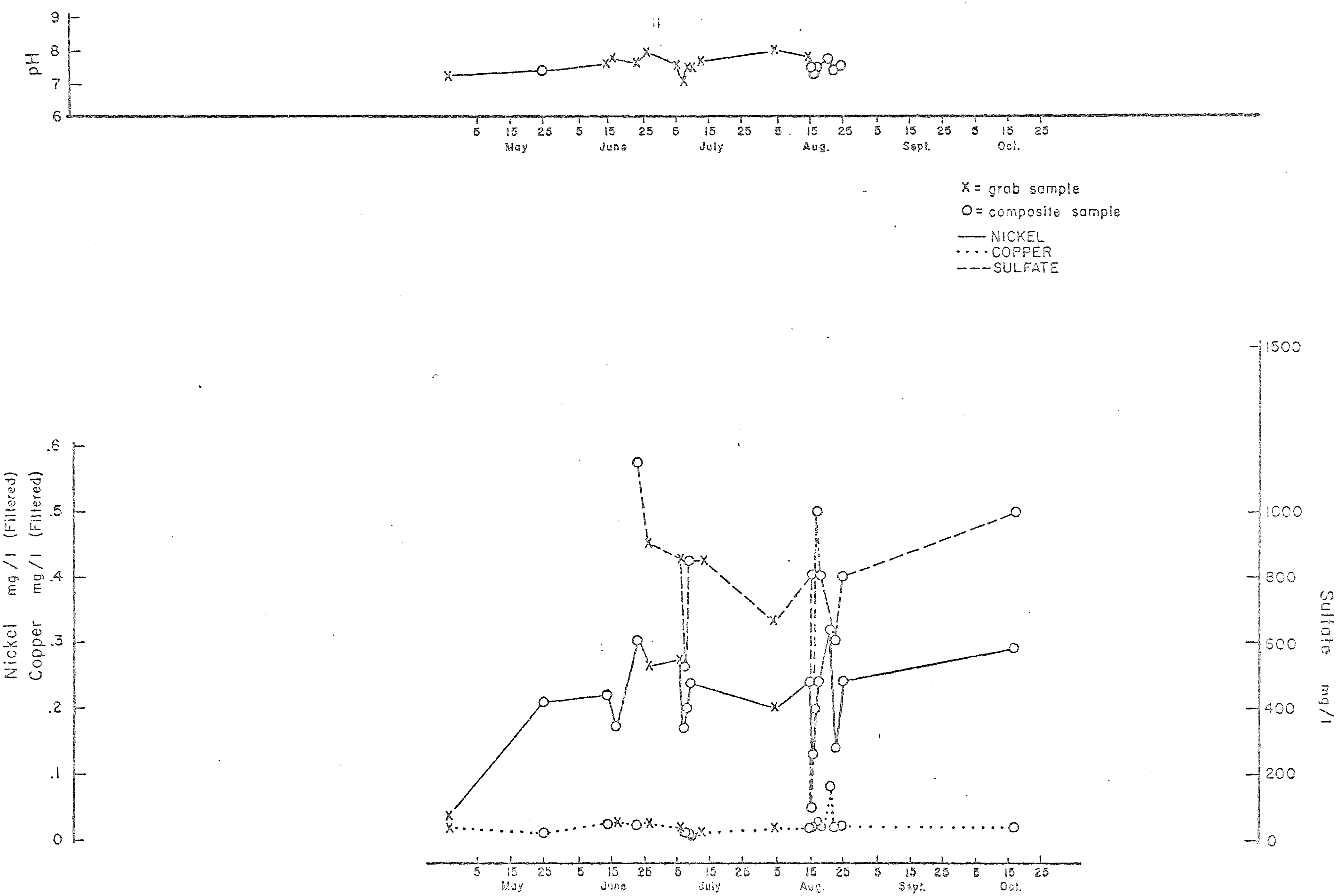


Figure 19

FL – 5, 1977

CONCENTRATION VS TIME

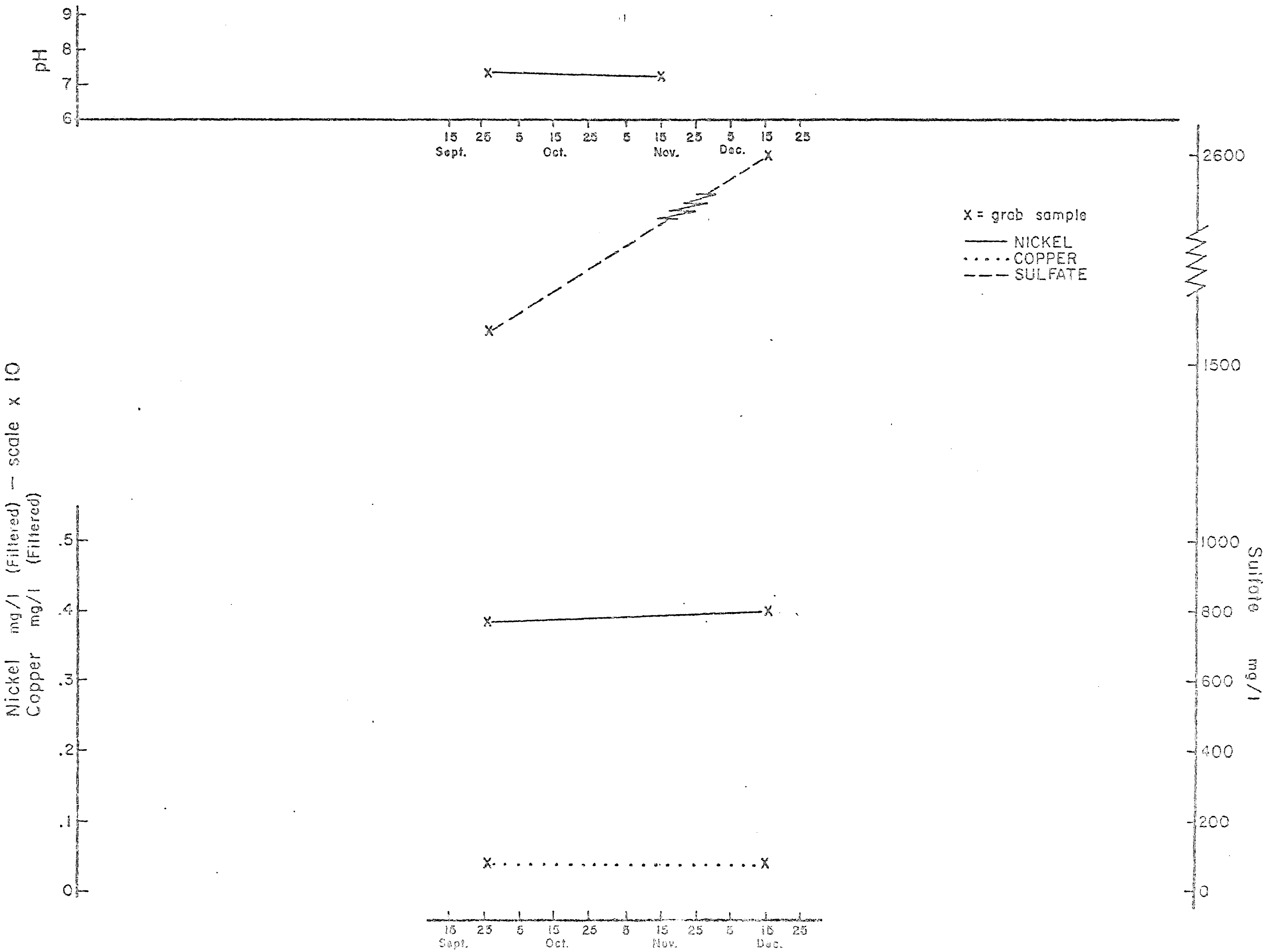


Figure 20
FL - 5, 1978

SULFATE CONCENTRATION VS TIME

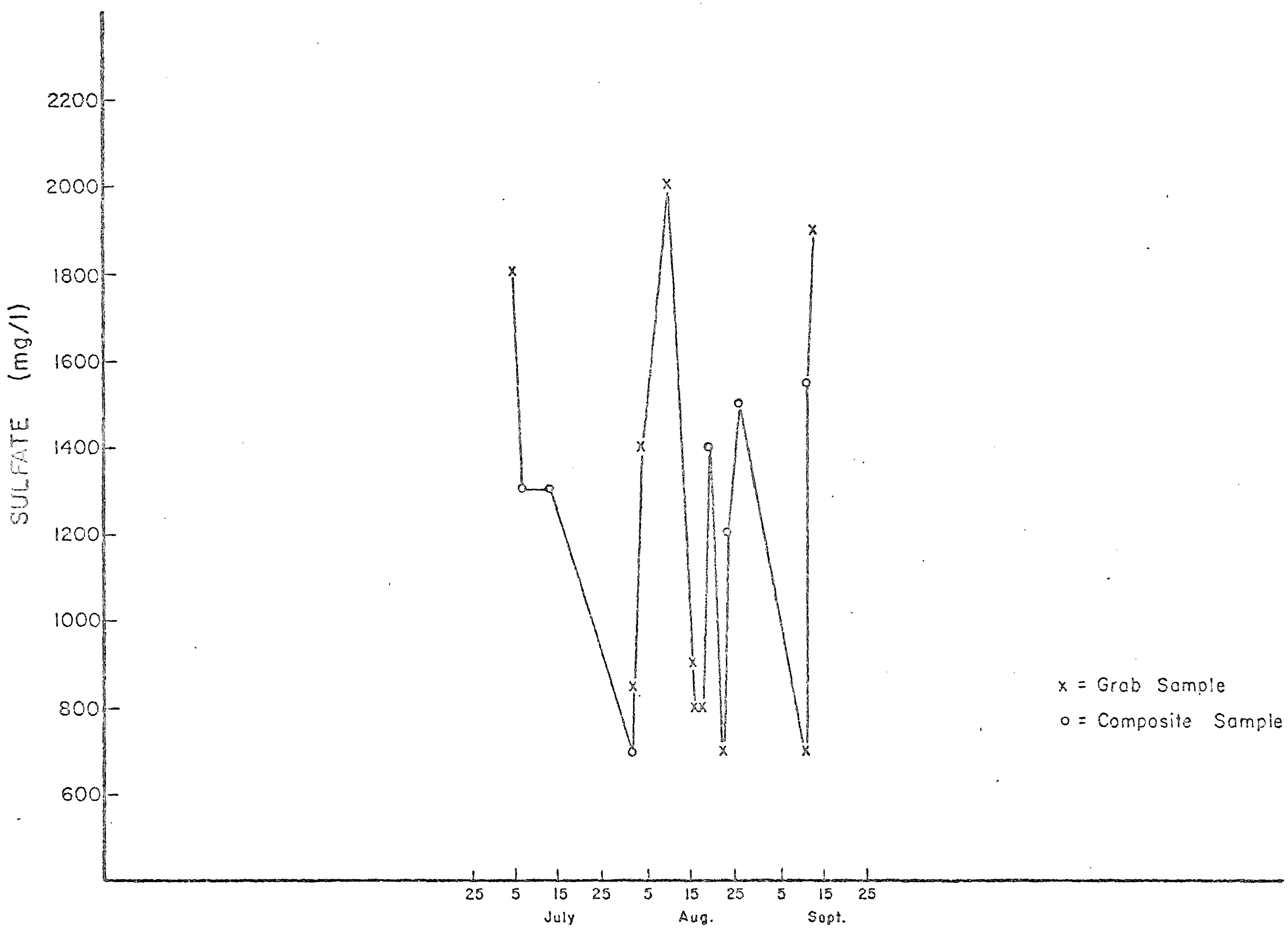


Figure 2[illegible]

FL-[illegible] 1978

CONCENTRATION VS TIME, NICKEL, pH

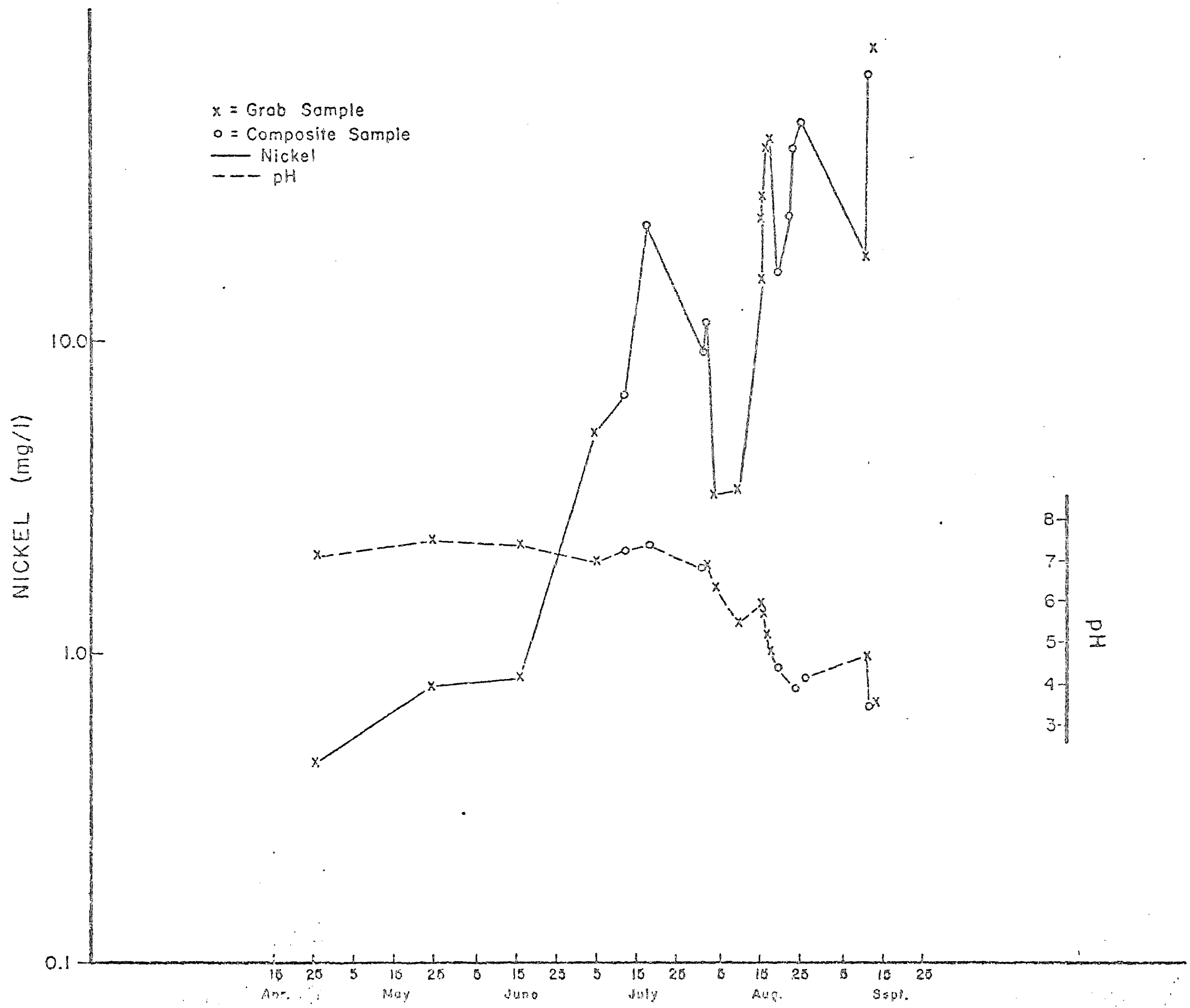
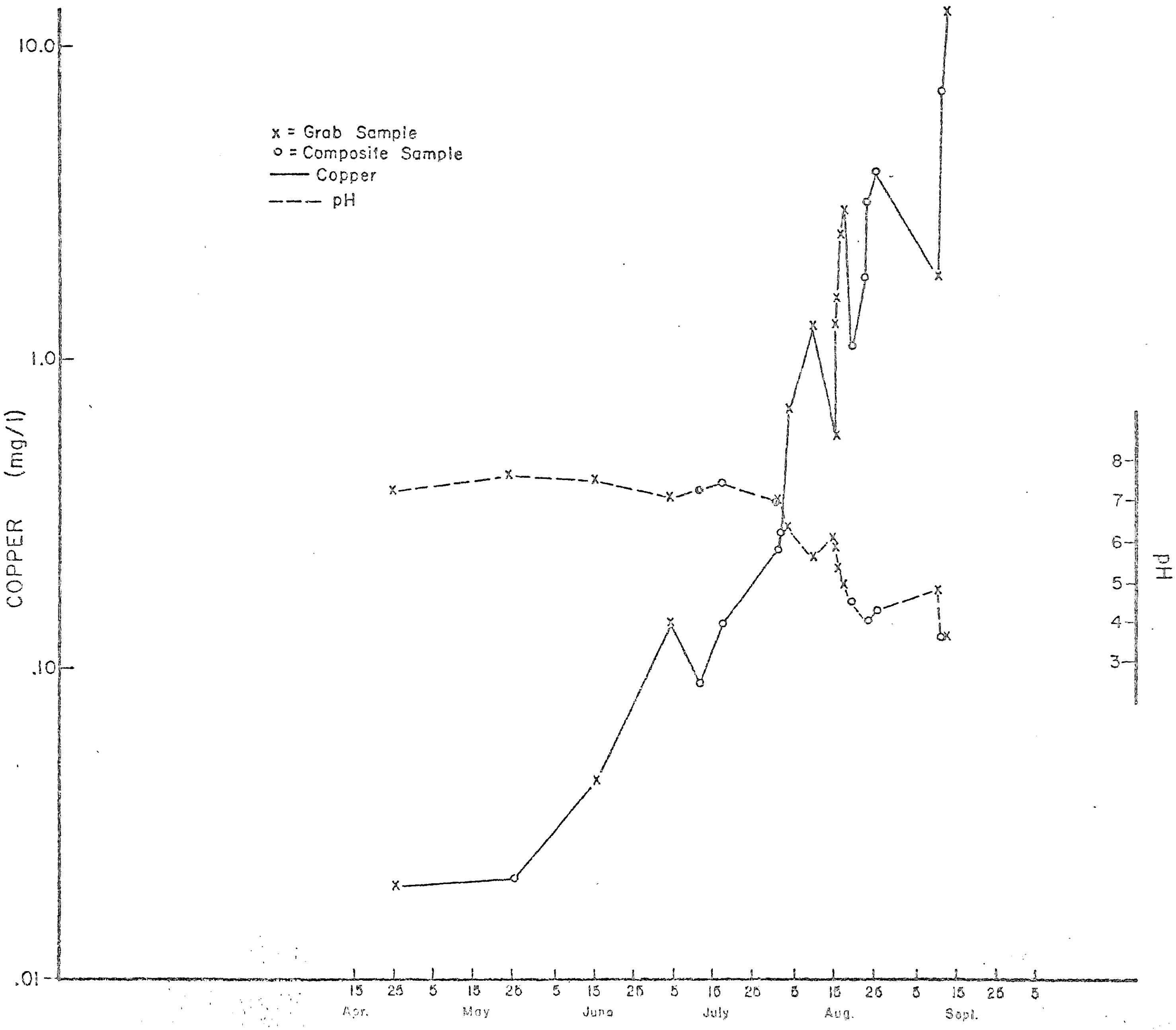


