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METAL SPECIATION AND IMMOBILIZATION REACTIONS AFFECTING THE TRUE EFFICIENCY OF ARTIFICIAL WETLANDS TO TREAT ACID MINE DRAINAGE

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UNIVERSITY OF KENTUCKY
WATER RESOURCES RESEARCH INSTITUTE
LEXINGTON, KENTUCKY

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August 1990

DISCLAIMER

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The findings of this study suggest that metal distribution and speciation patterns in surface effluents and substrates of field-constructed wetlands and the mechanisms controlling metal retention can be sufficiently modelled by laboratory-simulated wetland chambers, but significant variations can result in wetland efficiency due to flow rate variability and construction design.

DESCRIPTORS: Toxins, Wetlands, Acid Mine Drainage, Ecosystems

ABSTRACT

The ability of constructed wetlands to lower total metal concentrations and organically complex metals in acid mine drainage (AMD) was investigated under greenhouse and field conditions. In the greenhouse study, *Typha* plants grown in six different substrates received simulated acid mine drainage of low metal load for five months. Most effluents, especially those from ground flows, showed significant decreases in acidity and metal concentrations. The pine needle and hay substrates most effectively reduced acidity and total Al levels. Effluents from these substrates contained 80% less total Al than respective influents. Organically complexed Al levels were independent of matrix and varied from 10 to 30% of inflow total Al concentrations. Peat and *Sphagnum* moss most efficiently reduced Fe concentrations but only 10% of the total Fe was organically complexed. Matrix composition had little or no effect on Mn concentrations. Substrates lowered Cu and Zn levels by 40-90% in most effluents, but pine needle and hay mixtures were the most effective.

The metal concentration and acidity of a very high metal load AMD were also reduced substantially during the first six months of treatment with a wetland which was constructed by the U.S. Forest Service in McCreary County, KY and used mushroom compost as a substrate. After 8 months of operation, however, and during periods of high flow rates (> 10 gallons/min) the efficiency of the wetland was drastically reduced, apparently due to reduced residence time, insufficient size and metal overloading. No major differences were observed during high flow rate periods between input-output metal concentration, although input concentrations varied due to dilution effects. The majority of Fe, Mn, and Zn in surface effluents was present in inorganic metal species. Nearly 100% of Cu and about 40% of the Al, however, was organically bound. Substrate solutions extracted by centrifugation showed increased organic/inorganic metal species ratios apparently due to increased residence time. A great portion of the metals retained by the greenhouse and field substrates was in residual forms (oxyhydroxides, sulfides, sulfates, carbonates). The metals Fe, Mn, and Zn showed the highest tendency for residual retention, while Al and especially Cu showed high affinity for organic retention. Exchangeable and sorbed forms were present in very small concentrations and in many cases were almost negligible.

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PART I

METAL DISTRIBUTION AND SPECIATION IN EFFLUENTS AND SUBSTRATES OF GREENHOUSE-SIMULATED ACID MINE WETLANDS

INTRODUCTION

The elevated acidity and increased solubility of toxic metals such as Al, Fe, Mn, Cu and Zn associated with acid mine drainages is causing increasing concern about possible toxic effects to plants, aquatic life, animals and even humans in the coal regions of the Appalachian states (U.S. EPA, 1971; Biesecker and George, 1966; Caruccio and Geidel, 1978; Karathanasis et al., 1987). Recently, the construction of artificial wetland ecosystems has become increasingly popular as an inexpensive alternative treatment method for acid mine effluents and other hazardous waste sites with high heavy metal concentrations (Girts and Kleinmann, 1986; Erickson et al., 1987; Kleinmann, 1985; Hammer, 1989). The information that has been assembled over the last few years from the use of this ameliorative technology appears to be very promising in terms of effectiveness for lowering acidity and for heavy metal removal. So far, this effectiveness has been deduced only from inflow/outflow metal concentration comparisons (Huntsman et al., 1978, 1985; Weider et al; 1982; Gerber et al., 1985; Brodie et al., 1986, 1988). No attempts have been made to evaluate metal species distributions in effluents and substrates and the metal immobilization processes involved. However, the long term effectiveness of artificial wetland ecosystems to neutralize acid mine effluents cannot be established before these parameters and processes are fully understood. Monitoring only total concentrations of heavy metals in the treated effluent cannot provide any information about the possible toxic effects of metal species in solution (Florence, 1983). Significant quantities of organically bound metals may not be toxic at all (Stevenson and Fitch, 1986). Some plant species and substrates may be more effective than others in complexing certain metals without changing the total metal concentration of the effluent (Hargrove and Thomas, 1981; Langford et al., 1983). Furthermore, understanding the mechanisms involved in the immobilization process and identifying the most efficient forms of metal removal is very important for maintaining and even improving the efficiency of the treatment (Plankey and Patterson, 1987; Sposito et al., 1981; Mattigod et al., 1981; Emmerich et al., 1982; Bloom, 1981; Lake et al., 1984; Kerndorff and Schitzer, 1980).

