TECHNICAL INVESTIGATION OF THE ABATEMENT OF ACID MINE DRAINAGE IN A SUB-SURFACE WETLAND ENVIRONMENT

CONTRACT #J0209007

Prepared for:

U.S. Bureau of Mines

Prepared by:

Jonathan M. Dietz
Jacqueline Gruver
Dennis M. Stidinger, P.E.

The EADS Group
P.O. Box 684
Greenville Ave. Ext.
Clarion, PA 16214

September 1993

The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies or recommendations of the Interior Department's Bureau of Mines or of the U.S. Government.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

2. REPORT DATE: AML 02-94

3. REPORT TYPE AND DATES COVERED:

4. TITLE AND SUBTITLE
Technical Investigation of the Abatement of Acid Mine Drainage in a Sub-Surface Wetland Environment

5. FUNDING NUMBERS:

6. AUTHOR(S)
Jonathan M. Dietz; Jacqueline Gruver; Dennis M. Stidinger, P.E.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
The EADS Group, P.O. Box 684, Greenville Ave. Ext.
Clarion, Pennsylvania 16214

8. PERFORMING ORGANIZATION REPORT NUMBER:

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Bureau of Mines
810 Seventh Street, NW., MS 6205
Washington, DC 20241

10. SPONSORING/MONITORING AGENCY REPORT NUMBER:

11. SUPPLEMENTARY NOTES:

12a. DISTRIBUTION/AVAILABILITY STATEMENT:

12b. DISTRIBUTION CODE:

13. ABSTRACT (Maximum 200 words)

An experimental wetland design was developed to compare surface flow systems to sub-surface flow systems. In addition, the study was to evaluate the appropriate position (before or after) of a surface flow cell with respect to a sub-surface flow treatment cell.

The wetland design contained two wetland treatment systems, with each system containing equally sized sub-surface and surface flow treatment cells. The order in the first treatment system (Sub-system 1) was surface flow followed by sub-surface flow. The order was reversed in the second treatment system (Sub-system 2).

The water quality monitoring data clearly indicated sub-surface flow design produces water quality that is superior for a number of parameters that include pH, iron, aluminum, acidity and alkalinity. Neither wetland design significantly improved manganese; however, manganese removal is not probable in strongly reducing environments provided by a compost wetland.

14. SUBJECT TERMS:
Wetlands, AMD

15. NUMBER OF PAGES:

16. PRICE CODE:

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

TABLE OF CONTENTS

TABLE OF CONTENTS (cont.)

LIST OF TABLES

LIST OF TABLES (cont.)

LIST OF FIGURES

LIST OF FIGURES (cont.)

LIST OF FIGURES (cont.)

LIST OF APPENDICES

INTRODUCTION

Wetland Treatment Systems (WTS) have been constructed over the past decade for the treatment of Acidic Mine Drainage (AMD). These WTS have achieved variable and at times inconsistent success at improving and meeting established effluent limits. The variable success of WTS is attributable to differences in design, size and treatment material. Although treatment success is variable, all constructed WTS have, at a minimum, been successful in reducing chemical costs associated with AMD treatment and pollutant loading to receiving streams.

Potential benefits of wetlands were initially identified at naturally occurring wetlands that were receiving AMD inputs from past coal mining. Weider and Lang (1982), while monitoring a naturally occurring peat wetland, found the wetland to be effective at removing metals from AMD. Further investigations by Weider and Lang (1986) indicated the peatlands accumulated iron and aluminum as organically bound and oxide precipitates. In addition, the researchers found significant accumulation of sulfur within the peat.

Based on this initial research a number of investigators examined iron removal processes within constructed and experimental wetland systems. Snyder and Aharrah (1984) analyzed *Typha* tissues from existing wetland systems influenced by AMD and found much higher concentrations of iron on outer plant tissues, which may indicate removal by absorption. Tarleton et al. (1984), based on results from constructed microcosms containing *Sphagnum* moss, proposed mechanisms of iron removal by wetland systems that included plant uptake, microbial oxidation and precipitation, absorption by organic deposits, and sulfide precipitation. Burris et al. (1985) found a high rate of ferrous iron oxidation and removal within experimental troughs containing *Sphagnum* moss, which Stone (1985) determined to be related to the presence of *Thiobacillus ferrooxidans*, a chemotrophic bacteria, and a collective group of heterotrophic iron oxidizing bacteria.

An additional remediation process, sulfate reduction, was originally identified by Tuttle et al. (1969) during studies of seepage from a porous saw dust dam, which appeared to significantly increase pH and decrease iron concentrations. This process is an anaerobic biological process in which sulfate, during oxidation of organic substrates, is reduced to sulfide by a sulfate-reducing bacteria. In a laboratory study using microcosms containing *Sphagnum* peat, Dietz and Unz (1988) found high numbers of sulfate-reducing bacteria, low redox potentials and significant decreases in sulfate, which appeared to be linked to decreases in iron. In a field study of a constructed wetland (containing mushroom compost and cattails) to treat AMD, Hedin et al. (1988) found higher pH values and lower aluminum and iron concentrations within the compost. Dvorak et al. (1991), in pilot-scale reactors treated with metal contaminated water, also found sulfate reduction significantly improved discharge quality.

Initially, wetland treatment systems for AMD treatment were empirically designed surface flow wetlands that used substrates ranging from transplanted *Sphagnum* peat to spent mushroom compost and often contained limestone under the organic substrates. Kleinmann et al. (1983), using a portable trough system containing *Sphagnum* peat and limestone, found the system reduced metal concentrations (iron and aluminum) and increased pH. Pasavento (1984) indicated that constructed wetland systems, with a variety of empirical designs and substrates, reduced iron and aluminum levels and improved pH. A study by Brodie et al. (1988), with small scale constructed wetlands using a variety of substrates, provided preliminary results suggesting designs using artificial organic substrates (e.g., mushroom compost) may be beneficial in the treatment of AMD.

Recent investigations by Hedin et al. (1991) have proposed design (sizing) criteria for surface flow compost WTS based on removal rates for iron, manganese and aluminum. In a study by Dietz and Stidinger (1993) on constructed surface flow wetlands, the removal of acidity was correlated with the removal of iron and aluminum, but did not find any relationship between acidity removal and manganese removal. Based on these relationships and the consistency of acidity removal in the different wetlands, Dietz and Stidinger (1993) recommended the use of acidity as a design criteria.

Potential benefits of a new WTS design were originally identified at a WTS constructed at the Jennings Environmental Education Center (Dietz and Stidinger 1993). The system was originally constructed as a surface flow system; however, due to poor performance, the WTS was modified by placing limestone and drainline in trenches, to promote greater subsurface flow. The modifications decreased acidity, iron and aluminum and resulted in acidity removal rates 2 to 4 times greater than surface flow WTS.

The purpose of this study was to investigate the potential benefits of this new WTS design, which utilizes a sub-surface collection system, in comparison to conventional surface flow WTS design. In addition, this study was to investigate potential benefits and position (i.e., before or after) of surface flow when used in combination with the sub-surface flow systems. The following sections provide the experimental design, sampling program and results of this investigation.

WETLAND DESIGN

An experimental design was developed to compare surface flow systems to sub-surface flow systems. In addition, the study was to evaluate the appropriate position (before or after) of a surface flow cell with respect to a sub-surface flow treatment cell.

The wetland design contained two wetland treatment systems, with each system containing equally sized sub-surface and surface flow treatment cells. The order in the first treatment system (Sub-system 1) was surface flow followed by sub-surface flow. The order was reversed in the second treatment system (Sub-system 2).

Both systems received AMD from the same source and at the same flow rate of 11.4 L/min (3 gpm), which were controlled by intake valves. In addition to influent flow, gate valves and permanent weirs were located between treatment cells and at discharge locations to control and monitor flow through the WTS.

SITE SELECTION

The EADS Group evaluated a number of different sites for this research project. The site selected, which is located along an existing discharge from an abandoned mine area near Corsica, PA (EXIT 11 I-80), was selected for several reasons.

The site, located in the Little Mill Creek sub-watershed of the Mill Creek watershed, has a history of interest and monitoring. Several studies were conducted in the area in the 1970's, which used the discharge as a monitoring point. The studies identified this discharge as a major contributor of AMD to the Mill Creek watershed. These studies also provided background water quality data on the discharge.

Water quality data from the studies is summarized in Table 1. The iron concentrations and pH were slightly different from the discharge requirements proposed for site selection, which were 50 mg/L of iron, pH between 4 and 5, and sulfates greater than 500 mg/L. It was felt these slight differences would not effect the outcome of the research project.

Table 1. Background Water Quality of the Corsica acidic mine drainage discharge.

Flow gpm	pH	Alkalinity mg/L (as $CaCO_3$)	Acidity mg/L (as $CaCO_3$)	Total Iron mg/L	Total Manganese mg/L	Total Aluminum mg/L	Sulfate mg/L
10-100	3-4	0	250-400	20-40	15-40	10-30	1200-1800

The flows at the site originate from a combination of surface and deep mine flows from several abandoned mine sites located to the south of Interstate Route 80. Partial reclamation of the site in the 1970's consolidated the discharges into a single channel that was directed into a culvert and transported under Interstate Route 80 and into a constructed channel. Investigations at the site suggested that the flow in the channel was perennial and would provide sufficient volume (see Table 1) to sustain the research wetland treatment system.

The proposed location of the research project was in an open and forested area along the constructed channel to the north of Interstate Route 80 on property owned by Frank Zerbe and Maxwell Shostall. The two owners had furnished agreements to permit access and construction of the research project on their property.

In addition to the above, several other worthwhile considerations of this site existed. The close proximity of this site to the EADS Groups' Clarion office would allow for careful monitoring of the system and frequent site visits. The Soil Conservation Service and private citizens groups are currently working to reduce the impact of AMD on the Mill Creek watershed by constructing wetlands in the watershed, and it was felt that the research project had the potential, after the study was completed, to contribute to the clean-up effort.

WETLAND CONSTRUCTION

The contractor, Simpsons Excavating, Inc., began construction in April 1991, and completed construction late that same month. The contractor used a tracked excavator for clearing and general excavation of the site as well as a small backhoe for finish construction and placement of substrate materials.

Construction began with Sub-system 1 and proceeded down the slope to Sub-system 2. Treatment units were constructed using a combination of excavated and compacted fill areas. The physical parameters of the treatment units consisted of at least 0.5 m (1.5 ft) of freeboard, a minimum slope of a 1:1 ratio for the inside and outside slopes, and 0.6 m (2 ft) berm widths.

A buried log road consisting of 30 to 45 cm (12 to 18 inch) felled trees was encountered during excavation. The greater portion of the logs were removed; however, some of the logs were positioned in such a manner that they could not be removed. Fill material was placed over theses logs and compacted. The cell bottoms and banks of the treatment units were lined with clay found on-site during the excavation process. To reduce the probability of leakage, the on-site clay was mechanically compacted.

To control flow into Sub-system 1, a section of 4 inch PVC pipe was placed in the AMD channel and through the bank of Cell 1 of Sub-system 1. The pipe was equipped with a 4 inch PVC butterfly valve to control the flow volume. A riprap lined spillway was constructed to carry the outflow from Cell 1 of Sub-system 1 to Cell 2. A flexible, perforated PVC pipe was placed in a meandering fashion across the bottom of Cell 2. This line was installed to act as an underdrain system. The perforated PVC was connected to a section of 4 inch PVC pipe placed through the discharge embankment and equipped with a 4 inch brass gate valve to control flow. A flexible PVC line was attached to the Cell 2 discharge pipe that directed the discharge from Cell 2 back to the AMD channel.

To control flow into Sub-system 2, a 75 m (250 ft) section of 2 inch water line was placed in the AMD channel from the influent point of Cell 1 of Sub-system 1 to the influent end of Cell 1 of Sub-system 2. This line was installed to insure water quality to the two sub-systems would be similar. The pipe was equipped with a 2 inch brass gate valve to control influent flow volume. A flexible, perforated PVC pipe was placed in the bottom of Cell 1 similar to Cell 2 of Sub-system 1. The perforated PVC was connected to a section of 4 inch PVC pipe placed through the discharge embankment and equipped with a 4 inch brass gate valve to control flow. To transport water to Cell 2, a vegetated channel was constructed from the discharge of Cell 1 to Cell 2. The discharge from Cell 2 was directed back to the AMD channel via a riprap spillway.

In addition to the above flow controls, pipe weirs were installed after construction was completed at a number of locations for monitoring purposes. The weirs were installed at

the discharge of Cell 1 and influent to Cell 2 in Sub-system 1 and at the influent and discharge of Cell 2 in Sub-system 2. The weirs consisted of 3/4 inch plywood with a 3 inch PVC pipe installed through the board for flow measurement and sample collection.

Once excavation was complete the bottoms of the cells were lined with 1B limestone purchased from Central Valley Aggregates, to a depth of 30 cm (12 inches). The stone was covered with mushroom compost obtained from Moonlight Mushrooms (Worthington, PA). The compost was placed in the cells to a depth of 30 cm (12 inches) using a tracked loader and leveled by hand to prevent compaction of the compost. Once the compost was in place, the cells were allowed to fill and all areas disturbed by the construction activities were mulched and seeded with a grass/legume mix.

After a two week waiting period to assure that there were no leaks the cells were planted. All the plants were obtained from Frank Zerbe the landowner. Planting was accomplished by placing dug plant units in the mushroom compost on approximately 0.6 m (2 ft) centers, which allowed for full plant coverage of a wetland by the end of one complete growing season. The plant units consisted of one mature cattail (*Typha latifolia*) and roughly a 30 cm (12 inch) diameter of soil 25 cm (10 inch) thick that contained all of the roots and rhizomes necessary for plant propagation. Planting was completed in June of 1991.

The final wetland design, including sampling points and flow controls, is contained on Figure 1. Typical cross-sections of surface flow and sub-surface flow units are contained on Figure 2. The surface area of Sub-system 1 totaled 303 m^2 (3260 ft^2) with Cell 1 containing 113 m^2 (1215 ft^2) and Cell 2 containing 130 m^2 (1400 ft^2). The surface area of Sub-system 2 totaled 318 m^2 (3420 ft^2) with Cell 1 containing 116 m^2 (1250 ft^2) and Cell 2 containing 176 m^2 (1890 ft^2).

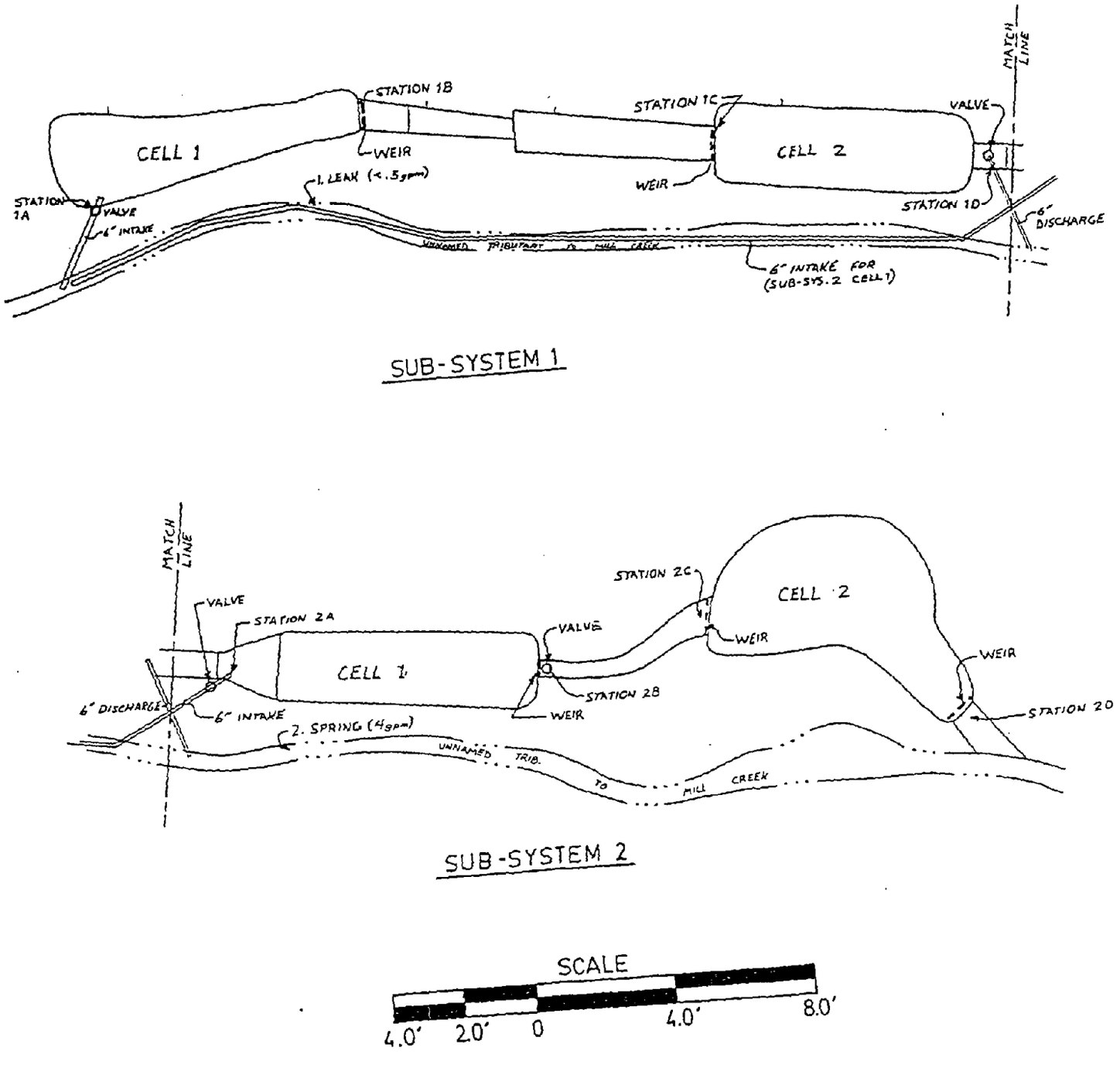

Figure 1. Site plan for the Bureau of Mines Acidic Mine Drainage wetland treatment system near Corsica, PA.

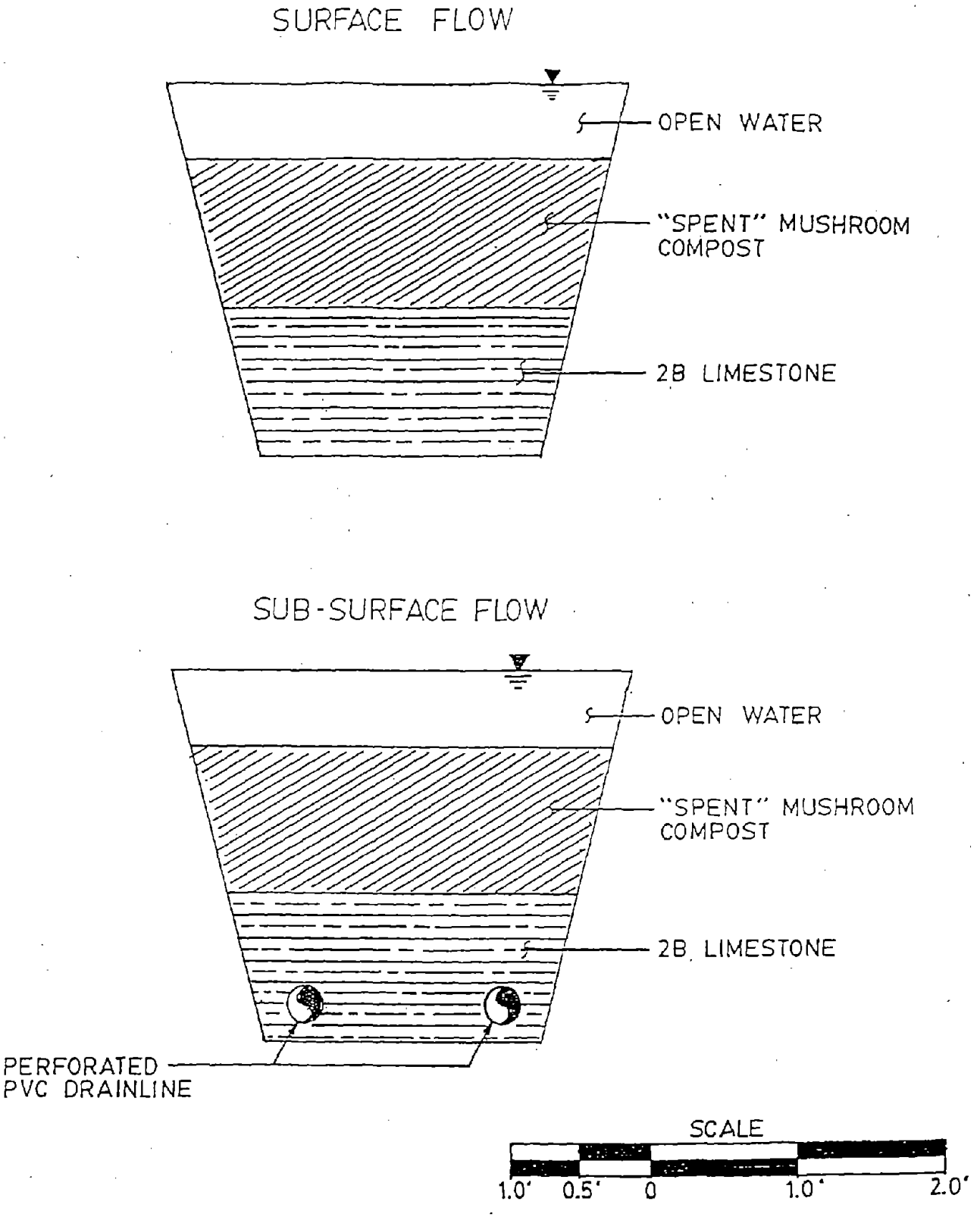

Figure 2. Cross-section design of sub-surface and surface flow units at the Bureau of Mines Acidic Mine Drainage wetland treatment system located near Corsica, PA.

SAMPLING PROGRAM

The sampling program included three elements: a weekly monitoring program to collect discharge water quality data; a pore water sampling program; and sediment core sampling program. The later two programs were conducted to evaluate wetland processes and functions. The different programs are discussed below.

WEEKLY MONITORING

For the weekly monitoring program, sampling stations were located in the two sub-systems to collect influent AMD, effluent from each sub-system and intermediate points between individual treatment units. Sampling stations (see Figure 1), summarized in Table 2, were located to sample influent, discharge, and intermediate locations in each sub-system at weirs and gate valves.

Table 2. Summary of sampling locations at the Corsica wetland treatment system.

Wetland Sub-system	Sampling Station	Station Description
Sub-system 1	1A	AMD influent to treatment Cell 1 (Surface flow)
	1B	Discharge from treatment Cell 1 (Surface flow)
	1C	Influent to treatment Cell 2 (Sub-surface flow)
	1D	Discharge from treatment Cell 2 (Sub-surface flow)
Sub-system 2	2A	AMD influent to treatment Cell 1 (Sub-surface flow)
	2B	Discharge from treatment Cell 1 (Sub-surface flow)
	2C	Influent to treatment Cell 2 (Surface flow)
	2D	Discharge from treatment Cell 2 (Surface flow)

Sampling of the wetland was initiated in May of 1991; however, the severe drought during the early spring and summer of 1991 resulted in a loss of AMD flow in August. Flow did not return until early March of 1992 and normal water levels and sufficient AMD flow did

not return until late March 1992. The weekly sampling was re-instated on March 25, 1992, continued through the spring, summer and fall of 1992 and was concluded on November 19, 1992.

Field measurements for dissolved oxygen, temperature and flow were determined weekly at each sampling station. Dissolved oxygen and temperature were measured with a YSI Model 51B Dissolved Oxygen meter. Estimates of flow were performed using a calibrated bucket (in liters) and a stop watch.

Water samples for laboratory analysis were collected weekly at each station, except stations 1A and 2A, which were collected on alternating weeks. Samples were collected in 500 mL polyethylene bottles and, due to close proximity of the project (approximately 15 min.), transported to the laboratory in a cooler at the collected temperature. Water samples were immediately analyzed for ferrous iron, using the phenanthroline method, and an aliquot of the sample was filtered (0.45 μm membrane filters) for soluble metal analysis. Parameters and procedures performed on water samples are summarized in Table 3.

Table 3. Analytical procedures used to determine concentrations for weekly monitored parameters at the Corsica wetland treatment system.

Parameter	Method	Instrument
Lab pH	Electrometric	Fisher Accumet 925 & Orion (Ross) combination electrode
Conductivity	Electrode Cell	Markeson Model 10
Alkalinity	Potentiometric Titration	Fisher Accumet 925 & Orion (Ross) combination electrode
Acidity	Potentiometric Titration (H_2O_2)	Fisher Accumet 925 & Orion (Ross) combination electrode
Sulfate	Turbidimetric	Milton-Roy Spectronic 20D
Iron	Phenanthroline	Milton-Roy Spectronic 20D
Aluminum	Eriochrome Cyanine R	Milton-Roy Spectronic 20D
Manganese	Periodate Oxidation	Milton-Roy Spectronic 20D
Calcium	Calculation (Hardness)	NA
Magnesium	EDTA Titrimetric	NA

A number of different iron measurements (i.e., total, dissolved and ferrous) were made on weekly samples. Total iron was measured on digested (acid) and reduced (hydroxylamine) samples using the phenanthroline method. Dissolved iron was analyzed similarly, but after filtration through a 0.45 μm membrane filter. Ferrous iron was measured directly on

samples using the phenanthroline method. Ferric iron was determined indirectly by subtraction of ferrous iron from total iron.

PORE WATER MONITORING

Pore water sampling was conducted on December 8, 1992 upon the completion of the weekly monitoring program. Pore water was extracted at the influent and effluent of each treatment pond and at various depths from the compost layer (Table 4); this was dependent on the depth of compost found at each sampling location. In general, pore water was extracted just below the surface, at 15 cm (6 in.) and 30 cm (12 in.) at each location. Cell 2 of Sub-system 2 contained only 15 cm (6 in.) of compost and could only be sampled at the surface and 15 cm depth.

Table 4. Summary of pore water and sediment sampling locations at the Corsica wetland treatment system.

Sample Number	Sample Location
111	Influent end of Cell 1 in System 1
112	Effluent end of Cell 1 in System 1
121	Influent end of Cell 2 in System 1
122	Effluent end of Cell 2 in System 1
211	Influent end of Cell 1 in System 2
212	Effluent end of Cell 1 in System 2
221	Influent end of Cell 2 in System 2
222	Effluent end of Cell 2 in System 2

Pore water samples were collected using a negative pressure apparatus, that consisted of an 125 mL erlenmeyer flask, a hand held vacuum pump, and a variety of tubing, connectors and rubber stoppers. Collected pore water samples were numbered according to station and stored in air tight containers and transported to the laboratory. The samples were immediately analyzed (within 12 hours of collection) for Eh, pH, ferrous iron and sulfide. Eh was measured with an Orion combination redox electrode in a closed cell. Sulfide was measured on extracted water by the methylene blue method (APHA 1992). The remaining

parameters, pH, alkalinity, acidity, total iron, ferrous iron, total manganese, total aluminum, sulfate and conductivity were analyzed in accordance with procedures listed in Table 3.

SEDIMENT CORE MONITORING

Sediment samples were collected in conjunction with the pore water sampling on December 8, 1992. Sediment cores were collected at influent and effluent of each cell by pressing a 1 m (3 ft) length of 4 in. PVC pipe into the compost sediment until limestone was impacted. The PVC pipe was withdrawn from the sediment with the core sample enclosed and both ends were capped.

The PVC pipe, containing the sediment core, was returned to the laboratory and the excess water was drawn off. The samples were then flash frozen at -29°C (-20°F) inside the PVC pipe for approximately 24 hours. The frozen cores were removed from the PVC pipe, between 5 and 8 cm (2 and 3 in) of sediment was removed from the top and bottom of each core, and placed in labeled freezer bags. The core sub-samples were transported to an analytical lab (G&C Laboratory) where the samples were homogenized and sub-samples (5 grams) were analyzed for sulfur forms and metals, using a total and sequential extraction procedure.

Total metals (aluminum, iron and manganese) in the core samples were determined by dry ashing portions of the sediment core samples. The ash residual was suspended into solution using an HCl digestion. The ashed and digested samples were analyzed using flame Atomic Absorption Spectrophotometry.

A sequential extraction procedure, modified from procedures in Weider et al. 1991, Miller et al. 1983, and Stover et al. 1976, was used to differentiate between forms of precipitated metals (e.g., organic bound, oxides, and sulfides) in the sediment. In general, sub-samples were extracted by mixing with a reagent (for a specified duration), centrifuging to separate the supernatant from the sub-samples and decanting the supernatant. Table 5 contains extracting reagents, duration of extraction, and metal fraction each reagent is intended to extract. Supernatant from each extraction procedure was analyzed for aluminum, iron, and manganese using flame Atomic Absorption Spectrophotometry.

Table 5. Sequential extraction procedures used to determine metal fractions on sediment samples collected from the Corsica wetland research project.

Step	Extraction Reagent	Extraction Duration	Metal Fraction
1	Deionized Water	30 min.	Soluble
2	1 Molar KNO_3	16 hours	Exchangeable
3	0.5 Molar KF	16 hours	Absorbed
4	0.1 Molar $Na_4P_2O_7$	16 hours	Organically bound
5	0.1 Molar EDTA	16 hours	Carbonate
6	0.3 Normal Na-Citrate & 0.1 Normal $NaHCO_3$ & 1g $NA_2S_2O_4$	30 min. @ 80°C	Oxide bound
7	1 Normal HNO_3	16 hours	Sulfide bound
8	Concentrated HNO_3	16 hours	Residual

RESULTS

The results of this research project are summarized in five separate sections:

- Discharge Water Quality
- Pore Water Results
- Sediment Core Results
- Sub-system & Unit Comparisons
- Loading & Removal Rates

As reported earlier, a period of no flow occurred during the drought of 1991, which resulted in lowered water levels in several of the treatment units and caused air exposure to the mushroom compost and limestone layers. In addition, the system was slightly modified in the Fall of 1991 to provide greater experimental control and statistical comparisons. Therefore, only a summary of the data collected in the second year is enclosed.

DISCHARGE WATER QUALITY

Discharge water quality is an important consideration in evaluating WTS performance and compliance with required effluent limits. To evaluate performance, discharge water quality from sub-systems and units were statistically compared to influent water quality using an ANOVA procedure (Sokal and Rohlf 1981). A probability (p) of 0.05 was selected as the criteria for significant differences. Water quality results (including statistical results) are summarized below.

Influent Comparison

Prior to influent and effluent comparisons, the water sample data from the two influent stations (1A and 2A) were compared (Table 6 and 7). An ANOVA analysis was conducted to determine whether the influent quality to each sub-system was similar and to determine whether water quality data from these two stations could be combined. All parameters (e.g., flow, pH, sulfate, etc.), except ferrous iron, were not significantly different; the majority had probabilities greater than 0.25. Ferrous iron was significantly lower (approximately 5 mg/L) at influent Station 2A than 1A, which was probably the result of oxidation to ferric iron in the 200 ft water line. The lower ferrous iron levels appear to have resulted in slightly lower total iron levels; however, this decrease was not significant.

Table 6. Comparison of water quality monitoring data from influent stations at the Corsica wetland treatment system.

SAMPLE NUMBER	PARAMETER	LAB pH	CONDUCTANCE umho's	ALKALINITY mg/L (as $CaCO_3$)	ACIDITY mg/L (as $CaCO_3$)	TOTAL Fe mg/L	DISSOLVED Fe mg/L	FERROUS Fe mg/L
1A	COUNT	18	18	18	18	18	18	18
	MINIMUM	3.12	1600	0	252	18.4	10.7	2.6
	MAXIMUM	3.99	2600	0	538	67.6	49	32.3
	AVERAGE	3.38	2183	0	382.1	37.99	28.33	13.53
	STD. DEV.	0.000162[1]	245.5	0	82.45	11.82	9.66	7.18
2A	COUNT	17	17	17	17	17	17	17
	MINIMUM	3.03	1800	0	204	6.8	6	1.6
	MAXIMUM	4	2600	0	566	52.5	50	37.8
	AVERAGE	3.42	2306	0	368.4	30.69	28.17	9.45
	STD. DEV.	0.000195[1]	183.0	0	109.5	12.54	11.70	8.58

[1] pH standard deviations are based on hydrogen ion concentrations.

Table 7. Comparison of water quality monitoring data from influent stations at the Corsica wetland treatment system.

SAMPLE NUMBER	PARAMETER	FERRIC Fe mg/L	TOTAL Mn mg/L	DISSOLVED Mn mg/L	TOTAL Al mg/L	SULFATE mg/L	CALCIUM mg/L	MAGNESIUM mg/L
1A	COUNT	18	18	18	18	18	18	18
	MINIMUM	3.8	20	19	8.69	890	224	106
	MAXIMUM	46.9	54.6	49.4	36.3	2100	392	194
	AVERAGE	24.46	34.37	30.94	20.99	1569	322.7	149.3
	STD. DEV.	13.30	7.19	6.54	9.27	317.1	50.74	26.75
2A	COUNT	17	17	17	17	17	17	17
	MINIMUM	0	18.7	18.5	10.1	980	232	63
	MAXIMUM	42.9	47.3	43.9	32.8	2020	384	223
	AVERAGE	22.04	32.99	29.79	18.78	1589	307.8	146.8
	STD. DEV.	14.09	6.62	5.79	7.56	263.0	41.90	38.71

Table 8. Summary of water quality monitoring data from Sub-system 1 at the Corsica wetland treatment system.