Figure 22

FL-6, 1978

CONCENTRATION VS TIME, COPPER, pH



Fi[illegible]e 23

FL - [illegible], 1978

SULFATE CONCENTRATION VS TIME

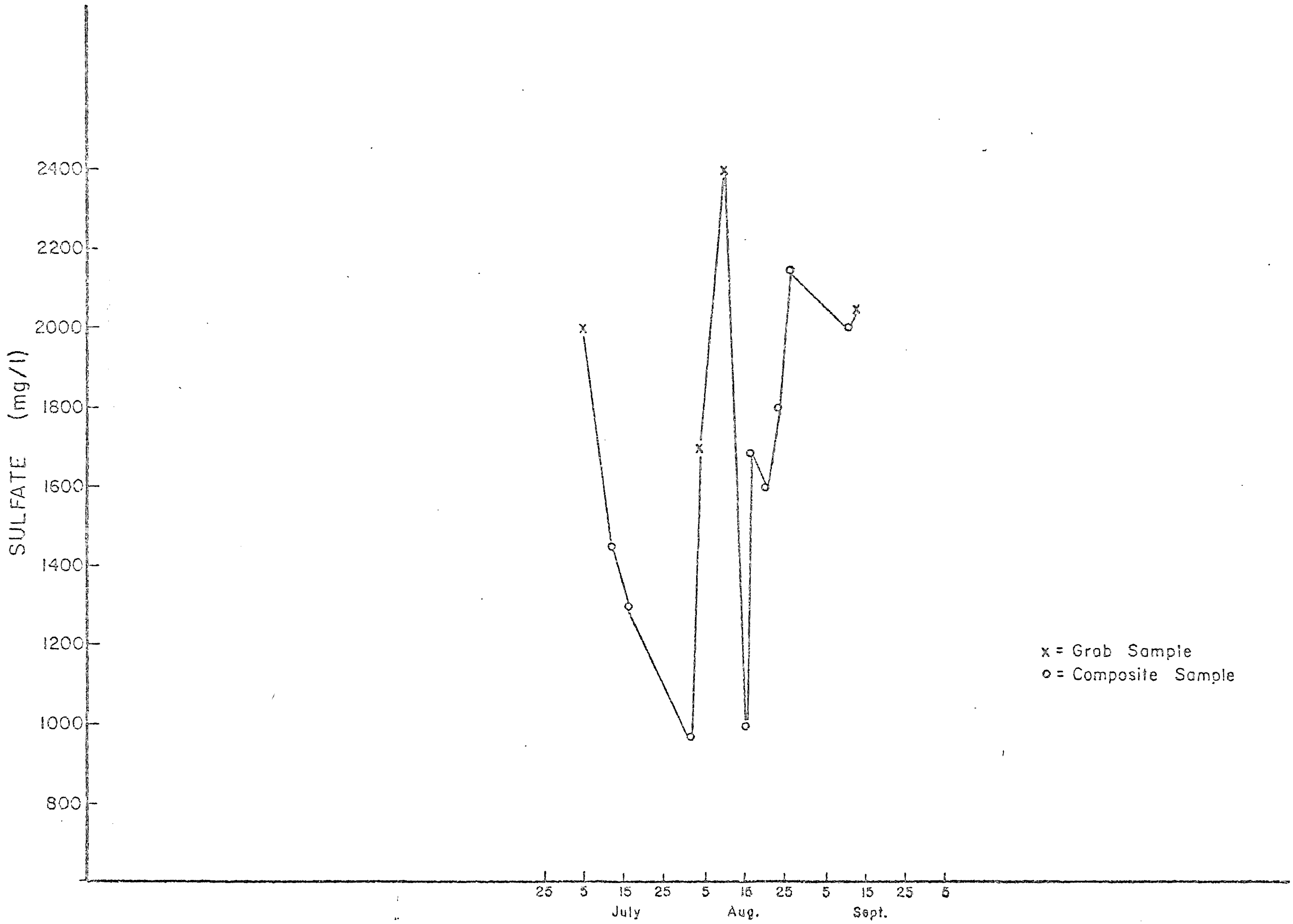
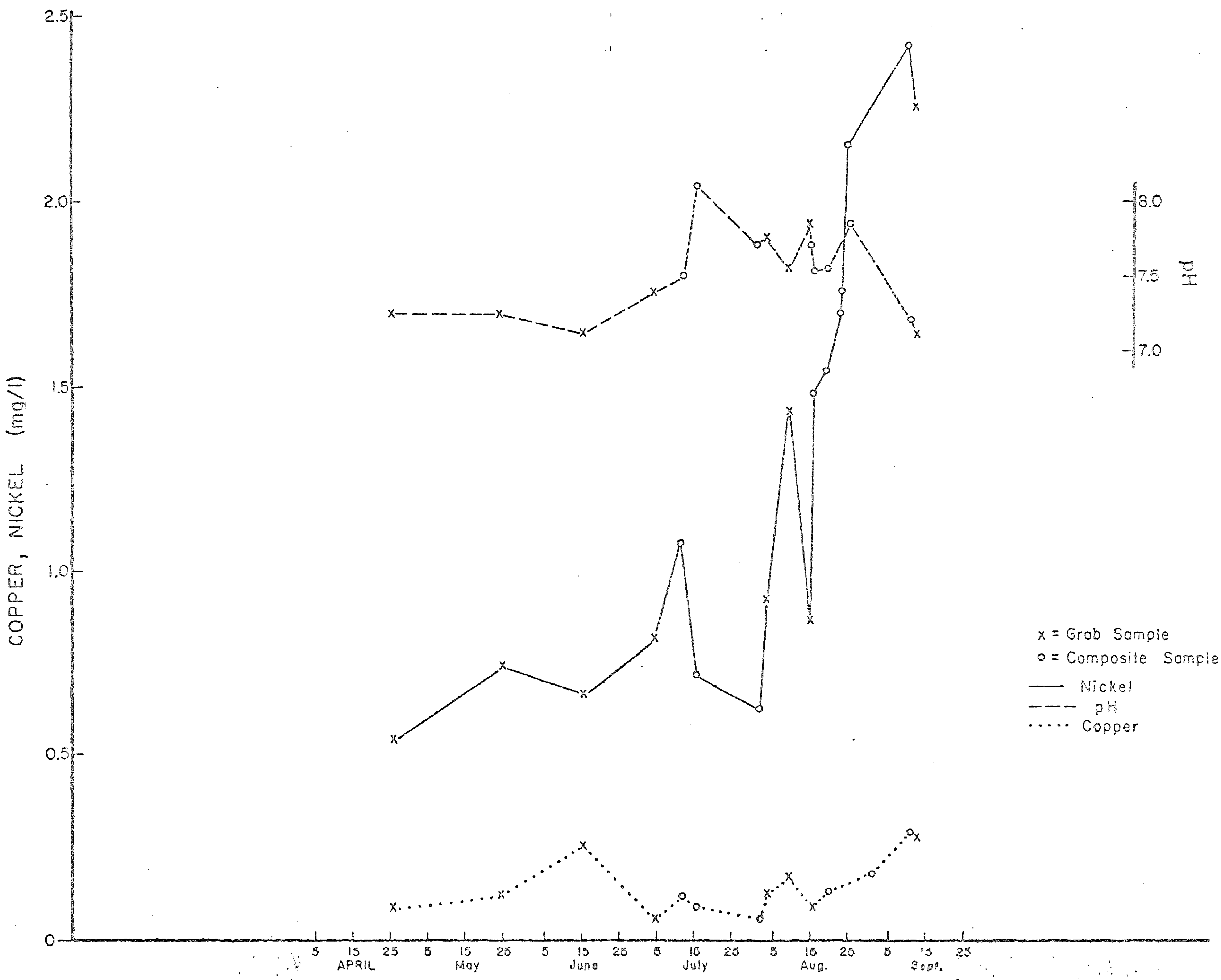


Fig. 24
FL - 1978
CONCENTRATION VS TIME, COPPER, NICKEL, pH



BOX PLOT, [illegible]

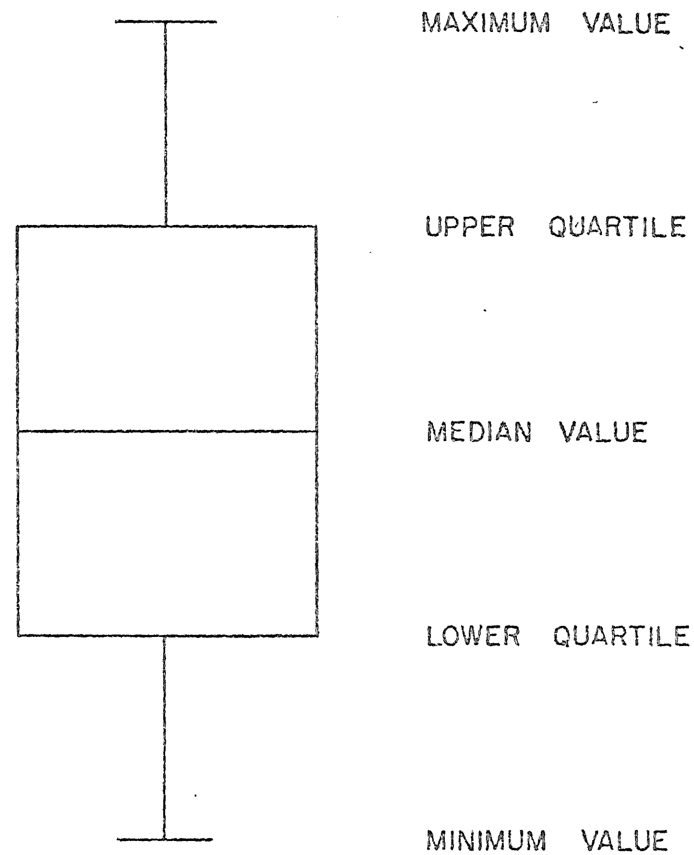

MAXIMUM VALUE
UPPER QUARTILE
MEDIAN VALUE
LOWER QUARTILE
MINIMUM VALUE

Table XVII. SAMPLES USED FOR BOX PLOT

DATE	TYPE OF SAMPLE	CONDITION
4-26	grab	low flow
6-16	grab	low flow
7-5	grab	tail of rain
7-12 to 7-13	composite	comp over rain for all, grab for FL4
7-14 to 7-19	composite	all piles except FL4
8-1 to 8-2	composite	over rain
8-4	grab	low flow
8-16	grab & composite	during & over rain event
8-23	composite	before and over rain
9-13	grab	tail of rain

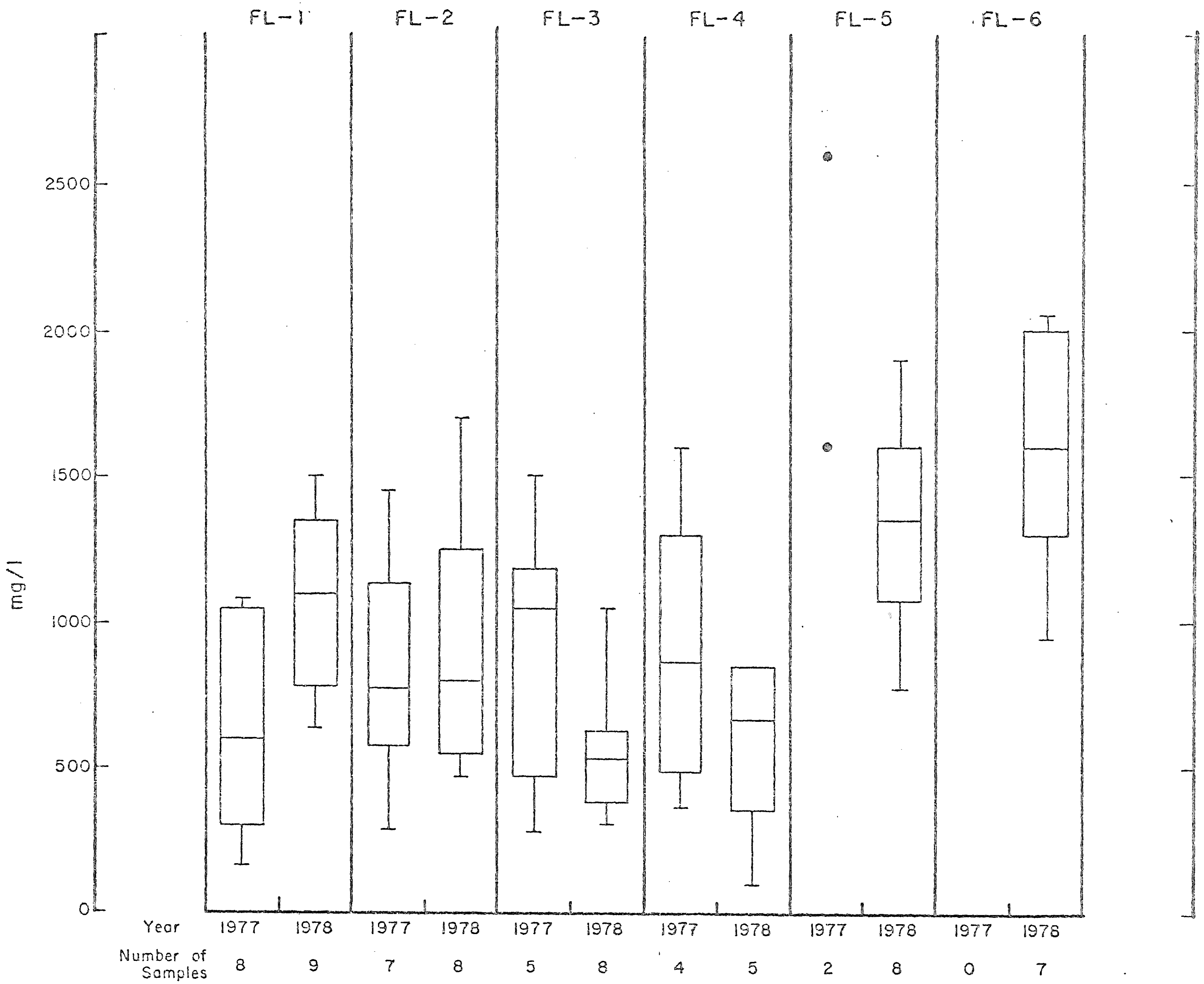
more detailed information is given in Appendix V documented that the oxidation of the metal sulfides results in acid production (Hawley, 1972; Eisenreich et al, 1976). Normally, the buffering capacity of the gabbro is sufficient to maintain the pH in the neutral to slightly basic range. If the oxidation rate increases or the buffering capacity decreases, the pH may drop. As pH decreases, the rate of metal transport from the stockpile increases. The drop in pH in FL 5, resulted in a 10 to 100 fold increase in metal transport.

With the exception of copper, the box plots indicate that piles 1-4 generally have comparable median concentrations. Median copper concentrations for piles 2 and 3 appear to have increased between 1977 and 1978, and the 1978 values are higher than those for piles 1 and 4. In 1977, the median copper concentration was comparable for all four piles. Median concentrations for piles 1 and 4 are essentially the same for 1977 and 1978. The fact that the median nickel concentrations are similiar for all piles, both in 1977 and 1978, suggests that the overall release rate has not changed. A selective increase in copper release has occured, due to increased copper mobility. Mobility could be increased by the introduction of organic compounds which have been washed out of the soil cover. Additional analysis is needed to determine the significance and the cause of this increase.

Median pH values for piles 1-4 increased slightly form 1977 to 1978. Comparison of the median sulfate data did not reveal any consistent pattern between the two years. Median sulfate concentrations decreased in FL 3 and 4, increased in FL 1 and essentially remained the same for FL 2.

Figure 26

BOX PLOT, SULFATE



BOX PLOT, C[illegible]PER

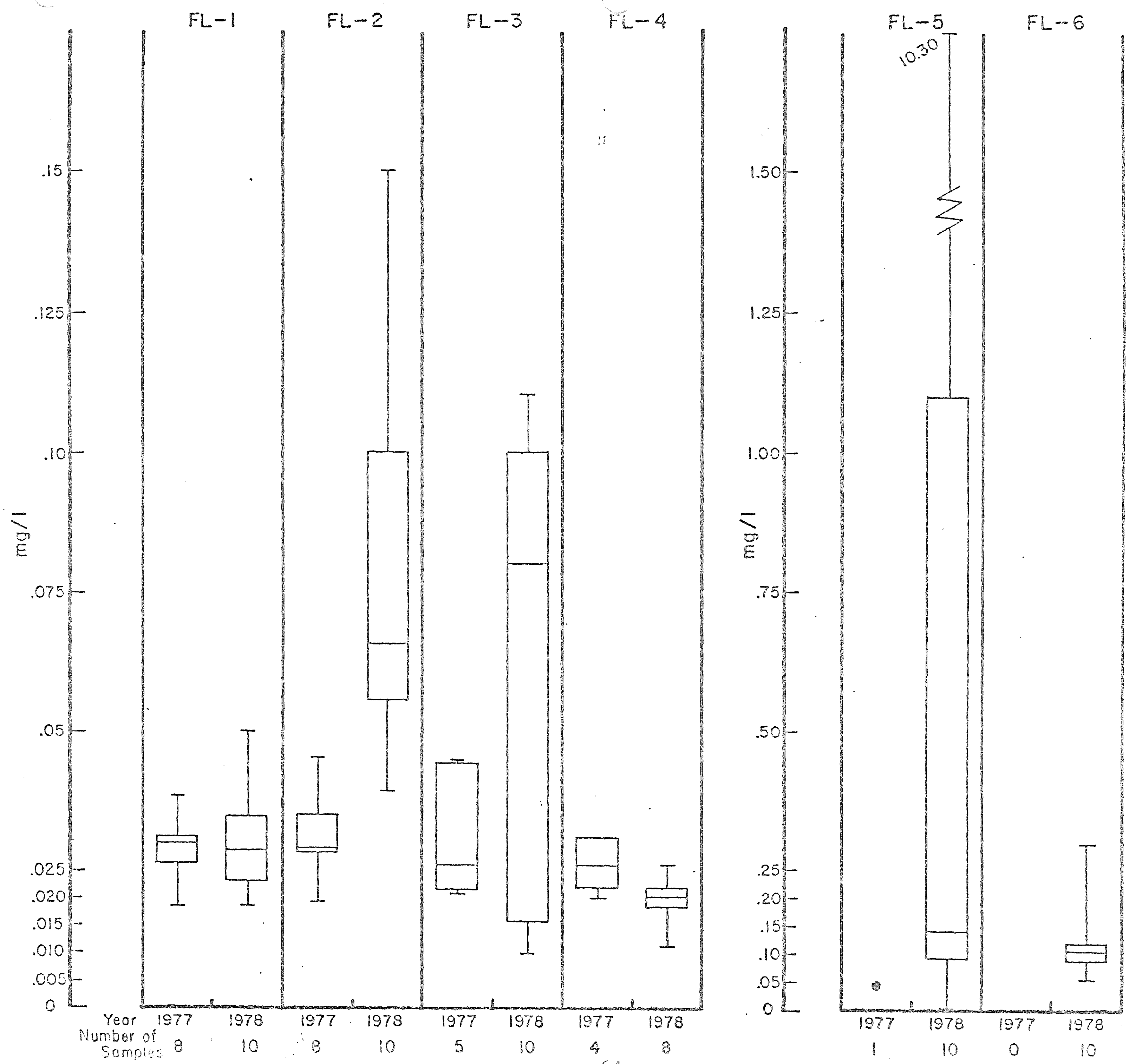


Figure 28.