This paper is a contribution to better understanding the chemistry of wetlands constructed to treat acid mine drainage. The data reported herein were obtained from greenhouse wetland chambers employing live _Typha_ plants and substrates with variable composition leached at different flow rates with simulated acid mine water. The specific objectives of the study were:

1. To monitor effluent solution composition changes with time as compared to influent solution compositions.

2. To speciate common toxic metals such as Al, Fe, Mn, Cu and Zn in the effluent solution and identify distribution of inorganic and organically-bound metal species.

3. To determine the most effective combinations of substrates and flow rates that produce the lowest inorganic/organic metal species ratios in effluent solutions and the most efficient immobilization of toxic metals.

4. To identify and characterize the metal immobilization forms controlling levels of toxic metals in effluent solutions.

MATERIALS AND METHODS

Twelve simulated wetland plots were established in 50x32x30 cm. polyethylene containers. Six substrate mixtures, each receiving simulated acid mine drainage at two flow rates, were utilized. The substrates were 2:1 volume mixtures of: ground pine needles with surface soil, peat moss with subsoil, peat moss with surface soil, ground hay with surface soil, Sphagnum moss with surface soil and a 1:1:1 volume mixture of peat moss, mine spoil and surface soil. The surface soil was collected from the Ap horizon of a Wolper soil (fine, mixed, mesic Typic Argiudoll) and the subsoil from the Bt horizon of a Maury soil (fine, mixed, mesic Typic Paleudalf). The mine spoil was a mixture of spoil materials collected at strip mine sites in Kentucky. The soils and mine spoil were finely ground. Each treatment had a 10 cm base of crushed limestone covered by 20 cm of the substrate mixture. Five cattail (Typha latifolia) plants of 30-50 cm height were planted in each container.

Thirty-liter tanks were filled with a solution representative of acid mine drainages in Kentucky. The simulated mine water consisted of a mixture of sulfate and chloride compounds which gave concentrations of Ca=200, Mg=200, Fe=70, Al=50, N=35, Cl=28, Mn=20, Na=20, Si=12, K=10, P=8, Zn=5, and Cu=5 mg/l, with the pH adjusted to 2.8 with H_2SO_4. The solution was allowed to saturate the substrates for one week prior to beginning the experiment. Two flow rates, 0.25 l/hr and 0.5 l/hr were established for each matrix and the acid solution was allowed to flow through the substrates for five months.

Drains for the effluent solutions were placed 1 cm above the substrate surface and 5 cm below the surface. Effluent samples were collected weekly from surface and ground flows and influent samples were collected monthly. Samples were refrigerated in polyethylene bottles until analysis. Atomic absorption spectrometry (AAS) was used to measure Ca, Mg, Na, K, Mn, Fe, Zn, and Cu (Page et al., 1982). Subsamples were acidified with HCl prior to measurement of the metal ions by AAS. Aluminum was determined colorimetrically using the Eriochrome Cyanine-R2 method (Jones and Thurman, 1958) and sulfate-S was measured turbidimetrically. Following the initial analysis, selected effluent samples were passed through cation exchange columns to remove inorganic metals (Campbell, et al., 1983). The resin

(Chelex) columns were buffered with 1M $NaHCO_3$ to pH values approximately that of the original sample pH. The resulting solution was analyzed for organically bound metals.

Following completion of the greenhouse experiment the substrates were allowed to dry, then sampled at 0-5 cm and 5-15 cm depths. Substrate samples were sequentially extracted with 0.5 M KNO_3, distilled water, 0.5 M NaOH, 0.1 M Na2EDTA and 4M HNO_3 (Emmerich, et al., 1982b) to determine the forms (exchangeable, sorbed, organic or residual) of metals bound to the substrate. A second extraction with 4M HNO_3 provided total concentrations of bound metals.

RESULTS AND DISCUSSION

Effect of Substrate on Surface Effluent Composition

The flow of simulated acid mine solution over the surface of the experimental wetland plots produced changes in pH, Al, Fe, Cu and Zn, but differences in Mn concentrations were less noticeable. The pH of surface flow effluents increased most noticeably by interaction with the substrates that contained hay or pine needles. The pH of effluents from the hay-surface soil substrate ranged from 6.0 to 8.1 and that of pine needle-surface soil from 4.5 to 8.0. Substrates containing peat moss or Sphagnum moss released surface flow effluents with lower pH values, in the range of 2.8-3.7 (Fig. 1).