SAMPLE NUMBER	PARAMETER	FLOW (gpm)	TEMP. (°C)	DISSOLVED OXYGEN mg/L	LAB pH	CONDUCTANCE umho's	ALKALINITY mg/L (as $CaCO_3$)	ACIDITY mg/L (as $CaCO_3$)	TOTAL Fe mg/L
1A	COUNT	35	34	33	35	35	35	35	35
	MINIMUM	1.5	6	7.2	3.12	1600	0	204	6.8
	MAXIMUM	4.5	20	12	4	2600	0	566	67.6
	AVERAGE	2.8	11.38	9.00	3.41	2243	0	375.4	34.4
	STD. DEV.	0.510	3.00	1.11	0.000157[1]	225.9	0	96.78	12.71
1B	COUNT	35	34	33	35	35	35	35	35
	MINIMUM	0.25	2	2	2.98	1800	0	180	6
	MAXIMUM	2.5	27	13.4	3.81	2600	0	506	39.5
	AVERAGE	1.06	13.03	7.42	3.26	2207	0	340.5	20.06
	STD. DEV.	0.512	5.84	2.96	0.000225[1]	207.1	0	84.67	8.75
1C	COUNT	35	34	33	35	35	35	35	35
	MINIMUM	0.75	4	4.2	3	1800	0	146	7.5
	MAXIMUM	4	26	11.9	3.96	2600	0	370	30.9
	AVERAGE	1.79	13.35	8.41	3.27	2251	0	231.9	15.79
	STD. DEV.	0.614	5.28	2.20	0.000192[1]	214.3	0	60.85	5.69

Table 8. Summary of water quality monitoring data from Sub-system 1 at the Corsica wetland treatment system.

SAMPLE NUMBER	PARAMETER	FLOW (gpm)	TEMP. (°C)	DISSOLVED OXYGEN mg/L	LAB pH	CONDUCTANCE umho's	ALKALINITY mg/L (as $CaCO_3$)	ACIDITY mg/L (as $CaCO_3$)	TOTAL Fe mg/L
1D	COUNT	35	34	34	35	35	35	35	35
	MINIMUM	0.75	4	0.1	6.39	1800	76	0	0.5
	MAXIMUM	2.5	19	0.8	7.35	2600	152	0	23.5
	AVERAGE	1.71	13.38	0.121	6.76	2220	111.7	0	7.14
	STD. DEV.	0.379	4.37	0.118	1.11e-07[1]	187.9	21.04	0	5.44

[1] pH standard deviations are based on hydrogen ion concentrations.

Table 9. Summary of water quality monitoring data from Sub-system 1 at the Corsica wetland treatment system.

SAMPLE NUMBER	PARAMETER	DISSOLVED Fe mg/L	FERROUS Fe mg/L	FERRIC Fe mg/L	TOTAL Mn mg/L	DISSOLVED Mn mg/L	TOTAL Al mg/L	SULFATE mg/L	CALCIUM mg/L	MAGNESIUM mg/L
1A	COUNT	35	35	35	35	35	35	35	35	35
	MINIMUM	6	1.6	0	18.7	18.5	8.7	890	224	63
	MAXIMUM	50	32.3	46.9	54.6	49.4	36.3	2100	392	223
	AVERAGE	28.25	10.99	23.28	33.61	30.38	19.92	1579	315.4	148.1
	STD. DEV.	10.70	6.90	13.74	6.80	6.22	8.55	292.3	47.24	33.13

Table 9. Summary of water quality monitoring data from Sub-system 1 at the Corsica wetland treatment system.

SAMPLE NUMBER	PARAMETER	DISSOLVED Fe mg/L	FERROUS Fe mg/L	FERRIC Fe mg/L	TOTAL Mn mg/L	DISSOLVED Mn mg/L	TOTAL Al mg/L	SULFATE mg/L	CALCIUM mg/L	MAGNESIUM mg/L
1B	COUNT	35	35	35	35	35	35	35	35	35
	MINIMUM	4.7	0.8	1.6	13.3	12.2	6.8	840	216	72
	MAXIMUM	36.4	8.1	33.2	47.3	44.2	34.3	2010	480	223
	AVERAGE	18.54	4.06	15.26	31.80	28.38	18.35	1481	313.6	144.4
	STD. DEV.	9.08	2.03	8.41	6.75	6.83	7.81	294.3	61.46	35.50
1C	COUNT	35	35	35	35	35	35	35	35	35
	MINIMUM	4.2	0.4	2.6	20.5	19.2	4.9	750	240	63
	MAXIMUM	23.3	4.2	29.9	44.2	44.2	19.2	1950	432	194
	AVERAGE	14.19	1.9	13.84	32.39	29.25	10.75	1458	320	133.6
	STD. DEV.	5.05	0.912	5.89	5.18	5.45	4.19	285.4	46.73	31.80
1D	COUNT	35	35	35	35	35	35	35	35	35
	MINIMUM	0.4	0.5	0	24.2	18.2	0.005	710	280	82
	MAXIMUM	18.7	12.8	14.9	42.3	40.3	0.145	1970	528	223
	AVERAGE	4.86	4.78	2.74	32.95	29.59	0.058	1351	376.9	133.9
	STD. DEV.	3.65	2.96	3.53	4.29	4.72	0.038	260.5	61.07	34.85

Based on this evaluation, the water quality of the two influents were determined to be similar and subsequently were combined for statistical comparisons and loading estimates for each sub-system. This evaluation also indicates observed differences in effluent quality between sub-systems is due to differences in design and not due to differences in influent water quality.

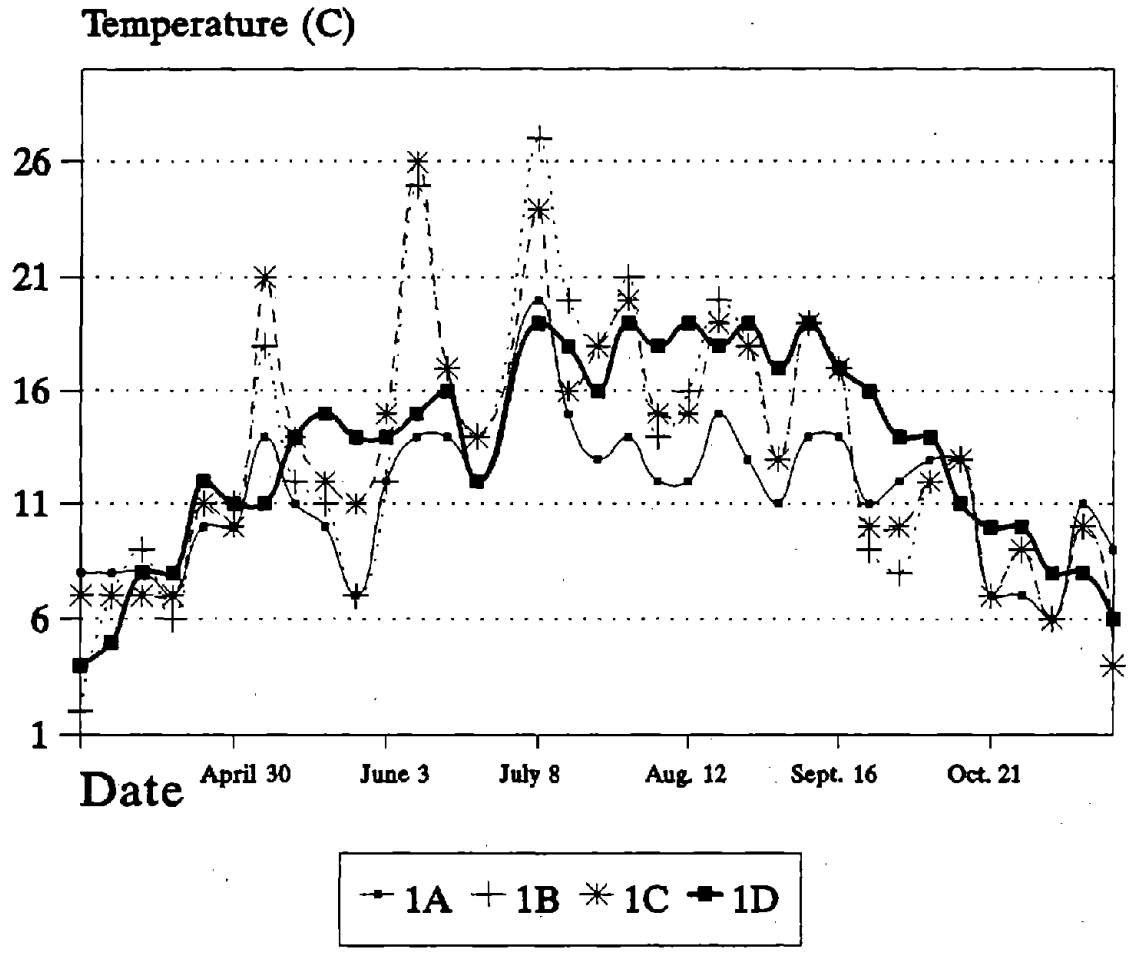

Figure 3. Sub-system 1 influent through effluent temperature variability from the Corsica wetland treatment system.

Sub-system 1

The water quality data for all parameters from Sub-system 1 are contained in Appendix A. Analysis of discharge water quality indicate that Sub-system 1: significantly decreased acidity, iron, aluminum and sulfate; significantly increased pH, alkalinity and calcium; did

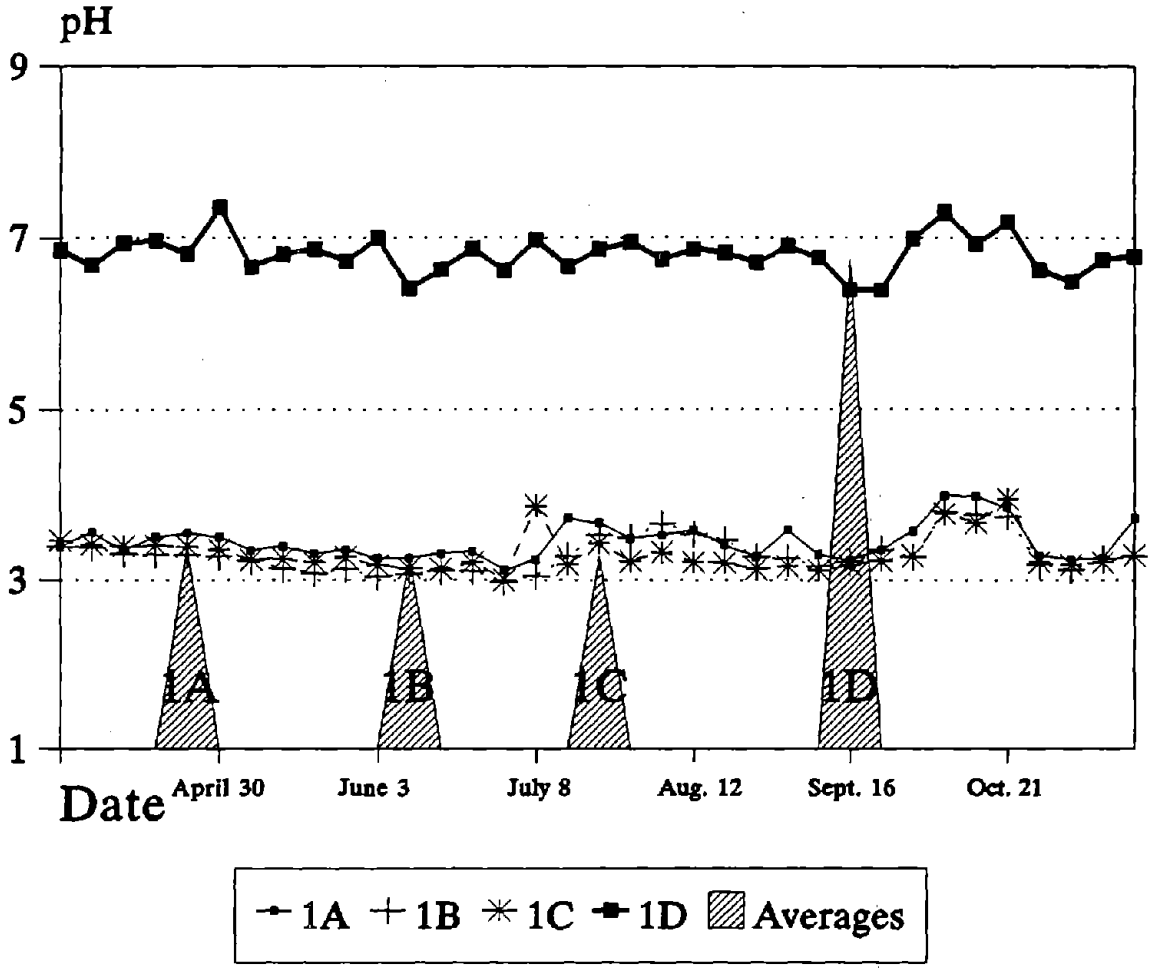

Figure 4. Sub-system 1 influent through effluent variability and average concentrations for pH from the Corsica wetland treatment system.

not significantly affect manganese and magnesium. Averages for key water quality parameters from Sub-system 1 are summarized in Table 8 and 9 and a statistical summary for all parameters monitored for the sub-system at each station are contained in Table 10.

Dissolved oxygen and temperature were also measured in the field. Dissolved oxygen was found at relatively high levels (> 4 mg/L) at all monitoring stations except the discharge from Cell 2 (1D). Dissolved oxygen measured at this monitoring station (the discharge from the sub-surface flow unit) was typically well below 1 mg/L. Temperatures monitored at stations within the sub-system averaged 13°C (55°F) during the monitoring program; however, Figure 3 indicates temperature variation was seasonal in each unit.

Table 10. Summary of averages for water quality parameters of special interest monitored in Sub-system 1 at the Corsica wetland treatment system.

SAMPLE NUMBER	LAB pH	ALKALIN. mg/L (as $CaCO_3$)	ACIDITY mg/L (as $CaCO_3$)	TOTAL Fe mg/L	TOTAL Mn mg/L	TOTAL Al mg/L	SO_4^{-2} mg/L	Ca mg/L	Mg mg/L
1A	3.41	0	375	34.4	33.6	19.9	1579	315	148
1B	3.26	0	340	20.1	31.8	18.4	1481	314	144
1C	3.27	0	232	15.8	32.4	10.8	1458	320	134
1D	6.76	112	0	7.1	33.0	0.06	1351	377	134

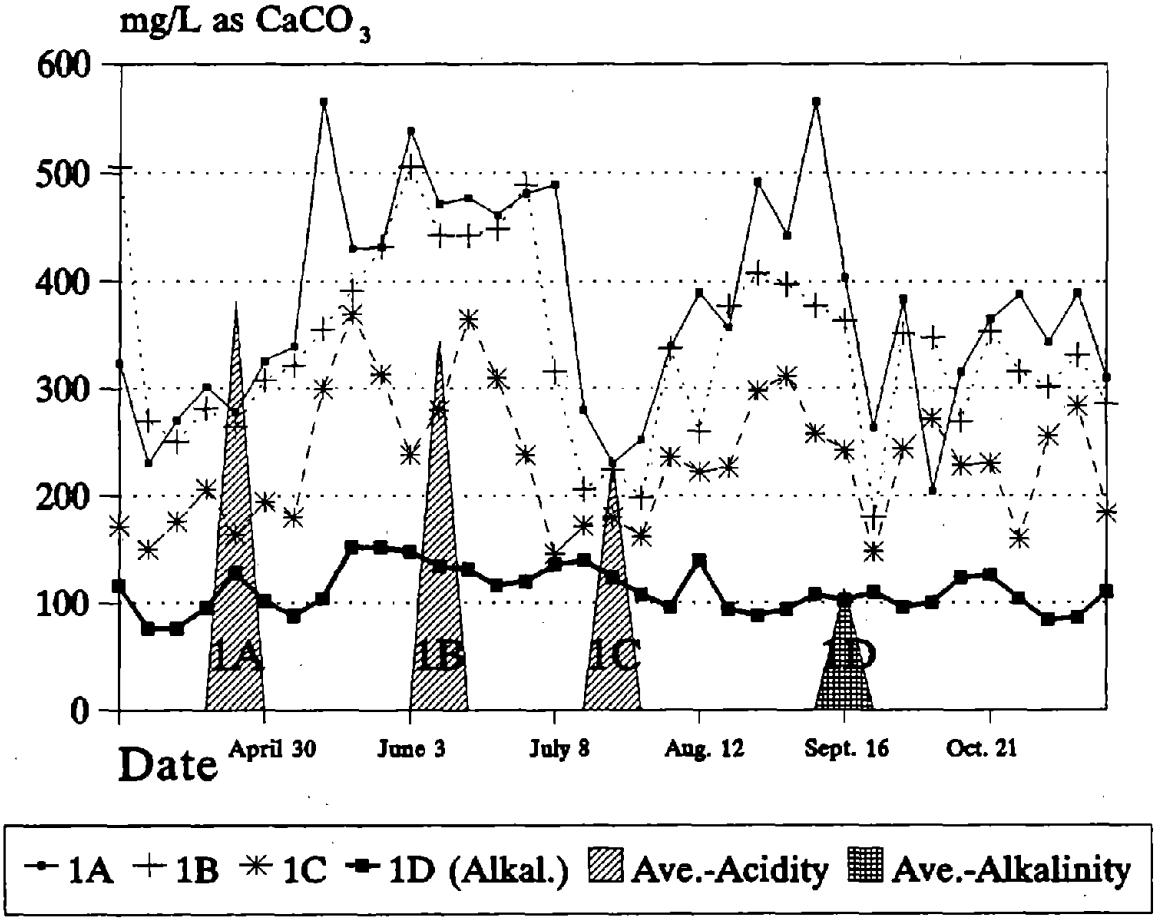

Figure 5. Sub-system 1 station variability and average concentrations for alkalinity and acidity from the Corsica wetland treatment system.

Flow was measured at pipe weirs and discharge pipes (sub-surface flow cell) located at sampling stations. The influent flow, which was adjusted weekly, averaged 10.6 L/min (2.8 gpm) and varied considerably from the intended flow of 11.5 L/min (3 gpm). This variability was a result of iron accumulation that reduced the valve opening and was minimized by weekly adjustment of the valve. Flow measured at the discharge from Cell 1 (1B), averaged 4.2 L/min (1.1 gpm) and was well below the 11.5 L/min design flow. The reduced flow at this station was a result of leakage in Cell 1, some of which (approximately 2 L/min) re-entered the sub-system in the riprap spillway from Cell 1. Flow measured at the influent to Cell 2 (1C) averaged 6.8 L/min (1.8 gpm) and reflects the return of flow from the leak in Cell 1. The discharge from Cell 2 (1D) averaged 6.5 L/min (1.7 gpm) over the course of the study, which suggests little if any leakage occurred from this unit.

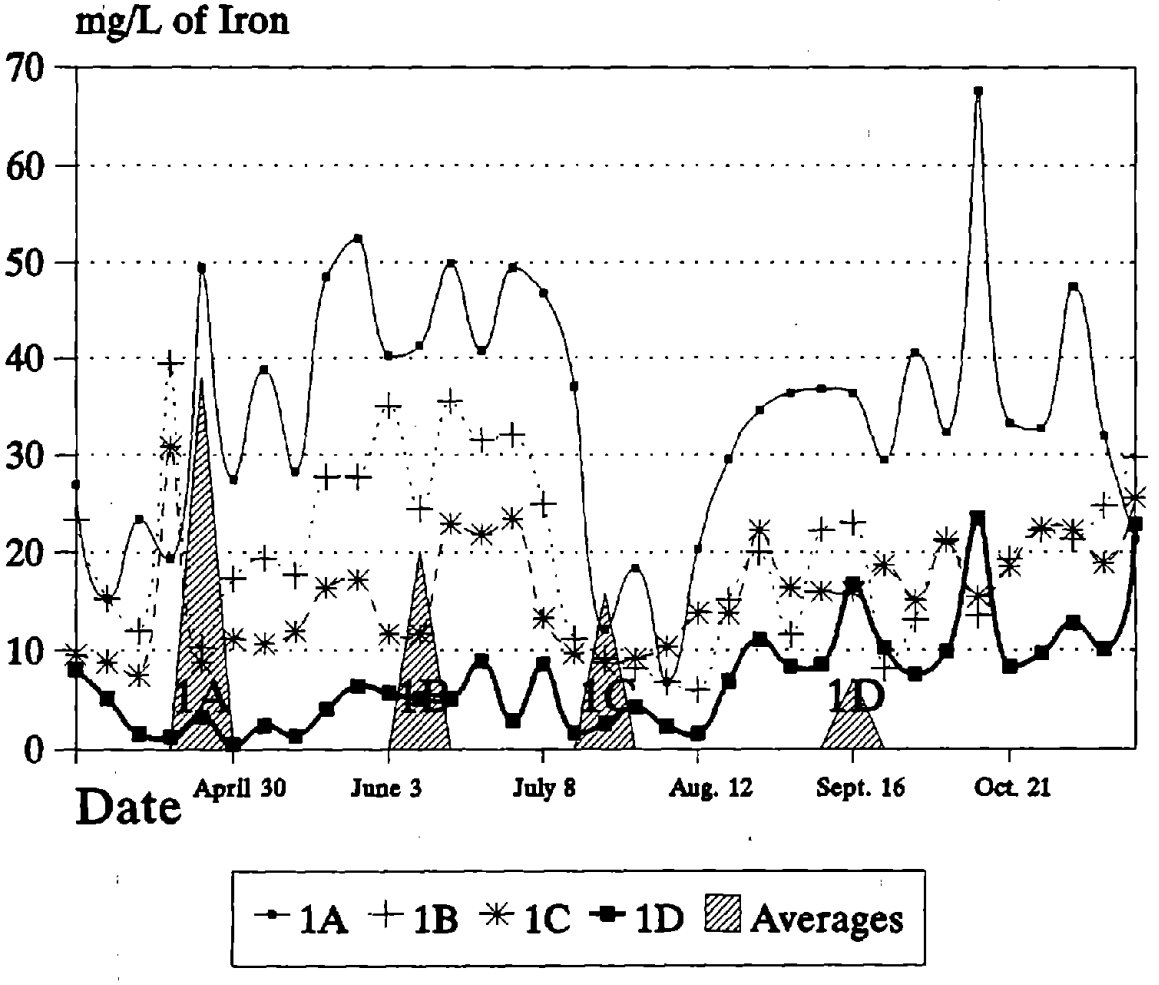

Figure 6. Sub-system 1 influent through effluent variability and average concentrations for iron from the Corsica wetland treatment system.

Influent pH averaged 3.41 and increased across Sub-system 1 to 6.76 on average, which is an almost complete removal of hydrogen ions. The pH in the sub-system initially decreased across Cell 1 (a surface flow unit) to an average of 3.26 and increased insignificantly to 3.27 between Cell 1 and 2. The pH then increased in Cell 2 to the discharge pH. Examination of Figure 4 indicates no seasonal or longterm trends were apparent from the pH data from Sub-system 1.

Acidity, which had an average influent concentration of 375 mg/L (as $CaCO_3$), decreased at all monitoring stations to an effluent of 0 mg/L (Figure 5). Station 1B, the Cell 1 discharge, had an average acidity of 344 mg/L, which indicates acidity decreased by approximately 40 mg/L. Greater decreases in acidity, which averaged 110 mg/L, were observed between Cell 1 and 2. However, the most significant decreases were observed in Cell 2, which decreased acidity from an average inflow of 232 mg/L to 0 mg/L. In addition, Cell 2 also increased alkalinity from 0 mg/L to an average effluent of 112 mg/L (as $CaCO_3$).

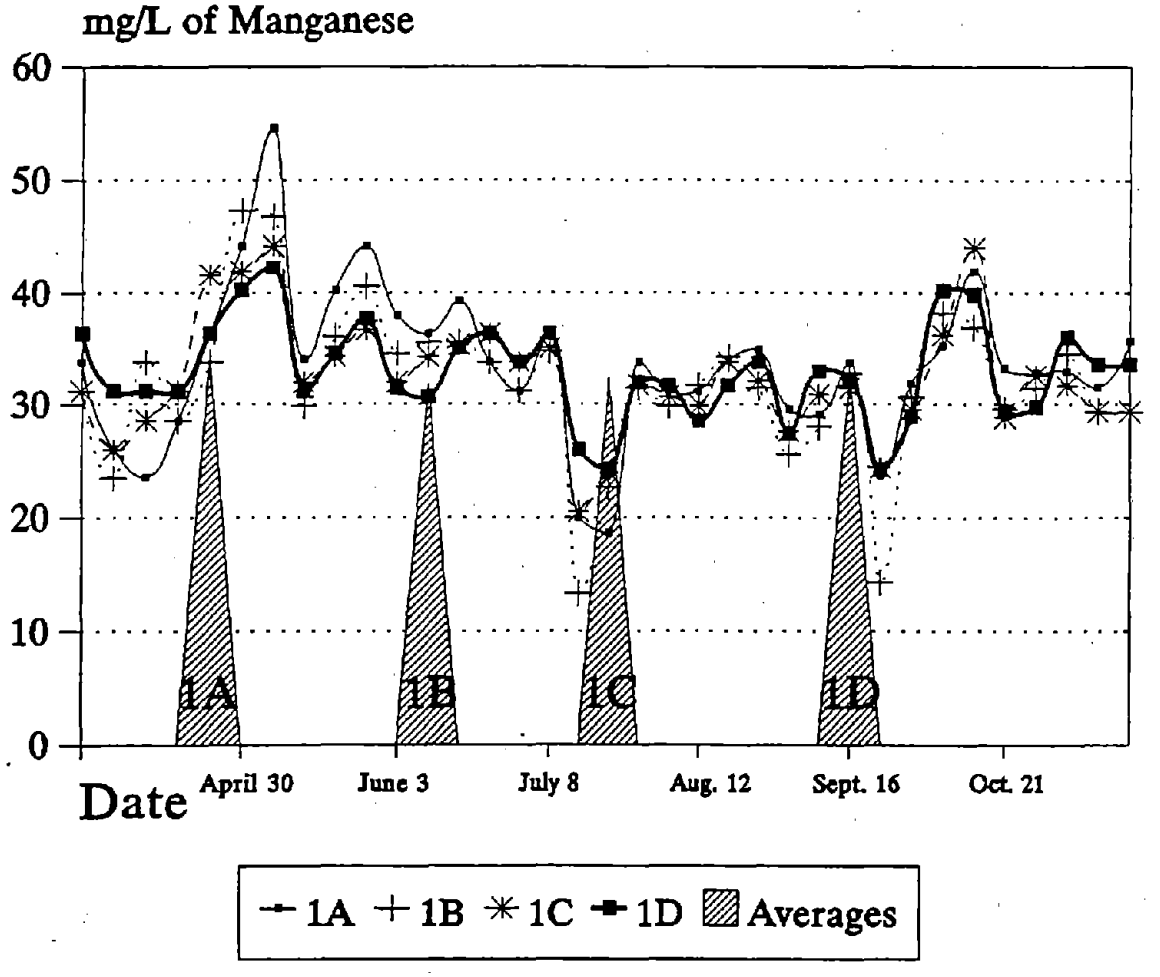

Figure 7. Sub-system 1 influent through effluent variability and average concentrations for manganese from the Corsica wetland treatment system.

A number of different fractions of iron (i.e., total, dissolved, ferrous and ferric) were determined on collected samples, all of which significantly decreased across Sub-system 1 (see Table 8 and 9). Total iron decreased on average from an influent (1A) of 34.4 mg/L to a discharge concentration of 7.1 mg/L; an 79% decrease. The decrease in total iron across Cell 1 and between Cell 1 and Cell 2 was linked to decreases in particulate (total - dissolved) and ferrous iron, which combined for a decrease of approximately 20 mg/L (9 and 11 mg/L, respectively). Based on an increase in average ferrous iron from 2 mg/L to 4.8 mg/L across Cell 2, total iron removal does not appear to be related to ferrous iron removal. Influent iron (1A) and Cell 1 effluent (1B) do not indicate any longterm changes (see Figure 6); however, the Sub-system 1 discharge (1D) had an increasing trend toward the end of the monitoring program in total iron concentrations.

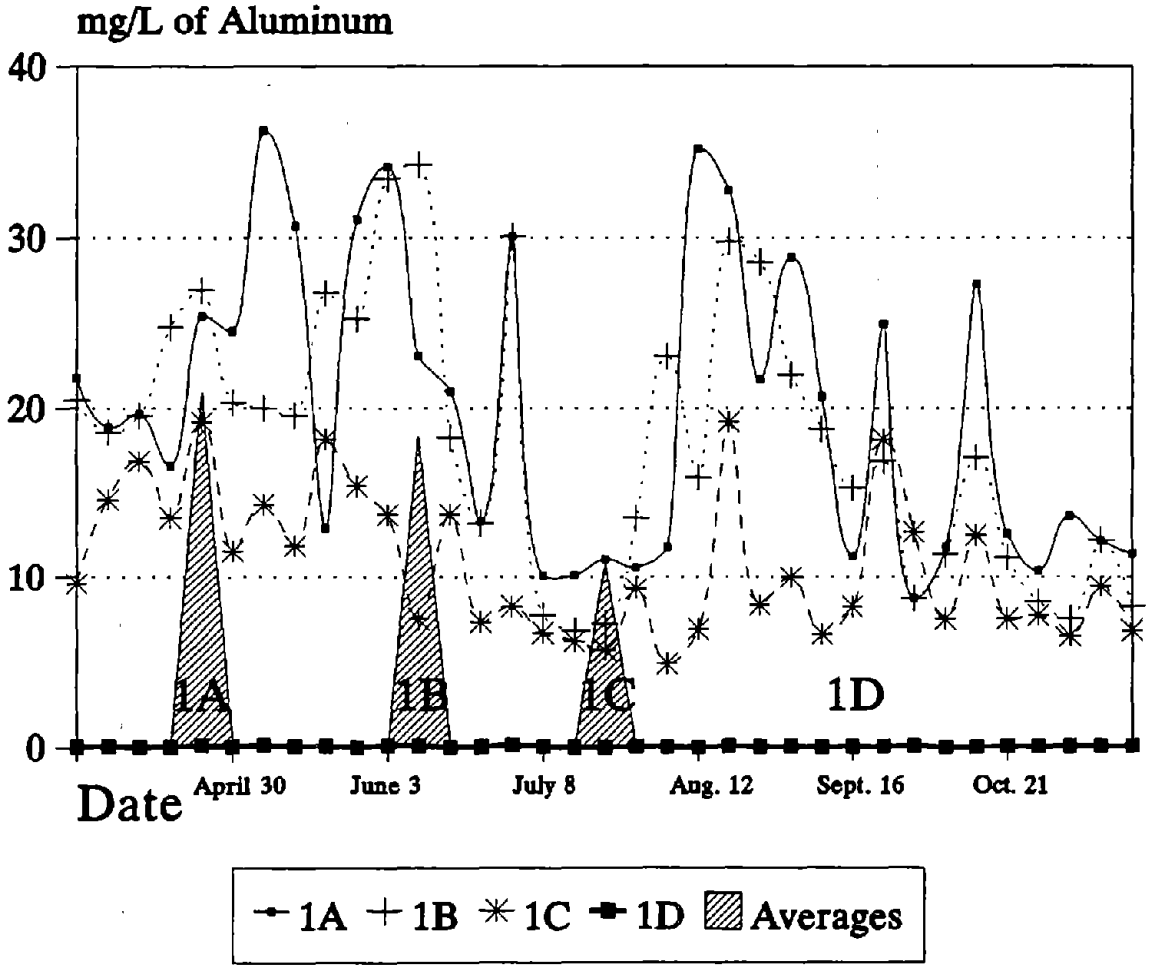

Figure 8. Sub-system 1 influent through effluent variability and average concentrations for aluminum from the Corsica wetland treatment system.

Two forms of manganese, total and dissolved, were analyzed on collected samples. The monitoring data (Figure 7) indicate influent manganese was not significantly effected (lowered) by Sub-system 1. Slight decreases of 2-3 mg/L in average manganese across Cell 1 were observed; however, slight increases, 1-2 mg/L, were observed at station 1C and the Sub-system discharge (1D). No seasonal or longterm effects in the manganese data were observed in Figure 7.

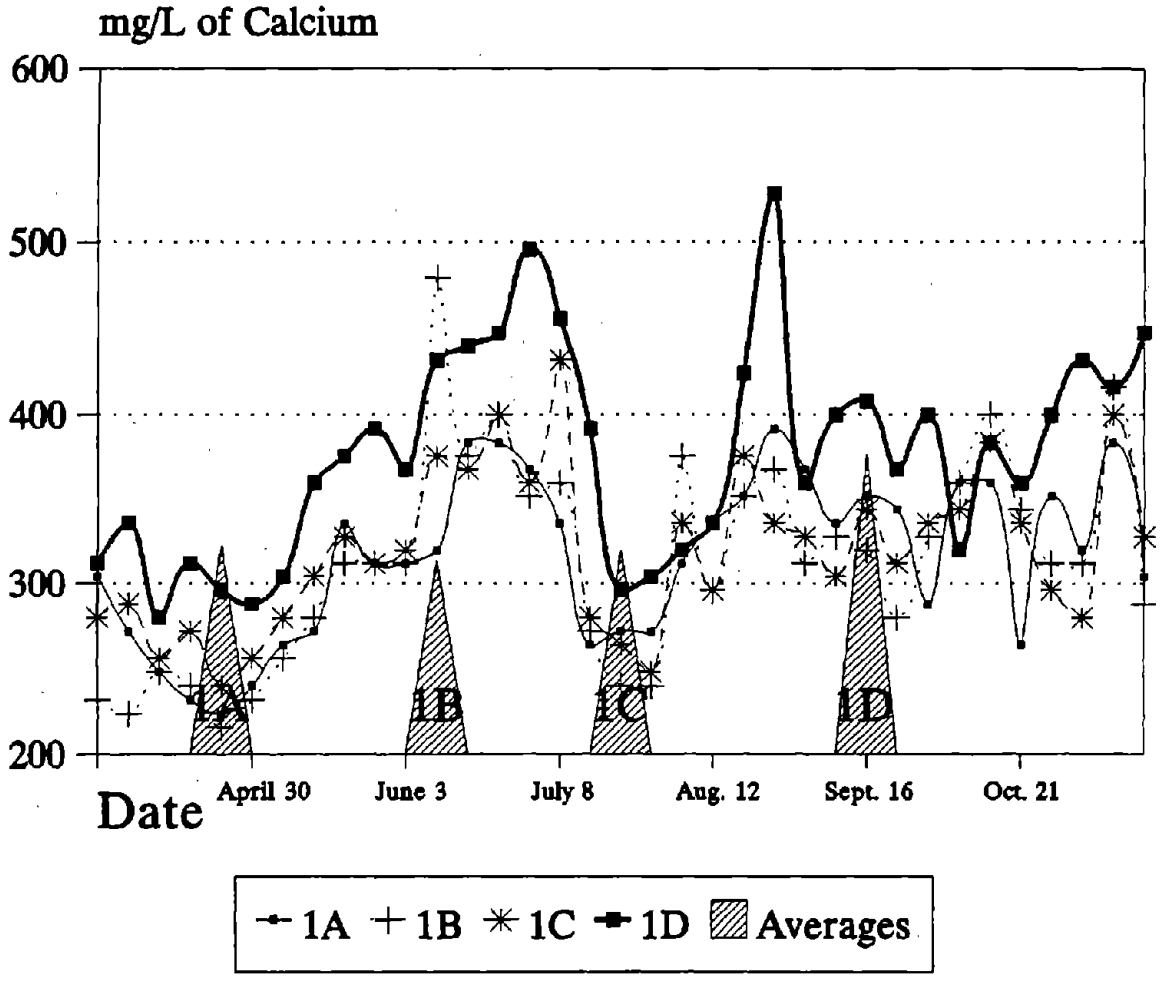

Figure 7. Sub-system 1 influent through effluent variability and average concentrations for calcium from the Corsica wetland treatment system.