BOX PLOT, [illegible]CKEL

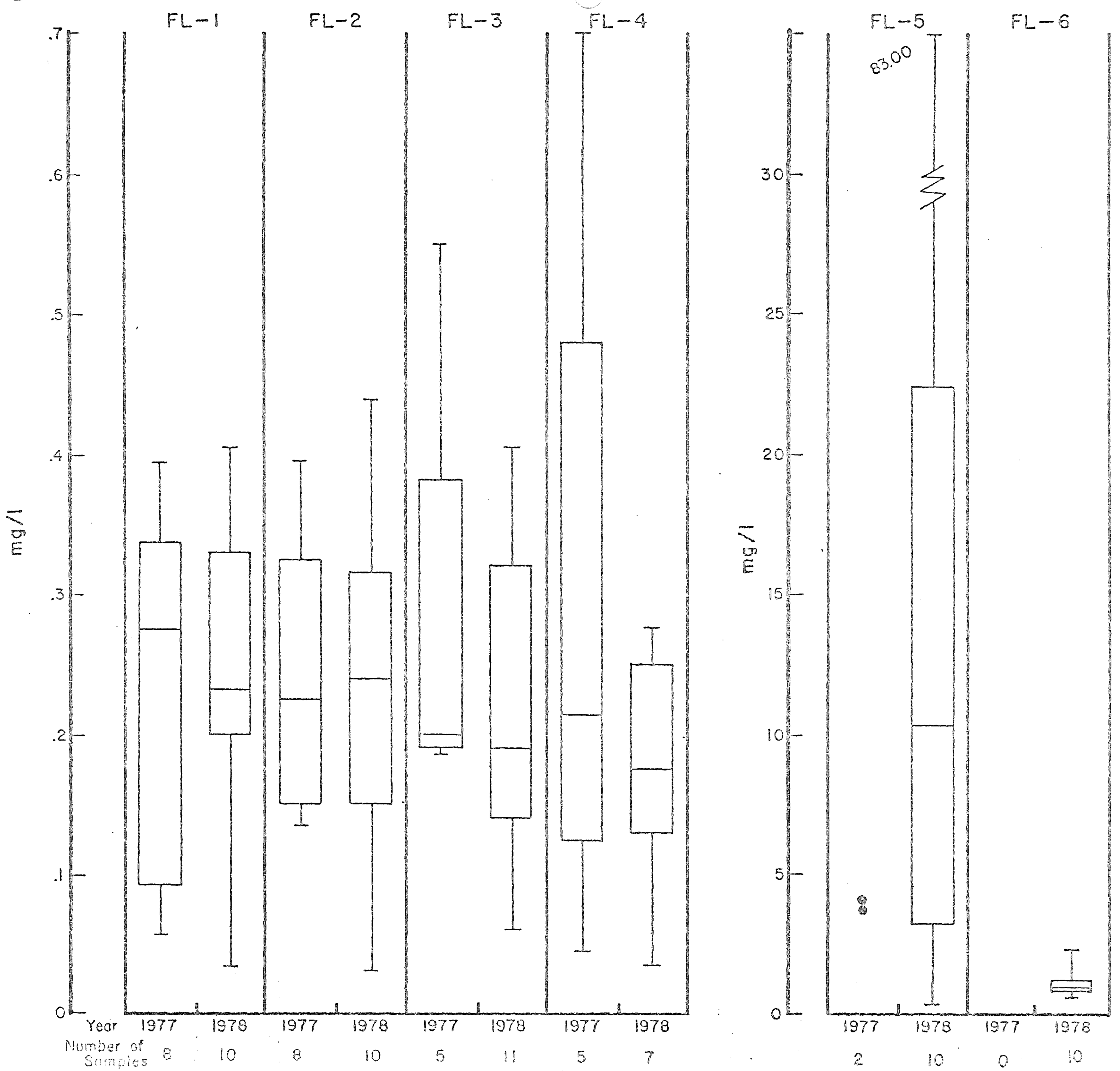


Figure 29

BOX PLOT, pH

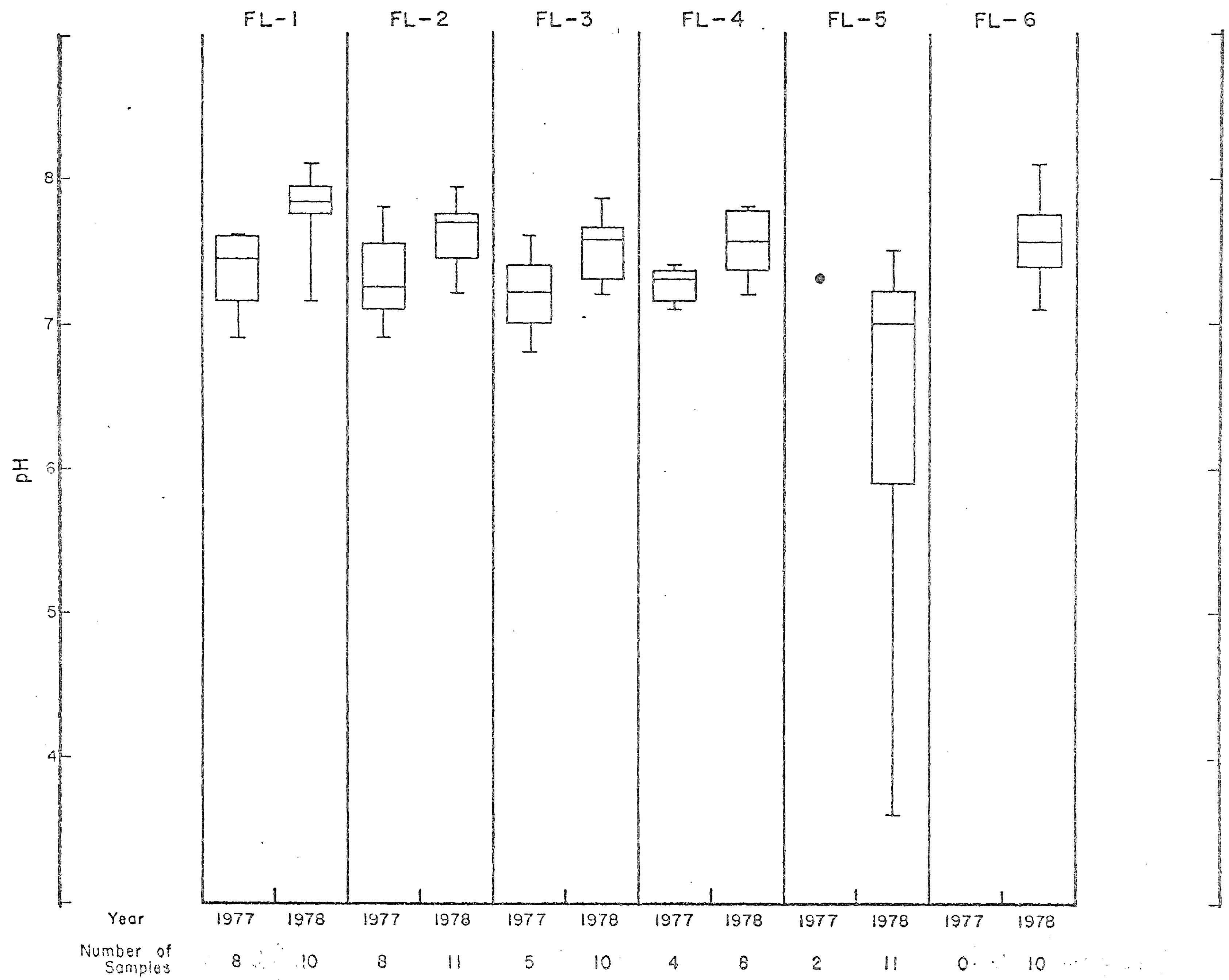
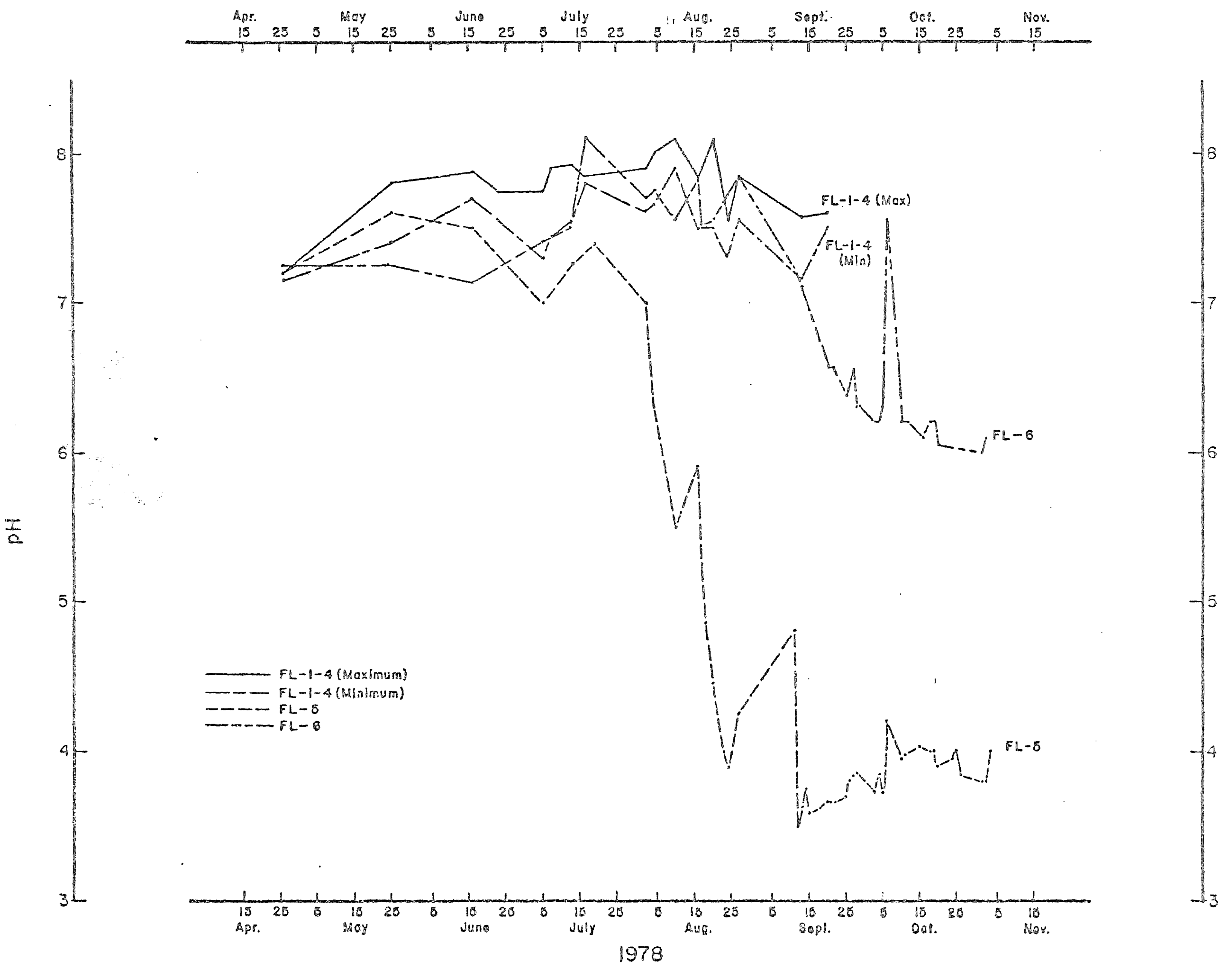


Figure 30
pH VS TIME



SUMMARY AND CONCLUSIONS

Preliminary analysis of the data indicates that for piles 1 through 4 median nickel concentrations in 1978 are comparable to those measured in 1977. There seems to be no significant differences in median nickel concentration among the first four piles.

Piles 2 and 3 exhibit increased copper concentration which appear to be the result of increased copper mobility. Organic compounds which are capable of complexing copper may have been washed out of the soil top cover, allowing more copper to remain in solution.

Piles 5 and 6 tend to behave differently than the first four. Pile 5 produced acidic leachate and the pH in pile 6 started to decrease before freeze up. When the pH declined, substantial amounts of metal were released in the leachate. The exact cause of the acidification is not known, but is being studied.

The overall runoff coefficients indicate that pile 2 had the least amount of runoff. Pile 2 was covered with topsoil and a good vegetative cover was established. Vegetative cover was sparse on the till covered piles and preliminary analysis suggests that the runoff from these piles was comparable to untreated piles. All conclusions are preliminary and analysis is continuing.

FUTURE ANALYSIS

An outline for future analysis is given below. Any recommendations or comments on the outline or suggestions for additional analyses would be appreciated.

I. Calculate mass release from each pile

A. flow calculations

1. flow records must be reanalyzed and daily flow estimates revised

2. flow records from periods of good record will be used to develop regression relations between the piles

a. these relationships will be used to examine periods of partial and estimated records.

b. readjustments in daily flows will be made

3. plot daily hydrographs

4. compute total outflow from each pile

B. assign "representative" concentrations

1. ideally, for each major event, there would be a flow weighted composite sample, then the mass released during that event would be

mass released	(mg) =	total flow	(liters) X	flow weighted concentration (mg/l)

2. due to the start up nature of the project, a flow weighted sample does not exist for each storm

a. concentration variation with time, flow, and rainfall will be studied

b. "representative" concentrations will be chosen and applied to different portions of the hydrograph

II. Factors affecting mass release

A. top dressing

1. is there a difference between the covered and uncovered piles

2. compare the mass released by each pile for each event

B. time between events

1. plot mass release vs time between events

2. is there a relationship - does mass release increase as time between events increases

C. rainfall

1. plot mass release versus

   a. rainfall (in)

   b. rainfall intensity (in/hr)

2. is there a relationship - does mass release increase as rainfall and/or intensity increase

D. PH

1. plot mass release vs pH for piles 5 and 6

2. compare SO_4 release with metals release - is there evidence for a large increase in sulfide dissolution

E. age of piles

1. is there a relationship between mass release and the total amount of rainfall that has fallen on the pile.

III. Other considerations

A. Acid forming potential

1. delineate the possible cause for the acidic conditions in FL5

2. check literature references and devise experimental tests to try and isolate the cause of the acidity.

3. compare the behavior of 5 and 6, is there a trend.

B. Peak runoff vs base flow

1. How much of the flow is "peak runoff" and how much "base flow"

2. On a yearly basis is most of the mass transported during peak flow or during base flow

C. Compute release rates for each pile (kg /ton yr)

1. how does the release rate vary between piles

   a. is there a correlation with the % S in the rock

2. how do the release rates compare to other studies conducted on gabbro material

3. use major cations to estimate rates of host rock weathering - is this consistent with what is already known

IV. Redesign sampling plan

A. re-evaluate parameter list

1. are there some parameters which are not providing useful information

B. re-evaluate - sampling plan

1. should more or less samples be collected?

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Appendix 1 Field Methods

Methods for sampling the field leach piles have undergone constant evaluation and change. Changes were made to produce a more representative sample. Documentation of these changes is necessary for proper interpretation of sample results.

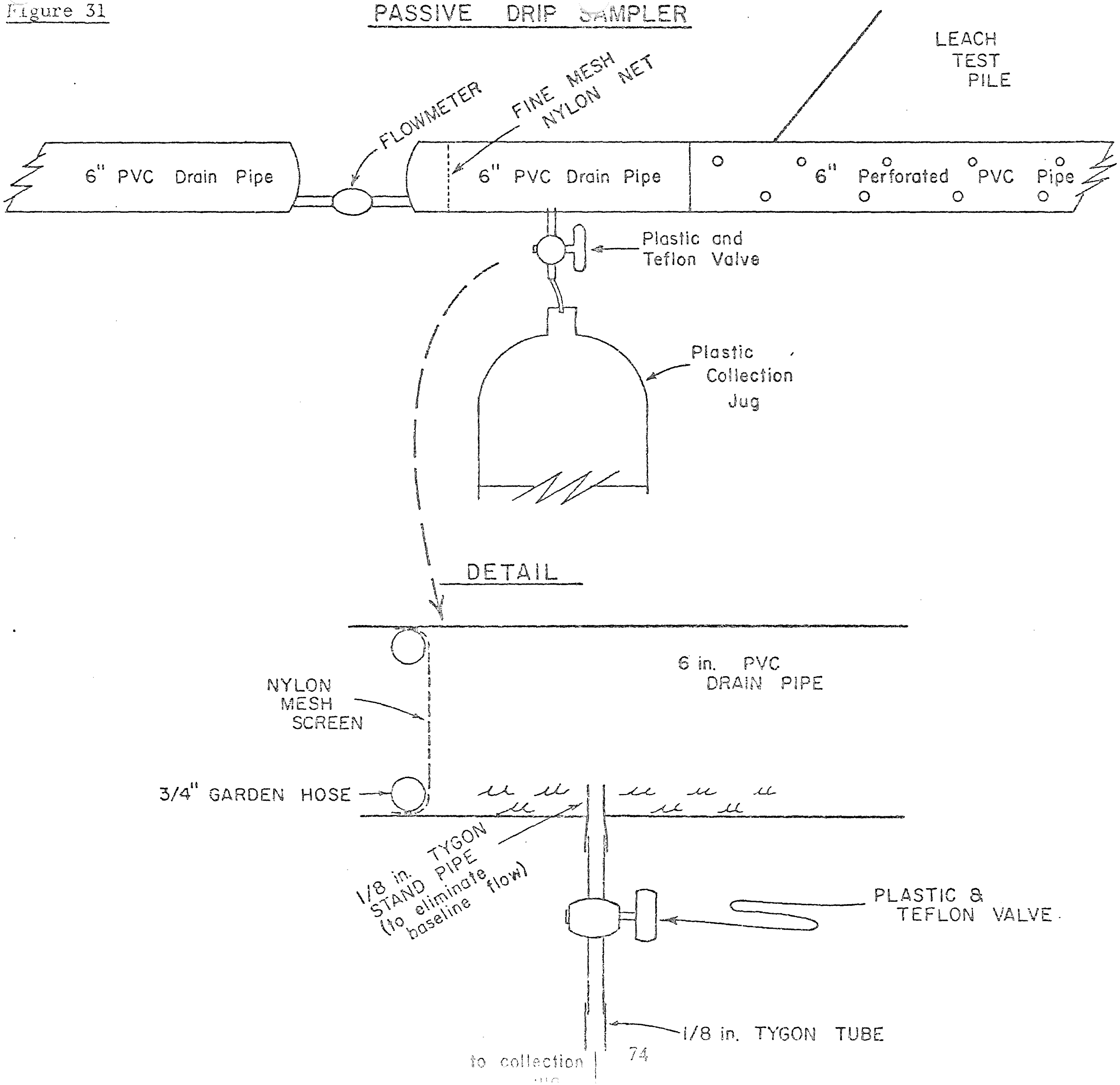
From April 26 to May 24 no volumetric discharges were obtained from individual leach piles. Instead, the discharge from the common sump (Figure 2) of the 6 leach piles was used to obtain average flow from individual piles. This method was not satisfactory because flow, and thus mass loadings, from individual piles could not be accurately calculated.

It was decided, therefore, to install low pressure, low volume flow meters in the discharge line of each leach-pile (Figure 3). The installation was completed on May 24. It soon became apparent that the flow meters were malfunctioning due to a combination of low water pressure and fine particulates. To correct this, two changes were made. A fine mesh nylon screen was installed upstream of the meter to filter particulates (Figure 31), and the position of the flow meter was lowered to give as much pressure drop as possible. These modifications were accomplished by July 14. Subsequently the meters functioned properly at high flows but continued to stop during low flows.

Release of metals is known to fluctuate with rain events, therefore, composite samples were needed to accurately estimate an average release for each rain event. To composite the flows a "passive drip sampler" (Figure 31) was developed and installed July 11. The passive drip sampler failed to operate as anticipated. Initially, the drip flow was expected to be proportional to the water level in the pipe; larger sample volumes being collected at high flow than at low flow. In practice, this did not work. The drip flow was difficult to regulate and showed very little response to the water level in the pipe. Since the drip rate did not

Figure 31

PASSIVE DRIP SAMPLER



change significantly with the flow, the composite sample tended to oversample base flow. After the filter screens (for the flow meters) were installed a standpipe was added so that only flow above base flow would be sampled. Thereafter the drip flow did not always begin with rising flow and had to be readjusted manually. Additional problems occured during backwater conditions. As the water backed up in the pipe, the drip flow continued and the sample did not represent the storm event. On several occasions, the backwater condition began during the night and by morning the five gallon collecting container had overflowed.