Aluminum concentrations showed a direct relationship to pH values. The hay and pine needle mixtures produced surface effluents with the lowest total Al levels, both generally less than 20% of the influent concentrations. The peat moss substrates released 80-100% of the influent Al levels into surface effluents. Aluminum output from the Sphagnum-surface soil substrate fluctuated sharply and varied from 20-100% of the influent concentrations (Fig. 2). The levels of the organically complexed Al in surface effluents were similar for all of the plots, ranging from 10-30% of inflow Al concentrations (Figs. 3 & 4).

Total Fe concentrations in surface flows fluctuated widely, but peat moss and Sphagnum moss mixtures appeared to be slightly more efficient in decreasing total Fe (Fig. 5). The surface effluents contained less than 10% organically complexed Fe except for the hay mixture which varied substantially (Fig. 6 & 7).

The matrix composition had little effect on reducing Mn concentrations. The matrices which contained hay or Sphagnum slightly decreased Mn levels in the effluent, but overall Mn concentrations remained at levels near or in excess of influent concentrations, apparently due to Mn dissolution from the soil matrix. Concentrations of Cu and Zn in surface effluents were low. The pine needle and hay mixtures reduced concentrations of Cu and Zn by 80-90%, while peat moss and Sphagnum reduced Cu and Zn levels to a lesser extent. All matrices showed greater efficiency in reducing Cu concentrations than those of Zn.

Effect of Substrate on Ground Effluent Composition

Percolation of the simulated acid mine solution through the substrates further reduced acidity and metal concentrations for most treatments, apparently due to increased interaction with the substrates. Ground flow and pH values ranged from 5.0-7.0 for all substrates except the peat moss-surface soil-mine spoil (pH = 3.0-3.5) (Fig. 8). Ground flow effluents released lower levels of total Al (<5% of influent concentration) than surface effluents (Fig. 9). Nearly 100% of the Al released was organically complexed except for the mine spoil mixture (Fig. 3). Total Fe levels in ground flows fluctuated erratically from 10-90% of influent Fe levels (Fig. 10). In general, ground flow effluents carried higher concentrations of both total and organically complexed Fe than the corresponding surface effluents (Figs. 5, 6, 7 and 10). Substrates which contained peat moss had less than 20% organic Fe. The concentrations of organic Fe in Sphagnum effluents fluctuated between 2 and 70%. The highest levels of organically complexed Fe were found in the pine needle and hay mixtures (20-100% of inflow concentrations). All substrates released higher levels of total and organically complexed Mn in ground flow than in surface effluents. Percolation through the matrix materials reduced the effluent levels of Cu and Zn to trace levels in five of the six mixtures. The peat moss-surface soil-mine spoil substrate reduced Cu concentrations as had the other matrices, but Zn levels remained near the concentration of the influent solution. The Cu species in the peat moss, hay and sphagnum substrate ground effluents were essentially 100% organically-bound (Fig. 11).

Effect of Flow Rate on Effluent Composition

To determine the influence of influent flow rate upon the metal immobilization process two inflow rates, 0.25 and 0.5 l/hr, were established for each substrate. The flow rates which were used had minimal effects on the composition of effluents. Composition changes which were influenced by the flow rate occurred primarily in the surface flows. Concentrations of Mn, Cu, and Zn and pH were not affected by flow rate, but Al and Fe showed some changes.

Influent rates affected Al concentrations only in the hay-surface soil matrix, but flow rate affected Fe levels in several matrices. Effluent of the 0.5 l/hr hay mixture showed a high initial Al concentration which later dropped to 10-20% of the influent level. The 0.25 l/hr effluent consistently produced lower (5%) and more stable Al concentrations throughout the experiment. Both flow rates produced approximately 50% organically-bound Al. The effect of flow rates on Fe was variable. Only the pine needle mixture showed some flow rate effects on Fe levels in the surface effluent. The 0.5 l/h surface effluent of the pine needle-substrate showed a lower Fe concentration (5-55%) than the 0.25 l/h effluent (10-99% of influent Fe levels). Ground flow effluents did show variation in organic Fe content. Organically complexed Fe levels in the ground flow effluents of substrates with surface soil and either peat moss or Sphagnum increased after week 12 in the 0.25 l/h treatment but remained constant in the 0.5 l/h flow. The ground flow effluents of the peat moss-surface soil-mine spoil substrate showed the opposite effect, but the 0.5 l/h effluent had increased concentrations of organic Fe.