Total aluminum levels were found to significantly decrease across Sub-system 1 from an average influent of 19.9 mg/L to an effluent concentration less than 0.5 mg/L. Decreases in aluminum occurred at all sampling locations in the sub-system, ranging from 1.5 mg/L in Cell 1 to in excess of 10 mg/L in Cell 2. Figure 8 indicates there were no longterm or seasonal effects on aluminum removal at any sampling location.

Calcium was found to significantly increase across Sub-system 1. Influent calcium averaged 315 mg/L and did not significantly increase across the first two monitoring stations (1B & 1C), which averaged 314 mg/L and 320 mg/L, respectively. Calcium concentrations increased significantly across the sub-surface flow cell (Cell 2) averaging 377 mg/L, which is a 50 mg/L increase across this unit. Longterm or seasonal effects on effluent concentrations were not observed in Figure 9.

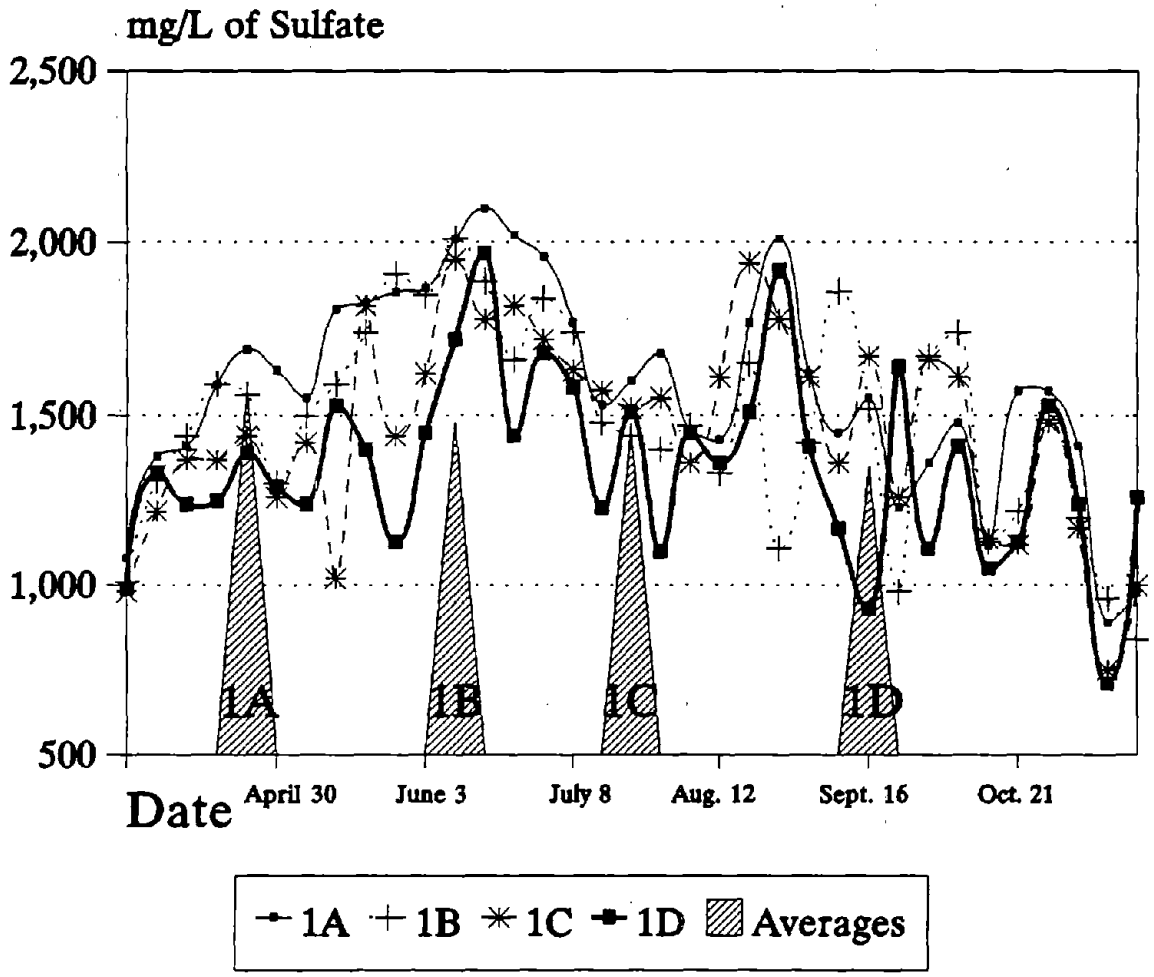

Figure 8. Sub-system 1 influent through effluent variability and average concentrations for sulfate from the Corsica wetland treatment system.

Conversely, magnesium did not significantly increase across the sub-system. Influent magnesium averaged 148 mg/L over the course of the study and decreased slightly to 134 mg/L in the discharge; however this decrease was not significant. The observed decreases may be the result of variation or due to slight interferences in the colorimetric titration procedure.

Sulfate, like calcium, was also monitored to evaluate processes within the wetland treatment system. Sulfate levels averaged 1580 mg/L in the influent, exhibited decreased levels at each subsequent monitoring station, and showed significantly decreased levels between the influent and discharge of Sub-system 1 (see Figure 10). Sulfate levels in the effluent average 1350 mg/L over the course of the study, which indicates the sub-system removed, on average, 230 mg/L of sulfate. Seasonal increases and decreases in sulfate concentrations are apparent in Figure 10 at several of the monitoring stations within the sub-system; however, influent sulfate data appears to follow a similar seasonal change.

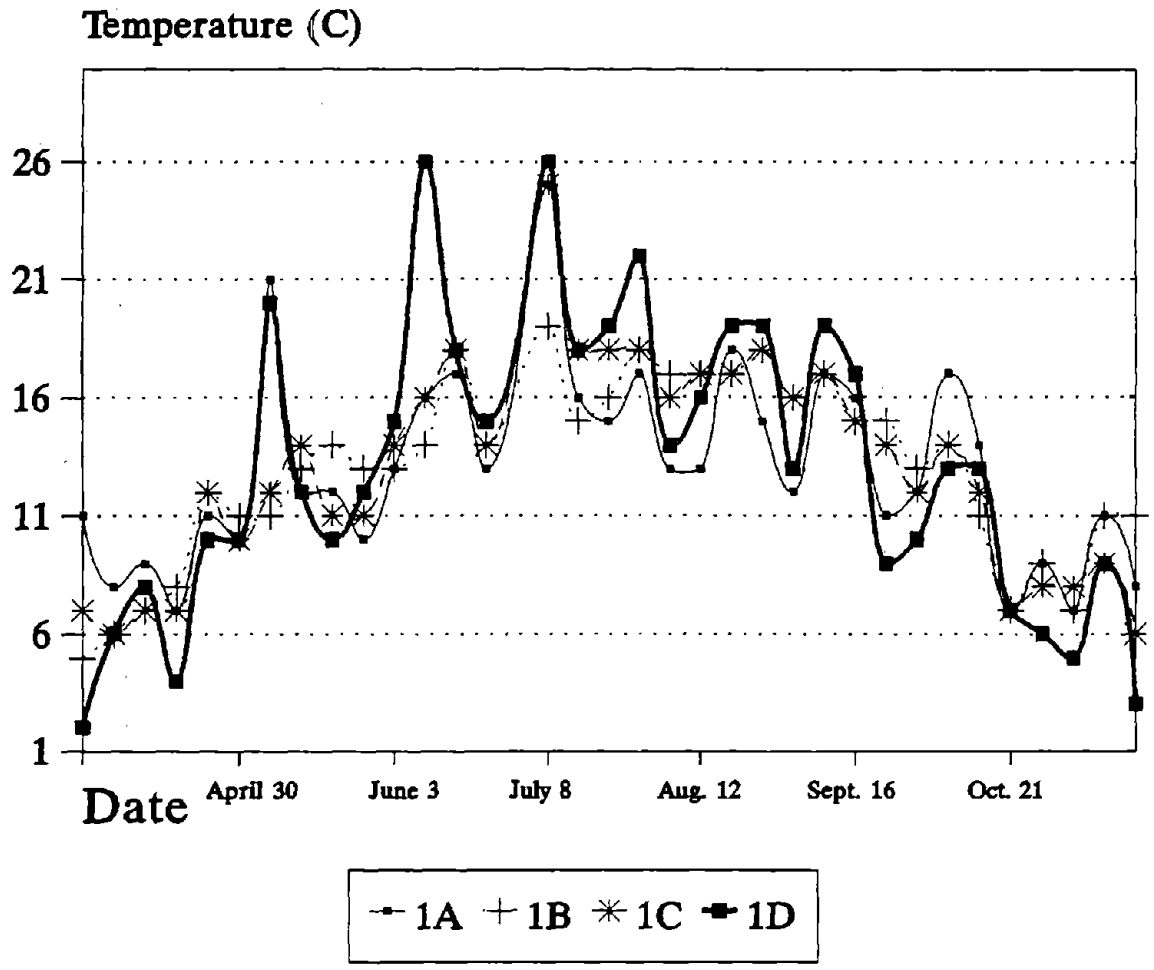

Figure 11. Sub-system 2 influent through effluent temperature variability in the Corsica wetland treatment system.

Sub-system 2

The water quality data for all parameters from Sub-system 2 are contained in Appendix B. Analysis of discharge water quality indicates Sub-system 2 affected AMD in Sub-system 1, in that the sub-system: significantly decreased acidity, iron, and aluminum; significantly increased pH, alkalinity and calcium; did not significantly effect sulfate, manganese and magnesium. A statistical summary for each sampling point in Sub-system 2 are summarized in Table 11 and 12 and discussed below; Averages for key parameters are contained in Table 13.

Table 11. Summary of water quality monitoring data from Sub-system 2 at the Corsica wetland treatment system.

SAMPLE NUMBER	PARAMETER	FLOW gpm	TEMP. (°C)	DISSOLVED OXYGEN mg/L	LAB pH	CONDUCTANCE umho's	ALKALINITY mg/L (as $CaCO_3$)	ACIDITY mg/L (as $CaCO_3$)	TOTAL Fe mg/L
2A	COUNT	35	34	33	35	35	35	35	35
	MINIMUM	1.5	7	6.4	3.12	1600	0	204	6.8
	MAXIMUM	4	25	11.9	4	2600	0	566	67.6
	AVERAGE	2.69	13.03	8.42	3.41	2243	0	375.4	34.45
	STD. DEV.	0.43	4.06	1.42	0.000157[1]	225.9	0	96.78	12.71
2B	COUNT	35	34	35	35	35	35	35	35
	MINIMUM	1	5	0.1	6.32	1700	90	0	0.4
	MAXIMUM	2.5	19	0.1	7.25	2800	146	0	26.4
	AVERAGE	1.79	13	0.1	6.62	2301	112.3	0	11.13
	STD. DEV.	0.44	3.80	0	1.13e-07[1]	219.2	14.17	0	7.72
2C	COUNT	35	34	33	35	35	35	35	35
	MINIMUM	1	6	0.1	6.31	2000	84	0	0.5
	MAXIMUM	2.25	25	8.4	7.28	2400	132	0	21.4
	AVERAGE	1.70	13.06	2.57	6.69	2279	103.3	0	6.94
	STD. DEV.	0.38	4.48	1.96	1.06e-07[1]	142.1	13.74	0	6.04

Table 11. Summary of water quality monitoring data from Sub-system 2 at the Corsica wetland treatment system.

SAMPLE NUMBER	PARAMETER	FLOW gpm	TEMP. (°C)	DISSOLVED OXYGEN mg/L	LAB pH	CONDUCTANCE umho's	ALKALINITY mg/L (as $CaCO_3$)	ACIDITY mg/L (as $CaCO_3$)	TOTAL Fe mg/L
2D	COUNT	35	34	33	35	35	35	35	35
	MINIMUM	0.25	2	2	6.47	1800	72	0	0.1
	MAXIMUM	1.25	26	12.4	7.44	2600	134	0	1.2
	AVERAGE	0.82	13.09	6.21	6.87	2233	98.06	0	0.511
	STD. DEV.	0.24	6.16	3.03	8.04e-08[1]	209.4	16.47	0	0.323

[1] pH standard deviations are based on hydrogen ion concentrations.

Table 12. Summary of water quality monitoring data from Sub-system 2 at the Corsica wetland treatment system.

SAMPLE NUMBER	PARAMETER	DISSOLVED Fe mg/L	FERROUS Fe mg/L	FERRIC Fe mg/L	TOTAL Mn mg/L	DISSOLVED Mn mg/L	TOTAL Al mg/L	SULFATE mg/L	CALCIUM mg/L	MAGNESIUM mg/L
2A	COUNT	35	35	35	35	35	35	35	35	35
	MINIMUM	6	1.6	0	18.7	18.5	8.7	890	224	63
	MAXIMUM	50	32.3	46.9	54.6	49.4	36.3	2100	392	223
	AVERAGE	28.25	10.99	23.28	33.61	30.38	19.92	1579	315.4	148.1
	STD. DEV.	10.70	6.90	13.74	6.80	6.22	8.55	292.3	47.24	33.13

Table 12. Summary of water quality monitoring data from Sub-system 2 at the Corsica wetland treatment system.

SAMPLE NUMBER	PARAMETER	DISSOLVED Fe mg/L	FERROUS Fe mg/L	FERRIC Fe mg/L	TOTAL Mn mg/L	DISSOLVED Mn mg/L	TOTAL Al mg/L	SULFATE mg/L	CALCIUM mg/L	MAGNESIUM mg/L
2B	COUNT	35	35	35	35	35	35	35	35	35
	MINIMUM	0.3	0	0	25	20.8	0.003	800	280	92
	MAXIMUM	17	23.1	22.9	59.8	46.8	0.144	2020	560	223
	AVERAGE	6.19	6.08	5.16	38.21	32.62	0.055	1555	416.2	159.7
	STD. DEV.	5.43	5.16	5.29	7.76	6.67	0.034	288.4	67.19	37.33
2C	COUNT	35	35	35	35	35	35	35	35	35
	MINIMUM	0.1	0	0	23.4	15.6	0.002	1020	312	87
	MAXIMUM	12.5	11	16.4	57.2	52	0.08	2000	568	218
	AVERAGE	3.65	3.30	3.65	37.37	32.39	0.034	1537	421.9	154.7
	STD. DEV.	3.58	3.04	4.26	7.62	7.92	0.021	259.4	65.34	34.06
2D	COUNT	35	35	35	35	35	35	35	35	35
	MINIMUM	0	0	0	23.1	20.8	0.001	690	264	78
	MAXIMUM	0.6	0.5	1.9	47.6	46.5	0.08	2060	536	242
	AVERAGE	0.229	0.200	0.346	33.72	30.90	0.026	1496	407.8	154.3
	STD. DEV.	0.189	0.117	0.401	5.93	7.12	0.024	310.9	73.11	40.00

Table 13. Summary of averages for water quality parameters of special interest monitored in Sub-system 2 at the Corsica wetland treatment system.

SAMPLE NUMBER	LAB pH	ALKALINITY mg/L (as $CaCO_3$)	ACIDITY mg/L (as $CaCO_3$)	TOTAL Fe mg/L	TOTAL Mn mg/L	TOTAL Al mg/L	SO_4^{-2} mg/L	Ca mg/L	Mg mg/L
2A	3.41	0	375.4	34.45	33.61	19.92	1579	315.4	148.1
2B	6.62	112.3	0	11.13	38.21	0.055	1555	416.2	159.7
2C	6.69	103.3	0	6.94	37.37	0.034	1537	421.9	154.7
2D	6.87	98.06	0	0.511	33.72	0.026	1496	407.8	154.3

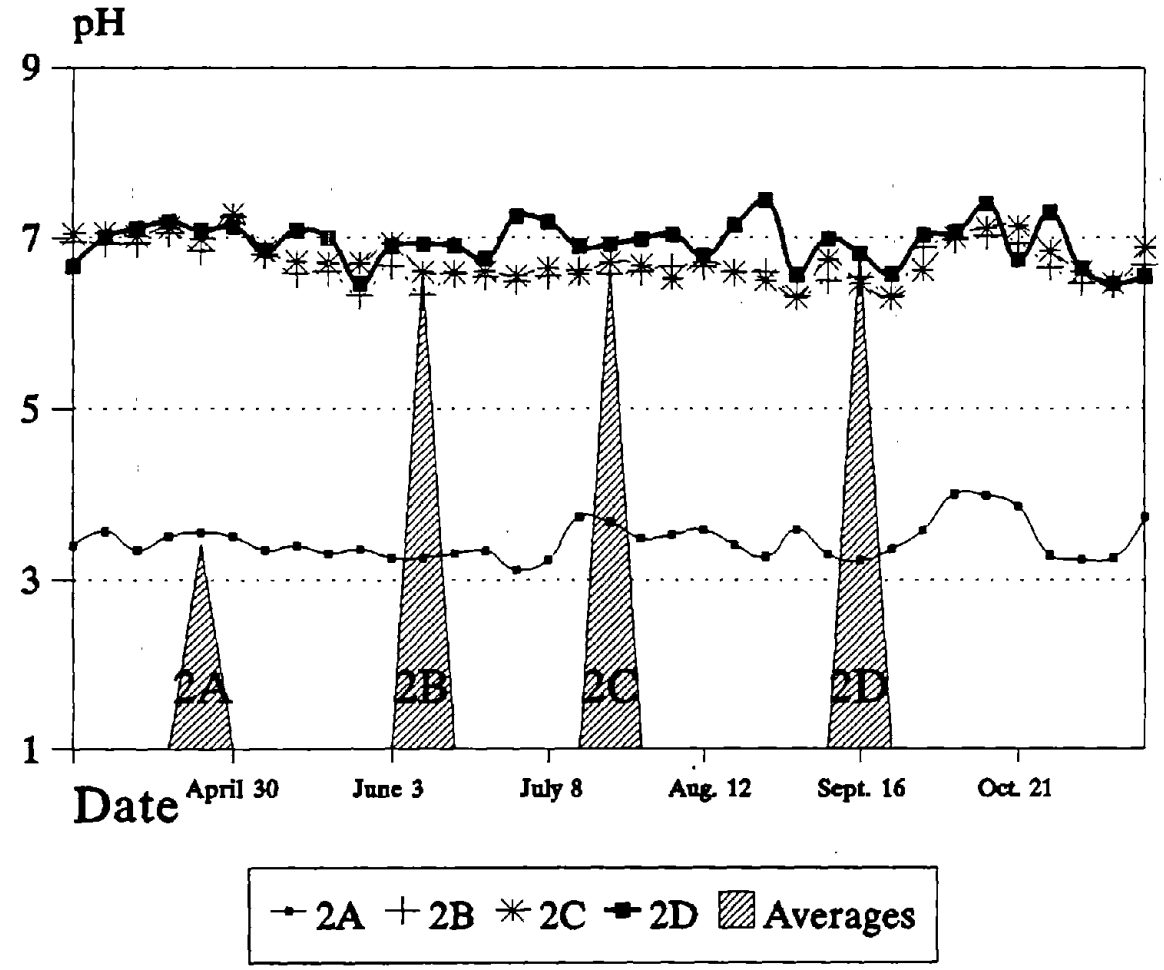

Figure 12. Sub-system 2 influent through effluent variability and average concentrations for pH in the Corsica wetland treatment system.

As with Sub-system 1, Sub-system 2 flows were measured at pipe weirs and discharge pipes (sub-surface flow cell) located at sampling stations. Similar to Sub-system 1, the influent flow (2A) varied considerably from the intended flow of 11.5 L/min (3 gpm), and averaged 10.2 L/min (2.7 gpm) over the course of the study. Flow measured at the discharge from Cell 1 (2B), averaged 6.8 L/min (1.8 gpm) and was well below the 11.5 L/min design flow. The reduced flow at this station was a result of a sub-surface leak in Cell 1 that apparently did not re-enter the sub-system. Flow measured at the influent to Cell 2 (2C) averaged 6.4 L/min (1.7 gpm), which was not statistically different from station 2B flow. The discharge from Cell 2 (2D) averaged 3.1 L/min (0.8 gpm) over the course of the study, which suggests additional leaks from this unit were present and appear to be located in close proximity to the monitoring point.

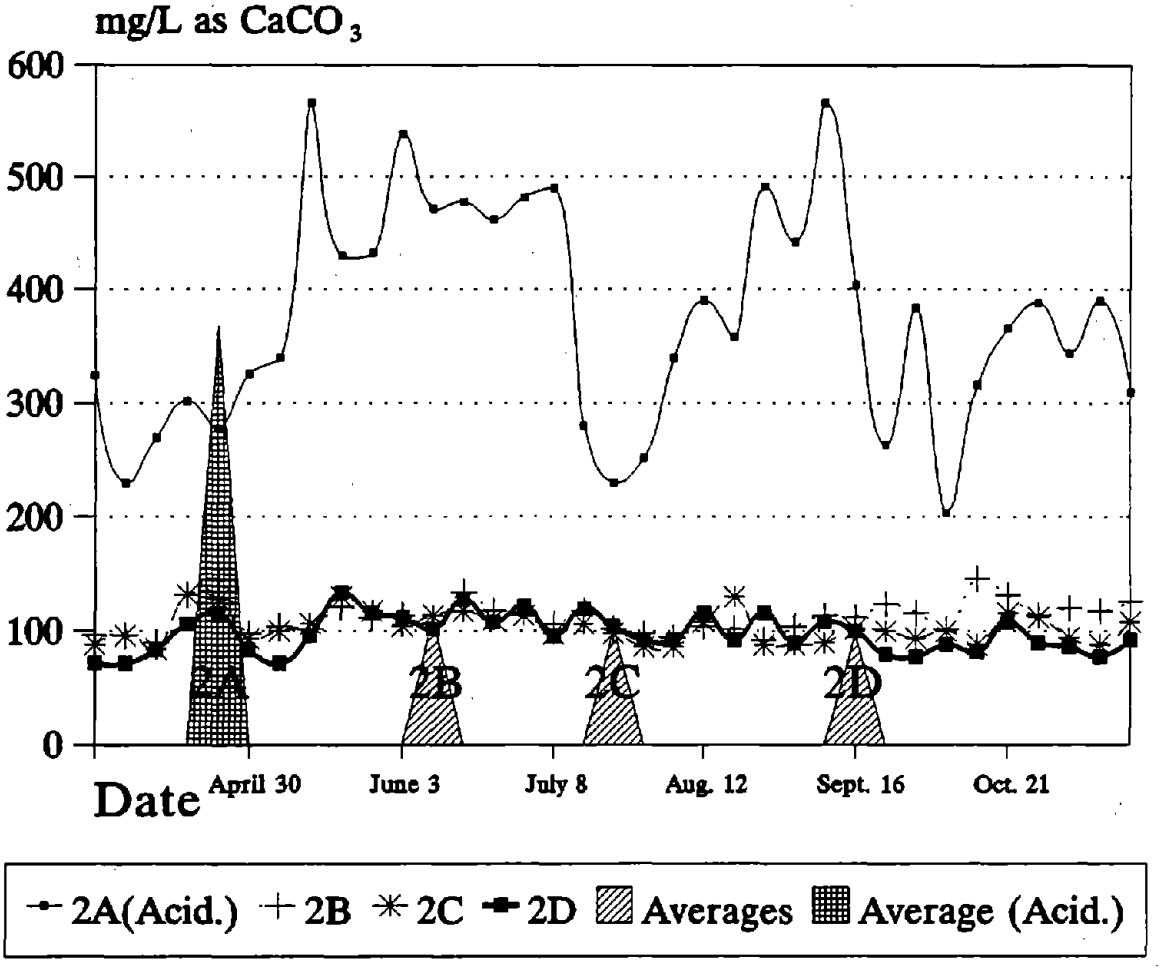

Figure 13. Sub-system 2 station variability and average concentrations for alkalinity and acidity in the Corsica wetland treatment system.

Dissolved oxygen concentrations were found to be similar at influent locations with Station 2A averaging 8.4 mg/L. Dissolved oxygen measured at the discharge of the sub-surface flow cell (2B) was nearly zero, averaging 0.1 mg/L over the duration of the study and reflects the reducing conditions in the compost. Dissolved oxygen gradually increased from this location to the discharge, averaging 2.6 mg/L at Station 2C and 6.2 mg/L at Station 2D. Temperature monitored at stations within the sub-system averaged 13°C (55°F) during the monitoring program, which is the same as was found for Sub-system 1. Figure 11 also indicates, similar to Sub-system 1, that temperature variation was seasonal in each unit.

Influent pH levels averaged 3.41 and increased across Sub-system 2 to an average of 6.83, which is an almost complete removal of hydrogen ions. The bulk of the pH increase was observed across Cell 1, the sub-surface flow unit, which averaged 6.62 in the effluent. The

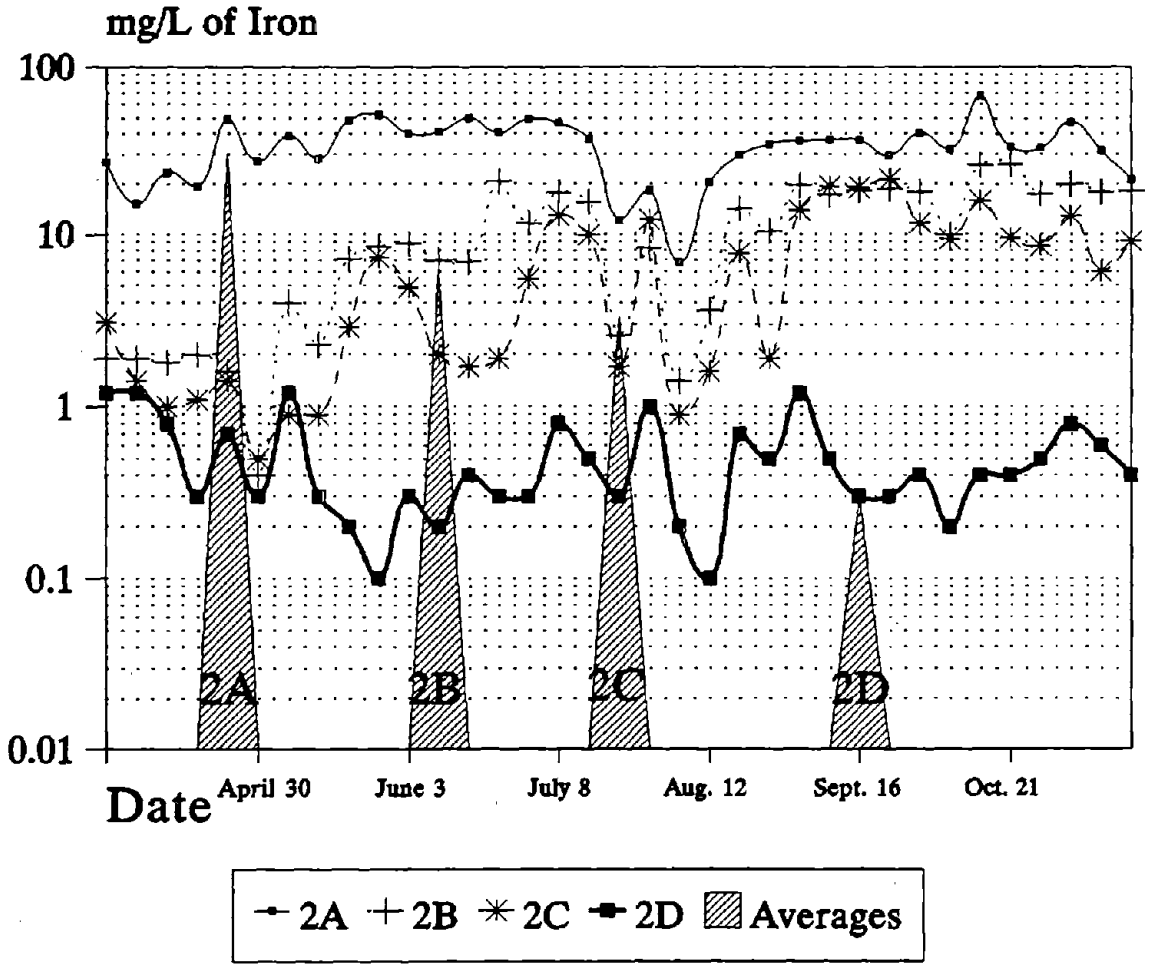

Figure 14. Sub-system 2 influent through effluent variability and average concentrations for iron in the Corsica wetland treatment system.

pH only increased slightly in the remainder of Sub-system 2, culminating with a discharge pH of 6.83. No seasonal or longterm trends is apparent in Figure 12 for the pH data from Sub-system 2.

Acidity, which had an average influent concentration of 375 mg/L (as $CaCO_3$) decreased to 0 mg/L across Cell 1, the sub-surface flow unit, and remained at 0 mg/L throughout Sub-system 2 (see Figure 13). In addition, Cell 1 also exhibited an increased alkalinity from 0 mg/L to an average effluent of 112 mg/L (as $CaCO_3$). Average alkalinity decreased slightly across the remainder of the sub-system to 103 mg/L at Station 2C and 98 gm/L at the discharge. No longterm or seasonal effect on acidity removal or alkalinity generation was observed in Figure 13.

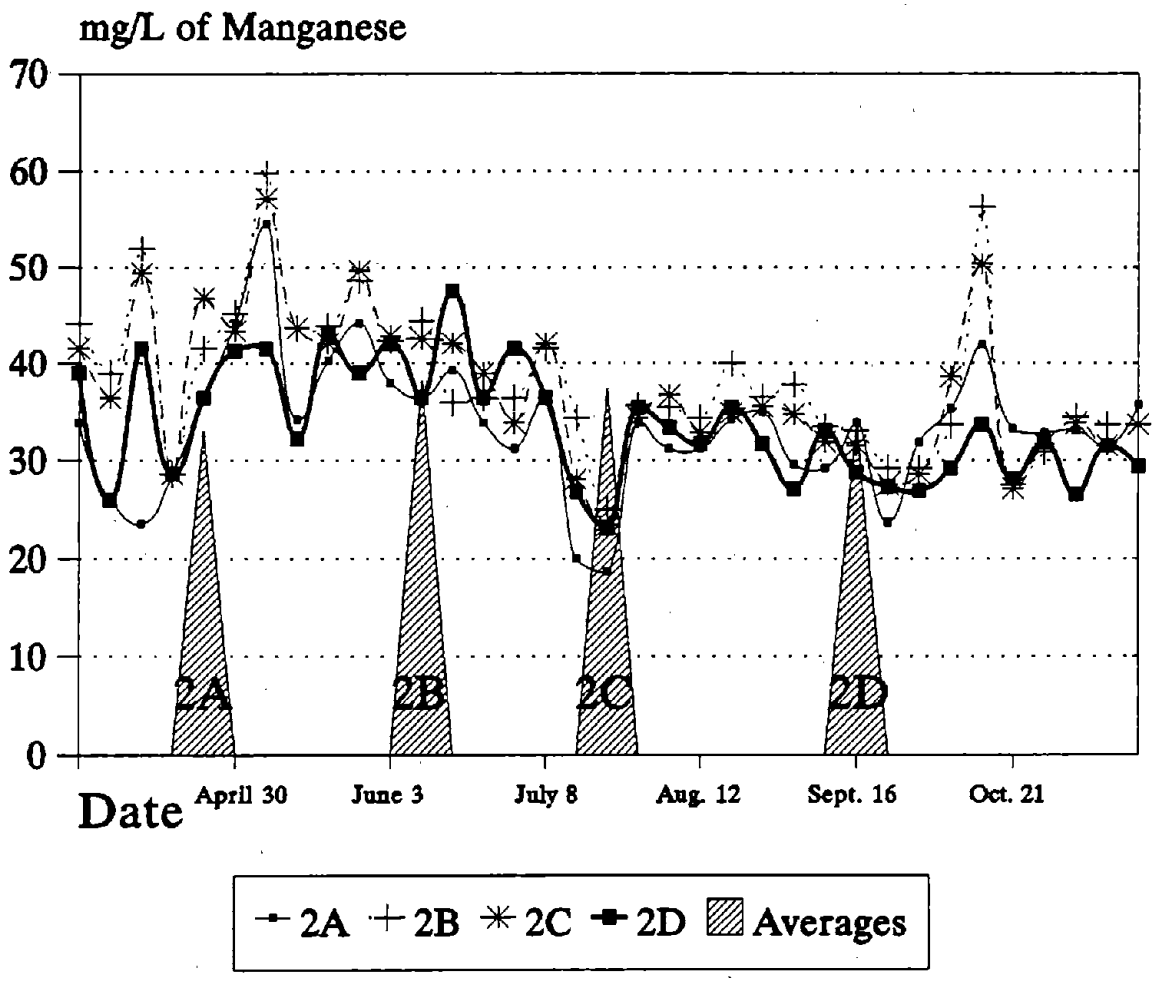

Figure 15. Sub-system 2 influent through effluent variability and average concentrations for manganese in the Corsica wetland treatment system.