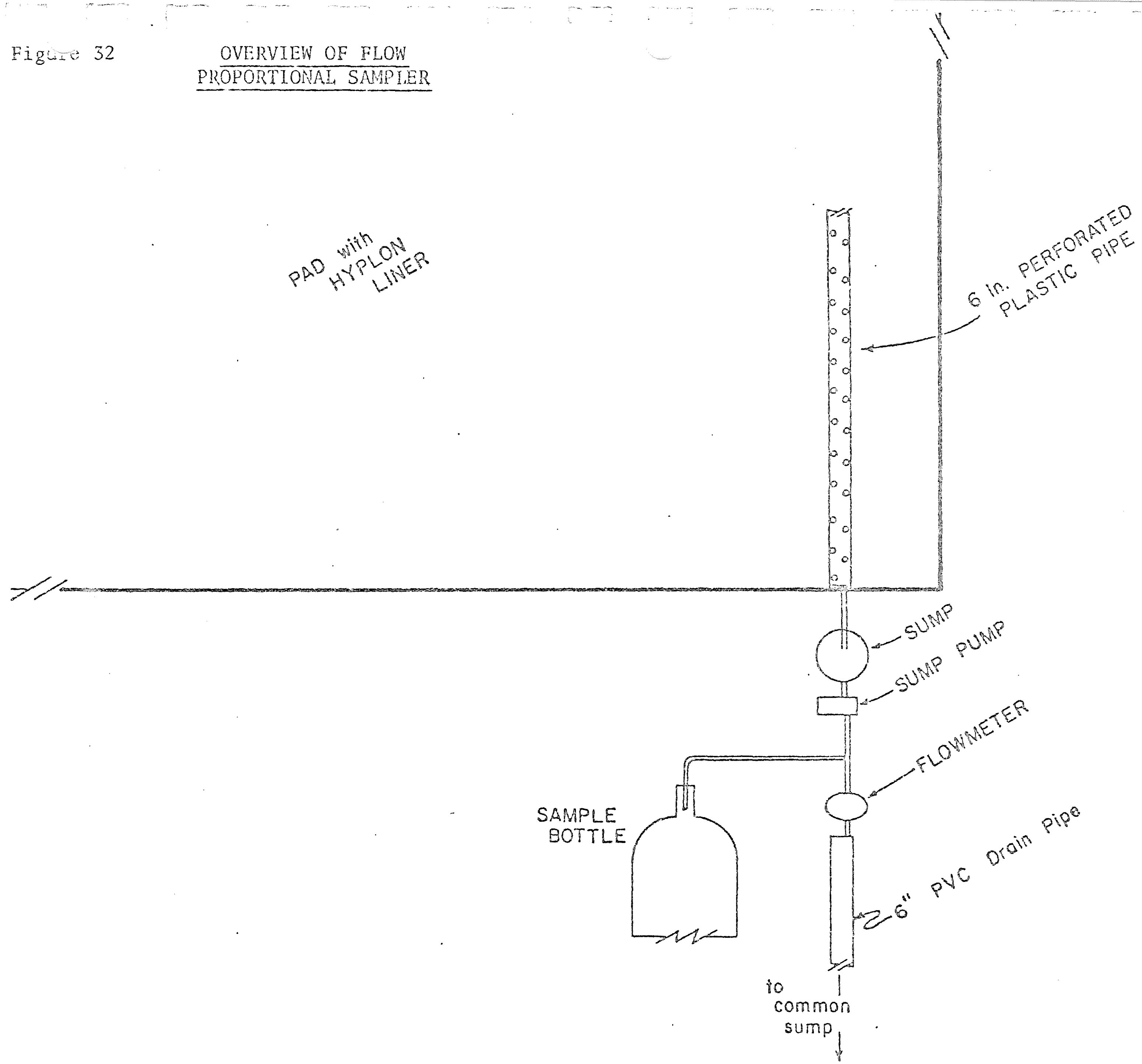
An attempt was made to solve both problems by developing a sump pump and a compositing system (Figures 3 and 32). The flow from the leach pile empties into a five gallon sump. The sump pump is controlled by a float switch in the sump. Each time the pump is activated the event is recorded on a Rustrak recorder. A flow meter installed on the pump outlet records total discharge. A small sample line has been installed in the pump discharge line. Each time the pump is activated a small aliquot is placed in the sampling container. This produces a flow weighted composite sample; more sample is collected at high flow since the pump is activated more frequently. This sampling and recording system was tested first on leach pile number 4 (installed August 11). The system operated well and it was decided to similiarly instrument the remaining piles. By November 3 instrumentation was completed on leaching piles 1,2 and 5. Instrumentation of piles 3 and 6 is nearing completion.

LABORATORIES

Analytical services for the study are provided by Serco Laboratories, Roseville, Minnesota; DNR Minerals laboratory, Hibbing, Minnesota; DNR field laboratory at Minnanax; and the Minnesota Department of Health laboratory in Minneapolis. The following is a list of the parameters analyzed by each laboratory.

Minnesota Dept. of Health	Serco Laboratories	DNR Hibbing	DNR Field Laboratory
Dissolved Organic Carbon	Chloride	Calcium	pH
	Nitrate	Magnesium	Specific Conductance
	Ammonia	Sodium	Temperature
	Total Phosphorus	Potasium	Alkalinity
	Sulfate	Copper	Dissolved Oxygen
		Nickel	
		Iron	
		Manganese	
		Cobalt	
		Zinc	

Figure 32 OVERVIEW OF FLOW PROPORTIONAL SAMPLER



Appendix II

FLOW CALCULATIONS

Flow meters were installed on each pile but did not always function satisfactorily. They were routinely read at 0800 and 1400-1600 every day during the week. The condition of the meter was noted (running, stopped, running but sticking). No readings were made on weekends and holidays.

After fine mesh screens were installed upstream of the meters, (July 14), the meters usually worked satisfactorily at high flows. Prior to July 14, the meters would sometimes jam during rain events and the flow would have to be estimated using volumetric flow measurements or through comparison with other piles. The meters rarely worked under low flow conditions. Base flows were generally computed using volumetric measurements. Normally the flow was measured between 1400-1600 and the recorded flow was assumed to be a good measure of the average daily flow rate.

Examples of the methods used to estimate daily flows are given in Table XVII. The general approach that was used was:

1 - meter readings were used whenever possible

2 - if a meter was stopped prior to a storm event, the assumption was made that it began to record when the runoff from the storm began.

3 - if the meter was recording at 1600 and still running at 0800 the next day the total flow was divided strictly by time i.e. one half of the flow was assigned to the time period 1600-2400, one half was assigned to the period 2400-0800.

4 - Weekend flows

a - if no rain occured during the weekend the flows would be interpolated from the Friday and Monday values.

b - if rain occured, meter readings would be used. Sometimes meter readings would be used to represent peak flow and base flow would be estimated from the Friday and Monday values.

5 - when there was no rain, the daily flow was computed from the volumetric measurement.

6 - in the early spring before individual meters were installed and before volumetric measurements were taken, the sump outflow was used to estimate the flow from each pile. The sump output divided by the number of piles that were flowing at that time gave the daily flow for each pile.

(A refinement could be made by weighting each pile by its collecting area. However, since the time period when these estimates were needed was relatively short and total flows were small, this refinement is probably not necessary).

EXAMPLE OF FLOW CALCULATIONS

The data for pile FL4 is shown below

(s=meter stopped, r=running; s-r, running, but sticking)

Date	Time	Meter Reading (gal)	Volumetric Flow Rate ml/min	Rainfall in Time	Daily Flow, liters
7-14	0800	6413s			
	1500	6412.9s	300	0	432
7-15	no readings			.08	432
7-16	weekend			0	281
7-17	0800	6413s		0	
	1400	6413s	90		130
7-18	0800	meter under water		1.51	
	1435	7235.2r	1020	2400-0200	3758
7-19	0800	7548s-r		.24 1400-1600	
	1455	7620.3r	2325		1274
7-20	0800	7849r		0	836

The calculations were made as follows:

Date	Rainfall	Method
7-14	0	volumetric flow used as daily average
7-15	.08	this was a small rain, the assumption was made that it was enough rain to maintain the overall flow at a level comparable to 7-14
7-16	0	since this was a weekend, no meter or volumetric measurements were made. The average of the flow on 7-15, which was assumed to be the same as the flow on 7-14, and 7-17 was used.

(cont'd)

Date	Rainfall	Method
7-17	0	volmetric flow was used as daily average
7-18	2400-0200 1.51	the assumption was that the meter began to record at 2400 the total flow from 2400-1435 was obtained from the meter the flow from 1435-2400 was obtained by time weighting the total recorded flow between 1435 and 0800, i.e. 2400-1435 = total flow from meter = 3113 l 1435 - 0800 = total flow from meter = 1184 l $1435 - 2400 = \frac{9.5}{17.5} (1184) = 643$ total daily flow =3113+643=3758 l
7-19	1400-1600 .24	1-the flow from 2400-0800 was obtained from the time weighted estimate as shown above 2-the flow from 0800-1500 was obtained from the meter 3-the flow from 1500-2400 was a time weighted estimate $2400\text{-}0800\ \frac{8}{17.5} (1184) = 541$ liters 0800-1500 meter = 276 1500-2400 9/17 (867) = 457 l Total Flow=541+276+457=1274

Appendix III

WATER QUALITY DATA

All the water quality samples that were collected by the DNR in 1978 are listed in Table XVIII. On April 24, one set of samples was collected by Amax and analyzed by Serco Laboratories (Table XIX). The results of all the samples are tabulated by pile and are presented in Tables XX - XXV.

C= composite sample
G= grab sample

Table XVIII WATER QUALITY SAMPLES COLLECTED IN 1978

DATE	FLOW CONDITIONS	PILES SAMPLED 1	2	3	4	5	6
4/26	Low Flow	G	G	G	G	G	G
5/24-26	Composite over rain		C	C	C	C	C
6/6	Peak	G					
6/7	After Peak	G					
6/14	Low Flow				2G		
6/16	Low Flow	G	G	G	G	G	G
6/23	Composite over rain	3G			13G		
6/26	Tail of rain	G			G		
7/5	Tail of rain	G	G	G		G	G
7/6	Low Flow				G		
7/7	Composite over rain				24G		
7/8	Composite over rain				13G		
7/9	Tail of rain				G		
7/6-7	Peak	C					
7/7-11	Tail of rain	C					
7/12-13	Peak	C	C	C		C	C
7/13	Tail of rain				G		
7/14-19	Composite over rain	C	C	C		C	C
8/1-2	Composite over rain	C	C	C		C	C
8/2	Tail of rain					C	
8/4	Low Flow	G	G	G	G	G	G
8/10	Low Flow	G		G		G	G
8/14-16	Composite over rain	C			C		
8/16	Composite over rain	G	3G	3G	C	4G	G,C
8/17	Tail of rain					G	
8/18	Tail of rain					G	

C= composite sample
G= grab sample

DATE	FLOW CONDITIONS	PILES SAMPLED 1	2	3	4	5	6
8/16-17	Tail of rain				C		C
8/17-18	Composite over rain				C		
8/18-21	Low Flow				C		
8/17-23	Composite over rain	C	C	C		C	C
8/21-23	Before Peak				C		
8/23	Peak				2C	C	
8/23-25	Tail of rain	C	C	C	C	C	C
8/25-28	Composite over rain	C	C		C	C	C
9/10-13	Composite over rain		C	C	C		
9/10-11	Composite over rain				C		C
9/11	Before Peak					G	
9/11-12	Peak and after peak					C	
9/12-13	After peak	C					
9/13	Tail of rain	G	G	G	2G	G	G
10/14-17	Composite over rain	C			C		C

Table XIX
Amax Samples -- Serco

Date	4-24	4-24	4-24	4-24	4-24	4-24
Sample type	grab	grab	grab	grab	grab	grab
Time						
Site	FL-1	F1-2	F1-3	FL-4	FL-5	FL-6
Parameters						
Alkalinity	82	66	55	53	58	80
pH	7.8	7.8	7.6	7.5	7.7	7.7
Temperature						
Specific Conductance	967	819	642	776	1520	5150
Calcium	115	75	67	88	165	430
Magnesium	11	17	12	8.2	12	150
Sodium	110	90	58	63	162	516
Potassium	9.0	8.2	8.2	17	4.5	8.5
Copper	.025	.019	.013	.017	.039	.086
Nickel	.110	.095	.075	.090	.725	.960
Iron	.15*	7.5*	.35*	.20*	.25*	.45*
Manganese	.06	.06	.06	.09	.33	.66
Cobalt	.007	.006	.005	.007	.082	.042
Zinc	.033	.029	.017	.048	.021	.011
Sulfate	540	400	300	350	780	680
Chloride	3	3	2	5	32	569
Nitrate	2.7	4.3	3.1	1.3	28	460
Ammonia						
Total Phosphorus	0.1	.2	.1	.1	.1	0.1
Dissolved Organic Carbon	8.9	6.8	4.0	5.0	10	5.8

* Total Metal

Explanation of comment statements

1. Rain — If the sample was collected during a rainfall event, the total amount of rainfall and its time of occurence is given. If the sample was collected between events, the time and amount of the preceding rainfall is given.

2. Portion of the hydrograph sampled
   If the sample was a grab sample, the general position of the sample relative to the peak in stockpile runoff is given. If the sample was a composite, the portion over which the sample was collected is given.

3. Other — These comments refer to field observations on pile behavior, sample appearance, etc.

Table XX WATER QUALITY DATA FL 1, 1978

FL-1 Date	4-26	6-6	6-7	6-16	6-23	6-23	6-23	6-26
Sample type	grab	grab	grab	grab	grab	grab	grab	grab
Time		2110	0900	1025	0950	1300	1525	0900
Parameters								
Alkalinity								
pH	7.15		7.60	7.84	7.49	7.82	7.85	6.35
Temperature	9.0	7.0		11.0	14.0	12.0	13.0	15.0
Specific Conductance	1120	1900	3325	2700	1775	2150	2200	2400
Calcium	112	216	253	244	189	180	181	195
Magnesium	11	19	23	22	18	17	17	20
Sodium	113	268	327	368	313	273	279	313
Potassium	13	20	23	22	23	21	20	21
Copper	.032	.030	.041	.028	.027	.024	.023	.024
Nickel	.037 a	.250	.272	.155 a	.274	.228	.250	.294
Iron	.20 a	.02	.03	.05	.02	.02	.03	.04
Manganese	.06	.13	.15	.14	.10	.09	.08	.09
Cobalt	.003	.009	.005	.001	.013	.012	.012	.014
Zinc	.017	.002	.030 a	.002	.004	.002	ND	.010
Sulfate					1400	1400	1000	
Chloride	Not on computer				6	6	3	
Nitrate								
Ammonia								
Total Phosphorus								
Dissolved Organic Carbon								
Discharge at time of Sample (ml/min)	trickle	2558	-	120	175	207	127	59
Total Volume over composite (liters	-	-	-	-	-	-	-	-

Comments

1. All parameters in mg/l except as follows.
   a. Temperature = ^{o}C
   b. Specific Conductance = umhos
   c. Nitrates and ammonia are mg/l as nitrogen, total phosphorus is mg/l as phospho[illegible] and dissolved organic carbon is mg/l as carbon.

2. All metal values are filtered, unless otherwise specified.

3. a = Value appears anomalous b = reanalysis

Comments

3. Rain		.75" 1730-2400	last rain 6-6 0.75" 1730-2400	last rain 6-10 0.19" 2300-2400	0745-1045 1915-2000	.35"	.29" .06"	last rain 6-25 .04" 1800-1830
4. Portion of hydrograph sampled	low flow	Peak	After peak	low flow	Before peak	After peak	After peak	Tail of 0.4" rain
5. Other	Initial sample Snow Run off					Some gray matter in water		

FL-1

Date Sample type Time	7-5 Grab 0830	7-7 Comp. 1600 on 7-6 to 1630 on 7-7	7-11 Comp. 1630 on 7-7 to 1525 on 7-11	7-13 Comp. 1200 on 7-12 to 0840 on 7-13	7-18 Comp. 1530 on 7-14 to 1400 on 7-19	8-2 Comp. 8-1 - 1700 to 1515 on 8-2	8-4 Grab 1045	8-10 Grab 1340
Parameters								
Alkalinity								70
pH	7.75	7.90	7.70	7.92	7.80	7.90	7.80	8.10
Temperature	14.0	19				22	22	24
Specific Conductance	2100	1900	2450		1400	1100	1650	2400
Calcium	202	221	303[b]	531[a]	340	176	300	414
Magnesium	20	23	26	31	19	11	23	26
Sodium	206	222	286	395	220	127	209	317
Potassium	28	34	38	45	34	25	37	46
Copper	.018	.024	.024, .03[b]	.027	.023	.027	.034	.03
Nickel	.206	.285	.405, .37[b]	.405[a]	.255	.21	.33	.46
Iron	.01	.04	.03	.01	.01	.01	.03	.02
Manganese	.09	.09	.14	.16	.11	.09	.13	.16
Cobalt	.007	.019	.022, .03[b]	.026	.019	.010	.016	.03[b]
Zinc	ND	.005	.01[b]	.058[a]	.003	.010	.013	.025
Sulfate	900	800	1150	1500	1050	650	1200	1600
Chloride	4	4	5	4	1	1	3	4
Nitrate		5.7	5.7	6.2	3.9	3.4	5.0	-
Ammonia		.44	.64	0.55	0.5	0.7	< 0.08	< 0.13
Total Phosphorus		< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.1	< 0.1
Dissolved Organic Carbon								
Discharge at time of sample (ml/min)	177 (Q at 1535)						167	70
Total Volume over composite (liters)								

1. All parameters in mg/l except as follows.
   a. Temperature = °C
   b. Specific Conductance = umho
   c. Nitrates and ammonia are mg/l as nitrogen, total phosphorus is mg/l as phosphorus and dissolved organic carbon is mg/l as carbon.
2. All metal values are filtered, unless otherwise specified.
3. Comp. = Composite a= Value appears anomalous b = reanalysis

Comments 4. Rain	Last rain 7-1, 7-2 1.36" 1400 on 7-1 to 1100 on 7-2	1.38" 0600-1400	1.38" from 0600-1400 on 7-7; 0.15" from 1100 7-8 to 0200 7-9	0.77" from 1400-1600 and 2000-2300 on 7-12	1.51" 0001-0200	Last rain 8-1 0.95"	Last rain 8-1 0.95"	Last rain 8-1 0.95" 0.13" on 8-10 time 1100-1200
5. Portion of hydrograph	Tail of 1.36" rain	Peak	Tail	Peak	Comp. over rain 7-18	Comp. over rain 8-1	Tail of 0.95" rain	Low flow
6. Other			Comp. was 18165 mls		First of the present drip comps.			