Distribution of Metal Forms in the Substrates

Following completion of the leaching process substrate samples were extracted to determine the forms in which metal species were immobilized. Residual forms (sulfates, sulfides, oxyhydroxides and carbonates) dominated the immobilization process for every metal except Cu, for which organic forms were dominant (Figs. 12, 13, 14, 15 and 16). Organic complexes (Fig. 12) also constituted a substantial portion of the Al forms (17-27%). The surface layers (0-5 cm) of some substrate mixtures revealed differences in metal immobilization as a result of inflow rate, but no effects of flow rate were noted in the 5-15 cm layer.

Before treatment 95% of Al, Fe, Mn, Cu and Zn extracted from the pine needle mixture were in residual forms. Leaching with simulated acid mine water caused changes in the forms of Al, Mn and Cu, but Fe and Zn remained unchanged (Figs. 12, 13, 14, 15 and 16). After treatment organic Al complexes increased to 20% and sorbed Al to 30% of total Al in the extracts (Fig. 12). Treatment with the acid solution caused the conversion of some residual Mn to exchangeable forms (Fig. 14). Surface layers (0-5 cm) contained about 40% exchangeable Mn and the 5-15 cm layer approximately 20% exchangeable Mn. Organic Mn was less than 5%. The organic forms of Cu dominated the pine needle substrate after leaching, comprising 60-70% of the surface layer Fig. 15). At the 5-15 cm depth the 0.25 l/hr substrate had 60% Cu in organic forms, but the 0.5 l/hr substrate had 30% organic Cu. Zinc forms were dominated by oxyhydroxides (80%). However, in the 0-5 cm layer of the slower (0.25 l/hr) rate a larger percentage of Zn occurred in sulfide-sulfate (25%) and organic (8%) forms (Fig. 16).

Prior to leaching the peat moss-subsoil mixture contained 95% of Al, Fe and Mn and 80% of Cu and Zn as residuals. After treatment organic Al was present (16-20%) and sulfate-sulfide Al content had increased from 5% to 30% (Fig. 12). Oxyhydroxide forms of Mn increased to 86%, and exchangeable Mn and organic Mn comprised 10% and 4% of total Mn, respectively (Fig. 14). Organic Cu dominated the post-treatment substrate. Surface layers (0-5 cm) of the peat moss-subsoil substrate contained a higher content of exchangeable, organic and sulfate-sulfide Cu than the 5-15 cm layer (Fig. 15). Leaching produced no change in Fe forms and little in Zn (Figs. 13 and 16). Exchangeable Zn was absent in the surface layer, but the 5-15 cm layer contained 10% exchangeable Zn.

Leaching of the peat moss-surface soil matrix caused changes in the forms of Al, Mn, and Cu. Aluminum content of the untreated matrix was 90% residual (Fig. 12). After treatment sorbed Al had increased to 30%, organic Al to 15-25% and sulfate-sulfide residuals to 25%. Flow rate affected the substrate surface only. The 0.5 l/hr substrate completely lost sorbed Al and gained organic (25%) and sulfide-sulfate (45%) forms of Al. Leaching caused little change in Fe complexes (Fig. 13). Small amounts (2-6%) of organic Fe developed, with the higher amounts (6%) concentrated in the 5-15 cm layer. The only evident change in Mn forms was the development of exchangeable Mn (30%) in surface layers with the remainder of Mn remaining in residual forms (Fig. 14). Copper complexes were dominated by organic (50-80%) and residual forms Fig. 15). Residual forms of Zn were 85-95%, with 5% organic and 10% exchangeable Zn present. The exchangeable Zn was present only in the 5-15 cm layer (Fig. 16).

Treatment with the hay mixture affected sorbed and organic Al, and organic Fe, Mn and Cu (Figs. 12, 13, 14 and 15). Differences at depths were evident in Al forms. The surface layer (0-5 cm) contained 35% organic and 2% sorbed Al while the 5-15 cm depth contained 20% organic and 42% sorbed Al. After treatment Fe was still present in residual forms, but organic complexes had also appeared. Organic Fe was more abundant in the surface layer. Residual forms of Mn decreased with extensive leaching in favor of organic and exchangeable Mn. In the 0-5 cm layer, exchangeable Mn was more abundant in the 0.25 l/hr flow (30%) than in the 0.5 l/hr flow (10%). The slower flow also produced slightly more organic Mn. Treated substrates were dominated by organic forms of Cu. Oxyhydroxide forms of Zn also dominated (80-90%).