All the different fractions of iron (i.e., total, dissolved, ferrous and ferric) significantly decreased across Sub-system 2 (see Table 11 and 12). Total iron concentrations decreased on average from an influent (2A) of 34.4 mg/L to a discharge concentration of 0.5 mg/L (Figure 14); a 99% decrease. The removal of iron across Cell 1 accounted for 68% of the removal, the area between Cell 1 and Cell 2 accounted for 12% of the removal, and Cell 2 accounted for 19% of the removal. Decreases in total iron across Cell 1 appear to be related to the removal of ferric iron, which decreased from an influent of 22.0 mg/L to an effluent of 5.2 mg/L. Only slight decreases in ferrous iron levels (approximately 3 mg/L) were observed across Cell 1. Total iron decreases across the remainder of the sub-system appear to be related to ferrous iron removal (by oxidation and precipitation), which decreased by almost 6 mg/L. Influent iron (2A) and discharge data from Cell 2 (2D) do not indicate any longterm changes (see Figure 14); however, discharge from Cell 1 (2B), the sub-surface flow unit, had an increasing trend in iron (total and ferrous) toward the end of the monitoring program.

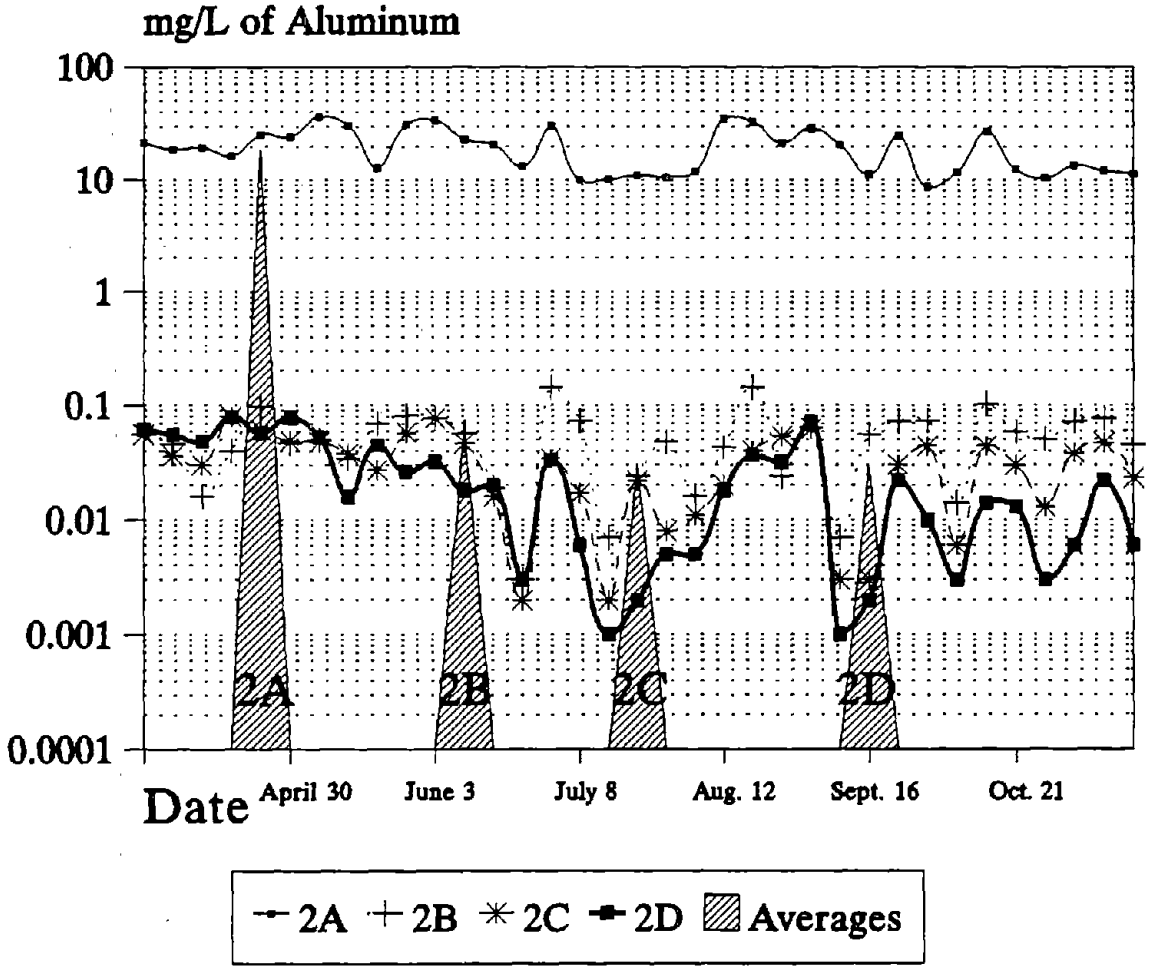

Figure 16. Sub-system 2 influent through effluent variability and average concentrations for aluminum in the Corsica wetland treatment system.

As was found for Sub-system 1, the monitoring data for Sub-system 2 indicate influent manganese (total or dissolved) was not significantly effected (lowered). Slight increases of approximately 5 mg/L in average manganese levels were observed across Cell 1. Slight decreases, approximately 4 mg/L, were observed across the remainder of the sub-system. No seasonal or longterm effects were observed in Figure 15.

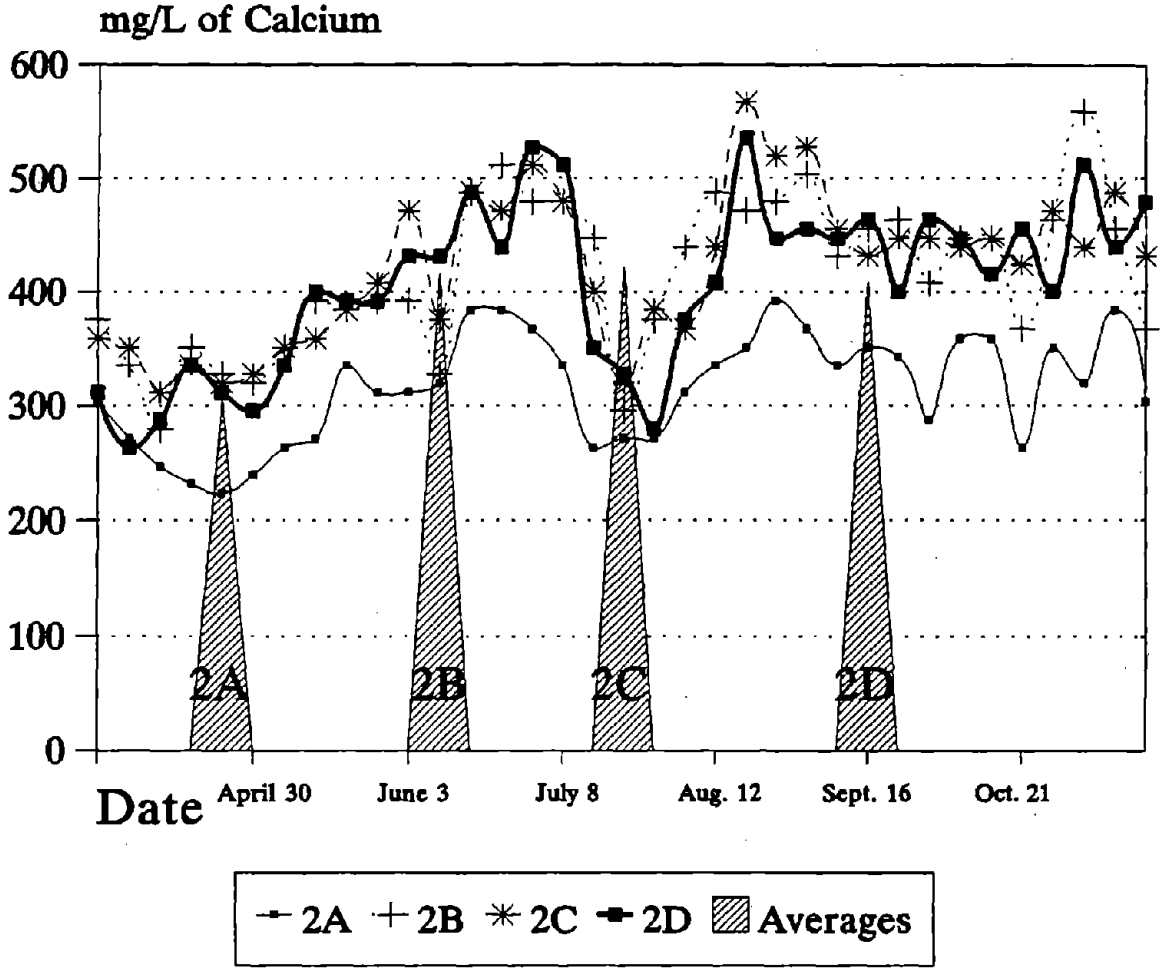

Figure 7. Sub-system 2 influent through effluent variability and average concentrations for calcium in the Corsica wetland treatment system.

Total aluminum concentration was found to significantly decrease across Sub-system 2 from an average influent of 19.9 mg/L to an effluent concentration less than 0.5 mg/L. Decreases in aluminum levels predominately occurred in Cell 1 of the sub-surface flow unit. The remainder of Sub-system 2 decreased aluminum on average, but only by less than 0.5 mg/L. No longterm effects of treatment on aluminum removal were indicared by Figure 16.

Calcium concentrations were also found to significantly increase across Sub-system 2. Influent calcium levels averaged 315 mg/L and increased significantly across the first treatment unit (Cell 1) to an average of 416 mg/L. No significant increase was observed at the two remaining monitoring stations (2C & 2D), which averaged 422 mg/L and 408 mg/L, respectively. No longterm or seasonal effects on effluent concentrations of calcium were observed in Figure 17.

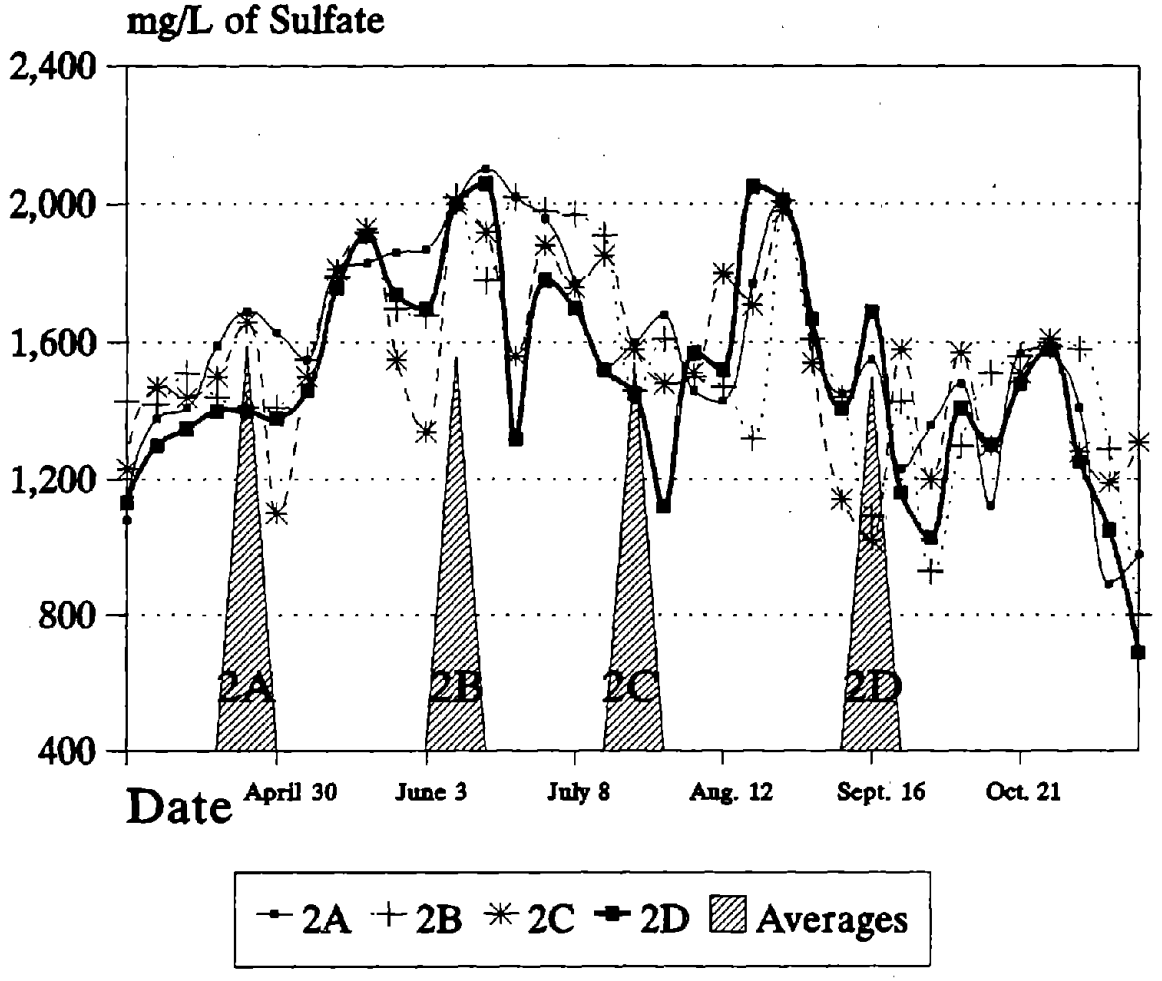

Figure 18. Sub-system 2 influent through effluent variability and average concentrations for sulfate in the Corsica wetland treatment system.

Similar to Sub-system 1, magnesium did not significantly increase across the sub-system. Influent magnesium averaged 148 mg/L over the course of the study and increased slightly to 154 mg/L in the discharge; however, the increase was not significant. The observed decreases may be the result of variation or slight interferences in the colorimetric titration procedure.

The remaining parameter, sulfate, exhibited average concentrations of 1580 mg/L in the influent and decreased (not significantly) slightly across the sub-system to an average discharge level of 1500 mg/L (Figure 18). The decreases may have occurred, but the variability of sulfate levels during the monitoring program resulted in the absence of significance. Over the course of the study, the sub-system removed, on average, 90 mg/L of sulfate, which is less than the sulfate decrease observed across Sub-system 2 (230 mg/L). Figure 18 suggests seasonal increases and decreases in sulfate occurred in Sub-system 2; however, influent sulfate data appears to follow a similar seasonal change.

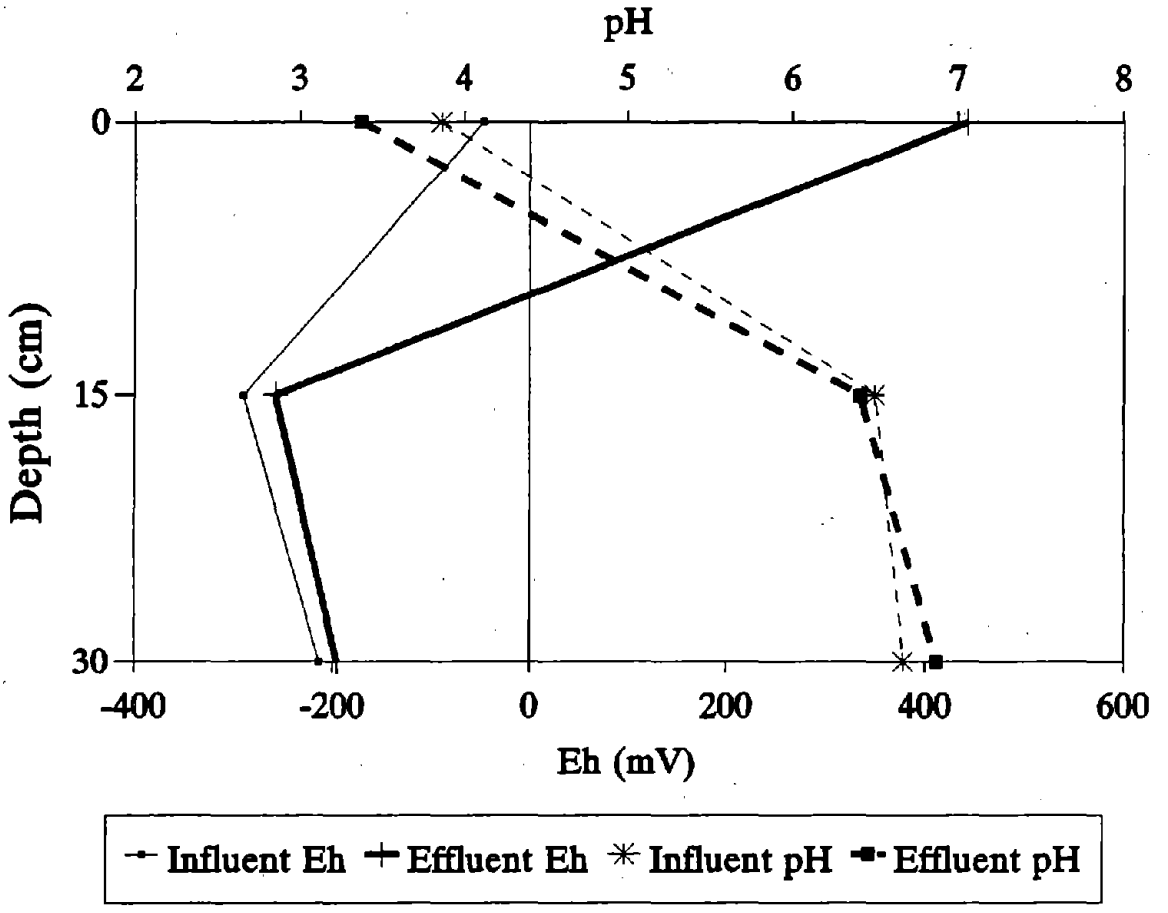

Figure 19. Eh and pH in the compost from influent and effluent of Cell 1 in Sub-system 1 at the Corsica wetland treatment system.

PORE WATER RESULTS

Pore water samples were collected from various depths at influent and effluent ends of each of the treatment units in both sub-systems. A variety of parameters (e.g., Eh, pH, alkalinity

and sulfide) were analyzed on the collected samples. The pore water results are contained in Appendix C and summarized below.

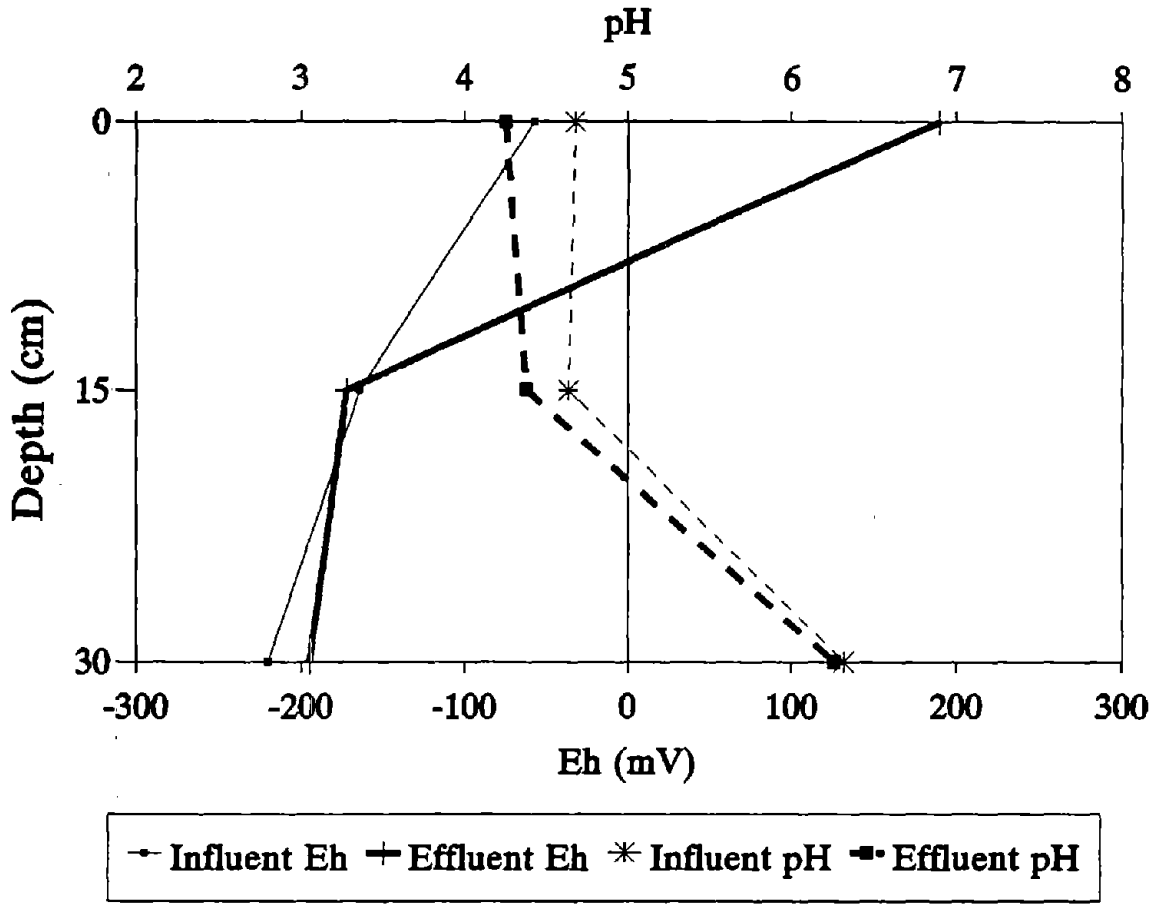

Figure 20. Eh and pH in the compost from influent and effluent of Cell 2 in Sub-system 1 at the Corsica wetland treatment system.

Sub-system 1

The Eh and pH collected in the two units are presented in Figures 19 and 20. The Eh in both units was similar, decreasing with compost depth to levels of approximately -200 mV, which is within the range expected for sulfate reduction to occur. The pH found in the compost increased with depth in each unit; however, the pH in Cell 1 (surface flow) increased within the first 15 cm compared to Cell 2 (Sub-surface flow), which did not exhibit an increase in pH until below 15 cm.

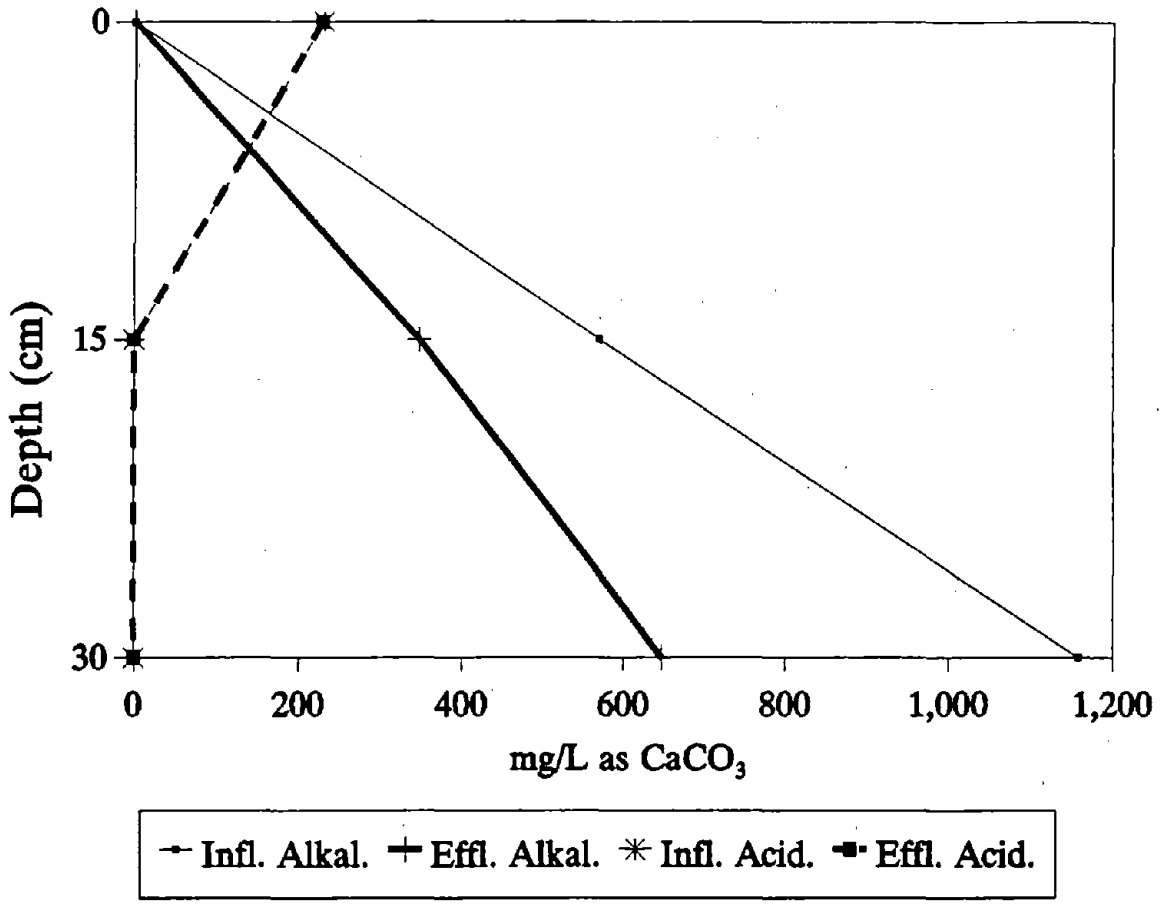

Figure 21. Alkalinity and acidity in the compost from influent and effluent of Cell 1 in Sub-system 1 at the Corsica wetland treatment system.

Alkalinity and acidity were also measured on pore water samples in the treatment units (Figure 21 and 22). Acidity was found only at the shallowest depth in Cell 1 and was absent at greater depths. Alkalinity in this unit increased from 0 mg/L to greater than 600 mg/L at the 30 cm depth, which was substantially greater than measured in the effluent from this unit during the weekly monitoring program. Cell 2 of Sub-system 1 contained acidities of between 200 and 300 mg/L, which are similar to influent acidities, at the 0 and 15 cm depth (see Table 8, Point 1C). Acidity was absent in both profiles at the 30 cm depth and alkalinity in the depth profiles of Cell 2 were only found at a depth of 30 cm.

Sulfur forms (i.e., sulfate and sulfide) were measured in pore water samples to evaluate the presence of sulfate reduction. Sulfide was found (Figure 23) at measurable concentrations at all compost depths in Cell 1, with maximum concentrations of approximately 9 mg/L at the 15 cm depth. Sulfate levels in the Cell 1 compost layer increased slightly from surface

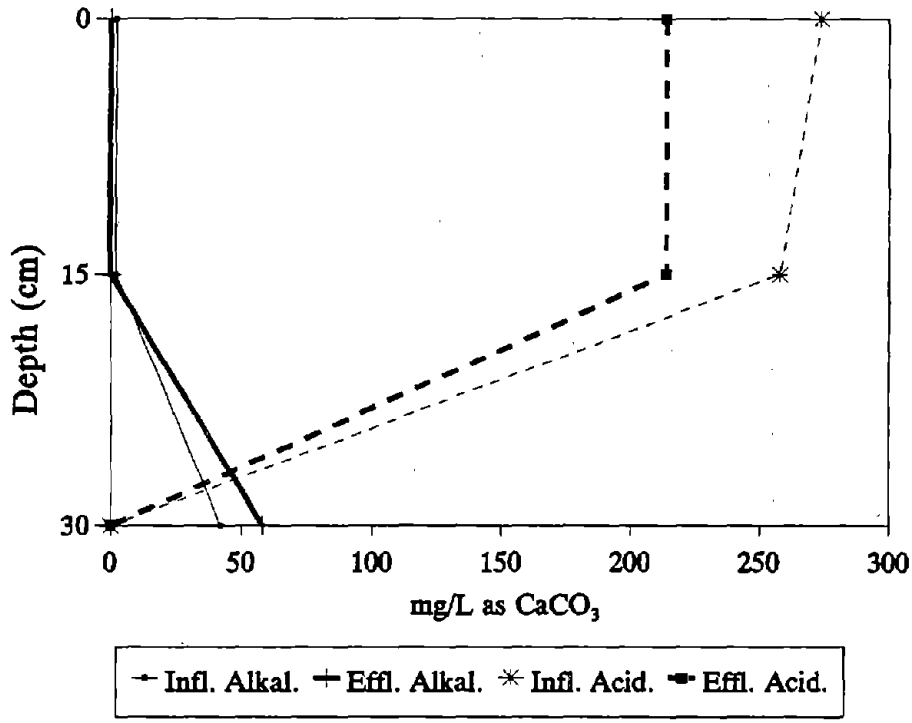

Figure 22. Alkalinity and acidity in the compost from influent and effluent of Cell 2 in Sub-system 1 at the Corsica wetland treatment system.

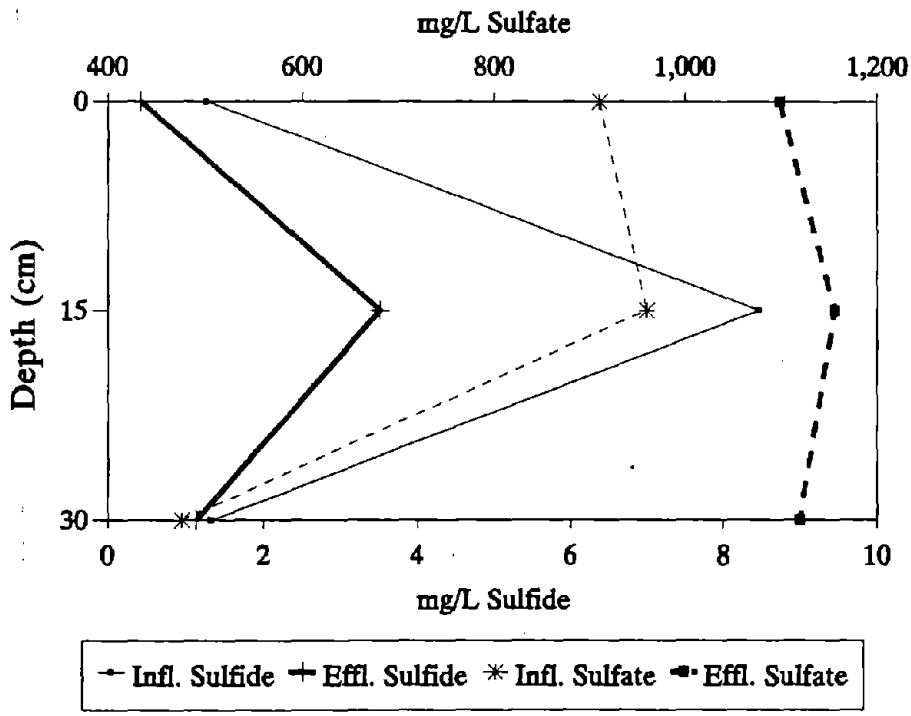

Figure 23. Sulfate and sulfide in the compost from influent and effluent of Cell 1 in Sub-system 1 at the Corsica wetland treatment system.

depths to the 15 cm depth, but decreased by 500 mg/L (influent) and 100 mg/L (effluent) to the 30 cm depth. Sulfide was also found throughout the compost depth in Cell 2 with maximum concentrations of 5 mg/L occurring at the 15 cm depth (see Figure 24) sulfate increased with depth in Cell 2, with increases ranging from 200 to 700 mg/L. The increase probably reflects influent sulfate variability and not actual addition of sulfate to the pore water.

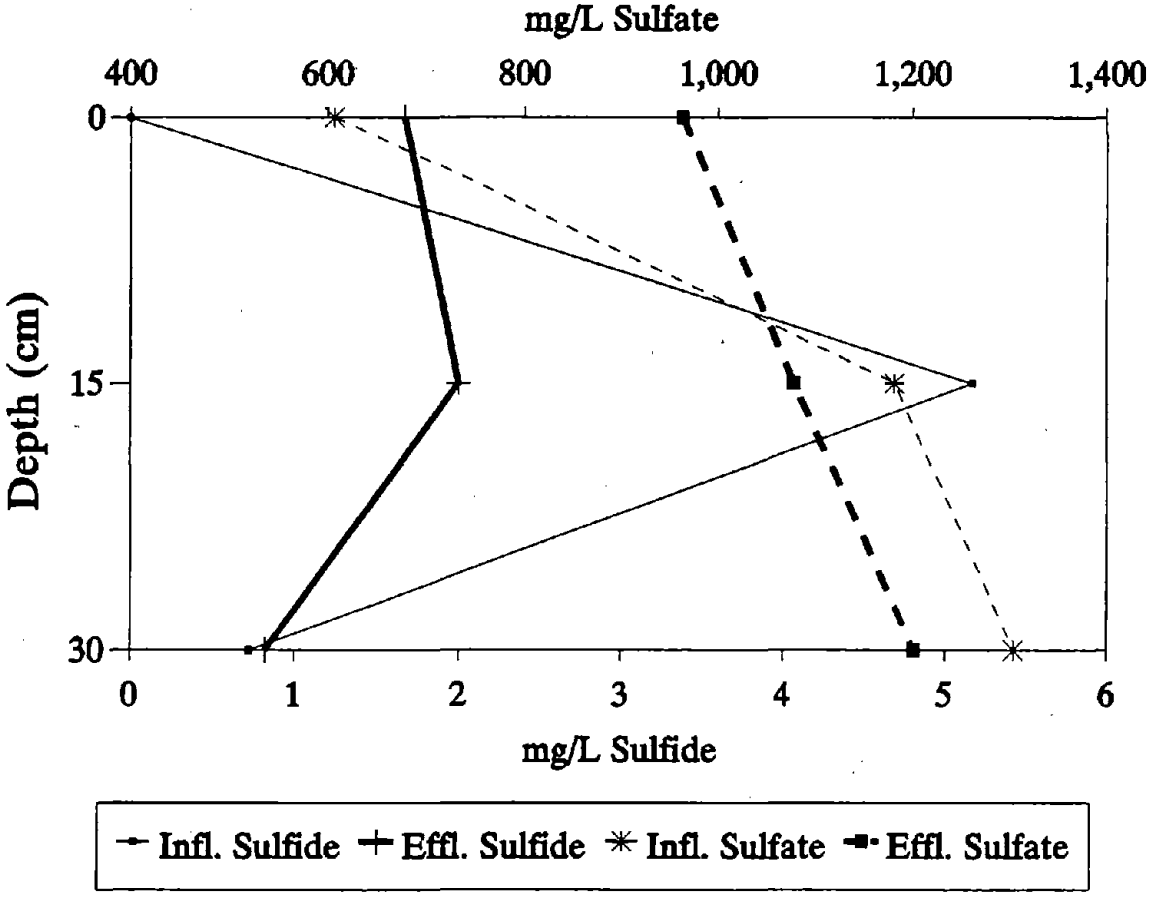

Figure 24. Sulfate and sulfide concentrations in the compost from influent and effluent of Cell 2 in Sub-system 1 at the Corsica wetland treatment system.