FL-1

Date	8-16	8-16	8-24	8-25	8-28	9-13	9-13
Sample type	Grab	Comp.	Comp.*	Comp.	Comp.	Grab	Comp.
Time	1015	8-14 2030 to 1450 on 8-16	1025 on 8-17 to 1945 on 8-23	1945 on 8-23 to 0830 on 8-25	0830 on 8-25 to 0820 on 8-28	1020	1130 on 9-12 to 1020 on 9-13
Parameters							
Alkalinity		42	50	47	59	41	40
pH	8.00	7.70	8.10	7.55	7.85	7.6	7.55
Temperature	23	16		22		14	
Specific Conductance	1400	1675	2600	2500	2700	2175	2000
Calcium	190	149	302	300	308	254	238
Magnesium	15	13	26	26	26	20	18
Sodium	107	97	240	229	280	169	151
Potassium	28	22	40	43	40	41	38
Copper	.02	.02	.04	.04	.05	.05	.04
Nickel	.20	.17	.36	.35	.42	.27	.28
Iron	.02	.02	.06	.02	.04	.03	.03
Manganese	.07	.07	.14	.14	.15	.14	.10
Cobalt	.02	.02	.04	.03[b]	.07[b]	.02	.02
Zinc	.01	.02	.02	.02	.02	.01	.01
Sulfate		640	1400	1300		1100	1000
Chloride		2	1	1		1	2
Nitrate		2.5	5.0	4.6		-	-
Ammonia		-	-	0.40		-	-
Total Phosphorus		<0.1	<0.1	0.2		<0.1	<0.1
Dissolved Organic Carbon							
Discharge at time of sample (ml/min)	3441					426	
Total Volume over composite (liters)							

1. All parameters in mg/l except as follows.
   a. Temperature = °C
   b. Specific Conductance = umho
   c. Nitrates and ammonia are mg/l as nitrogen, total phosphorus is mg/l as phosphorus and dissolved organic carbon is mg/l as carbon.
2. All metal values are filtered, unless otherwise specified.
3. Comp. = Composite   a = Value appears anomalous   b = reanalysis

Comments 4. Rain	1.28" 0400-0800 .60" on 8-14 .26" on 8-15	1.28" 0400-0800 .60" on 8-14 .26" on 8-15	Last rain 8-22,8-23 1.75" 2000 on 8-22 to 1100 on 8-23	Last rain 8-22, 8-23 1.75" 2000 on 8-22 to 1100 on 8-23	Last rain 8-27 0.20" 1200-1400	Last rain 9-10, 11,12 2.46" total 1.00" 1200-1530 9-10 1.31" 0830-1200 9-11 .15" 0300-1000 0-12	
5. Portion of hydrograph	Peak	Comp. over rain 8-16	Comp. over rain 8-22,23	Tail of 175" rain	Comp. over rain 8-27	Tail of 2.46" rain	After Peak
6. Other							

*Mean of duplicate samples

Table XXI Water Quality Data, FL2, 1978

Date	4-26	5-25	6-16	7-5	7-13	7-19	8-2	8-4
Sample type	Grab	Comp.	Grab	Grab	Comp.	Comp.	Comp.	Grab
Time			1120	0830	1155 on 7-12 to 0840 on 7-13	0810 on 7-18 to 1400 on 7-19	Start of rain to 0930 on 8-2	1030
Parameters								
Alkalinity								
pH	7.20	7.70	7.72	7.5	7.92	7.80	7.75	7.75
Temperature	4.0		11.0	12			19	22
Specific Conductance	1000	1900	4200	2700		1300	2000	2500
Calcium	99	177	323	218	491	291	191	341
Magnesium	13	23	47	33	43	24	21	42
Sodium	101	241	555	313	376	189	241	410
Potassium	12	15	23	28	37	28	26	33
Copper	.038	.040	.056	.057	.049	.062	.08	.07
Nickel	.030[a]	.240	.200[a]	.316[a]	.410	.24[b]	.26	.44
Iron	.82[a]	.05	.03	.04	.03	.01	.04	.05
Manganese	.07	.16	.31	.22	.29	.16	.18	.28
Cobalt	.003	.008	.015	.021	.033	.01, .019	.01[b]	.029
Zinc	.020	.028	.075	.084	.09[b]	.033	.055	.113[a]
Sulfate				1400	800[r]	800[r]	1100[r]	1700
Chloride				34	30	41	14	19
Nitrate					23	24	19	26
Ammonia					.70	.55	.8	< .08
Total Phosphorus					< 0.1	< 0.1	< 0.1	< 0.1
Dissolved Organic Carbon								
Discharge at time of sample (ml/min)	Trickle		192	133				100
Total Volume over composite (liters)								

1. All parameters in mg/l except as follows.
   a. Temperature = °C
   b. Specific Conductance = umho
   c. Nitrates and ammonia are mg/l as nitrogen, total phosphorus is mg/l as phosphorus and dissolved organic carbon is mg/l as carbon.
2. All metal values are filtered, unless otherwise specified.
3. Comp. = Composite
4. a = Value appears anomalous b = reanalysis
5. r = Analysis rerun, see 10-5-78 memorandum from Serco.

Comments								
4. Rain		0.29" 0630-0730	Last rain 6-10 0.10" 2300-2400	Last rain 7-1,7-2 1.36" 1400 on 7-1 to 1100 on 7-2	0.77" from 1400-1600 & 2000-2300 on 7-12	1.51" from 0001-0200 on 7-18; 0.24" on 7-19 (time unknown)	Last rain 8-1 0.95"	Last rain 8-1 0.95"
5. Portion of hydrograph		Comp. over rain 5-25	Low flow	Tail of 1.36" rain	Peak	Tail of 1.51" rain on 7-18	Comp. over rain 8-1	Tail of 0.95" rain
6. Other	Initial sample					First of the pre-set drip comps.		

FL-2

Date Sample type Time	8-16 Grab 1010	8-16 Grab 1345	8-16 Grab 1655	8-23 Comp. 1000 on 8-17 to 1940 on 8-23	8-25 Comp. 1940 on 8-23 to 0840 on 8-25	8-28 Comp. 0840 on 8-25 to 0820 on 8-28	9-13 Grab* 1045	9-13 Comp. Rain on 9-10 to 1045 on 9-13
Parameters								
Alkalinity		38	41	31	35	48	41	17
pH	7.20	7.80	7.75	7.60	7.50	7.55	7.45	7.05
Temperature	23				23		15	
Specific Conductance	975	1100	1200	1100	1600	2300	1725	950
Calcium	100	108	116	103	170	253	182	84
Magnesium	12	15	16	15	24	34	22	10
Sodium	88	95	104	86	125	196	138	74
Potassium	17	16	17	18	28	32	30	23
Copper	.14,.17[b]	.12,.14[b]	.13,.14[b]	.13,.15[b]	.11	.10	.10	.14
Nickel	.15	.18	.21	.18	.24	.38	.26	.12
Iron	.05	.05	.04	.04	.01	.01	.02	.03
Manganese	.08	.10	.10	.10	.15	.23	.16	.06
Cobalt	.01[b]	.02	.04	.02	.03	.05,.04[b]	.02	.02
Zinc	.02	.02	.04	.02	.05	.09[b]	.06	.03
Sulfate		500	500	460	680	1100	600	567
Chloride		17	17	15	25	34	18	6
Nitrate		10	11	9.4	17	24	13	-
Ammonia		-	-	-	0.64	-	<0.10	-
Total Phosphorus		0.1	0.8	< 0.1	<0.1	0.1	<0.1	< 0.1
Dissolved Organic Carbon		17						
Discharge at time of sample (ml/min)	1500	632	420				130	
Total Volume over composite (liters)								

1. All parameters in mg/l except as follows.
   a. Temperature = °C
   b. Specific Conductance = umho
   c. Nitrates and ammonia are mg/l as nitrogen, total phosphorus is mg/l as phosphorus, and dissolved organic carbon is mg/l as carbon.
2. All metal values are filtered, unless otherwise specified.
3. Comp. = Composite
4. a = Value appears anomalous b = reanalysis

Comments								
4. Rain	1.28" from 0400-0800 on 8-16 also: .60" from 2030-2400 on 8-14 .26" from 0001-0100 and 1000-1130 on 8-15			.23" on 8-18 0001-0100 .60" on 8-22 2000-2400 1.15" on 8-23 0001-1100	Last rain 822 8-23 1.75" 2000 on 8-22 to 1100 on 8-23	Last rain 8-27 0.20" 1200-1400	Last rain 9-10,11, 12 2.46" total 1.00" 1200-1530 9-1 1.31" 0830-1200 9-1 .15" 0300-1000 9-12	
5. Portion of hydrograph	Peak	After Peak	After Peak	Comp. over rain 8-18, 22 8-23	Tail of 1.75" rain	Comp. over rain 8-27	Tail of 2.46" rain	Comp. over rain 9-10, 11,12
6. Other			Water was yellow colored					
*Mean of duplicate samples								

Table XXII Water Quality Data, FL3, 1978

Date Sample type Time	4-26 Grab	5-25 Comp.	6-16 Grab 1205	7-5 Grab 0845	7-13 Comp. 1210 on 7-12 to 0840 on 7-13	7-19 Comp. 1530 on 7-14 to 1400 on 7-19	8-2 Comp. 8-1 1800 to 1515 on 8-2	8-4 Grab* 1100
Parameters								
Alkalinity								
pH	7.20	7.80	7.79	7.3	7.55	7.85	7.60	7.65
Temperature	4.5		6.0	9.0			22	22
Specific Conductance	675	1200	3000	1600		1000	650	950
Calcium	62	106	214	142	352	241	96	156
Magnesium	10	24	57	34	46	28	14	24
Sodium	52	122	372[a]	102	207	-	60	88
Potassium	12	15	21	23	32	27	21	26
Copper	.023	.013	.026	.20[b]	.049	.074, .11[b]	.08	.08
Nickel	.06[b]	.042[a]	.185	.282, .36[b]	.405	.140, .33[b]	.21	.32
Iron	.70[b]	.04	.06	< .02	.03	.01	.03	.02
Manganese	.05	.09	.24	.17	.24	.15	.16	.16
Cobalt	0	.050[a]	.012	.017	.030	.020	.010	.020
Zinc	0	.020	.059	.037	.092	.055	.025	.044
Sulfate				600	1050[r]	550[r]	367[r]	500
Chloride				78	34	35	12	17
Nitrate					12	10	8.0	11
Ammonia					1.0	0.75	0.2	<0.08
Total Phosphorus					<0.1	0.1	0.2	< 0.1
Dissolved Organic Carbon								
Discharge at time of sample (ml/min)	Trickle		496[BW]	293				1000[BW]
Total Volume over composite (liters)								

1. All parameters in mg/l except as follows.
   a. Temperature = ^{o}C
   b. Specific Conductance = umho
   c. Nitrates and ammonia are mg/l as nitrogen, total phosphorus is mg/l as phosphor and dissolved organic carbon is mg/l as carbon.
2. All metal values are filtered, unless otherwise specified.
3. Comp. = Composite
4. a = Value appears anomalous b = reanalysis
5. r = Analysis rerun, see 10-5-78 memorandum from Serco.

Comments								
4. Rain		0.29" 0630-0730	Last rain 6-10 0.10" 2300-2400	Last rain 7-1, 7-2 1.36" 1400 on 7-1 to 1100 on 7-2	0.77" from 1400-1600 & 2000-2300 on 7-12	1.51" from 0001-0200 on 7-18; 0.24" on 7-19 (time unknown)	Last rain 8-1 0.95"	Last rain 8-1 0.95"
5. Portion of hydrograph		Comp. over rain 5-25	Low flow	Tail of 1.36" rain	Peak	Tail of 1.51" rain on 7-18	Comp. over rain 8-1	Tail of 0.95" rain
6. Other	Initial sample					First of the pre-set drip comps.; comp. didn't drip over rain period. Caught tail of rain from about 0810 on 7-18 to 1400 on 7-19		

*Mean of duplicate samples

BW=backwater is present

Date Sample type Time	8-10 grab 1340	8-16 grab 1025	8-16 grab 1400	8-16 grab 1640	8-23 Comp. 1050 on 8-17 to 1955 on 8-23	8-25 Comp. 1955 on 8-23 to 0835 on 8-25	9-13 grab 1030	9-13 Comp. Rain on 9-10 to 1020 on 9-13
Parameters								
Alkalinity	40		28	30	33	25	43	29
pH	7.90	7.60	7.65	7.60	7.50	7.30	7.3	7.30
Temperature	24	23	22	16		24	14	
Specific Conductance	1900	700	750	800	750	1150	1350	29
Calcium	348	79	89	83	75	115	147	120
Magnesium	51	13	15	16	14	23	24	19
Sodium	188	42	50	46	45	67	81	68
Potassium	49	17	20	16	17	23	28	27
Copper	.05,.07[b]	.11,.12[b]	.11,.13[b]	.10,.13[b]	.10	.08	.08	.09
Nickel	.56,.57[b]	.20,.18[b]	.24,.17[b]	.23,.22[b]	.19	.25	.30	.30
Iron	.01	.05	.08	.08	.07	.04	.04	.03
Manganese	.28	.07	.08	.09	.08	.10	.14	.10
Cobalt	.09	.02	.01	.02	< .02[b]	.01	.01	.03
Zinc	.073	.02	.02	.02	.02	.03	.04	.03
Sulfate	1200		300		300	500	750	567
Chloride	48		10		7	11	8	6
Nitrate	-		5.3		3.6	8.5	5.5	-
Ammonia	< 0.13		1.1		-	1.3	< 0.08	-
Total Phosphorus	< 0.1		0.1		0.1	< 0.1	< 0.1	< 0.1
Dissolved Organic Carbon								
Discharge at time of sample (ml/min)	30	14,195[d]	2839	2103			451	
Total Volume over composite (liters)								

1. All parameters in mg/l except as follows.
   a. Temperature = °C
   b. Specific Conductance = umho
   c. Nitrates and ammonia are mg/l as nitrogen, total phosphorus is mg/l as phosphorus and dissolved organic carbon is mg/l as carbon.
2. All metal values are filtered, unless otherwise specified.
3. Comp. = Composite   a = Value appears anomalous   b = reanalysis

[d] Backwater suspected

FL-3 Date Sample type	8-10 grab	8-16 grab	8-16 grab	8-16 grab	8-23 Comp. 1050 on 8-17 to 1955 on 8-23	8-25 Comp. 1955 on 8-23 to 0835 on 8-25	9-13 grab 1030	9-13 Comp. Rain on 9-10 to 1020 on 9-13
4. Rain	last rain 8-1 0.95"	1.28" from 0400-0800 on 8-16. Also: 0.60" from 2030-2400 on 8-14 0.26" from 0001-0100 and 1000-0130 and 1000-1130			.23" on 8-18 0001-0100 .60" on 8-22 2000-2400 1.15" on 8-23 0001-1100	last rain 8-22,23 1.75" 2000 on 8-22 to 1100 on 8-23	last rain 2.46 total 1.00" 1200-1530 9-1 1.31" 0830-1200 9-1 0.15" 0300-1000 9-1	
5. Portion of hydrograph	low flow	Peak	After peak	After peak	Comp. over rain 8-18,8-22, 8-23	Tail of 1.75" rain	Tail of 2.46" rain	Comp. over rain 9-10,11,1
6. Other								

Table XXIII Water Quality Data, FL4, 1978

Date	4-26	5-25	6-14	6-16	6-23	6-23	6-23	6-23
Sample type	Grab	Comp.	Grab*	Grab	Grab	Grab	Grab	Grab
Time			0745	0800	0950	1045	1200	1245
Parameters								
Alkalinity								
pH	7.20	7.40	7.60	7.70	7.49	7.35	7.2	7.59
Temperature	4.0		9.0	11	14.0	13.0	13.0	14.0
Specific Conductance	1100	1750	2500	2600	1300	1775	2575	2800
Calcium	121	204	228	247	134	151	207	223
Magnesium	11	20	29	30	17	19	28	31
Sodium	84	165	262	277	154	192	275	308
Potassium	27	35	37	41	27	30	39	43
Copper	.018	.012[a]	.024	.026	.022	.023	.026	.028
Nickel	.035[a]	.210	.220	.175	.172	.216	.314	.336
Iron	.42 [a]	.02	.04	.04	.01	.06	.05	.05
Manganese	.10	.19	.21	.26	.16	.17	.22	.23
Cobalt	.004	.012	.016	.015	.009	.015	.025	.028
Zinc	.048	.112	.128	.120	.017	.042	.124	.174
Sulfate					600	900	1400	1400
Chloride					17	20	27	30
Nitrate								
Ammonia								
Total Phosphorus								
Dissolved Organic Carbon								
Discharge at time of sample (ml/min)	Trickle		125	94	90	423	475	400
Total Volume over composite (liters)								

1. All parameters in mg/l except as follows.
   a. Temperature = ^{o}C
   b. Specific Conductance = umho
   c. Nitrates and ammonia are mg/l as nitrogen, total phosphorus is mg/l as phosphorus and dissolved organic carbon is mg/l as carbon.
2. All metal values are filtered, unless otherwise specified.
3. Comp. = Composite
4. a = Value appears anomalous

Comments								
4. Rain		0.29" 0630-0730	Last rain 6-10 0.10" 2300-2400	Last rain 6-10 0.10" 2300-2400	Total rainfall on 6-23 = 0.35" .29" from 0745 - 1045 .06" from 1915 - 2000			
5. Portion of hydrograph	Low flow	Comp. over rain 5-25	Low flow sample just prior to rain.	Low flow				
6. Other	Initial sample				Some cloudy grey when filtered on surface of unit.		Water grey in color prior to filtering	Water not as turbid as previous sample.

*Mean of duplicate samples.

type	6-23 Grab 1420	6-23 Grab* 1540	6-23 Grab 1700	6-23 Grab 1800	6-23 Grab 1900		6-23 Grab* 2100	
eters								
alinity								
[illegible]	7.45	7.45	7.82	7.55	7.8		7.75	
perature	14.0	14		7.0				
ific uctance	2650	2650	2650	2500	2625		2500	
lcium	225	223	215	228	220		216	
esium	31	30	29	32	30		30	
dium	300	296	291	306	293		292	
ssium	43	42	41	43	43		42	
pper	.026	.024	.020	.015	.020		.020	
kel	.336	.325	.314	.360	.336		.320	
1	.03	.02	.02	.03	.01		< .02	
nganese	.23	.22	.20	.24	.23		.22	
[illegible]	.026	.026	.022	.026	.023		.022	
inc	.156	.152	.170	.173	.160		.154	
fate	1200	1200	1200		1300			
hloride	28	21	31		30			
rate								
monia								
otal osphorus								
Dissolved rganic rbon								
Discharge at ime of sample al/min)	280	175						
Total Volume over omposite (liters)								

1. All parameters in mg/l except as follows.
   a. Temperature = ^{o}C
   b. Specific Conductance = umho
   c. Nitrates and ammonia are mg/l as nitrogen, total phosphorus is mg/l as phosphorus, and dissolved organic carbon is mg/l as carbon.
2. All metal values are filtered, unless otherwise specified.
3. Comp. = Composite

Comments							
4. Rain			Total rainfall on 6-23 = 0.35" 0.29" from 0745 - 1045 0.06" from 1915 - 2000				
5. Portion of hydrograph							
6. Other	Clear water		Isco #2 pH taken 6-26 1350; filtered 6-26; added to Isco #3 for SO_4 Cl	Isco #3	Isco #4 pH taken 6-26 1340; filtered 6-26; added to Isco #5 for SO_4 and Cl		Isco #6 pH taken 6-26 1555; filtered at 1445 on 6-26; kept separate for SO_4 Cl

* Mean of duplicate samples.

Date	6-23	6-26	7-6	7-7	7-7	7-7	7-7	7-7
Sample type	Grab	Grab	Grab	Grab	Grab	Grab	Grab	Grab
Time	2300	0920	0830	0400	0500	0600	0700	0800
Parameters								
Alkalinity								
pH	7.7	7.90	7.58	7.65	7.60	7.45	7.2	7.3
Temperature		17	17					
Specific Conductance	2400	2150	1825	2050	2050	2050	1200	1400
Calcium	213	186	212	234	242b	234	132	166
Magnesium	29	24	25	25	24b	27	15	17
Sodium	278	260	190,173b	201	220b	239	137	156
Potassium	41	41	52	45	43b	42b	20b	29b
Copper	.013	.021	.019	.017	.02	.02	.01	.02
Nickel	.36b	.260	.275	.290	.32	.31	.17	.18
Iron	.01b	0a	.03	.03	.01	.02	.04	.01
Manganese	.22	.18	.18	.20	.19	.19	.12	.13
Cobalt	.025	.019	.019	.022	.06	.06	.02	.04
Zinc	.147	.084	.073	.132	.13	.12	.06	.07
Sulfate		900	850r	1000r		--		550
Chloride		28	11	17				9
Nitrate								
Ammonia								
Total Phosphorus			0.1	< 0.1				< 0.1
Dissolved Organic Carbon								
Discharge at time of sample (ml/min)		5	88					
Total Volume over composite (liters)								

1. All parameters in mg/l except as follows.
   a. Temperature = ^{o}C
   b. Specific Conductance = umho
   c. Nitrates and ammonia are mg/l as nitrogen, total phosphorus is mg/l as phosphorus and dissolved organic carbon is mg/l as carbon.
2. All metal values are filtered, unless otherwise specified.
3. Comp. = Composite
4. a = Value appears anomalous b = reanalysis
5. r = Analysis rerun, see 10-5-78 memorandum from Serco.