Sub-system 2

The Eh and pH collected in the two units in Sub-system 2 are presented in Figure 25 and 26. The Eh in these units were dissimilar from each other and from units in Sub-system 1. Cell 1 (Sub-surface flow) Eh levels decreased with compost depth to slightly below 0 mV, which is not as reducing as measured in Cell 2 of Sub-system 1, but is still within the range expected for sulfate reduction to occur. Cell 2 contained very low Eh values, less than -100

mV, throughout the influent compost depth. Effluent results were also low, but the shallow compost depth encountered in the effluent area only permitted analysis to 15 cm. In addition to Eh, the pH measured in the compost of Sub-system 2 differed from the pH measured in Sub-system 1. The pH values in the compost of Cell 1 increased with depth, but only to slightly above 4, which was well below the circumneutral pH found throughout the compost depth in Cell 2. Further, the pH values found in Cell 1 (Sub-surface flow) did not increase as significantly with depth as observed in Cell 2 of Sub-system 1.

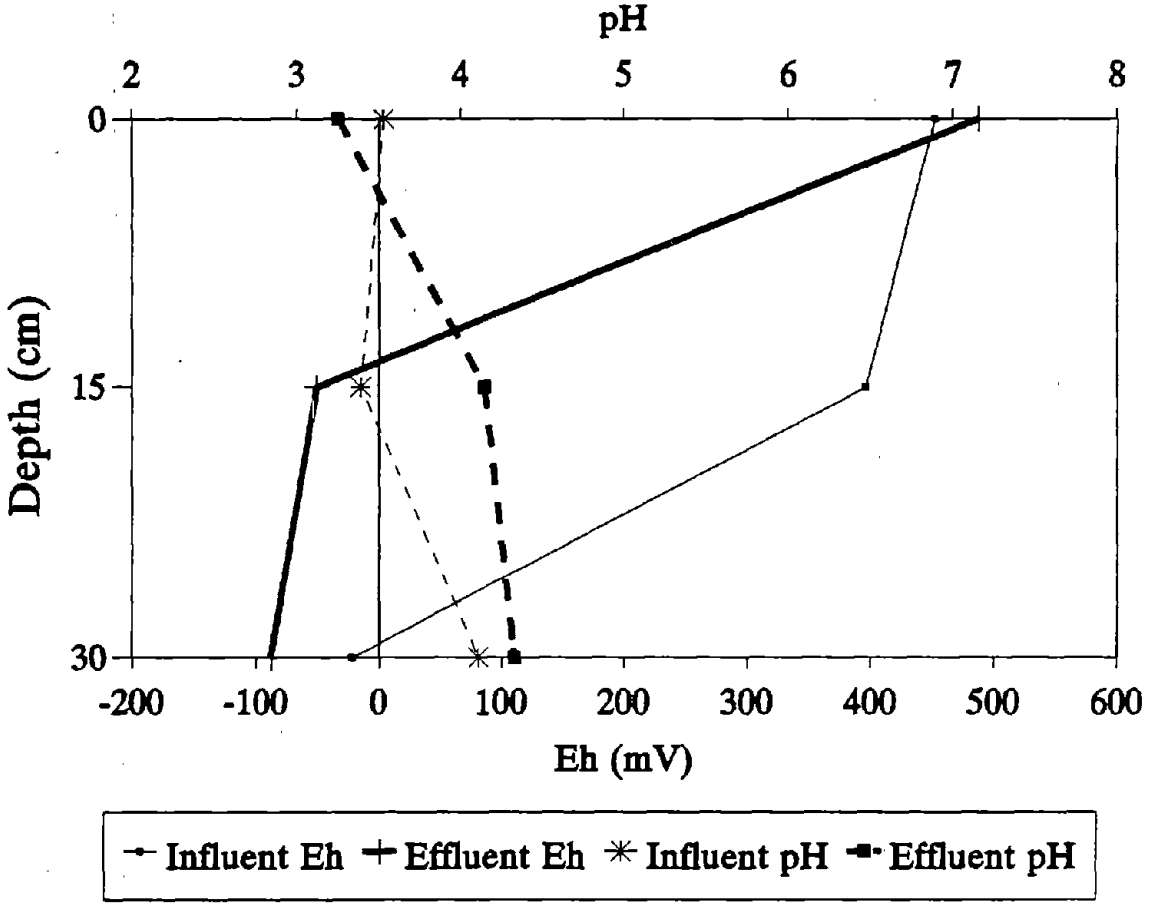

Figure 25. Eh and pH in the compost from influent and effluent of Cell 1 in Sub-system 2 at the Corsica wetland treatment system.

Alkalinity and acidity in pore water samples from Sub-system 2 treatment units are presented in Figure 27 and 28. Alkalinity was completely absent from compost depths in Cell 1 and acidity was measured between 200 and 500 mg/L at various depths. Alkalinity and acidity in Cell 2 compost porewater were found to be completely opposite from Cell 1 with the unit containing no acidity, and porewater alkalinity between 100 and 800 mg/L.

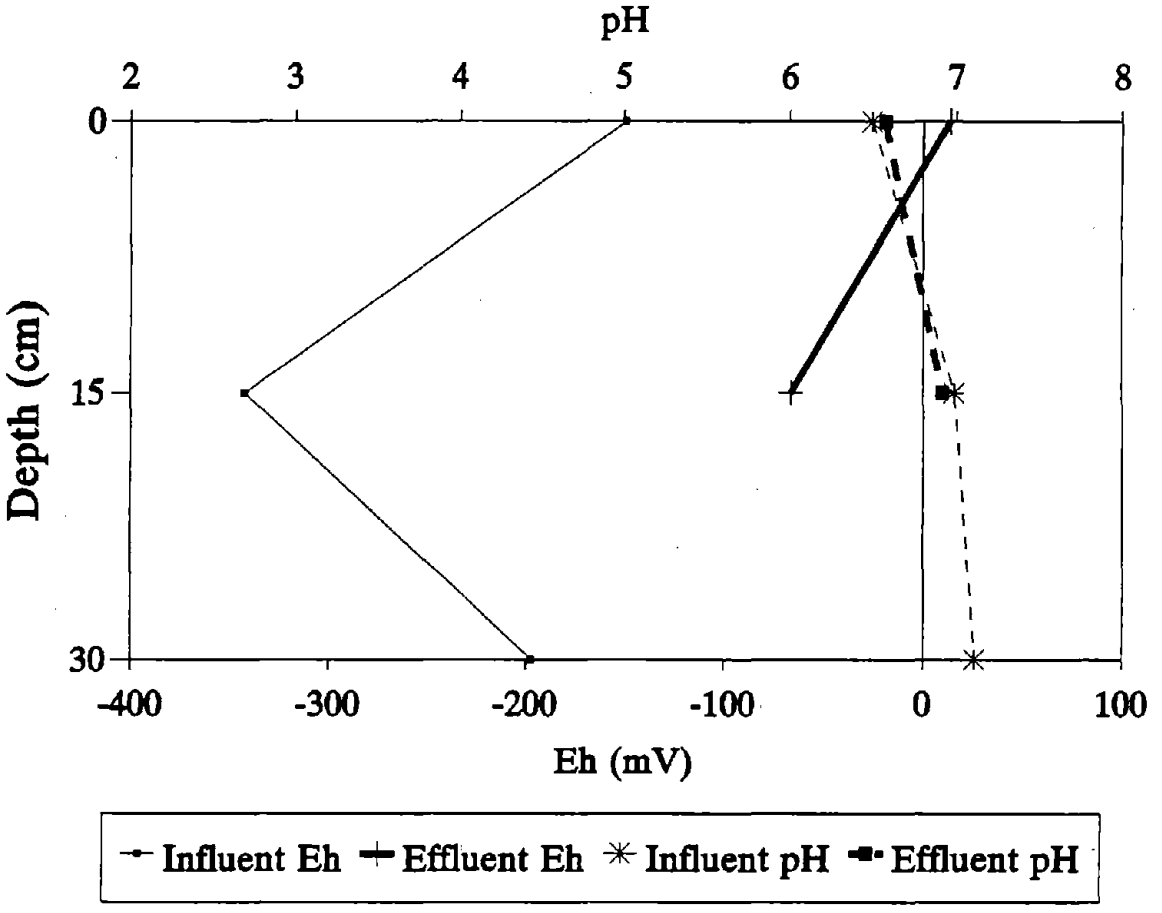

Figure 26. Eh and pH in the compost from influent and effluent of Cell 2 in Sub-system 2 at the Corsica wetland treatment system.

Sulfur forms (i.e., sulfate and sulfide) measured in pore water samples from Sub-system 2 are presented in Figure 29 and 30. Sulfide concentrations in Cell 1 compost increased with increasing depth from non-detectable at the 0 cm depth to 0.7 mg/L (influent) and 2.2 mg/L (effluent) at the 30 cm depth. Sulfate concentrations in the Cell 1 compost layer decreased slightly from surface depths (approximately 1400 mg/L) by between 50 mg/L (influent) and 300 mg/L (effluent). Sulfide found at compost depths below the 0 cm depth in Cell 2, ranged from 0.8 to 5.8 mg/L. Sulfate levels were found to increase slightly from the 0 cm depth to the 15 cm depth, by between 50 and 100 mg/L, respectively. Sulfate levels decreased below the 15 cm depth in the influent profile by greater than 200 mg/L.

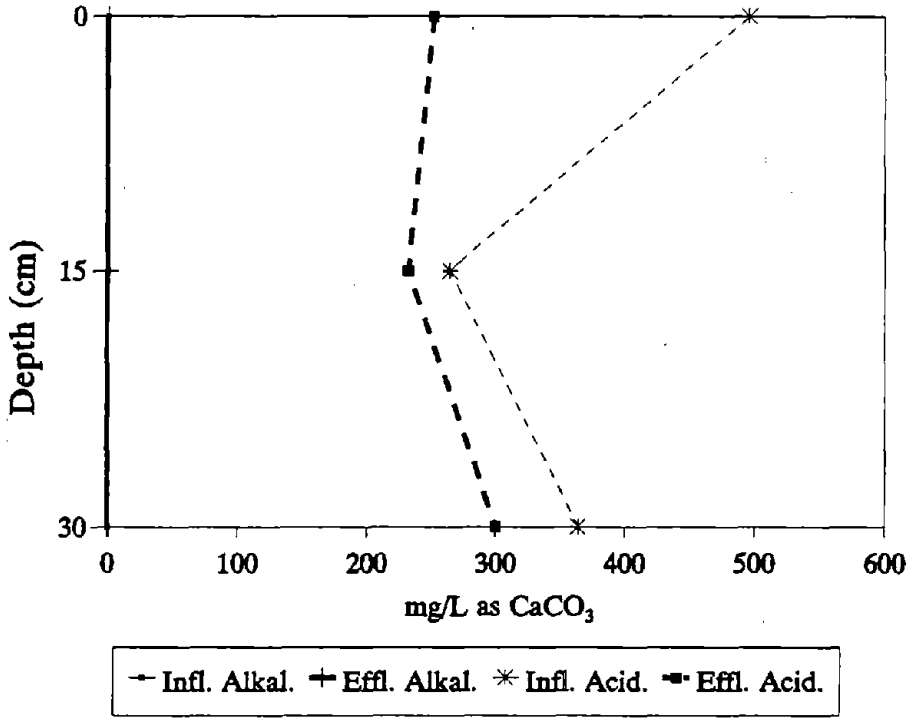

Figure 27. Alkalinity and acidity in the compost from influent and effluent of Cell 1 in Sub-system 2 at the Corsica wetland treatment system.

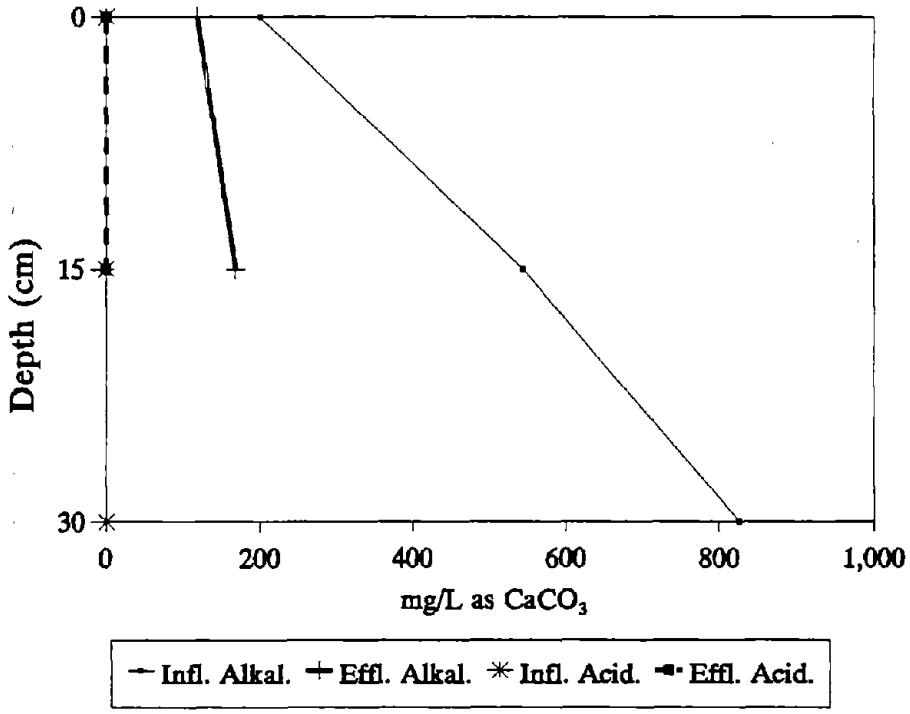

Figure 28. Alkalinity and acidity in the compost from influent and effluent of Cell 2 in Sub-system 2 at the Corsica wetland treatment system.

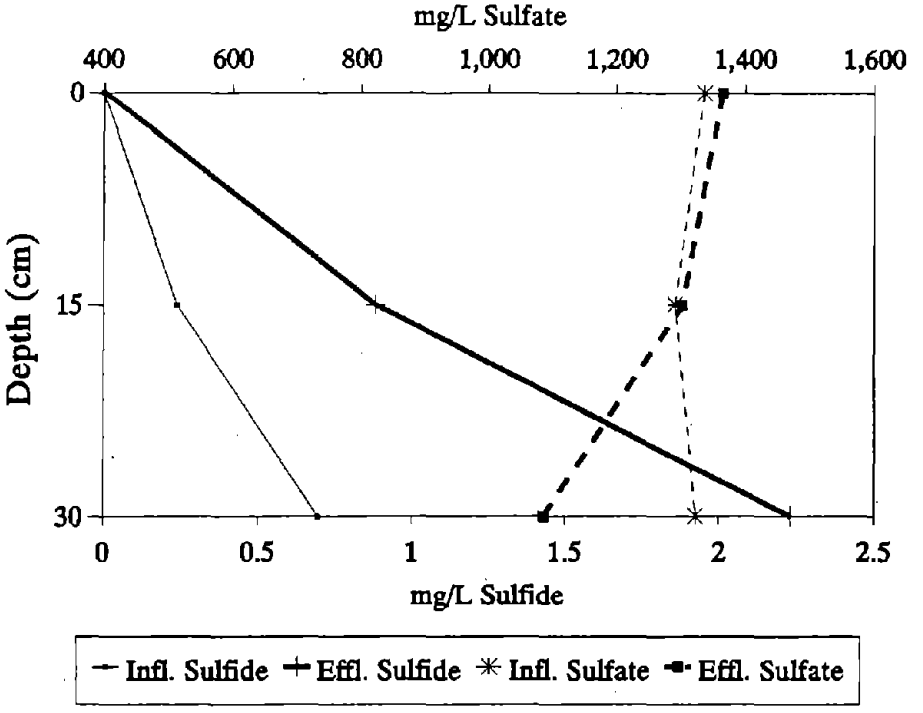

Figure 29. Sulfate and sulfide concentrations in the compost from influent and effluent of Cell 1 in Sub-system 2 at the Corsica wetland treatment system.

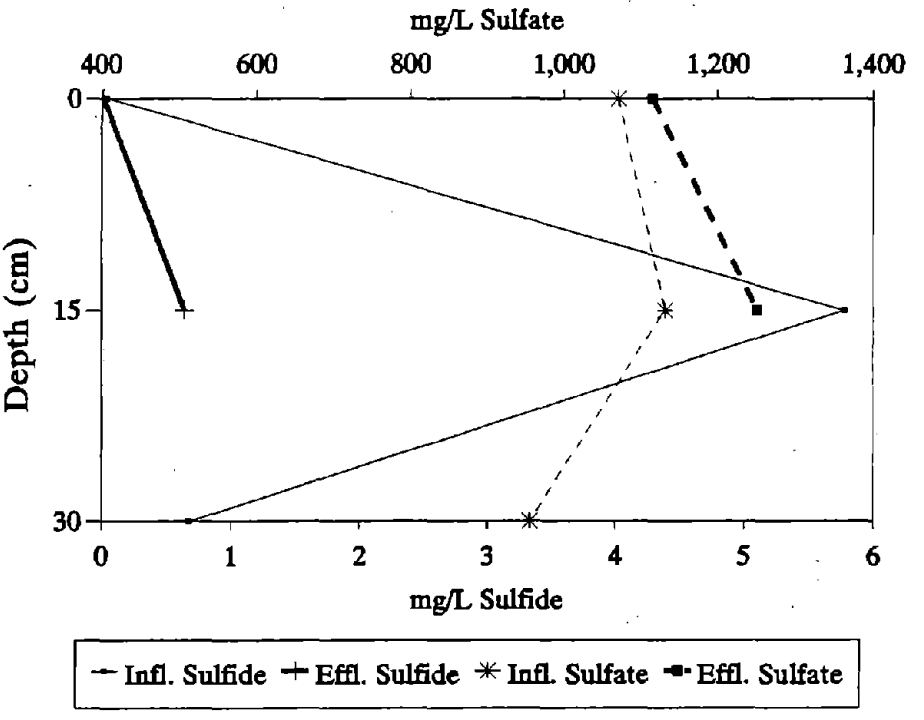

Figure 30. Sulfate and sulfide concentrations in the compost from influent and effluent of Cell 2 in Sub-system 2 at the Corsica wetland treatment system.

SEDIMENT CORE RESULTS

Sediment (compost) samples were collected from influent and effluent ends of each of the treatment units in both sub-systems. The samples were analyzed for three metals: iron, aluminum, and manganese. The sediment results are contained in Appendix D and are summarized below.

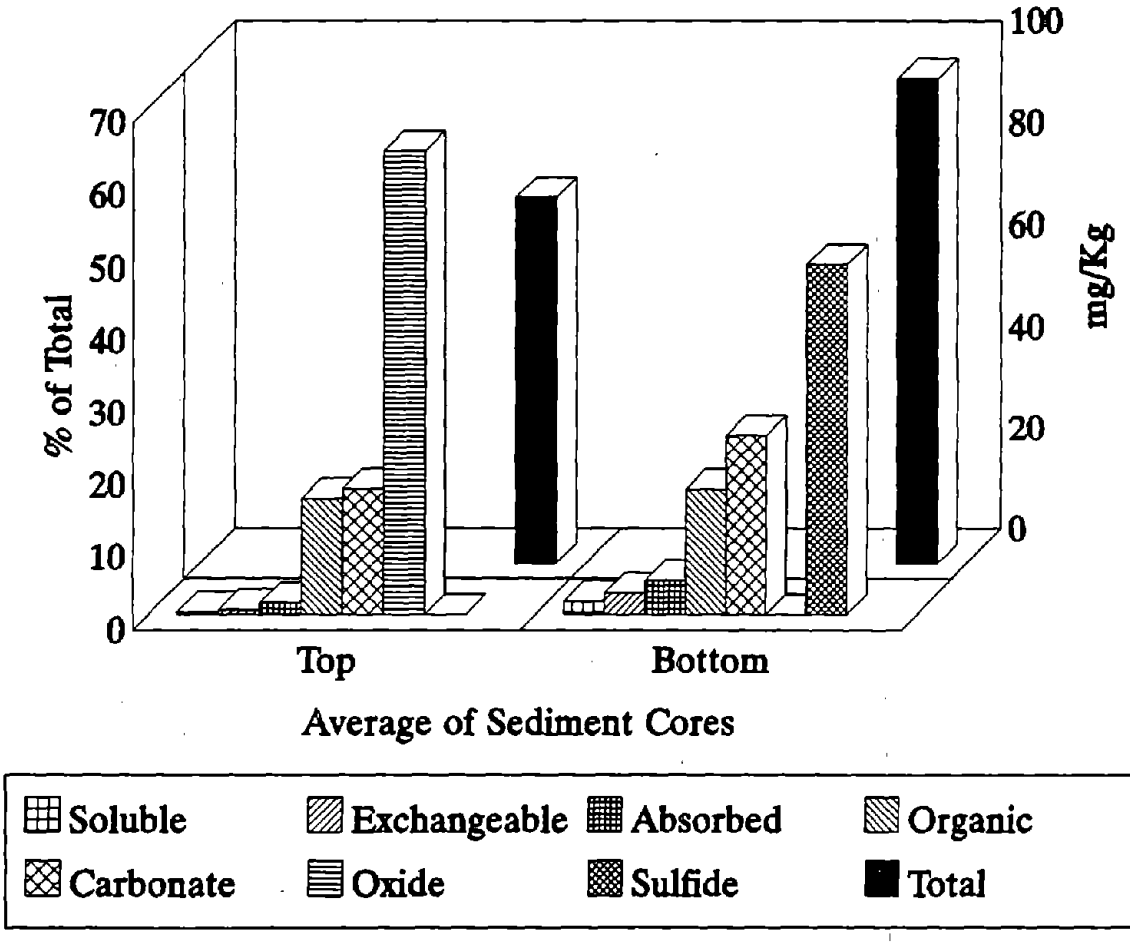

Figure 31. Composition (average) of iron deposits found in sediment cores collected from both sub-systems at the Corsica wetland treatment system.

The sediment results for each metal and extraction step were variable within sediment cores (top vs. bottom), within treatment units and within sub-systems. Table 14, which summarizes the total metals found in each sediment core, indicates both iron and aluminum were found at significant concentrations, suggesting that these two metals were accumulating in the compost. Manganese concentrations were low in comparison, which suggests this

metal was not accumulating in the sediments. The lack of initial compost analysis data limits the ability to evaluate the degree of accumulation.

With respect to oxidizing zones (top) and reducing zones (bottom), no differences in total iron accumulation were found in the sediment cores. Iron in the top layers averaged 72.2 gr/Kg and ranged from 11.6 to 158.9 gr/Kg. Iron in the bottom layers averaged 93.7 gr/Kg and ranged from 17.0 to 316.9 gr/Kg. Although no major differences in accumulation were exhibited, there were major differences in the fractions in which the metal was removed (see Figure 31). The accumulation in surface layers was primarily in the form of oxide deposits and the accumulation in the bottom layers was as sulfide deposits. In addition, bottom layers contained greater removal in the absorbed, organic and carbonate fraction than surface layers.

Table 14. Total Metal Sediment Core Results in treatment units at the Corsica wetland treatment system.

	Unit	Location	Iron (mg/Kg - Dry)		Manganese (mg/Kg - Dry)		Aluminum (mg/Kg - Dry)	
			Top	Bottom	Top	Bottom	Top	Bottom
Sub-system 1	Cell 1	Influent	158,900	23,000	147	939	18,100	23,200
	Cell 1	Effluent	44,600	316,900	193	294	21,500	30,900
	Cell 2	Influent	70,700	21,500	133	299	16,800	19,600
	Cell 2	Effluent	11,600	44,800	144	220	30,700	17,000
Sub-system 2	Cell 1	Influent	71,200	24,400	129	386	18,100	24,300
	Cell 1	Effluent	34,300	31,200	163	1470	37,100	36,100
	Cell 2	Influent	69,400	286,200	2200	869	22,000	45,000
	Cell 2	Effluent	117,400	17,000	2540	746	18,800	11,200

Aluminum accumulation was slightly lower than iron accumulation, but was similar between bottom and top layers of the compost. Aluminum concentrations in the top layers averaged 23.0 gr/Kg and ranged from 16.8 to 37.1 gr/Kg. Aluminum concentrations in the bottom layers averaged 25.9 gr/Kg and ranged from 11.2 to 45.0 gr/Kg. The accumulation in both layers was similar and primarily within the hydroxide fraction (see Figure 32). In addition, bottom layers contained slightly greater removal in the carbonate fraction compared to surface layers.

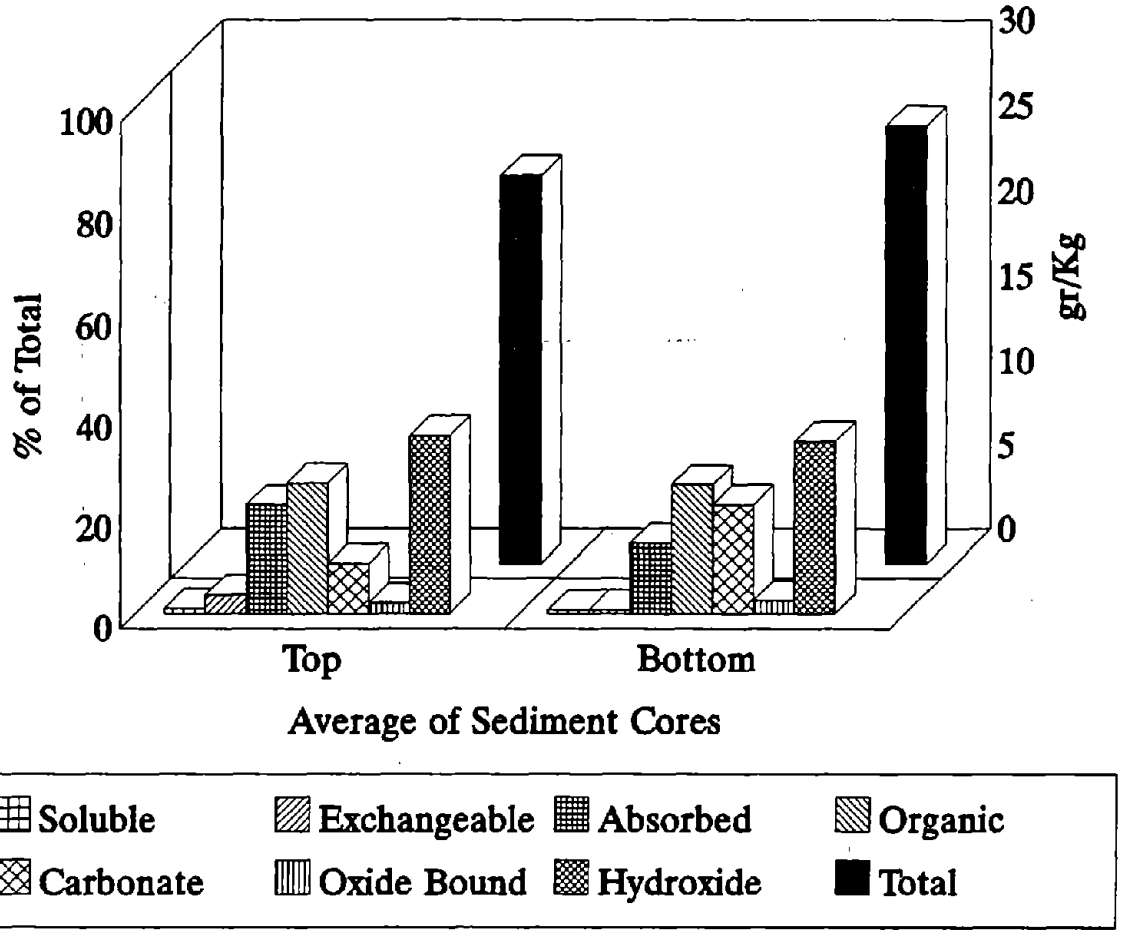

Figure 32. Composition (average) of aluminum deposits found in sediment cores collected from both sub-systems at the Corsica wetland treatment system.

SUB-SYSTEM AND UNIT COMPARISONS

A statistical analysis was conducted to compare surface flow design (Sub-system 1 - Cell 1) to sub-surface flow design (Sub-system 2 - Cell 1) and to compare Sub-system 1 to Sub-system 2. This analysis consisted of comparing water quality monitoring data for individual parameters using an ANOVA procedure (Sokal and Rohlf 1981). Parameters included in this analysis were selected based on effluent requirements of wetland systems (i.e., pH, acidity, alkalinity, total iron, total manganese, and aluminum) and wetland processes (i.e., sulfate, calcium and magnesium). The results of the analysis are summarized below.

Sub-surface flow vs. Surface flow

The results of the statistical analysis comparing surface to sub-surface flow design are summarized in Table 15. The average pH discharged from the sub-surface flow system was significantly higher, greater than 3 s.u., than the average pH discharged from the surface flow. In comparison to the surface flow system, which discharged high concentrations of acidity and no alkalinity, the sub-surface system discharged significant concentrations of alkalinity and no acidity.

Table 15. Statistical results comparing water quality data of surface flow (Sub-system 1 - Cell 1) and sub-surface flow (Sub-system 2 - Cell 1).

Parameter	Sub-system 1, Cell 1 (1B) Mean	Sub-system 2, Cell 1 (2B) Mean	Probability (p)	Significant Difference
pH	3.26	6.58	$p<0.001$	Yes
Alkalinity (mg/L)	0	112.6	$p<0.001$	Yes
Acidity (mg/L)	335.4	0	$p<0.001$	Yes
Total Iron (mg/L)	19.5	10.6	$p<0.001$	Yes
Total Manganese (mg/L)	32.2	37.8	$0.001<p<0.005$	Yes
Total Aluminum (mg/L)	18.1	0.055	$p<0.001$	Yes
Sulfate (mg/L)	1476	1544	$0.25<p<0.5$	No
Calcium (mg/L)	309.3	414.4	$p<0.001$	Yes
Magnesium (mg/L)	144.4	160.4	$0.1<p<0.25$	No

Metal concentrations discharged by the treatment unit designs were also significantly different. The sub-surface flow system discharged significantly lower aluminum, approximately 0 mg/L, and iron concentrations were approximately half the iron discharged from the surface flow system. Conversely, manganese concentrations were significantly higher, approximately 6 mg/L, from the sub-surface flow system than the surface flow system.

Table 16. Statistical results comparing water quality discharged by Sub-system 1 and Sub-system 2.

Parameter	Sub-system 1 Mean	Sub-system 2 Mean	Probability (p)	Significant Difference
pH	6.76	6.87	$0.1<p<0.05$	No
Alkalinity (mg/L)	111.7	98.1	$0.005<p<0.001$	Yes
Acidity (mg/L)	0	0	$p>0.75$	No
Total Iron (mg/L)	7.1	0.51	$p<0.001$	Yes
Total Manganese (mg/L)	33.0	33.7	$0.75<p<0.5$	No
Total Aluminum (mg/L)	0.058	0.026	$p<0.001$	Yes
Sulfate (mg/L)	1351	1496	$0.025<p<0.05$	Yes
Calcium (mg/L)	376.9	407.8	$0.05<p<0.1$	No
Magnesium (mg/L)	133.9	154.3	$0.05<p<0.1$	No

The only process parameter that was significantly different between the two designs was calcium levels. This parameter measured approximately 100 mg/L greater in the discharge

from the sub-surface flow unit than the surface flow unit. The remaining two parameters, sulfate and magnesium, had averages that were slightly different between flow systems; however, the differences were not significant.

Sub-system 1 vs. Sub-system 2

The results of the statistical analysis conducted to evaluate position of sub-surface to surface flow units, are summarized in Table 16. The average pH values discharged from the sub-systems were not significantly different. Both systems provided complete removal of acidity throughout the monitoring program. A slightly higher (approximately 14 mg/L) average alkalinity was discharged by Sub-system 1 in comparison to Sub-system 2; this was found to be significant.

Several of the metal concentrations measured in the discharge of the sub-systems were significantly different. Sub-system 2 exhibited an average total iron of less than 1 mg/L, which was significantly lower than the 7.1 mg/L average total iron exhibited by Sub-system 1. In addition, the average aluminum concentration from Sub-system 2 was significantly lower than the level from Sub-system 1; however, in both sub-systems the average aluminum level was well below 1 mg/L. The remaining metal analyzed, manganese, was not found to significantly different between the two sub-systems.

The only process parameter that was significantly different between the two designs was sulfate. On average, sulfate concentrations were approximately 150 mg/L lower in Sub-system 1 than in Sub-system 2. The remaining two parameters, calcium and magnesium, had averages that were slightly higher for Sub-system 2 than Sub-system 1; however, the differences were not significant.

REMOVAL RATES

Data from each sub-system was used to determine loadings to and removal rates for each sub-system and units within each sub-system. Loading rates, in grams per day (GPD) and lbs. per day (PPD), were calculated for each sample date and treatment unit using influent concentration and flow data collected at influent locations. Removal rates, also in GPD, were calculated for each sample date using effluent flow data (due to loss of flow across individual units) and the difference between influent concentration data and effluent concentration data. The sample date loading and removal rates were the used to determine average loading and removal rates for eavh treatment unit over the course of the study. Average removal rates were also adjusted to unit area rates, in grams per day per square meter (GDM) and lbs. per day per square foot (PDF), using the surface areas of each unit. Total sub-system removal rates were the sum of individual unit removal rates.

Table 17. Average loading and removal rates for Sub-system 1 and individual treatment units at the Corsica wetland treatment system in grams per day (GPD) and grams per day per square meter (GDM).

Treatment Unit	Parameter	Loading GPD	Removal GPD	Unit Area Removal GDM
Cell 1 113 m^2	Iron	528	214	1.89
	Aluminum	295	22.5	0.20
	Manganese	512	25.9	0.23
	Acidity	5740	540	4.78
	Sulfate	24,240	1470	13.0
	Calcium	4820	50.8	0.45
Between Cell 1 & Cell 2 60 m^2	Iron	202	45.0	0.75
	Aluminum	173	66.9	1.12
	Manganese	313	-3.74	-0.062
	Acidity	3300	1010	16.9
	Sulfate	14,460	347	5.79
	Calcium	3030	-81.0	-1.35
Cell 2 130 m^2	Iron	148	79.7	0.61
	Aluminum	97.9	97.4	0.75
	Manganese	302	-5.67	-0.044
	Acidity	2170	3210*	24.7
	Sulfate	13,650	976	7.51
	Calcium	3010	-534	-4.11
Total Sub-system 303 m^2	Iron	528	338	1.12
	Aluminum	295	187	0.62
	Manganese	512	16.5	0.054
	Acidity	5740	4760	15.7
	Sulfate	24,240	2800	9.23
	Calcium	4820	-565	-1.86

Table 18. Average loading and removal rates for Sub-system 2 and individual treatment units at the Corsica Wetland Treatment System in grams per day (GPD) and grams per day per square meter (GDM).

Treatment Unit	Parameter	Loading GPD	Removal GPD	Unit Area Removal GDM
Cell 1 116 m^2	Iron	515	351	3.02
	Aluminum	289	288	2.48
	Manganese	497	-68.3	-0.59
	Acidity	5530	7170	61.8
	Sulfate	23,220	324	2.79
	Calcium	4630	-1500	-12.9
Between Cell 1 & Cell 2 26 m^2	Iron	119	43.4	1.67
	Aluminum	0.56	0.25	0.010
	Manganese	370	9.53	0.37
	Acidity	-1100	-94.0	-3.61
	Sulfate	15,200	203	7.80
	Calcium	4130	-65.4	-2.52
Cell 2 176 m^2	Iron	75.4	70.7	0.40
	Aluminum	0.32	0.093	0.0005
	Manganese	361	34.3	0.19
	Acidity	-1000	-42.7	-0.24
	Sulfate	14,990	364	2.07
	Calcium	4190	127	0.72
Total Sub-system 318 m^2	Iron	515	465	1.46
	Aluminum	289	288	0.91
	Manganese	497	-24.6	-0.077
	Acidity	5530	7030	22.1
	Sulfate	23,220	890	2.80
	Calcium	4630	-1430	-4.51

The loading and removal rates for Sub-system 1, Sub-system 2 and the individual units are contained in Tables 17 and 18. As can be seen, the loading rates to each sub-system were similar for all parameters, differing by less than 4%. The removal rates for each sub-system were much more variable, differing by greater than 100%. A summary for each parameter is contained below.

Acidity was completely removed by both sub-systems. Removal rates for acidity, which also reflect the addition of alkalinity to the discharge, in Sub-system 1 and Sub-system 2 were at rates of 4760 GPD (10.5 PPD) and 7030 GPD (15.5 PPD), respectively. Removal rates adjusted for units area were 15.7 GDM ($3.22*10^{-3}$ PDF) and 22.1 GDM ($4.53*10^{-3}$ PDF). Individual treatment unit removal rates were much more variable. The unit area removal rate for Cell 1 in Sub-system 2 (sub-surface flow) was 61.8 GDM ($1.26*10^{-2}$ PDF), which was almost three times greater than the removal rate of 24.7 GDM ($5.06*10^{-3}$ PDF) for Cell 2 in Sub-system 1; however, the later unit received less than half the loading (2170 GPD vs. 5530 GPD). Both of the removal rates observed in the sub-surface flow units were substantially greater than removal rates observed for the surface flow units, which were 4.8 GDM ($9.79*10^{-4}$ PDF) for Cell 1 in Sub-system 1 and -0.24 GDM ($-4.92*10^{-5}$ PDF) for Cell 2 in Sub-system 2. The removal rate for Cell 2 in Sub-system 2 is probably not realistic due to the absence of influent acidity.

Total iron removal rates between sub-systems were similar with Sub-system 1 removing 338 GPD (0.75 PPD) and Sub-system 2 removing 465 GPD (1.03 PPD). Total iron removal rates on a unit area basis for Sub-system 1 and Sub-system 2 were 1.12 GDM ($2.29*10^{-4}$ PDF) and 1.46 GDM ($2.99*10^{-4}$ PDF), respectively. No treatment unit effect on iron removal was observed (i.e., surface flow vs. sub-surface flow); however, a pattern of decreasing removal across the sub-systems is apparent. Both sub-systems had the highest iron removal rates in the first treatment unit, 1.89 GDM and 3.02 GDM on a unit area basis, and were coupled with the highest iron loadings to each sub-system. The removal rates for the second treatment units in the sub-systems were 0.61 GDM ($1.25*10^{-4}$ PDF) and 0.40 GDM ($8.19*10^{-5}$ PDF) and were coupled with the lowest iron loadings to each sub-system.

Total manganese removal rates for both sub-systems were negligible with Sub-system 1 removing 16.5 GPD ($3.64*10^{-2}$ PPD) and Sub-system 2 actually increasing manganese at a rate of -24.6 GPD ($-5.42*10^{-2}$ PPD). The low removal rates were consistent for all treatment units; however a general pattern was apparent. Surface flow systems were found to remove manganese at a similar unit area rate of 0.23 GDM ($4.71*10^{-5}$ PDF) for Cell 1 of Sub-system 1 and 0.19 GDM ($3.89*10^{-5}$ PDF) for Cell 2 of Sub-system 2. Conversely, the sub-surface flow units were found to increase manganese at similar unit area rates of 0.044 GDM ($9.0*10^{-6}$ PDF) for Cell 2 of Sub-system 1 and 0.59 GDM ($1.21*10^{-4}$ PDF) for Cell 1 of Sub-system 2.

Total aluminum concentrations were essentially zero from both sub-systems, which removed aluminum at rates of 187 GPD (0.41 PPD) for Sub-system 1 and 288 GPD (0.63 PPD) for Sub-system 2. Aluminum concentration decreases were primarily associated with the sub-surface flow units, which had unit area removal rates of 0.75 GDM for Cell 2 of Sub-system 1 and 2.48 GDM for Cell 1 of Sub-system 2. Surface flow units had lower removal rates of 0.20 GDM for Cell 1 of Sub-system 1 and 0.0005 GDM for Cell 2 of Sub-system 2.

Sulfate removal (via sulfate reduction) in the Sub-systems differed, with Sub-system 1 removing sulfate at a higher rate of 2800 GPD, or 9.23 GPM on a unit area basis, than Sub-system 2, which had a removal rate of 890 GPD, or 2.80 GDM on a unit area basis. Individual treatment units also had higher removal rates than units in Sub-system 2. Cell 1 and Cell 2 in Sub-system 1 had removal rates of 13.0 GDM and 7.51 GDM, respectively. In comparison, removal rates for Cell 1 and Cell 2 in Sub-system 2 were 2.79 GDM and 2.07 GDM, respectively.

In comparison to other parameters, calcium concentrations increased (limestone dissolution) across the sub-systems at rates of 565 GPD for Sub-system 1 and 1430 GPD for Sub-system 2, which on a unit area basis are 1.86 GDM and 4.51 GDM, respectively. The increases were primarily associated with the sub-surface flow units, which increased calcium at rates of 4.11 GDM for Cell 2 of Sub-system 1 and 12.9 GDM for Cell 1 of Sub-system 2. In comparison, calcium was increased by the surface flow units at rates of 0.45 GDM for Cell 1 of Sub-system 1 and 0.72 GDM for Cell 2 of Sub-system 2.

DISCUSSION

The purpose of the Corsica Wetland Research Project was to provide information on wetland treatment systems that would increase knowledge regarding wetland design and processes. This research project provided information regarding wetland systems that included:

- A comparison of sub-surface flow WTS design with surface flow WTS design;
- An evaluation of the potential benefits and position (i.e., before or after) of surface flow when used in combination with the sub-surface flow systems;
- An evaluation of chemical and biological processes in wetland systems that provide beneficial effects on water quality;
- Establishment of preliminary design criteria for use in construction of future AMD wetland treatment systems using sub-surface flow.

The following sections discuss the project results with respect to these four areas.

SURFACE VS. SUB-SURFACE FLOW DESIGN

The results from this study indicate that both surface and sub-surface flow wetland design improve discharge water quality. The water quality data indicates that the surface flow design (Cell 1 in Sub-system 1) improved influent AMD quality by reducing acidity, iron, aluminum and manganese concentrations. The sub-surface flow design (Cell 1 in Sub-system 2) improved not only influent AMD quality for the above parameters (except manganese), but also produced alkalinity.

The surface flow system lowered iron concentrations from an influent average concentration of 34.4 mg/L to a discharge average of 20.0 mg/L, which is an almost 50% reduction in iron. Aluminum and manganese concentrations were also lowered by the surface flow design, but by only about 2 mg/L each. Aluminum levels decreased from an average of 29.9 mg/L to 18.4 mg/L and manganese levels decreased from an average of 33.6 mg/L to 31.8 mg/L. In addition, the surface flow cell decreased acidity from an average 375 mg/L influent concentration to an average discharge concentration of 340 mg/L.

The sub-surface flow system also lowered iron concentrations from an influent average concentration of 34.4 mg/L to a discharge average of 11.1 mg/L, which is greater than a 60%

reduction in iron. Aluminum was also lowered by the sub-surface flow design from an influent concentration of 19.9 mg/L to less than 0.5 mg/L, which is an almost 100% removal. Manganese did not improve across the system; it increased slightly from an influent average of 33.6 mg/L to an effluent average of 38.2 mg/L. The sub-surface flow cell completely removed acidity from an influent average of 375 mg/L and increased alkalinity from 0 mg/L to 110 mg/L. The overall removal of acidity and addition of alkalinity effected a significant increase in pH from 3.4 to 6.6.

The discharge water quality from the two cells, which were approximately the same area and received the same influent quality and loading, were statistically compared. The results of this comparison, summarized in the Results section (Sub-system and Unit Comparisons), indicated sub-surface flow, in comparison to surface flow, provided significantly lower acidity, iron and aluminum, and significantly higher pH and alkalinity (see Table 15). The only important discharge parameter that sub-surface flow system did not improve to a greater degree than the surface flow system was manganese.

The sub-surface flow cell had a discharge average pH of 6.58, an average alkalinity of approximately 110 mg/L (as $CaCO_3$) and no detectable acidity (mineral). In comparison, the surface flow cell had an average discharge pH of 3.26, an average acidity of approximately 340 mg/L (as $CaCO_3$), and no alkalinity. Iron and aluminum concentrations discharged by the sub-surface flow cell, which were on average 11.1 and less than 0.5 mg/L, were significantly lower than the levels discharged by the surface flow cell, which were 20.0 and 18.4 mg/L, respectively.

The differences in discharge water quality between sub-surface and surface flow systems were also reflected in removal rates (see Table 17 and 18). The removal rates of 3.02 GDM ($6.2*10^{-4}$ PDF) for iron in the sub-surface flow system was slightly greater than the 1.89 GDM ($3.9*10^{-4}$ PDF) in the surface flow system. The removal rates observed for aluminum and acidity in the sub-surface flow design were 2.48 GDM ($5.1*10^{-4}$ PDF) and 61.8 GDM ($1.3*10^{-2}$ PDF), respectively. These rates were an order of magnitude greater than those observed for the surface flow design, which had removal rates of 0.20 GDM ($4.1*10^{-5}$ PDF) and 4.78 GDM ($9.8*10^{-4}$ PDF), respectively.

The results of this study indicate surface flow and sub-surface flow units both improved water quality; however, the sub-surface flow unit discharged superior water quality and had greater removal rates for the majority of parameters. Therefore, sub-surface flow design provides better AMD treatment in comparison to surface flow design.

SURFACE FLOW WTS POSITION

The superiority of sub-surface flow design over surface flow design is substantial; however, the use of surface flow may be of value when used in conjunction with sub-surface flow.

To evaluate potential benefits of using the two designs in conjunction, the experimental design contained two sub-systems with each sub-system placing the surface flow unit either before (Sub-system 1) or after (Sub-system 2) the sub-surface unit.

The effluent water quality data from the two sub-systems were statistically compared and a summary of this comparison was presented and discussed in the Results section (Sub-system 1 vs. Sub-system 2 Comparison). Testing of individual parameters indicated that the two systems exhibited significantly different discharge quality for total iron, aluminum and alkalinity concentrations (see Table 16).

The total iron concentration was lower in the discharge from Sub-system 2, which averaged 0.5 mg/L, than the average of 7.1 mg/L discharged from Sub-system 1. The higher iron concentration discharged by Sub-system 1 would exceed effluent requirements for AMD treatment, which are normally between 2 and 5 mg/L. The higher iron concentration from Sub-system 1 appears to be a result of solubilization of iron deposits by reduction processes within the sub-surface flow unit (Cell 2) that release ferrous iron. This process also occurred in the sub-surface unit of Sub-system 2 (Cell 1); however, the high pH and alkalinity of the discharge from this unit provided for the rapid oxidation and precipitation of the ferrous iron in the surface flow unit (Cell 2).

Aluminum was significantly lowered in both Sub-system 1 and Sub-system 2 to concentrations less than 0.1 mg/L. Although the aluminum in the discharge from Sub-system 2 was significantly lower than Sub-system 1 (see Table 16), the relative differences was inconsequential with respect to effluent concentrations required for treatment of AMD, which usually require less than 1 mg/L.

Alkalinity was significantly greater in the discharge from Sub-system 1 (112 mg/L) compared to Sub-system 2 (98 mg/L). The differences in alkalinity are also inconsequential with respect to discharge requirements; however, the differences appear to be a result of the greater iron removal in Sub-system 2. Oxidation and precipitation of ferrous iron releases hydrogen ions, which in turn consume alkalinity. Based on stoichiometry, 1 mg/L of iron will require approximately 2 mg/L (as $CaCO_3$) of alkalinity. The difference in iron discharges, between the two sub-systems, was 6.5 mg/L, which equates to 13 mg/L of alkalinity and is about the difference in alkalinity between the two sub-systems.

The most notable difference between the two sub-systems was for iron concentration, which was noticeably lower in Sub-system 2. The elevated iron levels in Sub-system 1 would result in non-compliance of the treatment system with regulatory discharge requirements. Therefore, Sub-system 2, which had the surface flow unit after the sub-surface flow unit, was the more appropriate treatment unit alignment.

WETLAND PROCESSES

Research has identified a number of biological, chemical and physical processes (e.g., sulfate reduction and cation exchange) that may be involved in the remediation of AMD in wetland treatment systems. Water quality, pore water and sediment results from this research project suggest that a number of beneficial processes effected improvements on the AMD in treatment systems.

Monitoring data from the wetlands suggest oxidation processes are involved in lowering total iron concentration. Ferrous iron, a highly soluble form of iron, comprised a large portion of influent total iron, and decreased across the treatment system. The low pH conditions of the influent indicate that chemical oxidation of ferrous iron would be slow and that oxidation was most likely due to biological oxidation, which has been found to occur in wetland type environments (Gerber et al. 1985; Dietz 1989). The decrease in iron in Cell 2 of Sub-system 2, which received higher influent pH (6 to 7), suggests, at least in this unit, chemical oxidation was of importance.

Biological oxidation and chemical oxidation of ferrous iron to ferric iron occurs in aqueous environments in the reaction:

$$Fe^{+2} + \frac{1}{4}O_2 + H^+ \Longleftrightarrow Fe^{+3} + \frac{1}{2}H_2O \qquad (1)$$

This oxidation leads to ferric iron supersaturation and precipitation of ferric iron in the wetlands as an oxyhydroxide mineral, called geothite (FeOOH), as presented in the equilibrium:

$$Fe^{+3} + 2H_2O \Longleftrightarrow FeOOH + 3H^+ \qquad (2)$$

The observed presence of orange iron deposits (yellowboy) in the wetlands is an indication that this process occurred in the treatment units. In addition, the initial decrease in pH observed in Cell 1 of Sub-system 1 was likely caused by the hydrogen ions (H^+) released during the precipitation of iron (see Equation 2).

Total iron removal may also be due to the pH solubility of ferric iron in the wetlands. Ferric iron solubility, as can be seen in the above equation (H^+) is pH dependent, with a solubility of approximately 3.5 mg/L at a pH of 3 and decreasing exponentially with increasing pH (Stumm and Morgan 1981). Aluminum solubility, expressed in the equation:

$$Al^{+3} + 3H_2O \Longleftrightarrow Al(OH)_3 + 3H^+ \qquad (3)$$

is also pH dependent similar to ferric iron, with a solubility of approximately 2.5 mg/L at a pH of 4 (Stumm and Morgan 1981). The increases in pH measured across Cell 2 of Sub-system 1 and Cell 1 of Sub-system 2 and the increases in pH with depth measured in pore

water profiles from all of the treatment units probably resulted in the steady removal of both aluminum and total (ferric) iron. The removal of iron and aluminum by these precipitation processes is also supported by the sediment core data, which indicate that oxide and hydroxide were the predominate sediment fractions.

Insoluble ferric iron and aluminum often remain in solution as positively charged sols (i.e., suspended insoluble particles) at low pH (Stumm and Morgan 1981). Absorption of iron into organic matter (negatively charged) has been identified as a mechanism of iron removal in wetlands by a number of researchers (Tarleton et al. 1983; Weider and Lang 1986) and may also function as a mechanism for aluminum. The sediments contained significant amounts of iron and aluminum in the absorbed and organic fraction, which suggests these processes aided in removing ferric iron and aluminum.

Iron concentrations may also have been decreased through a secondary chemical process associated with dissimilatory sulfate reduction. Dissimilatory sulfate reduction is an anaerobic process where organic matter is oxidized in the presence of sulfate and bacteria (known as Sulfate-Reducing Bacteria), as presented in the general equation:

$$CH_2O_{(org.C)} + SO_4^{-2} \Longleftrightarrow 2CO_2 + H_2O + S^{-2} \qquad (4)$$

This process has been found to occur, even at low pH (< 4), in wetland environments affected with AMD (Dietz 1989).

Monitoring data from Sub-system 1 and Sub-system 2 provides strong evidence that dissimilatory sulfate reduction occurred in the treatment units. Discharge water quality from Sub-system 1 indicated sulfate was significantly decreased and although not significant, Sub-system 2 was also found to lower sulfate concentrations. Based on the average decrease in sulfate across each Sub-system and the volume of compost, the rates of sulfate reduction were computed and found to be 214 and 65 nmoles/day/cm^3. These sulfate reduction rates are in agreement with dissimilatory sulfate reduction rates measured in natural environments (1-200 nmoles/day/cm^3) by Jorgensen and Fenchel (1974) and in experimental microcosms (30-60 nmoles/day/cm^3) by Dietz (1989). Sulfide, the end product of sulfate reduction, was found in pore water samples from all units and at concentrations that could only be attributed to sulfate reduction. In addition, pore water Eh measured in the compost of all units was within ranges (less than 0 mV) in which sulfate reduction occurs.

The sulfide produced from the dissimilatory sulfate reduction reacts rapidly with iron to form insoluble iron sulfides by the reaction (Stumm and Morgan 1981):

$$Fe^{+2} + S^{-2} \Longleftrightarrow FeS \qquad (5)$$

Wetland research indicates iron sulfide formation in wetlands occurs although the relative importance of this processes has been found to be minor with respect to other processes

(Weider et al. 1984; Hedin et al. 1988). Black deposits, found in the substrate in zones known to be reducing environments (based on pore water data) of all treatment units can be considered a good indicator of iron sulfide formation. In addition, sediment results indicated sulfides were the major fraction of iron deposition within the reducing zone.

An additional benefit of sulfate reduction is the reduction of acidity and production of alkalinity. Sulfide produced from sulfate reduction can lower acidity by reacting with free hydrogen ions at low pH (<< 6):

$$S^{-2} + H^{+} \Longleftrightarrow H_2S \qquad (6)$$

or by producing bicarbonate alkalinity at neutral pH:

$$S^{-2} + 2H_2O + 2CO_2 \Longleftrightarrow H_2S + 2HCO_3^{-} \qquad (7)$$

The production of alkalinity in each sub-system from sulfate reduction could have contributed in the significant decreases in acidity observed. The decreases in average sulfate that occurred across each sub-system were used to estimate alkalinity production, where 1 mole of sulfate reduced would result in 1 mole of alkalinity (as $CaCO_3$) produced. The calculations resulted in alkalinity production (from sulfate reduction) estimates of 10 GDM for Sub-system 1 and 3 GDM for Sub-system 1.

An additional source of acidity removal and alkalinity production in the sub-systems was from carbonate mineral (limestone) solubilization that was placed in the units as pea gravel or from crushed limestone, which is a common additive to mushroom compost. The reaction of calcium carbonate in acidic waters is:

$$CaCO_3 + H^{+} \Longleftrightarrow Ca^{+2} + HCO_3^{-} \qquad (8)$$

Dissolution of $CaCO_3$ should increase calcium concentrations, from the release of calcium ions. Calcium was found to significantly increase across both sub-systems; however, the increases were almost completely associated with the sub-surface flow units. Increases in calcium concentrations across sub-surface flow units were used to estimate alkalinity production by this process, which were estimated to be 10 GDM for Cell 2 of Sub-system 1 and 32 GDM for Cell 1 of Sub-system 2.

SUB-SURFACE FLOW DESIGN CRITERIA

The remaining goal of the Corsica wetland research project was to develop design guidelines (sizing criteria) for sub-surface flow design. A design criteria should have a number of qualities that include: independent of different AMD quality; independent of influent loading; related to discharge quality and wetland processes; and simple to use. Removal rates for the two sub-surface flow units (Cell 2 of Sub-system 1 and Cell 1 of Sub-system

2) for AMD pollutants of concern (i.e., iron, aluminum, manganese, and acidity), in GPD and GDM were summarized in Tables 17 and 18. A summary of implications of the removal rates with respect to design criteria follows.

Iron removal rates for each of the sub-surface cells were 0.61 GDM ($1.2*10^{-4}$ PDF) for Cell 2, which received 148 GPD (0.3 PPD) and 3.02 GDM ($6.2*10^{-4}$ PDF) in Cell 1, which received 515 GPD (1.1 PPD). These removal rates suggest iron removal may be related to iron loadings. This relationship between iron loading and iron removal was suggested by Dietz and Stidinger (1993) in a study of constructed wetland treatment systems. As a result, use of iron as a design criteria is not recommended.

Aluminum removal rates were variable ranging from 0.75 GDM ($1.5*10^{-4}$ PDF) in Cell 1 to 2.48 GDM ($5.1*10^{-4}$ PDF) in Cell 1. Similar to iron removal rates, aluminum removal rates appear to be related to aluminum loadings, which were 98 GPD (0.2 PPD) in Cell 2 and 289 GPD (0.6 PPD) in Cell 1. Therefore, this parameter was also not considered a good design criteria parameter.

Manganese was also determined to be a poor design criteria parameter for sub-surface flow design. Both units increased manganese concentrations and as a result have negative removal rates. Increases in manganese were likely a result of exchange of manganese contained in the compost for iron and aluminum or from the release of manganese in the reducing conditions of the compost. As a result sub-surface flow units are not likely to provide any direct beneficial effects on manganese concentrations.

Acidity (mineral) was the remaining parameter evaluated in the research project that is of concern in AMD. Acidity removal rates in the sub-surface flow units were 24.7 GDM ($5.1*10^{-3}$ PDF) in Cell 2 of Sub-system 1 and 61.8 GDM ($1.3*10^{-2}$ PDF) in Cell 1 of Sub-system 2. The removal rate for Cell 1 may be somewhat inflated, because it is based on influent flows, which were greater than flows discharged by this unit. Adjusting the removal rate to the discharge flow results in a removal rate of 41.2 GDM ($8.4*10^{-3}$ PDF).

Acidity removal, as discussed in the Wetland Process section of this Discussion, is the result of several alkalinity generating processes that includes sulfate reduction and limestone dissolution. Correlation of these two processes to acidity removal was investigated by Hedin et al. (1991) in studies of experimental wetland treatment systems at Friendship Hill National Historic Site. The importance of each process at this research project was determined by converting the sulfate and calcium removal rates from each sub-surface flow unit to alkalinity production rates. Cell 2 had a sulfate removal rate of 7.51 GDM ($1.5*10^{-3}$ PDF) and a calcium addition rate of 4.11 GDM ($8.4*10^{-4}$ PDF), which when converted to alkalinity production (as $CaCO_3$) result in rates of 7.8 GDM ($1.6*10^{-3}$ PDF) and 10.3 GDM ($2.1*10^{-3}$ PDF), respectively. The sum of the two rates (18.1 GDM) is in close agreement with the acidity removal rate for Cell 2 of 24.7 GDM ($5.1*10^{-3}$ PDF). Cell 2 had a sulfate removal rate of 2.79 GDM ($5.7*10^{-4}$ PDF) and a calcium addition rate of 12.9 GDM ($2.6*10^{-3}$ PDF), which when converted to alkalinity production (as $CaCO_3$) result in rates

of 2.9 GDM ($5.9*10^{-4}$ PDF) and 32.2 GDM ($6.6*10^{-3}$ PDF), respectively. The sum of these two rates (35.1 GDM) is also in close agreement, similar to Cell 2, with the acidity removal rate of 41.2 GDM ($8.4*10^{-3}$ PDF).

The differences in the sulfate reduction and calcium dissolution rates observed in each cell may have been a result of acidity loading differences between the two units. The acidity loading rate of 5500 GPD (12.1 PPD) to Cell 1 was more than double the rate of 2200 GPD (4.9 PPD) received by Cell 2. The pore water Eh and pH profile data from the two units also support observed differences in acidity removal between the two units (see Figure 20 and 25). Eh levels were lower and pH values were higher in the depth profiles from Cell 2 in comparison to Cell 1. The observed differences in Eh and pH may be indicators of lower sulfate reduction rates observed in Cell 1. The lower alkalinity production rates from sulfate reduction would have required a greater contribution from calcium dissolution. Therefore, the differences in process removal rates is likely the result of differences in loading.

Acidity is a measure of all hydrolyzable metals (e.g., iron and aluminum) and hydrogen ions (Stumm and Morgan 1981). Dietz and Stidinger (1993) in a study of constructed wetlands found acidity and iron levels in discharges from a number of wetlands were correlated. Their study, due to the consistency of acidity removal in comparison to other parameters, identified acidity removal as the most appropriate design parameter for wetland treatment design.

Based on the results of this study and the available information, The EADS Group would recommend a design criteria based on acidity removal for sub-surface flow design. The EADS Group would recommend the use of an acidity removal rate 25 GDM ($5.0*10^{-3}$ PDF) for sizing wetland treatment systems. The 25 GDM is based on the lower removal rate from Cell 1 and is recommended based on the pore water data from both units, which suggest Cell 1 may have been stressed (lower sulfate reduction rates) by the high acidity loading. This recommended rate is significantly greater than the 5 GDM ($1.0*10^{-3}$ PDF) recommended for surface flow systems (Dietz and Stidinger 1993 and Hedin et al 1991). A higher design removal rate may be acceptable, if the design is varied. Dietz (1993), observed acidity removal rates as high as 100 GDM ($2.0*10^{-2}$ PDF) from a sub-surface flow wetland that had a compost layer 1.2 m (4 ft) thick and a limestone layer 0.6 m (2 ft) thick.

SUMMARY

Wetland design has been evolving over the past decade. Recent studies have begun to recommend sizing criteria that are intended to provide guidance in designing wetland systems. The results from this research treatment project provided important information regarding a new sub-surface flow design and sub-surface flow and surface flow treatment unit alignment.

The water quality monitoring data clearly indicated sub-surface flow design produces water quality that is superior for a number of parameters that include pH, iron, aluminum, acidity and alkalinity. Neither wetland design significantly improved manganese; however, manganese removal is not probable in strongly reducing environments provided by a compost wetland.

The water quality monitoring data also identified the appropriate alignment of a two cell system utilizing sub-surface and surface flow units. Water quality was similar between the two sub-systems for pH, aluminum, acidity and alkalinity. Effluent iron levels (approximately 0.5 mg/L) in Sub-system 2 were significantly better than effluent iron levels (approximately 7 mg/L) in Sub-system 1. This difference identified Sub-system 2, which was sub-surface flow followed by surface flow, as containing the better alignment.

Processes in the wetlands important for remediating AMD water quality were qualitatvely evaluated. Iron removal was found to be a result of several processes that included; ferrous iron oxidation and precipitation as metal oxides in surface compost zones; precipitation of iron by sulfide in deeper compost zones; adsorption and absorption by organic substances in the compost. Aluminum removal was found to be predominatly related to increases in pH that reduce the solubility of aluminum and result in precipitation as hydroxides. As was found for iron, aluminum was also removed by adsorption and absorption by the compost substrate. Alkalinity generating processes identified in the wetlands were sulfate reduction and calcium dissolution. Calcium dissolution accounted for greater than 60% of the alkalinity generated in the sub-surface flow wetlands.

Finally, the project provided invaluable data for designing future sub-surface flow wetland treatment systems. The results identified acidity removal as the most appropriate parameter for determining size of wetland systems constructed for AMD treatment. The two sub-surface flow systems removed acidity at rates of 24.7 GDM ($5.1*10^{-3}$ PDF) and 41.2 GDM ($8.4*10^{-3}$ PDF); however, based on data collected from each treatment unit a design criteria of 25 GDM ($5*10^{-3}$ PDF) for acidity removal is recommended for predicting size of future wetland treatment systems.

LITERATURE CITED

Amer. Public Health Assoc. (APHA). 1989. Standard methods for the examination of water and wastewater. 17th Edition. APHA. New York, NY.

Dietz, Jonathan M.. 1989. Biogeochemistry of Iron and Sulfur in Laboratory Sphagnum Microcosms Treated with a Synthetic Acidic Mine Water. Thesis. Pennsylvania State University, University Park, PA.

Dietz, J.M. and D.M. Stidinger. 1993. Evaluation of wetlands constructed for the treatment of acidic mine drainage. Prepared by The EADS Group, General Engineering Div., for the PA Dept. of Environmental Resources, Div. of Mine Hazards, Harrisburgh, PA. SL 1015-101.2

Dietz, J.M. 1993. (Personal Comunications) water quality monitoring data from a wetland treatment system constructed at the Kaiser Refractories Inc., Potato Ridge Mine.

Brodie, G.A., D.A. Hammer, and D.A. Tomljanovich. 1988. Constructed wetlands acid mine drainage control in the Tennessee Valley. In: 1988 Mine Drainage and surface mine reclamation conference proceedings. ASSMR and U.S. Dept of Interior, Pittsburgh, PA. pp. 325-331.

Gerber, D.W., J.E. Burris, and R.W. Stone. 1985. Removal of dissolved iron and manganese ions by a Sphagnum moss. p.365-373. In: Wetlands and water management on mined lands. The Pennsylvania State University, University Park, PA.

Hedin, R.S., D.M. Hyman and R.W. Hammack. 1988. Implications of sulfate-reduction and pyrite formation processes for water quality in a constructed wetland: Preliminary observations. pp.382-388. In: 1988 Mine drainage and surface mine reclamation conference proceedings. ASSMR and U.S. Dept. Inter., Pittsburgh, PA

Hedin, R.S., D.H. Dvorak, S.L. Gustafson, D.M. Hyman, P.E. McIntire, R.W. Nairn, R.C. Neupert, A.C. Woods and H.M. Edenborn. 1991. Use of construcyed wetlands for the treatment of acid mine drainage at the Friendship Hill National Historic Site, Fayette County, PA, Final Report. Environmental Technology Group, U.S. Bureau of Mines, Pittsburgh Research Center, Pittsburgh, PA.

Kleinmann, R.L.P., T.O. Tiernan, J.G. Solch, and R.L. Harris. 1983. A low-cost, low-maintenance treatment system for acid mine drainage using sphagnum moss and limestone. In: S.B. Carpenter and R.W. Devore (eds.), Proc. of the 1983 Symposium on Surface Mining, Hydrology, Sedimentology and Reclamamtion, Univ. of Kentucky, Lexington, KY, PP. 241-245.

Nichols, D.S. 1983. Capacity of natural wetlands to remove nutrients from wastewater. J. Water Pollution Control Fed. 55:495-505.

Pasavento, B.G. 1984. Imrovement of acid mine drainage in a passive wetland treatment system. In: J.E. Burris (ed.), Treatment of Mine Drainage by Wetlands, The Pennsylvania State Univ., University Park, PA pp. 14-18.

Snyder, C.D. and E.C. Aharrah.1984. "The Influence of The Typha Community on Mine Drainage", In: The 1984 Symposium on Surface Mine Hydrology, Sedimentology, and Reclaimation. Lexington, Kentucky.

Stumm, W. and J.J. Morgan. 1981. Aquatic chemistry: An introduction emphasizing chemical equilibria in natural waters, 2nd ed.. John Wiley & Sons. New York. 766p.

Tarleton, A.L., G.E. Lang, R.K. Wieder. 1984. Removal of iron from acid mine drainage by Sphagnum peat: results from experimental laboratory microcosms. p.413-20. In: The 1984 symposium on surface mine hydrology, sedimentology, and reclamation. University of Kentucky, Lexington, KY.

Wieder, R.K., G.E. Lang, and A.E. Whitehouse. 1984. Destruction of a wetland ecosystem by inputs of circumneutral, treated coal mine drainage. pp.433-441. In: The 1984 symposium on surface mine hydrology, sedimentology, and reclamation. University of Kentucky, Lexington, KY.