Comments

4. Rain		Last rain 6-25 .04" 1800 -1830	Last rain 7-1,7-2 1.36" 1400 on 7-1 to 1100 on 7-2	Total rainfall on 7-7 = 1.38" from 0600 - 1400				
5. Portion of hydrograph		Tail of .04" rain	Low flow after 1" rain					
6. Other	Isco #8 pH taken 6-26 1540; filtered 6-26 added to Inco #7 for SO_4 and Cl			Isco filtered 1450	Isco filtered 1455	Isco combined for SO_4 #Cl	Isco	Isco filtered 1520 combined with 0900 for general parameters

Date	7-7	7-7	7-7	7-7	7-7	7-7	7-7	7-7
Sample type	Grab	Grab	Grab	Grab	Grab*	Grab	Grab	Grab
Time	0830	0900	1000	1100	1200	1300	1400	1500
Parameters								
Alkalinity								
pH	7.20	7.15	7.40	7.40	7.40	7.40	7.15	
Temperature					11	11	11	
Specific Conductance	1000	1450	1550	1275	1125	1050	950	
Calcium	176	172	179	145	126	115[b]	104	
Magnesium	18	18	19	15	13	10[b]	10	
Sodium	161	157	164	122	110	88[b]	80	
Potassium	1363[a]	29[b]	33[b]	268[a]	607[a]	22[b]	20[b]	
Copper	.02	.02	.02	.02	.02	.01	.01	
Nickel	.25	.21	.24	.20	.14	.14	.10	
Iron	.03	.07	.05	.01	.02	.02	.02	
Manganese	.12	.13	.12	.10	.08	.08	.07	
Cobalt	.02	.02	< .01	.02	.02	.01	< .02	
Zinc	.07	.07	.08	.05	.04	.04	.04	
Sulfate	600	550	600[r]	450[r]	450	400	250[r]	500
Chloride	9	9	11	8	6	6	5	5
Nitrate	2.0				1.8		1.4	
Ammonia	.76				1.1		.96	
Total Phosphorus	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.1
Dissolved Organic Carbon								
Discharge at time of sample (ml/min)	13,360		11,238	8,051	5,002	4,732	6,489	5,344
Total Volume over composite (liters)								

1. All parameters in mg/l except as follows.
   a. Temperature = °C
   b. Specific Conductance = umho
   c. Nitrates and ammonia are mg/l as nitrogen, total phosphorus is mg/l as phosphorus and dissolved organic carbon is mg/l as carbon.
2. All metal values are filtered, unless otherwise specified.
3. Comp. = Composite
4. a = Value appears anomalous b = reanalysis
5. r = Analysis rerun, see 10-5-78 memorandum from Serco.

Comments							
4. Rain				Total rainfall on 7-7 = 1.38" from 0600 - 1400			
5. Portion of hydrograph							
6. Other		Isco filtered 1530 combined with 0800 for G.P.	Isco				

*Mean of duplicate samples.

Date Sample type Time	7-7 Grab 1600	7-7 Grab 1700						
Parameters								
Alkalinity								
pH	7.65	7.35						
Temperature	11	11						
Specific Conductance	950	1100						
Calcium	144	119						
Magnesium	11	11						
Sodium	84	89						
Potassium	22 b	24 b						
Copper	.01	.01						
Nickel	.11	.12						
Iron	.01	.03						
Manganese	.08	.09						
Cobalt	< .01	< .01						
Zinc	.04	.05						
Sulfate	430 r	450 r						
Chloride	5	5						
Nitrate								
Ammonia								
Total Phosphorus	< 0.1	0.1						
Dissolved Organic Carbon								
Discharge at time of sample (ml/min)	3586	2074						
Total Volume over composite (liters)								

1. All parameters in mg/l except as follows.
   a. Temperature = °C
   b. Specific Conductance = umho
   c. Nitrates and ammonia are mg/l as nitrogen, total phosphorus is mg/l as phosphoru and dissolved organic carbon is mg/l as carbon.
2. All metal values are filtered, unless otherwise specified.
3. Comp. = Composite
4. a = Value appears anomalous b = reanalysis
5. r = Analysis rerun, see 10-5-78 memorandum from Serco.

Comments								
4. Rain	Total rainfall on 7-7 = 1.38" from 0600 - 1400							
5. Portion of hydrograph								
6. Other								

Date	7-7	7-7	7-7	7-7	7-7		7-7	7-7
Sample type	Grab	Grab*	Grab	Grab	Grab		Grab	Grab
Time	1800	1900	2000	2100	2200		2300	2400
Parameters								
Alkalinity								
pH	7.65	7.50	7.50	7.45	7.40		7.55	7.65
Temperature	11	11	11	11	11			
Specific Conductance	1125	1150	1175	1200	1200		1175	1200
Calcium	129	128	134	136	139		132	189
Magnesium	12	12	14	14	13		13	15
Sodium	97	92	110	111	99		96	114
Potassium	35	26[b]	38	37	28[b]		32	40
Copper	.012	.015	.012	.014	.01		.01	.009
Nickel	.170	.135	.170	.150	.14		.14	.160
Iron	.05	.02	.02	.02	.02		.02	.02
Manganese	.10	.10	.10	.10	.10		.09	.11
Cobalt	.011	.01	.011	.011	$<$ .01[b]		.01	.033
Zinc	.049	.05	.047	.056	.04		.05	.050
Sulfate		480		500			540	
Chloride		5		5			5	
Nitrate		1.5		1.5				
Ammonia		.44		.40				
Total Phosphorus		$<$ 0.1		$<$ 0.1			$<$ 0.1	
Dissolved Organic Carbon								
Discharge at time of sample (ml/min)	2469	2055	1747	1822	1431			
Total Volume over composite (liters)								

1. All parameters in mg/l except as follows.
   a. Temperature = ^{o}C
   b. Specific Conductance = umho
   c. Nitrates and ammonia are mg/l as nitrogen, total phosphorus is mg/l as phosphorus and dissolved organic carbon is mg/l as carbon.
2. All metal values are filtered, unless otherwise specified.
3. Comp. = Composite
4. a = Value appears anomalous   b = reanalysis

Comments								
4. Rain		Total rainfall on 7-7 = 1.38" from 0600 - 1400						
5. Portion of hydrograph								
6. Other					Filtered immediately	Isco #1 filtered 7-10 1330	Isco #2 filtered 7-10 1330	Isco #3 filtered 7-10 1330

*Mean of duplicate samples.

...e ...ple type ...	7-8 Grab 0100	7-8 Grab 0200	7-8 Grab 0300	7-8 Grab 0400	7-8 Grab 0500	7-8 Grab 0600	7-8 Grab 0700	7-8 Grab 0800
...rameters								
...lkalinity								
-	7.65	7.60	7.72	6.65	7.60	7.50	7.50	7.60
...mperature								
Specific Conductance	1225	1250	1275	1350	1325	1325	1350	1400
Calcium	194	212	210	224	233	245	159[a]	168,175[b]
...gnesium	15	16	15	12	16	16	16	17
Sodium	111	121	118	116	121	124	113	119
...otassium	39	43	40	40	41	42	34	38
...opper	.014	.012	.007	.014	.012	.009	.02	.02
Nickel	.160	.160	.170	.225	.215	.205	.18	.18
...ron	.02	.04	.07	.04	.03	.01	.02	.04
Manganese	.12	.12	.12	.12	.13	.14	.11	.12
...alt	.011	.015	.013	.015	.015	.015	.02	.04[b]
Zinc	.049	.049	.055	.053	.061	.056	.05	.06
...ulfate							650[r]	
...hloride							6	
...itrate								
Ammonia								
Total Phosphorus							< 0.1	
Dissolved Organic Carbon								
Discharge at time of sample (ml/min)								
Total Volume over composite (liters)								

1. All parameters in mg/l except as follows.
   a. Temperature = °C
   b. Specific Conductance = umho
   c. Nitrates and ammonia are mg/l as nitrogen, total phosphorus is mg/l as phosphorus, and dissolved organic carbon is mg/l as carbon.
2. All metal values are filtered, unless otherwise specified.
3. Comp. = Composite
4. a = Value appears anomalous
5. r = Analysis rerun, see 10-5-78 memorandum from Ser...
   b = reanalysis

Comments								
4. Rain	1.38" from 0600 - 1400 on 7-7, 0.15" from 1100 on 7-8 to 0200 on 7-9							
5. Portion of hydrograph								
6. Other	Isco #4 Filtered 7-10 1330	Isco #5 Filtered 7-10 1330	Isco #6 Filtered 7-10 1330	Isco #7 Filtered 7-10 1530	Isco #8 Filtered 7-10 1530	Isco #9 Filtered 7-10 1530 Lack of H_2O	Isco #10 Filtered 7-10 1530	Isco #11 Filtered 7-10 1530

FL-4

Date Sample type Time	7-8 Grab 0900	7-8 Grab 1600	7-8 Grab 2000	7-8 Grab* 2300	7-9 Grab 0100	7-13 Grab 1130	8-4 Grab 1010	8-15 Comp. 8-14 to 0930 on 8-15
Parameters								
Alkalinity								39
pH	7.3	7.48	7.55	7.40	7.55	7.65	8.00	7.80
Temperature							22	21
Specific Conductance	1425	1600	1650	1700	1550		1100	1275
Calcium	303	167,177[b]	302	212,222[b]	300	273	191	201
Magnesium	20	16	21	21	20	18	13	19
Sodium	153	121	155	152	149	153	115	158
Potassium	49	37	48	42	46	44	43	39
Copper	.012	.01	.012	.02	.009	.012	.020	.02
Nickel	.255	.21[a]	.255	.26	.240	-	.20[a]	.24
Iron	.01	.01	.02	.02	.02	.02	.02	.02
Manganese	.16	.12,.16[b]	.18	.16	.16	.14	.14	.15
Cobalt	.019	.03[b]	.019	.03	.017	.015	.010	.01[b]
Zinc	.064	.06	.064	.07	.005[a]	.004[a]	.052	.07
Sulfate		950	950[r]			850	660	800
Chloride		8	7			7	3	6
Nitrate						2.2	1.2	1.2
Ammonia						0.90	< 0.08	1.2
Total Phosphorus		< 0.1	< 0.1			< 0.1	< 0.1	< 0.1
Dissolved Organic Carbon								
Discharge at time of sample (ml/min)							95	
Total Volume over composite (liters)								

1. All parameters in mg/l except as follows.
   a. Temperature = °C
   b. Specific Conductance = umho
   c. Nitrates and ammonia are mg/l as nitrogen, total phosphorus is mg/l as phosphorus and dissolved organic carbon is mg/l as carbon.
2. All metal values are filtered, unless otherwise specified.
3. Comp. = Composite
4. a = Value appears anomalous b = reanalysis
5. r = Analysis rerun, see 10-5-78 memorandum from Serco.

Comments								
4. Rain	1.38" from 0600 - 1400 on 7-7, 0.15" from 1100 on 7-8 to 0200 on 7-9					0.77" from 1400-1600 and 2000-2300 on 7-12	Last rain 8-1 0.95"	.60" from 2030-2400 on 8-14; .26" from 0001-0100 1000-1150 on 8-15
5. Portion of hydrograph						Tail of 0.77"	Tail of 0.95"	Comp. over rain 8-14,15
6. Other	Isco #12 Filtered 7-10 1530	Isco #19 Filtered 7-11 1520	Isco #23 Filtered 7-11 1520	Isco #26 Filtered 7-11 1515	Isco #28 Filtered 7-11 1515			

*Mean of duplicate samples.

EL-4

Date Sample type Time	8-16 Comp. Start of rain to 1455 on 8-16	8-17 Comp. 1455 on 8-16 to 0800 on 8-17	8-18 Comp. 0800 on 8-17 to 1500 on 8-18	8-21 Comp. 1500 on 8-18 to 0830 on 8-21	8-23 Comp. 0830 on 8-21 to 0800 on 8-23	8-23 Comp. 0800 on 8-23 to 1440 on 8-23	8-23 Comp. 1445 on 8-23 to 1925 on 8-23	8-25 Comp. 1925 on 8-23 to 0835 on 8-25
Parameters								
Alkalinity	28	29	36		29	30	31	33
pH	7.50	7.29	7.60	7.75	7.65	7.05	7.70	7.55
Temperature						23		23
Specific Conductance	825	1175	1850	2050	1400	1000	1250	1750
Calcium	118	355	219	271	155	111	147	216
Magnesium	11	41	21	27	16	11	18	21
Sodium	60	158	110	142	102	67	85	115
Potassium	26	12	42	50	31	30	36	46
Copper	.02	.03	.02	.08	.02	.02	.02	.02
Nickel	.13	.20	.24	.32	.18	.11	.14	.24
Iron	.03	.04	.02	.46 [a]	.01	.01	.04	.01
Manganese	.09	.12	.16	.20	.11	.08	.10	.14
Cobalt	.02	.02	.04	.04 [b]	.03	.02	.02	.03
Zinc	.03	.05	.07	.10 [b]	.05	.03	.03	.06
Sulfate	100 ?	1000	800		700	500	610	800
Chloride	1	13	3		3	1	3	2
Nitrate	1.2	2.2	1.4		1.5	1.3	1.4	1.4
Ammonia	-	-	-		0.96	1.2	-	1.0
Total Phosphorus	< 0.1	< 0.1	< 0.1		< 0.1	< 0.1	< 0.1	< 0.1
Dissolved Organic Carbon								
Discharge at time of sample (ml/min)								
Total Volume over composite (liters)								

1. All parameters in mg/l except as follows.
   a. Temperature = °C
   b. Specific Conductance = umho
   c. Nitrates and ammonia are mg/l as nitrogen, total phosphorus is mg/l as phosphorus and dissolved organic carbon is mg/l as carbon.
2. All metal values are filtered, unless otherwise specified.
3. Comp. = Composite
4. a = Value appears anomalous   b = reanalysis

Comments

4. Rain	1.28" 0400-0800 .60" on 8-14 .26" on 8-15	Last rain 8-16 1.28" 0400-0800	0.23" 0001-0100	Last rain 8-18 0.23" 0001-0100	.60" from 2000-2400 on 8-22 1.15" from 0001 - 1100 on 8-23			Last rain 1.75" 2000 on 8-22 to 1100 on 8-23
5. Portion of hydrograph	Comp. over rain 8-16	Tail of 1.28" rain	Tail of 1.28" rain; Comp. over rain 8-18	Low flow	Before peak	Peak	After peak	Tail of 1.75" rain
6. Other								

FL-4

Date Sample type Time	8-28 Comp.* 0835 on 8-25 to 0815 on 8-28	9-11 Comp. 9-10 to 0835 on 9-11	9-13 grab 1100	9-13 grab 1100	9-13 Comp. 9-10 rain to 1100 on 9-13			
Parameters								
Alkalinity	41.8	35	34	34				
pH	7.55	7.30	7.40	7.40	6.9			
Temperature			12	12				
Specific Conductance	2350	2300	1875	1875	1200			
Calcium	280	256	226	226	123			
Magnesium	29	26	21	21	11			
Sodium	187	219	120	119	83			
Potassium	60	59	51	52	30			
Copper	.03	.03	.03	.03	.01			
Nickel	.34	.34	.25	.25	.13			
Iron	.02	.06	.08	.03	.06			
Manganese	.19	.20	.16	.16	.09			
Cobalt	.04	.05	.05	.04	.01			
Zinc	.10	.08	.06	.07	.03			
Sulfate	1250	1200		1070	633			
Chloride	2	10		2	3			
Nitrate	2.4	-		1.4	-			
Ammonia	-	-		< 0.08	-			
Total Phosphorus	< 0.1	< 0.1		< 0.1	< 0.1			
Dissolved Organic Carbon								
Discharge at time of sample (ml/min)								
Total Volume over composite (liters)								

1. All parameters in mg/l except as follows.
   a. Temperature = ^{o}C
   b. Specific Conductance = umho
   c. Nitrates and ammonia are mg/l as nitrogen, total phosphorus is mg/l as phosphor[illegible] and dissolved organic carbon is mg/l as carbon.
2. All metal values are filtered, unless otherwise specified.
3. Comp. = Composite

Date Sample type Time	8-28 Comp.* 0835 on 8-25 to 0815 on 8-28	9-11 Comp. 9-10 to 0835 on 9-11	9-13 grab 1100	9-13 grab 1100	9-13 Comp. 9-10 rain to 1100 on 9-13		
4. Rain	Last rain 8-27 0.20" 1200-1400	~1.00" from 1200 -1530 on 9-10	Last rain 9-10,11, 12 ~1.00" 9-10 ~1.31" 9-11 ~.15" 9-12	2.46" total 1200-1530 0830-1200 0300-1000			
5. Portion of Hydrograph	Comp. over rain 8-27	Comp. over rain 9-10	Tail of 2.46" rain	Comp. over rain 9-10,11, 12			
6. Other			Total Metals	Took 150 mls of each of 3 comp. and added together 9-10 to 9-11 0835 9-11 0835 to 9-11 1145 9-11 1145 to 9-13 1100		filtered metals	

* Mean of duplicate samples

Table XXIV Water Quality Data, FL5, 1973

Date Sample type Time	4-26 grab	5-25 Comp.	6-16 grab 1115	7-5 grab 0800	7-13 Comp. 1150 on 7-12 to 0830 on 7-13	7-19 Comp. 0900 on 7-18 to 1400 on 7-19	8-2 Comp. 8-1 1700 to 0900 on 8-2	8-2 Comp. 0900 on 8-2 to 1450 on 8-2
Parameters								
Alkalinity								
pH	7.20	7.6	7.5	7.05	7.22	7.40	6.95	7.05
Temperature	6.0		13	13			20	22
Specific Conductance	1750	2500	3300	2950		2050	1850	1600
Calcium	190	279	366	325	357[b]	565,596[b]	264	288
Magnesium	11	21	26	29	27	29	19	21
Sodium	153	273	336	231	248	245	139	150
Potassium	6	10	15	13	14	16	14	12
Copper	.020	.021	.044	.14[b]	.090	.141	.25	.28
Nickel	.445	.780	.835	5.100	6.7[b]	21.5	9.22[b]	11.34[b]
Iron	.17[a]	.02	.03	.02	.04	.02	.04	.05
Manganese	.27	.89	1.40	1.29	1.67	2.40	1.94	2.22
Cobalt	.045	.136	.160	.195	.81	1.9,2.42	1.22,1.07[b]	1.39,1.28[b]
Zinc		.096	.174	.257	.250	.396	.379	.420
Sulfate				1800	1300	1300	700	850
Chloride				78	50	59	25	25
Nitrate					39	54	43	90
Ammonia					13	12	4.6	6.8
Total Phosphorus					< 0.1	< 0.1	.4	< 0.1
Dissolved Organic Carbon								
Discharge at time of sample (ml/min)	trickle		192	370				
Total Volume over composite (liters)								

1. All parameters in mg/l except as follows.
   a. Temperature = °C
   b. Specific Conductance = umho
   c. Nitrates and ammonia are mg/l as nitrogen, total phosphorus is mg/l as phosphorus and dissolved organic carbon is mg/l as carbon.
2. All metal values are filtered, unless otherwise specified.
3. Comp. = Composite   a = Value appears anomalous   b = reanalysis

Date Sample type Time	4-26 grab	5-25 Comp.	6-16 grab 1115	7-5 grab 0800	7-13 Comp. 1130 on 7-12 to 0830 on 7-13	7-19 Comp. 0900 on 7-18 to 1400 on 7-19	8-2 Comp. 8-1 1700 to 0900 on 8-2	8-2 Comp. 0900 on 8-2 to 1450 on 8-2
4. Rain		0.29"	Last rain 6-10 0.10" 2300-2400	Last rain 7-1,7-2 1.36" 1400 on 7-1 to 1100 on 7-2	0.77" from 1400-1600 and 2000-2300 on 7-12	1.51" from 0001-0200 on 7-18; 0.24" on 7-19 1400	Last rain 8-1 0.95"	Last rain 8-1 0.95"
5. Portion of hydrograph		Comp. over rain 5-25	Low flow	Tail of 1.36" rain	Peak	Tail of 1.51" rain on 7-18; First of the present drip compositors	Comp. over rain 8-1	Tail of 0.95" rain
6. Other								

FL-5

Date Sample type Time	8-4 grab 1000	8-10 grab* 1320	8-16 grab* 0945	8-16 grab 1530	8-16 grab 1700	8-17 grab 0815	8-18 grab 1500	8-23 Comp. 1100 on 8-17 to 0910 on 8-23
Parameters								
Alkalinity		7		6	10	5	4	
pH	6.30	5.50	6.10	5.80	5.80	5.25	4.85	4.45
Temperature	22	22	15	22	16		16	
Specific Conductance	2350	4000	1150	1750	1575	2100	3100	1750
Calcium	483	636	202	264	270	400[b]	550[b]	200
Magnesium	32	47	20	27	31	40[b]	44	23
Sodium	238	338	97	111	106	178[b]	354	112
Potassium	17	20	9	11	9	33	8	9
Copper	.7,.13[b]	1.28	.58[a]	1.30	1.59	2.53	2.98	1.10
Nickel	3.23[b]	3.31[b]	15.26[b]	24.07[b]	28.03[b]	40.38[b]	42.21	15.98
Iron	.05	.12	3.38	9.73	10.78	11.54	5.28	.26[b]
Manganese	3.32	4.29	2.18	3.15	3.85	5.14	5.87	2.58
Cobalt	1.77,1.94	1.96,2.43[b]	2.63	4.05	4.69	6.73	7.22	2.86
Zinc	.774	1.18,1.25[b]	.42	.66	.79	1.24	1.45	.59
Sulfate	1400	2000		900	800	800	800	1400
Chloride	44	52		19	20	27	34	17
Nitrate	83	-		38	44	55	67	35
Ammonia	7.5	8.5		4.0	-	-	-	4.0
Total Phosphorus	< 0.1	< 0.1		< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Dissolved Organic Carbon								
Discharge at time of sample (ml/min)	333	147	11,356[x]	3785	2704	1714[x]	498	
Total Volume over composite (liters)								

1. All parameters in mg/l except as follows.
   a. Temperature = °C
   b. Specific Conductance = umho
   c. Nitrates and ammonia are mg/l as nitrogen, total phosphorus is mg/l as phosphorus and dissolved organic carbon is mg/l as carbon.
2. All metal values are filtered, unless otherwise specified.
3. Comp. = Composite

* mean of duplicate samples x Backwater suspected

a = Value appears anomalous b = reanalysis

FL-5

Date	8-4	8-10	8-16	8-16	8-16	8-17	8-18	8-23
Sample type	grab	grab*	grab*	grab	grab	grab	grab	Comp.
Time								1100 on 8- to 0910 on 8-
4. Rain	Last rain 8-1 0.95"	Last rain 8-1 0.95" 0.13" on 8-10 1100-1200	1.28" from 0400-0800 on 8-16 also: 0.60" from 2030-2400 on 8-14 0.26" from 0001-0100 and 1000-0100 and 1000-1130			Last rain 8-16 1.28" 0400-0800	0.25" 0001-0100	.25" on 8- 0001-0100 .60" on 8- 2000-2400 1.15" on 8- 0001-1100
5. Portion of hydrograph	Tail of 0.95" rain	Low flow	Peak	After peak	After peak	Tail of 1.28" rain	Tail of 0.25" rain	Before peak
6. Other								

FL-5

Date Sample type Time	8-23 Comp. 0910 on 8-23 to 1930 on 8-23	8-25 Comp. 1930 on 8-23 to 0835 on 8-25	8-28 Comp. 0835 on 8-25 to 0815 on 8-28	9-11 grab 1145	9-12 Comp. 1200 on 9-11 to 1455 on 9-12		9-13 grab 1100	
Parameters								
Alkalinity								
pH	4.00	3.90	4.25	4.80	3.50		3.62	
Temperature		21		17			13	
Specific Conductance	1800	2800	3250	1475	2650		3250	
Calcium	207	344	395	140	260		312	
Magnesium	26	42	50	20	50		65	
Sodium	102	177	220	79	133		183	
Potassium	11	15	18	9	17		21	
Copper	1.80	3.15	3.95	1.81	7.28		10.30	
Nickel	24.5	39.40	48.00	18.00	67.00		83.00	
Iron	7.75	2.78	2.38	.75	24.00[b]		25.00	
Manganese	3.40	5.40	6.47	2.90	10.00		15.00	
Cobalt	3.94	6.36	7.76	1.51	4.88		6.17	
Zinc	.66	1.18	1.49	.56	1.75		2.46	
Sulfate	700	1200	1500	700	1550		1900	
Chloride	16	22	30	8	9		15	
Nitrate	34	54	64	-	-		46	
Ammonia	-	8.3	-	-	-		0.1	
Total Phosphorus	< 0.1	< 0.1	< 0.1	0.2	< 0.1			
Dissolved Organic Carbon								
Discharge at time of sample (ml/min)				8801[c]			721	
Total Volume over composite (liters)								

1. All parameters in mg/l except as follows.
   a. Temperature = °C
   b. Specific Conductance = umho
   c. Nitrates and ammonia are mg/l as nitrogen, total phosphorus is mg/l as phosphorus and dissolved organic carbon is mg/l as carbon.
2. All metal values are filtered, unless otherwise specified.
3. Comp. = Composite
4. a = Value appears anomalous — b = reanalysis
   c Average value computed from flow meter readings over time interval 0945-1345

FL-5

Date	8-23	8-25	8-28	9-11	9-12	9-13	9-13
Sample type	Comp.	Comp.	Comp.	grab	Comp.	grab	grab
Time	0910 on 8-23 to 1930 on 8-23	1830 on 8-23 to 0835 on 8-25	0835 on 8-25 to 0815 on 8-28	1145	1200 on 9-11 to 1435 on 9-12	1100	1100
4. Rain	.23" on 8-18 0001-0100 .60" on 8-22 2000-2400 1.15" on 8-23 0001-1100	Last rain 8-22,23 1.75" 2000 on 8-22 to 1100 on 8-23	Last rain 8-27 0.20" 1200-1400	1.31" 0830-1200 Also: 1" from 1200-1530 9-10	Last rain 2.46" total 1.00" 1.31" 0.15"	9-10,11,12 1200-1530 0830-1200 0500-1000	9-10 9-11 9-12
5. Portion of hydrograph	Peak and after peak	Tail of 1.75" rain	Comp. over rain 8.27	Before Peak	Peak and after peak	Tail of 2.46" rain	Tail of 2.46" rain
6. Other						Total metals	Filtered metals split with Amax

FL-6 Table XXV Water Quality Data, FL6, 1978

Date Sample type Time	4-26 grab	5-25 Comp.	6-16 grab 1120	7-5 grab 0820	7-13 Comp. 1145 on 7-12 to 0830 on 7-13	7-19 Comp. 1530 on 7-14 to 0900 on 7-19	8-2 Comp. Start of rain to 1455 on 8-2	8-4 grab 0930
Parameters								
Alkalinity								
pH	7.25	7.25	7.12	7.4	7.49	8.1	7.70	7.75
Temperature	4.0		15.0	12		18	25	22
Specific Conductance	>5000		8860	4610		5700	2600	4150
Calcium	478	840	1028	455[b]	794	540	258	451
Magnesium	139	152	206	141[b]	124	95	61	120
Sodium	535	862	1106	491[b]	685	508	260	
Potassium	12	18	22	17[b]	16	12	9	12
Copper	.088	.121	.258	.060	.118	.092	.06	.11,.13[b]
Nickel	.540	.740	.665	.65,.82[b]	1.03[b]	1.0,.72[b]	.65	.95
Iron	.28	.12	.12	.02	.08	.05	.05	.04
Manganese	.60	1.14	1.64	.70	.95	.75	.62	1.04
Cobalt	.030	.062	.059	.051	.067	.052	.035	.17,.11[b]
Zinc	.022	.003	.033[a]	.006	.014	.006	.020	.030
Sulfate				2000	1450	1500	950	1700
Chloride				420	607	512	180	320
Nitrate					400	160	48	210
Ammonia					100	100	70	100
Total Phosphorus					<0.1	1.9	0.1	0.1
Dissolved Organic Carbon								
Discharge at time of sample (ml/min)	Trickle		135	223				287
Total Volume over composite (liters)								

1. All parameters in mg/l except as follows.
   a. Temperature = °C
   b. Specific Conductance = umho
   c. Nitrates and ammonia are mg/l as nitrogen, total phosphorus is mg/l as phosphorus and dissolved organic carbon is mg/l as carbon.
2. All metal values are filtered, unless otherwise specified.
3. Comp. = Composite
4. a = Value appears anomalous b = reanalysis

FL-6

Date Sample type Time	4-26 grab	5-25 Comp.	6-16 grab 1120	7-5 grab 0800	7-13 Comp. 1145 on 7-12 to 0830 on 7-13	7-19 Comp. 1330 on 7-14 to 0900 on 7-19	8-2 Comp. Start of rain to 1435 on 8-2	8-4 grab 0930
4. Rain		0.29"	Last rain 6-10 0.10" 2300-2400	Last rain 7-1, 7-2 1.36" 1400 on 7-1 to 1100 on 7-2	0.77 from 1400-1600 and 2000-2300 on 7-12	1.51" from 0001-0200 on 7-18; 0.24" on 7-19 (time unknown)	Last rain 8-1 0.95" Comp. over rain 8-1	Last rain 8-1 0.95" Tail of 0.95" rain
5. Portion of Hydrograph		Comp. over rain 5-25	Low flow	Tail of 1.36" rain	Peak	Before peak and peak		
6. Other								

FL- 6

Date	8-10	8-16	8-16	8-17	8-23	8-25	8-28	9-13
Sample type	Grab	Grab	Comp.	Comp.	Comp.	Comp.	Grab	Grab
Time	1315	1000	Start of rain to 1440 on 8-16	1440 on 8-16 to 1405 on 8-17	1405 on 8-17 to 1935 on 8-23	1935 on 8-23 to 0840 on 8-25	0840 on 8-25 to 0815 on 8-28	1600
Parameters								
Alkalinity	47		40	46	30	40	57	25
pH	7.55	7.85	7.71	7.52	7.55	7.40	7.85	7.1
Temperature	24	22				25		13
Specific Conductance	6840	2200	2250	4600	4320	4750	5290	3400
Calcium	748	231	269	396	368	373	481	367
Magnesium	178	70	78	46	112	119	135	125
Sodium	700	236	278	200	396	432	681	395
Potassium	22	6	6	14	12	12	15	14
Copper	.17	.09	.10	.13	.13	.15	.18	.28
Nickel	1.43	.87	1.00	1.48	1.54	1.70	2.15	2.25
Iron	.15	.03	.08	.05	.05	.07	.07	.06
Manganese	1.68	.75	.89	1.38	1.40	1.53	1.82	2.12
Cobalt	.28	.14	.18	.27	.24	.27	.39	.21
Zinc	.050	.03	.03	.05	.05	.05	.07	.12
Sulfate	2400		1000	1700	1600	1800	2150	2050
Chloride	600		150	190	280	220	390	180
Nitrate	-		140	120	170	140	230	-
Ammonia	160		-	-	-	98	-	-
Total Phosphorus	< 0.1		< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.1
Dissolved Organic Carbon								
Discharge at time of sample (ml/min)	77	28390						667 (Q at 1135)
Total Volume over composite (liters)								

1. All parameters in mg/l except as follows.
   a. Temperature = °C
   b. Specific Conductance = umho
   c. Nitrates and ammonia are mg/l as nitrogen, total phosphorus is mg/l as phosphorus and dissolved organic carbon is mg/l as carbon.
2. All metal values are filtered, unless otherwise specified.
3. Comp. = Composite

Comments

4. Rain	Last rain 8-1 0.95" 0.13" on 8-10 1100-1200	1.28" 0400-0800 .60" on 8-14 .26" on 8-15	1.28" 0400-0800 .60" on 8-14 .26" on 8-15	Last rain 8-16 1.28" 0400-0800	Last rain 8-22, 8-23 1.75" 2000 on 8-22 to 1100 on 8-23	Last rain 8-22, 8-23 1.75" 2000 on 8-22 to 1100 on 8-23	Last rain 8-27 0.20" 1200-1400	Last rain 9-10,11,12 2.46" total 1.00" 1200-1530 9-10 1.31" 0830-1200 9-11 .15" 0300-1000 9-12
5. Portion of hydrograph	Low flow	Peak	Comp. over rain 8-16	Tail of 1.28" rain	Comp. over rain 8-22, 8-23	Tail of 1.75" rain	Comp. over rain 8-27	Tail of 2.46" rain
6. Other								

FL- 6

Date	9-13							
Sample type	Comp.							
Time	9-10 rain to 1135 on 9-13							
Parameters								
Alkalinity	26							
pH	7.21							
Temperature								
Specific Conductance								
Calcium	408							
Magnesium	115							
Sodium	498							
Potassium	14							
Copper	.29							
Nickel	2.42							
Iron	.04							
Manganese	2.16							
Cobalt	.23							
Zinc	.12							
Sulfate	2100							
Chloride	360							
Nitrate	-							
Ammonia	-							
Total Phosphorus	0.1							
Dissolved Organic Carbon								
Discharge at time of sample (ml/min)								
Total Volume over composite (liters)								

1. All parameters in mg/l except as follows.
   a. Temperature = ^{o}C
   b. Specific Conductance = umho
   c. Nitrates and ammonia are mg/l as nitrogen, total phosphorus is mg/l as phosphorus and dissolved organic carbon is mg/l as carbon.
2. All metal values are filtered, unless otherwise specified.
3. Comp. = Composite

Comments								
4. Rain	Last rain 9-10,11, 12 2.46" total ~1.00" 1200-1530 9-10 ~1.31" 0830-1200 9-11 ~.15" 0300-1000 9-12							
5. Portion of hydrograph	Comp. over rain 9-10,11, 9-12							
6. Other								

Appendix IV

COMPUTATION OF THE PERCENT OF METALS THAT ARE RETAINED IN THE TEST PILES:

Assumptions: SO_4 is completely mobile and it is a measure of the total amount of sulfide dissolution that has occured. The goal is to compute the total sulfide dissolution rate and based on the percent of each metal sulfide in the pile, calculate the amount of each metal sulfide that has reacted. The inherent assumption is that all the sulfides are oxidized at the same rate.

The 1977 data from FL1 are used. Chemical data from Amax, as well as detailed chemical information from the regional copper nickel study are available (Tables I and III).

Filtered data was used for the metals, so that the influence of particulates could be eliminated. Since the piles are small, have fine material in them, and the samples are collected directly from the pile, fine particles may be in suspension. These particles could tend to bias the results to unusually high values.

It is assumed that all iron in solution comes from the sulfide minerals (Iron exists in the silicate minerals as well).

The calculations are shown in Table XXVI. The first column is the composition of the rock as given in Table III. The second column (Mole % of s) gives the distribution of each metal sulfide, i.e. 6.08 percent of the total sulfides contain nickel. Values in Column III were calculated by assuming all the sulfides are present as simple sulfides, i.e. NiS, CuS etc. and the amount of dissolution that would occur to yield a SO_4 concentration of 1000 mg/l was calculated.

Table XXVI Calculation of Metals Retained in Test Pile

Parameter	% determined from sample Ax 9001	Mole % of S	Concentration at base 1000 mg/l SO_4	At Base of 610 mg/l	Observed Median Concentration mg/l
$S-SO_4$	.655	100	1000	610	610
Ni	.073	6.08	37.2	22.7	.288
Cu	.306	23.6	156	95.2	.03
Zn	.016	1.20	8.18	5.0	.013
Co	.009	.750	4.60	2.8	.006
Fe(s)*	.697	61.3	356	217	<.05

* This is the iron that is in the sulfide minerals only, it does not include the iron that is in the silicates.

Appendix V

Rainfall Data

Table XXVII

April, 1978

PRECIPITATION AT MINNAMAX

Date	Net ppt (Inches)	Time of Rain	Remarks
1	.00		
2	.02		
3	.20		
4	.00		
5	.00		
6	.47		
7	.00		
8	.00		
9	.31		
10	.00		
11	.15		
12	.00		
13	.10		
14	.00		
15	.00		
16	.00		
17	.00		
18	.00		
19	.00		
20	.00		
21	.00		
22	.00		
23	.00		
24	.03		
25	.00		
26	.00		
27	.00		
28	.00		
29	.00		
30	.00		

From 4/1 - 5/2, rain was recorded from A.M. to A.M. with a standard rain gauge; rain during weekends would be added to the Monday rain figures.

From 5/2 on, all times midnight to midnight.

Table XXVIII May, 1978

PRECIPITATION AT MINNAMAX

Date	Net ppt (Inches)	Time of Rain	Remarks
1	.00		
2	.00		
3	.00		
4	.00		
5	.00		
6	.00		
7	.32	0300-0815	
8	.00		
9	.00		
10	.00		
11	.00		
12	.00		
13	.00		
14	.00		
15	.00		
16	.00		
17	.00		
18	.00		
19	.21	1830-2115	
20	.00		
21	.00		
22	.00		
23	.00		
24	.29	0630-0730	
25	.00		
26	.25	0500-0600	Quantity is an estimate.
27	.10	0800-0900	Quantity is an estimate.
28	1.92	0700-0830=1.86;1300-1400=.06	0700-0830 is an estimate.
29	.08	1215-1530	
30	.20	1830-2400	
31			

From 4/1 - 5/2, rain was recorded from A.M. to A.M. with a standard rain gauge; rain during weekends would be added to the Monday rain figures.

From 5/2 on, all times midnight to midnight.

Table XXIX June, 1978

PRECIPITATION AT MINNAMAX

Date	Net ppt (Inches)	Time of Rain	Remarks
1	.48	2400-0300=.30; 1815-1845=.18	
2	.02		Not traceable on the recorder
3	.00		
4	.00		
5	.00		
6	.75	1730-2400	
7	.21	0001-0900	
8	.00		
9	Trace		
10	.10	2300-2400	
11	.00		
12	.00		
13	.00		
14	.00		
15	.00		
16	.00		
17	.00		
18	.00		
19	.00		
20	.00		
21	.00		
22	.00		
23	.35	0745-1045=.29;1915-2000=.06	
24	.00		
25	.06	1800-1830	
26	.11	1730-2030	
27	.00		
28	.13	1630-1900	
29	.00		
30	.00		

From 5/2 on, all times midnight to midnight.

Table XXX July, 1978

PRECIPITATION AT MINNAMAX

Date	Net ppt (Inches)	Time of Rain	Remarks
1	.12	1400-2400	
2	1.24	0001-1100	
3	.00		
4	.00		
5	.00		
6	.00		
7	1.38	0600-1100=1.18";1200-1400=.20"	
8	.09	2300-2400 heavy	
9	.06	2400-0200 light	
10	.00		
11	.00		
12	.77	1400-1600, 2000-2300	
13	.00		
14	.00		
15	.00		
16	.20		
17	.00		
18	1.51	midnight-0200, heavy	
19	.24		
20	.00		
21	.01		
22	.29	1500-1600	
23	.00		
24	.26	1300-1600	
25	.00		
26	.10	2100-2200	
27	.00		
28	.11	2000-2100	
29	.00		
30	.00		
31	.00		

From 5/2 on, all times midnight to midnight.

Table XXXI August, 1978

PRECIPITATION AT MINNAMAX

Date	Net ppt (Inches)	Time of Rain	Remarks
1	.95		
2	.00		
3	.00		
4	.00		
5	.00		
6	.00		
7	.00		
8	.00		
9	.00		
10	.13	1100-1200	
11	.00		
12	.13	0600-0630	
13	.00		
14	.60	2030-2400	
15	.26	2400-0100, 1000-1130	
16	1.28	0400-0800	
17	.00		
18	.23	2400-0100	
19	.00		
20	.00		
21	.00		
22	.60	2000-2400	
23	1.15	0001-1100	
24	.00		
25	.00		
26	.00		
27	.20	1200-1400	
28	.00		
29	.00		
30	.00		
31	.00		

From 5/2 on, all times midnight to midnight.

Table XXXII September, 1978

PRECIPITATION AT MINNAMAX

Date	Net ppt (Inches)	Time of Rain	Remarks
1	.00		
2	.00		
3	.00		
4	.00		
5	.00		
6	.00		
7	.00		
8	.00		
9	.00		
10	1.00	1200-1530	quantity is an estimate
11	1.31	0830-1200	quantity is an estimate
12	.15	0300-1000	quantity is an estimate; Exact total 9/10-9/12 = 2.46"
13	.00		
14	.53	0001-0600	
15	.03	0810-1200	
16	.00		
17	.00		
18	.09		
19	.06	1700-1800	
20	.00		
21	.00		
22	.00		
23	.00		
24	.00		
25	.00		
26	.03	1500-1700	
27	.00		
28	.08	1900-2000	
29	.00		
30	.00		

From 5/2 on, all times midnight to midnight.