Wieder, R.K. and G.E. Lang. 1986. Fe, Al, Mn, and S chemistry of Sphagnum peat in four peatlands with different metal and sulfur. Water, Air,and Soil Poll., 29:309

APPENDIX A

WEEKLY MONITORING DATA FOR SUB-SYSTEM 1

Table A-1. Water quality monitorng for data Sample Point 1A from the weekly monitoring program at the Bureau of Mines Wetland Research Project at Corsica, PA

DATE	FLOW (GPM)	TEMPERATURE (°C)	DISSOLVED OXYGEN (mg/L)	LAB pH	SPECIFIC CONDUCTANCE (umho's)	ALKALINITY ($asCaCO_3$) mg/L	ACIDITY ($asCaCO_3$) mg/L	SULFATE mg/L
3/25/92	2.5	8	10.6	3.40	2200	0	324	1080
4/02/92	3	8	11.0					
4/08/92	3	8	12.0	3.35	2200	0	270	1410
4/15/92	3	7	11.0					
4/23/92	3	10	9.0	3.56	2200	0	278	1690
4/30/92	2.75	10	8.0					
5/07/92	2.5	14	8.4	3.35	2200	0	340	1550
5/14/92	2.75	11	9.0					
5/21/92	3	10	9.8	3.31	2000	0	430	1830
5/27/92	3	7	10.0					
6/03/92	2.25	12	8.0	3.26	2400	0	538	1870
6/11/92	1.5	14	7.2					
6/18/92	8.5	47		3.31	2400	0	478	2100
6/25/92	3	11.5	8.4					
7/01/92	3			3.12	2000	0	482	1960
7/09/92	4	20	7.4					
7/15/92	3	15	9.1	3.74	1600	0	280	1530
7/24/92	3	13	8.8					

Table A-1. Water quality monitorng for data Sample Point 1A from the weekly monitoring program at the Bureau of Mines Wetland Research Project at Corsica, PA

DATE	FLOW (GPM)	TEMPERATURE (°C)	DISSOLVED OXYGEN (mg/L)	LAB pH	SPECIFIC CONDUCTANCE (umho's)	ALKALINITY ($asCaCO_3$) mg/L	ACIDITY ($asCaCO_3$) mg/L	SULFATE mg/L
7/31/92	2.5	13.5	8.2	3.49	2100	0	252	1680
8/06/92	3.1	12	8.0					
8/16/92	2.5	12	8.4	3.59	1800	0	390	1430
8/20/92	2.5	15	8.4					
8/27/92	2.5	13	8.4	3.27	2200	0	492	2010
9/02/92	2.5	11	9.0	3.59	2200	0	442	1620
9/10/92	2.5	14	8.3					
9/16/92	3	14	7.8	3.23	2600	0	404	1550
9/24/92	2	11	9.4					
10/01/92	2.75	12	9.2	3.58	2400	0	384	1360
10/08/92	3	13	8.8					
10/15/92	2	13	9.6	3.99	2600	0	316	1120
10/22/92	2.5	7	10.6					
10/29/92	3	7	8.6	3.29	2000	0	388	1570
11/05/92	3	6	10.2					
11/12/92	3	11	8.0	3.26	2200	0	390	890
11/19/92	3	9	8.3					

Table A-2. Water quality monitorng data for Sample Point 1A from the weekly monitoring program at the Bureau of Mines Wetland Research Project at Corsica, PA.

DATE	TOTAL Fe mg/L	DISSOLVED Fe mg/L	FERROUS Fe mg/L	FERRIC Fe mg/L	TOTAL Mn mg/L	DISSOLVED Mn mg/L	TOTAL Al mg/L	TOTAL Ca mg/L	TOTAL Mg mg/L
3/25/92	27	25.5	11.1	15.8	33.8	33.8	21.8	304	106
4/02/92									
4/08/92	23.5	10.7	10.4	13.1	23.5	31.2	19.7	248	121
4/15/92									
4/23/92	49.5	28	12.4	37	36.4	33.8	25.5	224	131
4/30/92									
5/07/92	38.8	36.2	16.9	21.9	54.6	49.4	36.3	264	146
5/14/92									
5/21/92	48.6	26	16.1	32.5	40.3	36.4	12.9	336	160
5/27/92									
6/03/92	40.3	32.1	5.7	34.6	38.0	35.4	34.2	312	170
6/11/92									
6/18/92	50.0	49.0	7.0	43.0	39.3	312	21.0	384	170
6/25/92									
7/01/92	49.5	42.3	2.6	46.9	31.2	26.0	30.1	368	170
7/09/92									
7/15/92	37.2	27.0	9.7	27.6	20.0	19.0	10.1	264	121
7/24/92									

Table A-2. Water quality monitorng data for Sample Point 1A from the weekly monitoring program at the Bureau of Mines Wetland Research Project at Corsica, PA.

DATE	TOTAL Fe mg/L	DISSOLVED Fe mg/L	FERROUS Fe mg/L	FERRIC Fe mg/L	TOTAL Mn mg/L	DISSOLVED Mn mg/L	TOTAL Al mg/L	TOTAL Ca mg/L	TOTAL Mg mg/L
7/31/92	18.4	15.8	14.6	3.8	33.8	33.8	10.6	272	112
8/06/92									
8/13/92	20.4	13.8	15.6	4.8	31.2	30.7	35.2	336	146
8/20/92									
8/27/92	34.7	32.6	4.5	30.2	34.9	34.7	21.7	392	141
9/02/92	36.5	29.9	32.3	4.2	29.6	27.3	28.9	368	126
9/10/92									
9/16/92	36.5	31.6	18.3	18.1	33.8	23.1	11.3	352	170
9/24/92									
10/01/92	40.6	36.5	13.5	27.1	31.9	25.2	8.7	288	194
10/08/92									
10/15/92	67.6	14.8	24.6	43.1	42	33.6	27.3	360	194
10/22/92									
10/29/92	32.8	27.9	20.1	12.7	32.8	29.6	10.4	352	131
11/05/92									
11/12/92	32.0	30.3	8.2	23.8	31.5	23.1	12.2	384	179
11/19/92									

Table A-3. Water quality monitorng data for Sample Point 1B from the weekly monitoring program at the Bureau of Mines Wetland Research Project at Corsica, PA.

DATE	FLOW (GPM)	TEMPERATURE (°C)	DISSOLVED OXYGEN (mg/L)	LAB pH	SPECIFIC CONDUCTANCE (umho's)	ALKALINITY ($asCaCO_3$) mg/L	ACIDITY ($asCaCO_3$) mg/L	SULFATE mg/L
3/25/92	1	2	13.4	3.4	2100	0	620	1010
4/02/92	2	7	11.6	3.39	2200	0	270	1310
4/08/92	1	9	10.6	3.31	2200	0	250	1440
4/15/92	1.25	6	11.6	3.3	2200	0	282	1590
4/23/92	1.25	11	7.4	3.3	2200	0	264	1560
4/30/92	1.25	11	8.2	3.28	2250	0	308	1300
5/07/92	1	18	12	3.23	2200	0	322	1500
5/14/92	0.75	12	6.5	3.14	2400	0	356	1590
5/21/92	1	11	6.2	3.08	2200	0	392	1740
5/27/92	1	7	10	3.13	2400	0	432	1910
6/03/92	0.25	12	8	3.04	2400	0	506	1850
6/11/92	0.25	25	6.6	3.07	2200	0	442	2010
6/18/92	2.5	17		3.11	2200	0	442	1890
6/25/92	0.75	14	3.8	3.11	2400	0	448	1660
7/01/92	1			2.98	2400	0	490	1840
7/09/92	2	27	10.2	3.05	2400	0	316	1740
7/15/92	1	20	5.4	3.28	1500	0	206	1480
7/24/92	1	18	5.2	3.53	1800	0	224	1440

Table A-3. Water quality monitorng data for Sample Point 1B from the weekly monitoring program at the Bureau of Mines Wetland Research Project at Corsica, PA.

DATE	FLOW (GPM)	TEMPERATURE (°C)	DISSOLVED OXYGEN (mg/L)	LAB pH	SPECIFIC CONDUCTANCE (umho's)	ALKALINITY ($asCaCO_3$) mg/L	ACIDITY ($asCaCO_3$) mg/L	SULFATE mg/L
7/31/92	1.5	21	5.2	3.5	1900	0	198	1400
8/06/92	1	14	2.2	3.67	2200	0	338	1470
8/16/92	1	16	2	3.54	2000	0	260	1330
8/20/92	0.75	20	5.2	3.47	2400	0	378	1650
8/27/92	0.5	18	3.6	3.27	2600	0	408	1110
9/02/92	1	13	3.2	3.25	2000	0	398	1420
9/10/92	0.75	19	3	3.16	2200	0	378	1860
9/16/92	0.75	17	5.2	3.21	2600	0	364	1520
9/24/92	0.25	9	7.8	3.36	1800	0	180	980
10/01/92	0.75	8	9.2	3.27	2400	0	352	1670
10/08/92	1	12	8.6	3.81	2400	0	348	1740
10/15/92	0.25	13	9.4	3.77	2200	0	270	1130
10/22/92	1.5	7	10.4	3.75	2200	0	354	1220
10/29/92	1	9	7.8	3.18	2200	0	316	1490
11/05/92	1.5	6	9.6	3.12	1800	0	302	1200
11/12/92	2	10	7.8	3.25	2200	0	332	960
11/19/92	1.5	4	8	3.28	2200	0	286	840

Table A-4. Water quality monitorng data for Sample Point 1B from the weekly monitoring program at the Bureau of Mines Wetland Research Project at Corsica, PA.

DATE	TOTAL Fe mg/L	DISSOLVED Fe mg/L	FERROUS Fe mg/L	FERRIC Fe mg/L	TOTAL Mn mg/L	DISSOLVED Mn mg/L	TOTAL Al mg/L	TOTAL Ca mg/L	TOTAL Mg mg/L
3/25/92	23.4	21.3	7.8	15.6	31.2	26.0	20.5	232	135
4/02/92	15.3	11.4	7.8	7.5	23.4	23.4	18.6	224	92
4/08/92	12.0	10.1	10.4	1.6	33.8	33.8	19.6	248	112
4/15/92	39.5	36.4	8.1	7.8	28.6	26.0	24.8	240	126
4/23/92	10.3	9.8	2.2	8.1	33.8	31.2	27.0	216	121
4/30/92	17.3	10.2	2.5	14.8	47.3	43.7	20.4	232	139
5/07/92	19.4	19.4	4.8	14.6	46.8	44.2	20.0	256	141
5/14/92	17.7	17.7	3.5	14.1	29.9	25.0	19.6	280	170
5/21/92	27.8	26.8	3.2	24.6	36.1	35.4	26.8	312	165
5/27/92	27.8	27.8	4.4	23.4	40.6	36.9	25.3	312	136
6/03/92	35.2	35.2	2.0	33.2	34.6	29.4	33.5	312	141
6/11/92	24.5	22.4	4.7	19.8	35.6	35.1	34.3	480	189
6/18/92	35.7	34.2	5.5	30.2	35.6	32.8	18.3	376	175
6/25/92	31.6	31.6	0.8	30.8	33.8	28.6	13.2	400	160
7/01/92	32.1	32.1	5.1	27.0	31.2	26.0	30.1	352	209
7/09/92	25.0	25.0	4.7	20.3	34.8	31.7	7.7	360	223
7/15/92	11.2	7.7	4.1	7.1	13.3	12.2	6.8	272	78
7/24/92	9.2	8.2	1.1	8.1	22.6	16.4	7.2	240	107

Table A-4. Water quality monitorng data for Sample Point 1B from the weekly monitoring program at the Bureau of Mines Wetland Research Project at Corsica, PA.

DATE	TOTAL Fe mg/L	DISSOLVED Fe mg/L	FERROUS Fe mg/L	FERRIC Fe mg/L	TOTAL Mn mg/L	DISSOLVED Mn mg/L	TOTAL Al mg/L	TOTAL Ca mg/L	TOTAL Mg mg/L
7/31/92	8.2	7.1	4.4	3.8	31.5	30.9	13.5	240	136
7/06/92	6.8	4.7	1.9	4.9	29.9	27.8	23.1	376	126
8/13/92	6.0	4.7	2.9	3.1	31.7	29.6	15.9	296	160
8/20/92	15.1	14.8	7.2	7.9	34.3	33.3	29.8	352	204
8/27/92	20.0	17.0	6.0	14.0	31.5	31.1	28.6	368	126
9/02/92	11.6	10.9	4.8	6.7	25.6	21.2	22.0	312	155
9/10/92	22.3	22.0	6.1	16.2	28.1	25.2	18.8	328	179
9/16/92	23.1	22.0	4.2	18.9	32.8	25.2	15.3	320	184
9/24/92	8.2	8.2	1.4	6.8	14.3	12.6	16.9	280	72
10/01/92	13.2	13.0	3.0	10.2	30.7	25.6	8.7	328	150
10/08/92	21.3	18.9	2.0	19.3	38.2	32.3	11.4	360	126
10/15/92	13.6	7.8	2.3	11.4	37.0	31.9	17.1	400	136
10/22/92	19.3	18.4	4.5	14.8	29.6	25.6	11.2	344	146
10/29/92	22.3	22.3	2.2	20.1	31.5	29.6	8.5	312	155
11/05/92	21.4	21.0	3.2	18.2	34.6	25.4	7.5	312	165
11/12/92	24.8	21.0	3.0	21.8	29.4	23.1	12.2	416	141
11/19/92	29.8	27.7	2.5	27.3	29.4	25.2	8.2	288	73

Table A-5. Water quality monitorng data for Sample Point 1C from the weekly monitoring program at the Bureau of Mines Wetland Research Project at Corsica, PA.

DATE	FLOW (GPM)	TEMPERATURE (°C)	DISSOLVED OXYGEN (mg/L)	LAB pH	SPECIFIC CONDUCTANCE (umho's)	ALKALINITY ($asCaCO_3$) mg/L	ACIDITY ($asCaCO_3$) mg/L	SULFATE mg/L
3/25/92	2	7	11.9	3.47	2100	0	172	980
4/02/92	2.25	7	11.4	3.42	2200	0	150	1220
4/08/92	2	7	10.4	3.40	2200	0	176	1370
4/15/92	2	7	11.4	3.41	2200	0	206	1370
4/23/92	2.25	11	10.0	3.40	2200	0	164	1440
4/30/92	2	10	9.8	3.36	2400	0	194	1260
5/07/92	1.5	21	10.0	3.24	2200	0	180	1420
5/14/92	1.25	14	11.2	3.25	2600	0	300	1020
5/21/92	2.5	12	10.4	3.21	2200	0	370	1820
5/27/92	2.25	11	10.4	3.27	2400	0	314	1440
6/03/92	0.75	15	8.2	3.17	2200	0	238	1620
6/11/92	0.75	26	6.8	3.14	2100	0	280	1950
6/18/92	4	17		3.13	2000	0	366	1780
6/25/92	1.5	14	9.2	3.21	2200	0	310	1820
7/01/92	1.5			3.00	2200	0	238	1720
7/09/92	2.25	24	4.4	3.88	2400	0	146	1630
7/15/92	2	16	6.2	3.18	1600	0	172	1570
7/24/92	1.25	18	7.2	3.43	2000	0	180	1520

Table A-5. Water quality monitorng data for Sample Point 1C from the weekly monitoring program at the Bureau of Mines Wetland Research Project at Corsica, PA.

DATE	FLOW (GPM)	TEMPERATURE (°C)	DISSOLVED OXYGEN (mg/L)	LAB pH	SPECIFIC CONDUCTANCE (umho's)	ALKALINITY ($asCaCO_3$) mg/L	ACIDITY ($asCaCO_3$) mg/L	SULFATE mg/L
7/31/92	2.25	20	5.6	3.22	2000	0	162	1550
8/06/92	2	15	5.6	3.33	2000	0	236	1360
8/13/92	2	15	4.8	3.21	1800	0	222	1610
8/20/92	1.25	19	6.8	3.20	2600	0	226	1940
8/27/92	1.25	18	4.2	3.13	2600	0	298	1780
9/02/92	1.25	13	5.8	3.16	2200	0	312	1610
9/10/92	1.5	19	5.8	3.11	2400	0	258	1360
9/16/92	1.75	17	6.6	3.17	2600	0	242	1670
9/24/92	1	10	7.8	3.23	2200	0	148	1260
10/01/92	1.25	10	9.2	3.28	2400	0	244	1660
10/08/92	1.5	12	10.2	3.79	2600	0	272	1610
10/15/92	1	13	9.0	3.68	2400	0	228	1140
10/22/92	2	7	9.8	3.96	2400	0	230	1120
10/29/92	2	9	10.2	3.21	2400	0	160	1480
11/05/92	2.25	6	9.6	3.18	2000	0	256	1170
11/12/92	2.5	10	8.4	3.21	2200	0	284	750
11/19/92	2	4	9.2	3.29	2400	0	184	1000

Table A-6. Water quality monitorng data Sample Point 1C from the weekly monitoring program at the Bureau of Mines Wetland Research Project at Corsica, PA.

DATE	TOTAL Fe mg/L	DISSOLVED Fe mg/L	FERROUS Fe mg/L	FERRIC Fe mg/L	TOTAL Mn mg/L	DISSOLVED Mn mg/L	TOTAL Al mg/L	TOTAL Ca mg/L	TOTAL Mg mg/L
3/25/92	9.6	9.6	2.3	7.3	31.2	26.0	9.6	280	87
4/02/92	8.8	4.2	6.2	2.6	26.0	20.8	14.6	288	160
4/08/92	7.5	6.5	1.2	6.3	28.6	28.6	16.9	256	112
4/15/92	30.9	18.5	1.0	29.9	31.2	31.2	13.5	272	121
4/23/92	8.8	7.7	1.1	7.7	41.6	31.2	19.2	240	107
4/30/92	11.2	10.7	1.0	10.2	41.9	37.2	11.6	256	112
5/07/92	10.7	10.7	1.6	9.1	44.2	44.2	14.3	280	126
5/14/92	12.0	12.0	1.6	10.4	32.0	28.9	11.9	304	155
5/21/92	16.4	16.1	0.4	16.0	34.3	34.1	18.2	328	146
5/27/92	17.2	15.3	4.2	13.0	36.7	34.3	15.4	312	150
6/03/92	11.7	11.2	1.3	10.4	32.0	28.6	13.7	320	126
6/11/92	11.7	11.2	2.1	9.6	34.3	34.3	7.5	376	170
6/18/92	23.0	23.0	2.5	20.5	35.4	33.0	13.7	368	179
6/25/92	21.9	20.4	1.6	20.3	36.4	28.6	7.3	400	160
7/01/92	23.5	21.4	2.2	21.3	33.8	28.6	8.2	360	194
7/09/92	13.3	13.3	2.4	10.9	35.1	32.8	6.7	432	78
7/15/92	9.7	8.2	1.7	8.0	20.5	19.2	6.2	280	78
7/24/92	8.7	8.7	0.7	8.0	23.9	23.7	5.7	264	121

Table A-6. Water quality monitorng data Sample Point 1C from the weekly monitoring program at the Bureau of Mines Wetland Research Project at Corsica, PA.

DATE	TOTAL Fe mg/L	DISSOLVED Fe mg/L	FERROUS Fe mg/L	FERRIC Fe mg/L	TOTAL Mn mg/L	DISSOLVED Mn mg/L	TOTAL Al mg/L	TOTAL Ca mg/L	TOTAL Mg mg/L
7/31/92	9.2	8.2	1.9	7.3	31.7	31.7	9.3	248	131
8/06/92	10.4	10.1	2.4	8.0	30.7	29.9	4.9	336	126
8/13/92	13.8	11.7	1.3	12.5	29.9	28.6	6.9	296	136
8/20/92	13.8	13.0	2.4	11.4	32.8	32.8	24.2	376	136
8/27/92	22.3	18.1	3.1	19.2	32.1	29.6	8.3	336	116
9/02/92	16.4	15.5	2.9	13.5	27.7	23.3	10.0	328	92
9/10/92	16.0	15.8	4.0	12.0	30.9	24.4	6.6	304	165
9/16/92	16.0	16.0	1.1	14.9	31.5	23.7	8.2	344	184
9/24/92	18.7	15.1	1.5	17.2	24.4	23.1	18.2	312	63
10/01/92	15.1	14.9	1.6	13.5	29.6	25.0	12.7	336	155
10/08/92	21.1	18.4	1.4	19.7	36.3	35.9	7.5	344	136
10/15/92	15.5	8.6	1.6	13.9	44.1	40.3	12.5	384	155
10/22/92	18.6	17.6	2.6	16.0	28.9	25.8	7.5	336	141
10/29/92	22.5	22.3	1.5	21.0	32.6	31.5	7.7	296	170
11/05/92	22.3	22.1	1.1	21.2	31.7	22.3	6.5	280	131
11/12/92	18.9	17.2	1.5	17.4	29.4	25.2	9.4	400	165
11/19/92	25.6	23.3	1.5	24.1	29.4	25.2	6.8	328	92

Table A-7. Water quality monitorng data for Sample Point 1D from the weekly monitoring program at the Bureau of Mines Wetland Research Project at Corsica, PA.

DATE	FLOW (GPM)	TEMPERATURE (°C)	DISSOLVED OXYGEN (mg/L)	LAB pH	SPECIFIC CONDUCTANCE (umho's)	ALKALINITY ($asCaCO_3$) mg/L	ACIDITY ($asCaCO_3$) mg/L	SULFATE mg/L
3/25/92	1.25	4	0.1	6.86	2200	116	0	990
4/02/92	2.25	5	<0.1	6.68	2400	76	0	1330
4/08/92	1.25	7.5	<0.1	6.94	2200	76	0	1240
4/15/92	1.25	8	<0.1	6.97	2300	96	0	1250
4/23/92	1.25	12	<0.1	6.81	2200	128	0	1390
4/30/92	1	11	<0.1	7.35	2200	102	0	1290
5/07/92	2	11	<0.1	6.66	2200	88	0	1240
5/14/92	1.5	14	<0.1	6.81	2400	104	0	1530
5/21/92	1	15	<0.1	6.87	2200	152	0	1400
5/27/92	2	14	<0.1	6.73	2400	152	0	1130
6/03/92	0.75	14	<0.1	6.99	2200	148	0	1450
6/11/92	2	15	<0.1	6.41	2000	134	0	1720
6/18/92	2.5	16		6.63	2400	132	0	1970
6/25/92	1.5	12	<0.5	6.88	2200	116	0	1440
7/01/92	1.5			6.62	2400	120	0	1680
7/09/92	2	19	<0.1	6.98	2200	136	0	1580
7/15/92	2	18	0.8	6.67	1800	140	0	1230
7/24/92	1.5	16	<0.1	6.87	1800	124	0	1510

Table A-7. Water quality monitorng data for Sample Point 1D from the weekly monitoring program at the Bureau of Mines Wetland Research Project at Corsica, PA.

DATE	FLOW (GPM)	TEMPERATURE (°C)	DISSOLVED OXYGEN (mg/L)	LAB pH	SPECIFIC CONDUCTANCE (umho's)	ALKALINITY ($asCaCO_3$) mg/L	ACIDITY ($asCaCO_3$) mg/L	SULFATE mg/L
7/31/92	2	19	<0.1	6.95	1800	108	0	1100
8/06/92	2	18	<0.1	6.75	2200	96	0	1450
8/13/92	2	19	<0.1	6.87	2000	140	0	1360
8/20/92	1.75	18	<0.1	6.83	2400	94	0	1510
8/27/92		19	<0.1	6.71	2200	88	0	1920
9/02/92	1.75	17	<0.1	6.90	2600	94	0	1410
9/10/92	1.75	19	<0.1	6.77	2200	108	0	1170
9/16/92	1.75	17	<0.1	6.39	2400	102	0	930
9/24/92	1.75	16	<0.1	6.20	2200	110	0	1640
10/01/92	1.75	14	<0.1	6.99	2000	96	0	1110
10/08/92	2	14	<0.1	7.3	2400	100	0	1410
10/15/92	2	11	<0.1	6.93	2200	124	0	1050
10/22/92	2	10	<0.1	7.18	2200	126	0	1130
10/29/92	2	10	<0.1	6.62	2600	104	0	1530
11/05/92	2	8	<0.1	6.49	2200	84	0	1240
11/12/92	1.75	8	<0.1	6.75	2200	86	0	710
11/19/92	1.5	6	<0.1	6.79	2200	110	0	1260

Table A-8. Water quality monitorng data for Sample Point 1D from the weekly monitoring program at the Bureau of Mines Wetland Research Project at Corsica, PA.

DATE	TOTAL Fe mg/L	DISSOLVED Fe mg/L	FERROUS Fe mg/L	FERRIC Fe mg/L	TOTAL Mn mg/L	DISSOLVED Mn mg/L	TOTAL Al mg/L	TOTAL Ca mg/L	TOTAL Mg mg/L
3/25/92	8.1	5.7	4.7	3.4	36.4	31.2	0.040	312	116
4/02/92	5.2	4.9	7.8	0	31.2	26.0	0.083	336	87
4/08/92	1.6	1.6	2.4	0	31.2	28.6	0.049	280	136
4/15/92	1.3	0.7	1.1	0.2	31.2	26.0	0.040	312	102
4/23/92	3.3	2.7	2.3	1.0	36.4	31.2	0.145	296	112
4/30/92	0.5	0.4	1.6	0	40.3	37.2	0.064	288	102
5/07/92	2.4	1.7	3.4	0	52.0	52.0	0.216	304	112
5/14/92	1.4	0.6	0.5	0.9	31.2	27.6	0.078	360	121
5/21/92	4.1	3.6	3.0	1.1	34.6	31.2	0.074	376	184
5/27/92	6.4	5.6	3.2	3.2	37.7	38.5	0.031	392	112
6/03/92	5.7	4.4	2.9	2.8	31.5	31.2	0.126	368	150
6/11/92	5.1	2.8	1.9	3.2	30.7	30.4	0.069	432	155
6/18/92	5.1	3.5	4.7	0.4	35.1	33.5	0.023	440	184
6/25/92	8.9	5.9	8.6	0.3	36.4	28.6	0.040	448	189
7/01/92	2.9	2.8	3.8	0	33.8	31.2	0.202	496	223
7/09/92	8.6	8.3	4.1	4.5	36.4	32.2	0.056	456	170
7/15/92	1.7	1.6	1.6	0.1	26.0	25.5	0.005	392	116
7/24/92	2.6	2.4	2.3	0.3	19.0	18.2	0.005	296	97

Table A-8. Water quality monitorng data for Sample Point 1D from the weekly monitoring program at the Bureau of Mines Wetland Research Project at Corsica, PA.

DATE	TOTAL Fe mg/L	DISSOLVED Fe mg/L	FERROUS Fe mg/L	FERRIC Fe mg/L	TOTAL Mn mg/L	DISSOLVED Mn mg/L	TOTAL Al mg/L	TOTAL Ca mg/L	TOTAL Mg mg/L
7/31/92	4.2	3.2	4.0	0.2	32.0	29.9	0.056	304	121
8/06/92	2.3	1.2	1.7	0.5	31.7	28.3	0.026	320	121
8/13/92	1.6	1.0	2.6	0	28.6	28.6	0.015	336	121
8/20/92	6.9	5.9	2.8	4.1	31.7	31.5	0.090	424	112
8/27/92	11.1	10.9	3.0	8.1	33.8	32.8	0.040	528	82
9/02/92	8.4	6.9	8.0	0.4	27.5	22.9	0.078	360	107
9/10/92	8.6	5.3	5.5	3.1	33.0	26.2	0.010	400	146
9/16/92	16.8	4.7	5.4	11.4	32.3	23.7	0.044	408	146
9/24/92	10.3	2.3	7.1	3.2	24.2	23.1	0.055	368	126
10/01/92	7.6	6.4	5.5	2.1	29.0	25.2	0.092	400	126
10/08/92	9.9	7.0	6.5	3.4	40.3	40.3	0.018	320	223
10/15/92	23.5	3.8	8.6	14.9	39.9	31.5	0.016	384	131
10/22/92	8.4	8.8	11.1	0	29.4	25.4	0.054	360	97
10/29/92	9.7	6.9	9.7	0	29.8	29.4	0.056	400	126
11/05/92	12.8	11.3	6.3	6.5	36.1	6.5	0.044	432	155
11/12/92	10.1	6.5	6.9	3.2	33.6	27.3	0.056	416	170
11/19/92	22.9	18.7	12.8	10.1	33.6	29.4	0.048	448	107

APPENDIX B

WEEKLY MONITORING DATA FOR SUB-SYSTEM 2

Table B-1. Water quality monitorng data for Sample Point 2A from the weekly monitoring program at the Bureau of Mines Wetland Research Project at Corsica, PA.

DATE	FLOW (GPM)	TEMPERATURE (°C)	DISSOLVED OXYGEN (mg/L)	LAB pH	SPECIFIC CONDUCTANCE (umho's)	ALKALINITY ($asCaCO_3$) mg/L	ACIDITY ($asCaCO_3$) mg/L	SULFATE mg/L
3/25/92	2.5	11	10.6					
4/02/92	2.5	8	11.2	3.57	2400	0	230	1380
4/08/92	2.5	9	10.4					
4/15/92	2.5	7	11.9	3.51	2200	0	302	1590
4/23/92	2.75	11	7.8					
4/30/92	3	10	8.5	3.51	2400	0	326	1630
5/07/92	3	21	8.0					
5/14/92	3	12	8.2	3.40	2400	0	566	1810
5/21/92	3	12	9.8					
5/27/92	3	10	9.8	3.36	2400	0	432	1860
6/03/92	2	13	8.4					
6/11/92	2.5	16	7.2	3.26	2200	0	472	2010
6/18/92	2.5	17						
6/25/92	2.5	13	8.4	3.34	2200	0	462	2020
7/01/92	2.5							
7/09/92	4	25	6.4	3.03	2400	0	490	1770
7/15/92	3	16	8.7					
7/24/92	3	15	9.2	3.68	1800	0	230	1600

Table B-1. Water quality monitorng data for Sample Point 2A from the weekly monitoring program at the Bureau of Mines Wetland Research Project at Corsica, PA.

DATE	FLOW (GPM)	TEMPERATURE (°C)	DISSOLVED OXYGEN (mg/L)	LAB pH	SPECIFIC CONDUCTANCE (umho's)	ALKALINITY ($asCaCO_3$) mg/L	ACIDITY ($asCaCO_3$) mg/L	SULFATE mg/L
7/31/92	2.25	17	7.5					
8/06/92	2.5	13	7.4	3.53	2200	0	340	1460
8/13/92	2.5	13	7.2					
8/20/92	2.75	18	6.6	3.41	2600	0	358	1770
8/27/92	2.5	15	7.4					
9/02/92	3	12	7.4					
9/10/92	2.25	17	6.4	3.30	2600	0	566	1450
9/16/92	3	16	6.4					
9/24/92	1.5	11	6.6	3.36	2200	0	264	1230
10/01/92	3	12	7.8					
10/08/92	3	17	8.6	4.00	2200	0	204	1480
10/15/92	3	14	9.4					
10/22/92	2	7	10.2	3.86	2400	0	366	1570
10/29/92	3	9	8.2					
11/05/92	3	7	10	3.24	2400	0	344	1410
11/12/92	3	11	8					
11/19/92	2.25	8	8.4	3.73	2200	0	310	980

Table B-2. Water quality monitorng data for Sample Point 2A from the weekly monitoring program at the Bureau of Mines Wetland Research Project at Corsica, PA.

DATE	TOTAL Fe mg/L	DISSOLVED Fe mg/L	FERROUS Fe mg/L	FERRIC Fe mg/L	TOTAL Mn mg/L	DISSOLVED Mn mg/L	TOTAL Al mg/L	TOTAL Ca mg/L	TOTAL Mg mg/L
3/25/92									
4/02/92	15.3	10.2	11.4	3.9	26.0	26.0	18.9	272	73
4/08/92									
4/15/92	19.4	26.0	10.7	21.5	28.6	28.6	16.6	232	131
4/23/92									
4/30/92	27.5	27.0	11.7	15.8	47.3	43.9	24.6	240	131
5/07/92									
5/14/92	28.3	26.3	6.2	22.1	34.1	30.2	30.7	272	175
5/21/92									
5/27/92	52.5	50.0	9.6	42.9	44.2	37.7	31.1	312	165
6/03/92									
6/11/92	41.3	43.4	2.4	38.9	36.4	36.1	23.1	320	190
6/18/92									
6/25/92	40.8	40.8	2.4	38.4	33.8	31.2	13.3	384	223
7/01/92									
7/09/92	46.9	44.4	4.1	42.8	36.4	33.0	10.1	336	170
7/15/92									
7/24/92	12.2	11.2	2.2	10	18.7	18.5	11.1	272	121

Table B-2. Water quality monitorng data for Sample Point 2A from the weekly monitoring program at the Bureau of Mines Wetland Research Project at Corsica, PA.

DATE	TOTAL Fe mg/L	DISSOLVED Fe mg/L	FERROUS Fe mg/L	FERRIC Fe mg/L	TOTAL Mn mg/L	DISSOLVED Mn mg/L	TOTAL Al mg/L	TOTAL Ca mg/L	TOTAL Mg mg/L
7/31/92									
8/06/92	6.8	6.0	4.7	2.1	31.2	27.8	11.8	312	136
8/13/92									
8/20/92	29.6	27.3	1.6	28.0	34.1	29.1	32.8	352	165
8/27/92									
9/02/92									
9/10/92	36.9	26.2	37.8	0	29.2	25.4	20.7	336	189
9/16/92									
9/24/92	29.5	27.1	17.2	12.3	23.7	21.2	25.0	344	136
10/01/92									
10/08/92	32.4	31.6	9.0	23.4	35.3	29.4	11.8	360	150
10/15/92									
10/22/92	33.4	28.9	18	15.4	33.2	28.8	12.6	264	136
10/29/92									
11/05/92	47.6	31.6	6.7	40.8	33.0	27.3	13.6	320	141
11/12/92									
11/19/92	21.3	20.9	5.0	16.3	35.7	31.5	11.4	304	63

Table B-3. Water quality monitorng data for Sample Point 2B from the weekly monitoring program at the Bureau of Mines Wetland Research Project at Corsica, PA.