Table XXXIII October, 1978

PRECIPITATION AT MINNAMAX

Date	Net ppt (Inches)	Time of Rain	Remarks
1	.05"	2300-2400	
2	.17"	0001-0100=.02"; 0200-0400=.15"	
3	.00		
4	.00		
5	.32	0400-1700, drizzle	
6	.00		
7	.00		
8	.00		
9	.00		
10	.00		
11	.04	1200-1300	
12	.00		
13	.00		
14	.00		
15	.40	0800-1100	
16	.00		
17	.00		
18	.00		
19	.00		
20	.00		
21	.00		
22	.00		
23	.00		
24	.00		
25	.00		
26	.02	0800-1200	
27	.00		
28	.05	0600-1030	quantity is an estimate
29	.00		
30	.00		
31	.00		

From 5/2 on, all times midnight to midnight.

Table XXXIV November, 1978

PRECIPITATION AT MINNAMAX

Date	Net ppt (Inches)	Time of Rain	Remarks
1	.00		
2	.00		
3	.00		
4	.00		
5	.00		
6	.00		
7	.00		
8	.00		
9	.00		
10	.15	0630-1800	Snow; quantity is an estimate
11	.00		
12	.00		

From 5/2 on, all times midnight to midnight.

Appendix VI Samples Used In Box Plot

Date	1	2	3	4	5	6
4-26	grab	grab	grab	grab	grab	grab
6-16	grab at 1025	grab at 1120	grab at 1205	grab at 0800	grab at 1115	grab at 1120
7-5	grab at 0830	grab at 0830	grab at 0845	grab from 7-6	grab at 0800	grab at 0800
7-13	composite from 1200 on 7-12 to 0840 on 7-13	composite 1155 on 7-12 to 0840 on 7-13	composite from 1210 on 7-12 to 0840 on 7-13	grab at 1130 on 7-13	composite 1150 on 7-12 to 0830 on 7-13	composite from 1145 on 7-12 to 0830 on 7-13
7-18	composite from 1530 on 7-14 to 1400 on 7-19	composite 0810 on 7-18 to 1400 on 7-19	composite 1530 on 7-14 to 1400 on 7-19	no sample	composite 0900 on 7-18 to 1400 on 7-19	composite 1530 on 7-14 to 0900 on 7-19
8-2	composite 1700 on 8-1 to 1515 on 8-2	composite 1415 on 7-24 to 0930 on 8-2	composite 1800 on 8-1 to 1515 on 8-2	no sample	composite mean of two samples 1-1700 on 8-1 to 0900 on 8-2 2-0900 on 8-2 to 1450 on 8-2	composite
8-4	grab at 1045	grab at 1030	grab at 1100	grab at 1010	grab at 1000	grab at 0930
8-16	grab at 1015	grab at 1010	grab at 1025	composite	mean of 3 grabs, at 0945, 1330 1700	grab at 1000
8-23	composite 1025 on 8-17 to 1945 on 8-23	composite 1000 on 8-17 to 1940 on 8-23	composite 1050 on 8-17 to 1955 on 8-23	combined composite 1-0830, 8-21 to 0800, 8-23 2-0800, 8-23 to 1440, 8-23	composite 1100 8-17 to 0910, 8-23	composite 1405, 8-17 to 1935, 8-23
9-13	grab at 1020	grab at 1045	grab at 1030	grab at 1100	grab at 1100	grab at 1135

Appendix VII

QUALITY ASSURANCE

Duplicate, Blank Samples, Intralaboratory Splits

Six percent of all the water quality samples were masked duplicates. The data for the duplicate samples are given in Table XXXV. The results are summarized in Table XXXVI.

Distilled deionized water blanks were also analyzed as part of the quality assurance program. Table XXXVII summarizes the results.

Partial results for the intralaboratory study are given in Table XXXVIII. Except for zinc, the agreement is satisfactory.

HYPALON TESTS

The contamination potential of the Hypalon liner was evaluated in two tests. Runoff samples were collected from the tailings plot area prior to the deposition of tailings. In the second test a piece of Hypalon was soaked in distilled deionized water for 4 weeks. Some low level zinc contamination was observed (Table XXXIX).

PUMP TESTS

Distilled deionized water was passed through the compositing pumps. The results shown in Table XL indicate some low level zinc contamination.

Duplicate Samples — Table XXXV

Date	7-7	7-7	7-8	7-8	8-28	8-28
Sample type	grab	grab	grab	grab	Composite	Composite
Sample No.	73	74	93	94	181	184
Time	1900	1900	2300	2300	0835 on 8-25	to 0815 on 8-28
	FL-4	FL-4	FL-4	FL-4	FL-4	FL-4
Parameters						
Alkalinity					41.8	41.8
pH	7.50	7.50	7.40	7.40	7.55	7.55
Temperature	11	11				
Specific Conductance	1150	1150	1700	1700	2350	2350
Calcium	129	127	211	212	287	274
Manesium	12	12	21	21	30	28
Sodium	93	90	152	153	180	194
Potassium	348	111	43	42	57	64
Copper	.02	.01	.02	.02	.03	.03
Nickel	.15	.12	.25	.26	.33	.34
Iron	.02	.01	.03	.01	.01	.03
Manganese	.09	.10	.16	.16	.19	.19
Cobalt	.02	0	.02	.04	.03	.06
Zinc	.05	.05	.07	.07	.09	.10

Duplicate Samples

Date	8-16	8-16			6-14	6-14
Sample type	grab	grab			grab	grab
Sample number	135	138			14	15
Time	0945	0945			0745	0745
Site	FL-5	FL-5			FL-4	FL-4
Parameters						
Alkalinity						
pH	6.10	6.10			7.60	7.60
Temperature	15	15			9.0	9.0
Specific Conductance	1150	1150			2500	2500
Calcium	203	201			222	234
Magnesium	21	20			28	29
Sodium	98	96			256	267
Potassium	9	9			36	38
Copper	.59	.57			.025	.025
Nickel	15.26	15.25			.220	.219
Iron	3.44	3.31			.03	.05
Manganese	2.17	2.18			.21	.21
Cobalt	2.61	2.65			.016	.016
Zinc	.42	.42			.130	.125

Date	6-23	6-23	6-23	6-23	7-7	7-7
Sample type	grab	grab	grab	grab	grab	grab
Sample No.	31	32	41	42	56	57
Time	1540	1540	2100	2100	1200	1200
Site	FL-4	FL-4	FL-4	FL-4	FL-4	FL-4
Parameters						
Alkalinity						
pH	7.45	7.45	7.75	7.75	7.40	7.40
Temperature	14	14			11	11
Specific Conductance	2650	2650	2500	2500	1125	1125
Calcium	232	214	215	217	126	125
Magnesium	32	28	30	30	13	13
Sodium	310	283	292	291	110	111
Potassium	44	40	41	44	576	638
Copper	. 07?	.024	.020	.019	.02	.01
Nickel	.336	.314	.314	.325	.14	.14
Iron	.01	.02	.01	0	.04	.01
Manganese	.23	.21	.22	.22	.08	.08
Cobalt	.027	.025	.022	.021	.02	.03
Zinc	.169	.134	.153	.154	.04	.04

FL- Duplicate Samples

Date	8-24	8-24	9-13	9-13	8-4	8-4	8-10	8-10
Sample type	Comp.	Comp.	Grab	Grab	Grab	Grab	Grab	Grab
Sample #	166	168	191	193	121	122	128	130
Time	1025 on 8-17 to 1945 on 8-23		1500	1500	1100	1100	1320	1320
Site	FL-1	FL-1	FL-2	FL-2	FL-3	FL-3	FL-5	FL-5
Parameters								
Alkalinity	50	50	41	41			7	7
pH	8.10	8.10	7.45	7.45	7.65	7.65	5.50	5.50
Temperature			15	15	22	22		22
Specific Conductance	2600	2600	1725	1725	950	950	4000	4000
Calcium	305	300	181	182	156	157	634	638
Magnesium	26	25	21	22	23	25	43	51
Sodium	243	238	139	137	88	88	336	339
Potassium	41	39	30	29	26	26	20	21
Copper	.04	.04	.10	.11	.08	.08	1.28	1.27
Nickel	.38	.35	.27	.25	.33	.32	3.31	3.31
Iron	.05	.06	.03	.02	.01	.04	.15	.08
Manganese	.14	.14	.16	.16	.16	.16	4.32	4.26
Cobalt	.05	.02	.03	.02	.023	.017	1.96	1.96
Zinc	.02	.01	.06	.06	.044	.044	1184	1180
Sulfate								
Chloride								
Nitrate								
Ammonia								
Total Phosphorus								
Dissolved Organic Carbon								
Discharge at time of sample (ml/min)								
Total Volume over composite (liters)								

1. All parameters in mg/l except as follows.
   a. Temperature = ^{o}C
   b. Specific Conductance = umho
   c. Nitrates and ammonia are mg/l as nitrogen, total phosphorus is mg/l as phosphorus and dissolved organic carbon is mg/l as carbon.
2. All metal values are filtered, unless otherwise specified.
3. Comp. = Composite

Table XXXVI QUALITY ASSURANCE SUMMARY

$$\% \text{ error} = \frac{X_1 - X_2}{\frac{(X_1 + X_2)}{2}} \times 100\%$$

Parameter	Number of Samples	Median	Maximum	Minimum
Ca	12	.96	8.1	0
Mg	12	4.4	13.3	0
Na	12	2.1	9.8	0
K	12	5.1	19.2	0
Cu	12	2.9	66.6	0
Ni	12	3.05	22	0
Zn	12	0.17	66.6	0
Co	12	3.0	200	0
Fe	12	66.3	200	0
Mn	12	0	10.5	0

Table XXXVII

BLANKS

Parameter	High mg/l	Low mg/l	Median	Mean	σ
Co	.02	0	0	.001	.005
Cu	1.01	0	0	.067	.252
Ni	0	0	0	0	0
Zn	0	0	0	0	0
Ca	31	0	0	2.07	7.73
Fe	.01	0	0	.001	.002
K	3	0	0	.200	.56
Mg	10	0	0	.667	2.49
Mn	0	0	0	0	0
Na	34	0	0	2.2	8.50

Blanks without #172

Parameter	High mg/l	Low mg/l	Median	Mean	σ
Co	.02	0	0	.0014	.004
Cu	0	0	0	0	0
Ni	0	0	0	0	0
Zn	0	0	0	0	0
Ca	.06	0	0	.0043	.015
Fe	0	0	0	0	0
K	0	0	0	0	0
Mg	.01	0	0	.0007	.001
Mn	0	0	0	0	0
Na	0	0	0	0	0

15 Samples

Table XXXVIII INTRALABORATORY QUALITY ASSURANCE

Date		Co	Cu	Ni (ug/l)	Zn	Ca	Fe	K (Mg/l)	Mg	Mn	Na
9/11	Eml DNR	20	10	550	910	91	.03	5	72	.04	44
	Eml Serco	1	8.0	450	23	115	.05	4.1	81	.03	44
	Eml Erie										
	% Diff. Sero DNR	+100	20	18	+100	26	40	18	11	25	0
9/13	FL5 DNR	6170	10300	83000	2460	312	23	21	65	13	183
	FL5 Serco	7500	9500	78000	2480	380	20	20	76	12	200
	% Diff.	18	7.7	6.0	.81	18	13	4.8	14	7.7	8.5
7/13	FL4 Serco	12	15	150	64					.12	
	FL4 DNR	15	12		4					.14	
	% Diff.	20	20		100+					14	

Table XXXIX HYPALON CONTAMINATION TESTS

Parameters	Rainwater Runoff From Hypalon-covered Pad		1.4 cm by 1.7 cm Hypalon Section immersed in water for 28 days
Calcium	< .02	< .02	.70
Magnesium	< .01	< .01	.71
Sodium	< .01	< .01	.94
Potassium	< .01	< .01	.07
Copper	< .01	< .01	< .01
Nickel	< .02	< .02	< .02
Iron	< .02	< .02	< .02
Manganese	< .02	< .02	< .02
Cobalt	< .01	< .01	< .01
Zinc	< .01	< .01	.02

Table XL

PUMP CONTAMINATION TEST

September 29, 1978

Parameters	FL1	FL2	FL3	FL5	FL6	Blank*
Calcium	< .02	< .02	< .02	< .02	< .02	< .02
Magnesium	< .01	< .01	< .01	< .01	< .01	< .01
Sodium	< .01	< .01	< .01	< .01	< .01	< .01
Potassium	< .01	< .01	< .01	< .01	< .01	.01
Copper	.02	.02	< .01	< .01	< .01	< .01
Nickel	< .02	< .02	< .02	< .02	< .02	< .01
Iron	< .02	< .02	< .02	.10	< .02	< .02
Manganese	< .02	< .02	< .02	< .02	< .02	< .02
Cobalt	< .010	< .010	< .01	< .01	< .01	< .01
Zinc	.01	.02	.02	.02	.02	.01

*Distilled, deionized water

All values in mg/1

1978 SAMPLING SEASON - GENERAL EVENTS

APRIL

- 18 All leach piles unfrozen

MAY

- 11 FL-2, 3, and 5 covered with soil

JUNE

- 22 Fertilized soil-covered leach piles
- 23 Intensive leachate sampling of FL-4, .66 cm (.26") rain
- 27 Seeded soil-covered leach piles
- 28 Mulch applied to soil-covered leach piles

JULY

- 7 Intensive leachate sampling of FL-4, 3.88 cm (1.53") rain
- 11 Compositing Drip Samplers installed

AUGUST

- 11 Pressurized Flow Meter/Recorder/Compositor (Flow Proportional Sampler) Installed at FL-4

SEPTEMBER

OCTOBER

NOVEMBER

- 3 Flow proportional sampler installed at FL- 1,2,5, and 7
- 10 Freeze-up

DECEMBER

1977 - 1978

DETAILED EVENTS

4/20/77	FL-1, 2, 3, and 4 Constructed.
9/10/77	FL-5 Constructed.
9/30/77	FL-6 Constructed
4/18/78	All piles unfrozen.
4/26/78	First Sampling, 1978
5/02/78	Recording rain gauge started.
5/11/78	FL-3, 5, and 2 covered with soil.
5/24/78	Flow meters attached to pipelines.
5/25/78	Hand-made flow weighted composite FL-4.
6/13/78	Lowered FL-1 discharge pipe and adjusted flow meters to have more hydraulic head.
6/22/78	Fertilized soil-covered piles with 16,000 g/pile.
6/23/78	Intensive sampling FL-4 .89 cm (.35 inches) rain, also hydrograph obtained from FL-1.
6/27/78	Soil-covered piles seeded.
6/28/78	Soil-covered piles mulched.
7/07/78	Intensive sampling FL-4 3.88 cm (1.53 inches) rain, also hydrographs from FL-1, 2, 3, 4, 5, and 6.
7/11/78	Compositing drip samplers installed.
7/14/78	Filter screens placed above all flow meters.
8/11/78	Pressurized flow meter and flow Proportional Sampler Samplers) attached to FL-4; also Rustrack recorder attached
8/18/78	Pipe between Fl-3 and FL-1 lowered.
9/21/78	First hard frosts.
11/03/78	Flow Proportional Sampler installed at FL-1,2,5, and 7
11/10/78	First snow.
11/14/78	Heat tapes put on drains of piles.

Appendix IX

Reanalysis of Anomalous Values

Certain values in the original water quality data appeared anomalous. The anomalous values were reanalyzed, if a sufficient amount of the sample remained. The results of the reanalysis (performed in December) are given in Table XLI.

FL 1

Table XII Reanalysis

Sample #	Date		Parameter	original value mg/l		rerun value mg/l		
95	7-11		Ca	419		303		
			Cu	.024		.03		
			Ni	.405		.37		
			Co	.022		.03		
			Zn	.074		.01		
129	8-10		Co	.06		.03		
147	8-16		Co	.06		.02		
166	8-24		Co	.04		.04		
168	8-24		Co	.04		.04		
173	8-25		Co	.05		.03		
180	8-28		Co	.06		.07		
FL 2								
101	7-13		Zn	.008		.09		
108	7-19		Ni	20.5		.24		
			Co	.019		.01		
112	8-2		Co	40		.01		
			Zn	.055		.05		
137	8-16		Cu	.14		.17		
			Co	0		.01		
143	8-16		Cu	.12		.14		
150	8-16		Cu	.13		.14		
169	8-24		Cu	.13		.15		
183	8-20		Co	.05		.04		
			Zn	.09		.09		

FL 3

	Date		Para-meter	original value mg/l	rerun mg/l			
3	4-26		Ni	0	.06			
			Fe	.7	.7			
48	7-5		Cu	1.0	.20			
			Ni	.282	.36			
			Fe	0	<.02			
110	7-19		Cu	.074	.11			
			Ni	.140	.33			
131	8-10		Cu	.05	.07			
			Ni	.56	.57			
139	8-16		Cu	.11	.12			
			Ni	.20	.18			
142	8-16		Cu	.11	.13			
			Ni	.24	.17			
149	8-16		Cu	.10	.13			
			Ni	.23	.22			
167	8-24		Co	0	<.02			
FL 4								
44	6-23		Ni	.116	.36			
			Fe	0	.01			
52	7-6		Na	190	173			
60	7-7		Ca	118	242			
			Mg	12	24			
			Na	103	220			
			K	225	43			

	Date		Para-meter	original value mg/l	rerun mg/l			
61	7-7		K	135	42			
62	7-7		K	1393	20			
63	7-7		K	348	29			
64	7-7		K	1363	no sample	left		
65	7-7		K	356	29			
66	7-7		K	278	33			
1100	7-7		K	268	no sample			
58	7-7		K	295	22			
			Na	243	88			
			Mg	27	10			
			Ca	233	115			
68	7-7		K	148	20			
70	7-7		K	95	22			
71	7-7		K	248	24			
73	7-7		K	230	29			
74	7-7				24			
77	7-7		K	289	28			
			Co	0	2.01			
90	7-8		Ca	168	175			
			Mg	17	16			
			Co	0	.04			
91	7-8		Ca	167	177			
			Mn	.12	.16			
			Co	0	.03			
93	7-8		Ca	212	222			

FL 4 (cont.)

sample #	Date		Para-meter	Original	rerun			
133	8-15		Co	.03	.01			
156	8-21		Co	.06	.04			
			Zn	1.0	.10			
			Fe	.46	missed			
FL 5								
49	7-5		Cu	.90	.14			
103	7-13		Ca	533	357			
			Ni	12.50	6.70			
			Co	1.1	.81			
128	7-19		Ca	565	596			
			Co	1.9	2.42			
			Zn	.396	1.24			
			Ni	22.5	missed			
113	8-2		Ni	2.88	9.22			
			Co	1.22	1.07			
114	8-2		Ni	3.02	11.34			
			Co	1.39	1.28			
124	8-4		Cu	.7	.13			
			Ni	3.23	3.23			
			Co	1.77	1.94			
128	8-10		Ni	3.31	3.31			
130	8-10		Co	1.96	2.43			
			Zn	1.18	1.25			
135	8-16		Ni	15.26	15.26			

FL 5 (cont)

sample #	Date		Parameter	original	rerun			
	8-16		Ni	24.07	24.07			
148	8-16		Ni	28.03	28.03			
151	8-17		Ca	165	400			
			Mg	16	40			
			Na	82	178			
			Ni	40.38	40.38			
154	8-18		Mg	115	44			
161	8-23		Fe	.26	.26			
188	9-12		Fe	24.0	24.0			
FL 6								
47	7-5		Ca	309	435			
			Mg	124	140			
			Na	476	491			
			K	10	17			
			Ni	.65	.82			
104	7-13		Ni	.400	1.08			
106	7-19		Ni	1.0	.72			
125	8-4		Cu	.11	.13			
			Co	.17	.11			