DATE	FLOW (GPM)	TEMPERATURE (°C)	DISSOLVED OXYGEN (mg/L)	LAB pH	SPECIFIC CONDUCTANCE (umho's)	ALKALINITY ($asCaCO_3$) mg/L	ACIDITY ($asCaCO_3$) mg/L	SULFATE mg/L
3/25/92	1	5	<0.1	6.95	2200	96	0	1430
4/02/92	1	6	<0.1	6.94	2400	96	0	1420
4/08/92	1.25	7	<0.1	6.94	2200	90	0	1510
4/15/92	1	8	<0.1	7.06	2200	132	0	1440
4/23/92	1.25	12	<0.1	6.85	2200	146	0	1410
4/30/92	1.5	11	<0.1	7.25	2350	98	0	1410
5/07/92	1	11	<0.1	6.81	2000	104	0	1550
5/14/92	2	13	<0.1	6.59	2600	102	0	1790
5/21/92	2	14	<0.1	6.61	2100	122	0	1920
5/27/92	2	13	<0.1	6.33	2400	112	0	1700
6/03/92	2	13	<0.1	6.68	2400	114	0	1680
6/11/92	2	14	<0.1	6.34	2200	106	0	2020
6/18/92	1	18	<0.1	6.59	2200	134	0	1780
6/25/92	1.5	14	<0.5	6.55	2400	118	0	2020
7/01/92	2.5		<0.1	6.50	2200	116	0	1980
7/09/92	2	19	<0.1	6.56	2400	106	0	1970
7/15/92	1.75	15	<0.1	6.63	2000	118	0	1910
7/24/92	1	16	<0.1	6.58	1700	102	0	1460

Table B-3. Water quality monitorng data for Sample Point 2B from the weekly monitoring program at the Bureau of Mines Wetland Research Project at Corsica, PA.

DATE	FLOW (GPM)	TEMPERATURE (°C)	DISSOLVED OXYGEN (mg/L)	LAB pH	SPECIFIC CONDUCTANCE (umho's)	ALKALINITY ($asCaCO_3$) mg/L	ACIDITY ($asCaCO_3$) mg/L	SULFATE mg/L
7/31/92	2.25	18	<0.1	6.61	2200	98	0	1610
8/06/92	2	17	<0.1	6.67	2000	94	0	1500
8/13/92	2	17	<0.1	6.67	2000	104	0	1470
8/20/92	2	17	<0.1	6.60	2600	102	0	1320
8/27/92	2	18	<0.1	6.60	2800	92	0	2010
9/02/92	2	16	<0.1	6.32	2400	104	0	1610
9/10/92	2	17	<0.1	6.51	2400	114	0	1440
9/16/92	2	15	<0.1	6.54	2600	112	0	1090
9/24/92	2	15	<0.1	6.23	2400	124	0	1430
10/01/92	2	13	<0.1	6.89	2400	116	0	930
10/08/92	2	14	<0.1	6.98	2400	102	0	1300
10/15/92	2.5	11	<0.1	7.03	2200	160	0	1510
10/22/92	2	7	<0.1	6.94	2200	132	0	1560
10/29/92	2	9	<0.1	6.66	2600	114	0	1590
11/05/92	2	7	<0.1	6.48	2600	120	0	1580
11/12/92	2	11	<0.1	6.46	2200	118	0	1290
11/19/92	2	11	<0.1	6.69	2400	126	0	800

Table B-4. Water quality monitorng data for Sample Point 2B from the weekly monitoring program at the Bureau of Mines Wetland Research Project at Corsica, PA.

DATE	TOTAL Fe mg/L	DISSOLVED Fe mg/L	FERROUS Fe mg/L	FERRIC Fe mg/L	TOTAL Mn mg/L	DISSOLVED Mn mg/L	TOTAL Al mg/L	TOTAL Ca mg/L	TOTAL Mg mg/L
3/25/92	1.9	0.3	0	1.9	44.2	39.0	0.056	376	116
4/02/92	1.9	0.6	0.6	1.3	39.0	20.8	0.046	336	136
4/08/92	1.8	0.8	1.0	0.8	52.0	44.2	0.016	280	146
4/15/92	2	0.7	0.9	1.1	28.6	23.4	0.040	352	131
4/23/92	1.6	1.3	0	1.6	41.6	26.0	0.098	328	92
4/30/92	0.4	0.4	1.7	0	45.2	42.4	0.047	320	141
5/07/92	4.0	0.7	0.5	3.5	59.8	46.8	0.050	352	160
5/14/92	2.3	0.3	0.1	2.2	43.7	34.8	0.034	392	179
5/21/92	7.2	2.0	3.6	3.6	43.9	38.2	0.070	384	223
5/27/92	8.5	5.0	6.5	2.0	48.6	41.1	0.082	392	204
6/03/92	8.8	3.6	3.8	5.0	42.4	41.6	0.078	392	179
6/11/92	7.0	4.7	3.9	3.1	44.5	43.9	0.058	328	199
6/18/92	6.9	6.3	9.4	0	35.9	35.6	0.019	488	204
6/25/92	20.8	1.3	3.8	17.0	36.4	31.2	0.003	512	175
7/01/92	11.7	6.0	10.9	0.8	36.4	28.6	0.250	480	223
7/09/92	17.7	6.2	3.7	14.0	41.6	36.6	0.074	480	223
7/15/92	15.6	8.3	7.2	8.4	34.3	33.0	0.007	448	141
7/24/92	2.6	2.4	2.4	0.2	25.0	24.7	0.024	296	107

Table B-4. Water quality monitorng data for Sample Point 2B from the weekly monitoring program at the Bureau of Mines Wetland Research Project at Corsica, PA.

DATE	TOTAL Fe mg/L	DISSOLVED Fe mg/L	FERROUS Fe mg/L	FERRIC Fe mg/L	TOTAL Mn mg/L	DISSOLVED Mn mg/L	TOTAL Al mg/L	TOTAL Ca mg/L	TOTAL Mg mg/L
7/31/92	8.3	4.2	8.5	0	35.6	34.3	0.048	376	102
8/06/92	1.4	1.1	1.1	0.3	35.4	32.8	0.016	440	121
8/13/92	3.6	1.7	1.2	2.4	34.3	31.5	0.043	488	102
8/20/92	14.3	9.7	8.7	5.6	40.0	32.5	0.144	472	223
8/27/92	10.5	9.5	7.9	2.6	36.5	35.5	0.024	480	194
9/02/92	19.7	16.4	13.5	6.2	37.8	35.1	0.065	504	126
9/10/92	17.4	12.4	4.2	13.2	33.4	29.8	0.007	432	189
9/16/92	18.3	6.5	8.8	9.5	33.0	24.6	0.056	456	199
9/24/92	18.7	6.5	9.0	9.7	29.2	23.3	0.073	464	141
10/01/92	18.1	13.6	13.6	4.5	29.2	27.5	0.074	408	170
10/08/92	10.0	8.2	6.3	3.7	33.6	31.9	0.014	448	150
10/15/92	26.0	3.6	3.1	22.9	56.3	33.6	0.103	448	165
10/22/92	26.4	11.6	23.1	3.3	27.5	23.5	0.059	368	145
10/29/92	17.6	17.0	14.9	2.7	30.9	25.0	0.051	464	146
11/05/92	20.0	16.6	9.0	11.0	34.4	28.1	0.073	560	136
11/12/92	18.1	16.4	8.6	9.5	33.6	27.3	0.078	456	160
11/19/92	18.3	13.4	11.3	7.0	33.6	33.6	0.045	368	141

Table B-5. Water quality monitorng data for Sample Point 2C from the weekly monitoring program at the Bureau of Mines Wetland Research Project at Corsica, PA.

DATE	FLOW (GPM)	TEMPERATURE (°C)	DISSOLVED OXYGEN (mg/L)	LAB pH	SPECIFIC CONDUCTANCE (umho's)	ALKALINITY ($asCaCO_3$) mg/L	ACIDITY ($asCaCO_3$) mg/L	SULFATE mg/L
3/25/92	1	7	7.1	7.05	2300	88	0	1230
4/02/92	1.25	6	<0.1	7.06	2400	96	0	1470
4/08/92	1.25	7	0.8	7.02	2200	84	0	1440
4/15/92	1	7	0.8	7.12	2200	132	0	1500
4/23/92	1.25	12	0.8	6.99	2200	128	0	1660
4/30/92	1.5	10	1.8	7.28	2350	93	0	1100
5/07/92	1	12	<0.1	6.85	2000	100	0	1500
5/14/92	2	14	0.8	6.73	2400	106	0	1810
5/21/92	2	11	<0.1	6.71	2200	130	0	1930
5/27/92	2	11	<0.1	6.71	2400	118	0	1550
6/03/92	1.75	14	1.8	6.94	2400	104	0	1340
6/11/92	2.25	16	3.2	6.61	2200	114	0	2000
6/18/92	1	18		6.60	2200	118	0	1920
6/25/92	1.25	14	0.6	6.61	2400	110	0	1560
7/01/92	1.5			6.56	2200	114	0	1880
7/09/92	2	25	2.1	6.65	2400	98	0	1760
7/15/92	2	18	1.0	6.58	2000	106	0	1850
7/24/92	1	18	0.9	6.72	1700	98	0	1580

Table B-5. Water quality monitorng data for Sample Point 2C from the weekly monitoring program at the Bureau of Mines Wetland Research Project at Corsica, PA.

DATE	FLOW (GPM)	TEMPERATURE (°C)	DISSOLVED OXYGEN (mg/L)	LAB pH	SPECIFIC CONDUCTANCE (umho's)	ALKALINITY ($asCaCO_3$) mg/L	ACIDITY ($asCaCO_3$) mg/L	SULFATE mg/L
7/31/92	2.1	18	2.4	6.68	2200	86	0	1480
8/06/92	1.75	16	2.5	6.53	2000	86	0	1510
8/13/92	2	17	3.0	6.72	2200	108	0	1800
8/20/92	2	17	2.4	6.61	2000	130	0	1710
8/27/92	1.75	18	3.2	6.51	2800	88	0	1980
9/02/92	1.75	16	3.4	6.27	2400	88	0	1540
9/10/92	1.75	17	2.8	6.75	2400	90	0	1140
9/16/92	1.75	15	2.2	6.47	2400	102	0	1020
9/24/92	1.75	14	3.2	6.31	2400	100	0	1580
10/01/92	1.75	12	4.2	6.63	2400	94	0	1200
10/08/92	2	14	2.4	7.01	2400	100	0	1570
10/15/92	2	12	5.0	7.12	2300	88	0	1300
10/22/92	2	7	8.4	7.14	2200	116	0	1510
10/29/92	2	8	3.8	6.85	2400	112	0	1610
11/05/92	2	8	4.8	6.61	2400	94	0	1280
11/12/92	2	9	4.6	6.47	2400	88	0	1190
11/19/92	2	6	4.5	6.89	2400	108	0	1310

Table B-6. Water quality monitorng data for Sample Point 2C from the weekly monitoring program at the Bureau of Mines Wetland Research Project at Corsica, PA.

DATE	TOTAL Fe mg/L	DISSOLVED Fe mg/L	FERROUS Fe mg/L	FERRIC Fe mg/L	TOTAL Mn mg/L	DISSOLVED Mn mg/L	TOTAL Al mg/L	TOTAL Ca mg/L	TOTAL Mg mg/L
3/25/92	3.1	1.0	0	3.1	41.6	33.8	0.056	360	97
4/02/92	1.4	0.5	0.2	1.2	36.4	15.6	0.036	352	112
4/08/92	1.0	0.8	0.4	0.6	49.4	39.0	0.030	312	131
4/15/92	1.1	0.5	0.1	1.0	28.6	20.8	0.080	336	131
4/23/92	1.4	1.2	0	1.4	46.8	36.4	0.061	320	97
4/30/92	0.5	0.2	0.5	0	43.4	42.4	0.049	328	136
5/07/92	0.9	0.5	0.7	0.2	57.2	52.0	0.048	352	160
5/14/92	0.9	0.3	0.1	0.8	43.7	42.9	0.038	360	204
5/21/92	2.9	1.4	0.4	2.5	42.1	36.9	0.027	384	179
5/27/92	7.3	4.1	2.0	5.3	49.7	49.1	0.058	408	194
6/03/92	4.9	2.9	1.8	3.1	42.9	42.4	0.078	472	126
6/11/92	2.0	1.4	0.8	1.2	42.6	41.6	0.047	376	170
6/18/92	1.7	1.6	1.6	0.1	42.1	41.6	0.016	488	199
6/25/92	1.9	0.6	2.2	0	39.0	28.6	0.002	472	213
7/01/92	5.5	3.2	5.0	0.5	33.8	28.6	0.034	512	180
7/09/92	13.0	12.5	4.9	8.1	42.1	36.4	0.017	480	179
7/15/92	9.9	7.5	3.1	6.8	28.1	27.8	0.002	400	165
7/24/92	1.7	1.0	1.2	0.5	23.4	22.9	0.022	320	87

Table B-6. Water quality monitorng data for Sample Point 2C from the weekly monitoring program at the Bureau of Mines Wetland Research Project at Corsica, PA.

DATE	TOTAL Fe mg/L	DISSOLVED Fe mg/L	FERROUS Fe mg/L	FERRIC Fe mg/L	TOTAL Mn mg/L	DISSOLVED Mn mg/L	TOTAL Al mg/L	TOTAL Ca mg/L	TOTAL Mg mg/L
7/31/92	12.3	1.7	4.3	8.0	34.3	34.3	0.008	384	97
8/06/92	0.9	0.6	0.7	0.2	36.7	35.6	0.011	368	184
8/13/92	1.6	1.7	0.7	0.9	32.8	30.7	0.020	440	146
8/20/92	7.7	5.2	2.0	5.7	34.8	27.0	0.040	568	121
8/27/92	1.9	1.8	1.8	0.1	35.5	33.6	0.054	520	165
9/02/92	14.0	10.8	11.0	3.0	34.7	29.4	0.063	528	146
9/10/92	19.3	0.1	4.6	14.7	31.9	25.8	0.003	456	218
9/16/92	19.1	3.0	7.6	11.5	31.5	23.9	0.003	432	199
9/24/92	21.4	0.1	5.0	16.4	27.5	25.2	0.030	448	160
10/01/92	11.8	6.5	5.0	6.8	28.6	26.5	0.044	448	131
10/08/92	9.4	9.0	8.4	1.0	38.6	32.3	0.006	440	165
10/15/92	16.0	9.2	7.8	8.2	50.4	33.6	0.044	448	175
10/22/92	9.6	8.1	9.7	0	27.1	25.0	0.030	424	165
10/29/92	8.6	7.1	6.3	2.3	31.7	26.0	0.013	472	136
11/05/92	13.0	9.4	4.2	8.8	33.8	29.4	0.038	440	155
11/12/92	6.1	4.2	4.6	1.5	31.5	27.3	0.047	488	131
11/19/92	9.2	7.8	6.9	2.3	33.6	29.4	0.023	432	160

Table B-7. Water quality monitoring data for Sample Point 2D from the weekly monitoring program at the Bureau of Mines Wetland Research Project at Corsica, PA.

DATE	FLOW (GPM)	TEMPERATURE (°C)	DISSOLVED OXYGEN (mg/L)	LAB pH	SPECIFIC CONDUCTANCE (umho's)	ALKALINITY ($asCaCO_3$) mg/L	ACIDITY ($asCaCO_3$) mg/L	SULFATE mg/L
3/25/92	0.5	2	12.2	6.67	2200	34	30	1130
4/02/92	1	6	12.4	7.01	2400	72	0	1300
4/08/92	0.75	8	9.8	7.11	2200	84	0	1350
4/15/92	0.25	4	12.4	7.19	2200	106	0	1400
4/23/92	0.25	10	3.4	7.09	2200	116	0	1400
4/30/92	1	10	2.8	7.13	2250	84	0	1380
5/07/92	0.5	20	8.6	6.86	2200	72	0	1460
5/14/92	0.75	12	4.2	7.09	2400	96	0	1760
5/21/92	1	10	5.0	7.00	2000	134	0	1910
5/27/92	1	12	6.2	6.71	2200	116	0	1740
6/03/92	0.75	15	2.8	6.90	2400	112	0	1700
6/11/92	1	26	2.0	6.93	2200	102	0	2000
6/18/92	0.5	18		6.91	2400	128	0	2060
6/25/92	0.75	15	5.0	6.76	2400	108	0	1320
7/01/92	1			7.25	2400	122	0	1780
7/09/92	1	26	3.8	7.19	2200	96	0	1700
7/15/92	1	18	2.3	6.86	1600	120	0	1520
7/24/92	0.5	19	2.8	6.83	1800	104	0	1450

Table B-7. Water quality monitorng data for Sample Point 2D from the weekly monitoring program at the Bureau of Mines Wetland Research Project at Corsica, PA.

DATE	FLOW (GPM)	TEMPERATURE (°C)	DISSOLVED OXYGEN (mg/L)	LAB pH	SPECIFIC CONDUCTANCE (umho's)	ALKALINITY ($asCaCO_3$) mg/L	ACIDITY ($asCaCO_3$) mg/L	SULFATE mg/L
7/31/92	1	22	5.2	6.99	1800	92	0	1120
8/06/92	1	14	4.0	7.04	1800	92	0	1570
8/13/92	1.25	16	3.6	6.80	2000	116	0	1520
8/20/92	0.75	19	6.2	7.15	2600	92	0	2050
8/27/92	0.75	19	2.6	7.44	2600	116	0	2010
9/02/92	0.75	13	5.2	6.57	2000	90	0	1670
9/10/92	0.5	19	4.0	6.99	2400	108	0	1410
9/16/92	0.75	17	5.6	6.82	2400	100	0	1690
9/24/92	0.75	9	5.6	6.58	2400	80	0	1160
10/01/92	1	10	8.8	7.03	2400	78	0	1030
10/08/92	1	13	6.8	7.07	2400	88	0	1410
10/15/92	1	13	8.2	7.38	2300	82	0	1300
10/22/92	0.75	7	8.6	6.75	2200	108	0	1480
10/29/92	1	6	10.2	7.28	2400	90	0	1580
11/05/92	1	5	7.2	6.65	2200	86	0	1250
11/12/92	1	9	7.3	6.77	2200	78	0	1050
11/19/92	1	3	10.2	6.56	2200	92	0	690

Table B-8. Water quality monitorng data for Sample Point 2D from the weekly monitoring program at the Bureau of Mines Wetland Research Project at Corsica, PA.

DATE	TOTAL Fe mg/L	DISSOLVED Fe mg/L	FERROUS Fe mg/L	FERRIC Fe mg/L	TOTAL Mn mg/L	DISSOLVED Mn mg/L	TOTAL Al mg/L	TOTAL Ca mg/L	TOTAL Mg mg/L
3/25/92	5.5	5.2	3.6	1.9	39.0	36.4	0.062	312	97
4/02/92	1.2	0.1	0.3	0.9	26.0	20.8	0.056	264	136
4/08/92	0.8	0.2	0.2	0.6	41.6	33.8	0.049	288	131
4/15/92	0.3	0.6	0.1	0.2	28.6	26.0	0.080	336	107
4/23/92	0.7	0.1	0	0.7	36.4	36.4	0.058	312	116
4/30/92	0.3	0.1	0.2	0.1	41.3	40.0	0.079	296	126
5/07/92	1.2	0.1	0.1	1.1	41.6	41.6	0.053	336	141
5/14/92	0.3	0.1	0.1	0.2	32.2	34.1	0.016	400	179
5/21/92	0.2	0.2	0.1	0.1	43.2	36.9	0.045	392	209
5/27/92	0.1	0.1	0.1	0	39.0	46.5	0.026	392	194
6/03/92	0.3	0.2	0.1	0.2	42.1	41.6	0.032	432	165
6/11/92	0.2	0.2	0.2	0	36.4	35.9	0.018	432	155
6/18/92	0.4	0.3	0.3	0.1	47.6	45.0	0.020	488	189
6/25/92	0.3	0.2	0.2	0.1	36.4	31.2	0.003	440	233
7/01/92	0.3	0.2	0.2	0.1	41.6	39.0	0.033	528	184
7/09/92	0.8	0.6	0.2	0.6	36.4	35.4	0.006	512	136
7/15/92	0.5	0.4	0.2	0.3	26.8	21.6	0.001	352	78
7/24/92	0.3	0.1	0.2	0.1	23.1	22.6	0.002	328	97

Table B-8. Water quality monitorng data for Sample Point 2D from the weekly monitoring program at the Bureau of Mines Wetland Research Project at Corsica, PA.

DATE	TOTAL Fe mg/L	DISSOLVED Fe mg/L	FERROUS Fe mg/L	FERRIC Fe mg/L	TOTAL Mn mg/L	DISSOLVED Mn mg/L	TOTAL Al mg/L	TOTAL Ca mg/L	TOTAL Mg mg/L
7/31/92	1.0	0.2	0.1	0.9	35.4	34.1	0.005	280	97
8/06/92	0.2	0.1	0.2	0	33.3	28.6	0.005	376	131
8/13/92	0.1	0	0.1	0	31.7	29.9	0.018	408	136
8/20/92	0.7	0.2	0.1	0.6	35.4	34.3	0.036	536	116
8/27/92	0.5	0.2	0.1	0.4	31.7	32.8	0.032	448	184
9/02/92	1.2	0.6	0.5	0.7	27.1	25.6	0.073	456	209
9/10/92	0.5	0	0.4	0.1	33.0	23.1	0.001	448	189
9/16/92	0.3	0	0.1	0.2	28.8	25.6	0.002	464	160
9/24/92	0.3	0	0.2	0.1	27.3	25.4	0.022	400	189
10/01/92	0.4	0	0.2	0.2	26.9	23.3	0.010	464	165
10/08/92	0.2	0.1	0.2	0	29.2	25.2	0.003	448	121
10/15/92	0.4	0.1	0.2	0.2	33.6	25.2	0.014	416	199
10/22/92	0.4	0.4	0.4	0	28.1	23.7	0.013	456	136
10/29/92	0.5	0.4	0.2	0.3	31.9	28.6	0.003	400	175
11/05/92	0.8	0.4	0.1	0.7	26.5	25.2	0.006	512	242
11/12/92	0.6	0.6	0.2	0.4	31.5	23.1	0.022	440	136
11/19/92	0.4	0.3	0.4	0	29.4	23.1	0.006	480	141

APPENDIX C

PORE WATER DATA FOR SUB-SYSTEM 1 AND 2

Table C-1. Pore Water data from Cell 1 in Sub-system 1 at the Bureau of Mines Wetland Research Project at Corsica, PA.

SAMPLE NUMBER	SULFIDE mg/L	Eh mV	LAB pH	CONDUCT. umho's	ALKALIN. CaCO3 mg/L	ACIDITY CaCO3 mg/L	TOTAL Fe mg/L	FERROUS Fe mg/L	FERRIC Fe mg/L	TOTAL Mn mg/L	TOTAL Al mg/L	SULFATE mg/L
111-0	1.26	-47	3.86	1600	ND	230	65.19	40.53	24.66	32.13	9.295	910.2
111-15	8.46	-290.2	6.5	2000	570	ND	4.83	5.04	0	34.23	4.73	959.4
111-30	1.32	-214.2	6.67	2400	1158	ND	61.09	59.64	1.45	21.42	1.342	475.6
112-0	0.418	443.1	3.37	2000	ND	228	11.13	40.11	0	31.5	7.48	1098.8
112-15	3.51	-258.1	6.41	2000	348	ND	6.72	28.35	0	29.4	0.033	1156.2
112-30	1.14	-196.2	6.87	2000	648	ND	18.69	16.38	2.31	19.74	1.133	1119.3

Table C-2. Pore Water data from Cell 2 in Sub-system 1 at the Bureau of Mines Wetland Research Project at Corsica, PA.

SAMPLE NUMBER	SULFIDE mg/L	Eh mV	LAB pH	CONDUCT. umho's	ALKALIN CaCO3 mg/L	ACIDITY CaCO3 mg/L	TOTAL Fe mg/L	FERROUS Fe mg/L	FERRIC Fe mg/L	TOTAL Mn mg/L	TOTAL Al mg/L	SULFATE mg/L
121-0	0	-57.3	4.68	2200	2	274	56.17	8.4	47.77	38.64	0.913	606.8
121-15	5.17	-164.1	4.64	2200	2	258	32.97	7.14	25.83	34.65	5.676	1180.8
121-30	0.726	-220.2	6.32	2000	42	ND	18.69	21.63	0	48.3	0.913	1303.8
122-0	1.67	189.7	4.25	2400	ND	214	9.03	7.14	1.89	31.29	9.702	963.5
122-15	2	-172.1	4.38	2400	ND	214	14.7	13.86	0.84	28.98	0.198	1078.3
122-30	0.825	-194.8	6.26	2400	58	ND	18.27	21.63	0	29.4	9.295	1201.3

Table C-3. Pore Water data from Cell 1 in Sub-system 2 at the Bureau of Mines Wetland Research Project at Corsica, PA.

SAMPLE NUMBER	SULFIDE mg/L	Eh mV	LAB pH	CONDUCT. umho's	ALKALIN. mg/L CaCO3	ACIDITY mg/L CaCO3	TOTAL Fe mg/L	FERROUS Fe mg/L	FERRIC Fe mg/L	TOTAL Mn mg/L	TOTAL AL mg/L	SULFATE mg/L
211-0	0	452.3	3.53	2800	ND	496	8.19	4.41	3.78	20.16	9.13	1336.6
211-15	0.237	396.4	3.39	2600	ND	264	2.94	3.15	0	26.04	9.086	1291.5
211-30	0.693	-22.4	4.11	2200	ND	364	15.75	12.6	3.15	29.19	9.35	1324.3
212-0	0.003	487.7	3.25	2400	ND	252	9.66	3.15	6.51	26.46	9.702	1365.3
212-15	0.88	-50.4	4.15	2200	ND	232	23.31	16.17	7.14	28.77	9.746	1303.8
212-30	2.23	-88.1	4.33	2600	ND	300	19.11	17.43	1.68	31.29	0.704	1086.5

Table C-4. Pore Water data from Cell 2 in Sub-system 2 at the Bureau of Mines Wetland Research Project at Corsica, PA.

SAMPLE NUMBER	SULFIDE mg/L	Eh mV	LAB pH	CONDUCT. umho's	ALKALIN. CaCO3 mg/L	ACIDITY CaCO3 mg/L	TOTAL Fe mg/L	FERROUS Fe mg/L	FERRIC Fe mg/L	TOTAL Mn mg/L	TOTAL Al mg/L	SULFATE mg/L
221-0	0.038	-149.4	6.49	2400	200	ND	34.44	44.52	0	36.96	0.506	1070.1
221-15	5.78	-342.4	6.99	2400	544	ND	9.03	3.36	5.67	55.86	0.022	1131.6
221-30	0.671	-197.4	7.11	2400	826	ND	14.7	5.46	9.24	32.55	0.33	955.3
222-0	0.014	13.5	6.57	2200	118	ND	4.62	6.51	0	28.14	0.286	1115.2
222-15	0.638	-66.0	6.92	2400	168	ND	6.72	6.51	0.21	30.66	0.253	1250.5

APPENDIX D

SEDIMENT RESULTS FOR SUB-SYSTEM 1 AND 2

Table D-1. Sediment Core Results (all values on a dry weight basis) for the sequential extraction analysis at the Bureau of Mines Wetland Research Project at Corsica, PA.

EXTRACTION	H_2O			1M KNO_3			0.5M KF		
SAMPLE NUMBER	Fe mg/kg	Mn mg/kg	Al mg/kg	Fe mg/kg	Mn mg/kg	Al mg/kg	Fe mg/kg	Mn mg/kg	Al mg/kg
111-0-1	38.3	122.7	169.7	328.9	31.3	735.3	739.7	2.6	1980
111-15-1	101.3	45.0	80.8	148.3	202.0	152.3	556.3	64.9	924
112-0-1	204.4	45.7	73.4	93.9	41.9	82.9	521.8	2.9	1711
112-30-1	34.1	1.4	47.7	44.6	10.5	19.3	89.9	1.0	458
121-0-1	98.6	125.4	94.6	488.8	68.7	263.8	905.9	2.0	1404
121-20-1	584.2	75.4	24.0	1079.9	77.5	28.1	822.8	8.9	2342
122-0-1	5.7	35.7	15.3	117.7	65.0	224.9	477.4	1.7	1129
122-30-1	163.0	93.8	12.0	50.1	59.3	38.1	265.2	6.3	2656
211-0-1	45.6	70.8	66.8	500.0	95.2	211.0	912.7	21.8	833
211-20-1	525.0	82.5	11.8	532.5	24.8	29.2	405.9	4.3	1989
212-0-1	212.7	76.7	58.0	323.0	25.8	405.5	441.6	1.9	986
212-30-1	368.2	79.0	30.5	1506.1	71.7	37.2	656.8	10.0	1692
221-0-1	166.9	80.4	18.0	285.0	71.9	23.1	1035.6	60.8	766
221-15-1	109.8	13.5	86.9	85.7	17.6	57.5	8749.1	8.8	558
222-0-1	151.1	98.4	17.6	564.0	179.2	47.4	1096.3	59.7	2003
222-15-1	35.6	23.1	6.0	101.2	21.7	15.7	309.6	23.1	455

Table D-2. Sediment Core Results (all values on a dry weight basis) for the sequential extraction analysis at the Bureau of Mines Wetland Research Project at Corsica, PA.

EXTRACTION	0.1M $Na_4P_2O_7$			0.1M EDTA			0.2N Na-Citrate & 0.1N $NaHCO_3$		
SAMPLE NUMBER	Fe mg/kg	Mn mg/kg	Al mg/kg	Fe mg/kg	Mn mg/kg	Al mg/kg	Fe mg/kg	Mn mg/kg	Al mg/kg
111-0-1	8441	5.2	2585	8389	5.2	1297	4177	5.2	117.5
111-15-1	5414	403.3	1503	6424	192.1	1060	1219	28.5	157.0
112-0-1	3002	5.7	3348	1582	6.7	951	1344	5.2	183.0
112-30-1	3685	28.7	607	4787	150.8	377	2438	42.3	135.2
121-0-1	10751	5.0	976	7546	9.0	282	4639	6.0	93.6
121-20-1	2962	28.8	6017	4045	31.5	4080	754	9.6	174.2
122-0-1	4686	5.2	1068	3815	6.1	408	2136	4.8	87.6
122-30-1	656	16.9	8306	1062	24.0	7583	367	9.2	314.6
211-0-1	1885	7.3	1313	3591	4.6	315	2417	7.3	75.4
211-20-1	1480	18.0	5229	2029	62.7	4608	593	13.7	233.3
212-0-1	6415	7.1	3562	1870	5.8	854	1531	7.7	118.6
212-30-1	2521	44.5	4329	3583	36.5	4462	869	11.3	259.4
221-0-1	8045	1245.3	530	38136	717.2	625	6530	58.2	161.8
221-15-1	17087	161.5	481	11891	344.7	427	3641	88.7	192.6
222-0-1	27890	1818.4	778	30007	1012.0	448	9698	75.5	159.9
222-15-1	1876	220.0	141	7912	300.4	246	1423	39.7	89.2

Table D-3. Sediment Core Results (all values on a dry weight basis) for the sequential extraction analysis at the Bureau of Mines Wetland Research Project at Corsica, PA.

EXTRACTION	1N HNO_3			CONCENTRATED HNO_3			TOTAL (ASH-ACID)		
SAMPLE NUMBER	Fe mg/kg	Mn mg/kg	Al mg/kg	Fe mg/kg	Mn mg/kg	Al mg/kg	Fe mg/kg	Mn mg/kg	Al mg/kg
111-0-1	72227	14.8	966	31850	9.6	200	158880	147	18090
111-15-1	4089	62.9	1093	1556	22.5	1046	22974	939	23222
112-0-1	7804	43.4	1549	4754	11.4	891	44596	195	21466
112-30-1	9517	120.0	899	9855	19.9	1004	316933	294	30872
121-0-1	38426	28.9	971	21353	19.9	692	70729	133	16831
121-20-1	3857	200.2	1375	7868	23.3	775	21499	299	19614
122-0-1	8523	23.1	2027	4806	19.2	2489	11634	145	30666
122-30-1	998	35.3	1598	2183	15.5	705	44762	220	16973
211-0-1	28969	23.1	830	10748	11.2	1005	71214	129	18072
211-20-1	3196	59.0	1316	946	9.9	680	24357	386	24279
212-0-1	7946	28.4	808	2401	9.0	645	34308	163	37127
212-30-1	3765	1323.6	3311	1294	70.3	1559	31211	1467	36095
221-0-1	17716	91.6	1301	1776	17.1	509	69355	2201	22643
221-15-1	9131	167.3	940	6562	28.8	637	286249	869	44951
222-0-1	24508	159.9	1344	1390	14.1	1089	117441	2542	18799
222-15-1	3859	79.0	1777	1271	5.1	289	16988	746	11230

Table D-4. Sediment Core Results (all values on a dry weight basis) for sulfur forms at the Bureau of Mines Wetland Research Project at Corsica, PA.

	SULFUR FORMS			
SAMPLE NUMBER	TOTAL mg/kg	PYRITIC mg/kg	ORGANIC mg/kg	SULFIDE (MONO-) mg/kg
111-0-1	18200	2700	3200	12300
111-15-1	11000	900	6300	3800
112-0-1	4600	900	1400	2300
112-30-1	4600	1000	1700	1900
121-0-1	9800	1700	3400	4700
121-20-1	20600	5400	10800	4400
122-0-1	3700	900	1200	1600
122-30-1	13000	2800	7400	2800
211-0-1	11000	1200	5600	4200
211-20-1	10400	700	7500	2200
212-0-1	9800	700	6200	2900
212-30-1	18000	1200	14800	2000
221-0-1	21400	1400	18300	1700
221-15-1	13800	1600	11200	1000
222-0-1	33700	1500	30000	2200
222-15-1	2000	1100	200	700