The principal changes in Sphagnum-surface soil matrix were increases in amounts of organic Al, exchangeable and residual Mn and organic Cu (Figs. 12, 14 and 15). The treatment altered the forms of Al by decreasing the oxyhydroxide species in favor of sulfate-sulfide and organic forms. The 5-15 cm layer of the 0.5 l/hr substrate showed a considerable amount of sorbed Al (24%) which was absent elsewhere. Iron in the Sphagnum substrate changed very little after treatment, remaining in residual forms (96%). Leaching decreased the sulfate-sulfide and carbonate Mn forms from 65% to 8% in the post treatment matrix. Exchangeable and residual forms of Mn increased but little organic Mn formed. While the pre-treatment Sphagnum matrix contained a mixture of Cu forms, after leaching organic Cu complexes dominated (45-60%). Surface layers (0-5 cm) contained more organic Cu while the 5-15 cm layer had higher percentages of residual forms. Zinc complexes were dominated by oxyhydroxides (80-90%). Small amounts of exchangeable Zn (5-8%) were present only in the 0-5 cm layer.

The matrix mixture which contained mine spoil showed uniformity for every metal complex at both substrate depths. Inflow rates also produced little effect on the metals (Figs. 12,13, 14, 15 and 16). The aluminum species were 30-35% oxyhydroxide, 40-50% sulfide-sulfate and 15-20% organic. The 0.5 l/hr substrate had the highest concentration of organic Al. Iron complexes remained as 90% oxyhydroxide and 10% sulfate-sulfide residuals. Manganese forms were 50% residual oxyhydroxide, 30-40% exchangeable and 10% sorbed. No organic Mn was present. More exchangeable Mn was present in the 0.5 l/hr substrate with correspondingly fewer amounts of residual oxyhydroxide forms. Copper complexes were dominated by organic forms. Only the surface (0-5 cm) layer showed the effects of inflow rate. The 0.5 l/hr matrix contained more organics (60%) and less residual oxyhydroxides (5%). Depth affected the amount of exchangeable Cu. The 0-5 cm layer contained 20-30% exchangeable Cu, but none was present at 5-15 cm. Zinc complexes were 86% oxyhydroxide, 9% exchangeable, 4% sulfate-sulfide, and 1% sorbed, with no organic forms present.

CONCLUSIONS

1. Significant reductions in acidity and total metal concentrations were observed in laboratory simulated wetland systems utilizing 6 different substrate mixtures and cattail plants for a period of 5 months.

2. The pine needle and hay mixtures were the most efficient in reducing acidity and Al concentrations. All substrates were equally effective in reducing Fe and especially Cu and Zn effluent concentrations.

3. The reductions were more dramatic in ground effluents where the maximum amounts of organically bound metal forms were observed.

4. The *Sphagnum* substrate effluents had the highest organic/inorganic soluble Al ratios and the peat substrate effluents the highest organic/inorganic soluble Fe ratios. Soluble Cu and Zn in *Sphagnum*, peat and hay substrate ground effluents were essentially 100% organic.

5. Metal input-output comparisons suggest the pine needle, hay and *Sphagnum* mixtures as the most efficient substrates, retaining as much as 70% Al, 80% Fe and almost 90% of the other metals (except Mn).

6. The dominant metal immobilization forms in the substrates were residual (sulfides, sulfates, carbonates, and oxyhydroxides) except for Cu, which was mostly organic.

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Fig. 13. Exchangeable, sorbed, organic, residual 1 (sulfides, sulfates, carbonates) and residual 2 (oxyhydroxides) forms of Fe extracted from the 0-5 and 5-15 cm depths of the six substrates at the end of the experiment.

Fig. 14. Exchangeable, sorbed, organic, residual 1 (sulfides, sulfates, carbonates) and residual 2 (oxyhydroxides) forms of Mn extracted from the 0-5 and 5-15 cm depths of the six substrates at the end of the experiment.

Fig. 15. Exchangeable, sorbed, organic, residual 1 (sulfides, sulfates, carbonates) and residual 2 (oxyhydroxides) forms of Cu extracted from the 0-5 and 5-15 cm depths of the six substrates at the end of the experiment.

Fig. 16. Exchangeable, sorbed, organic, residual 1 (sulfides, sulfates, carbonates) and residual 2 (oxyhydroxides) forms of Zn extracted from the 0-5 and 5-15 cm depths of the six substrates at the end of the experiment.

FIG. 1

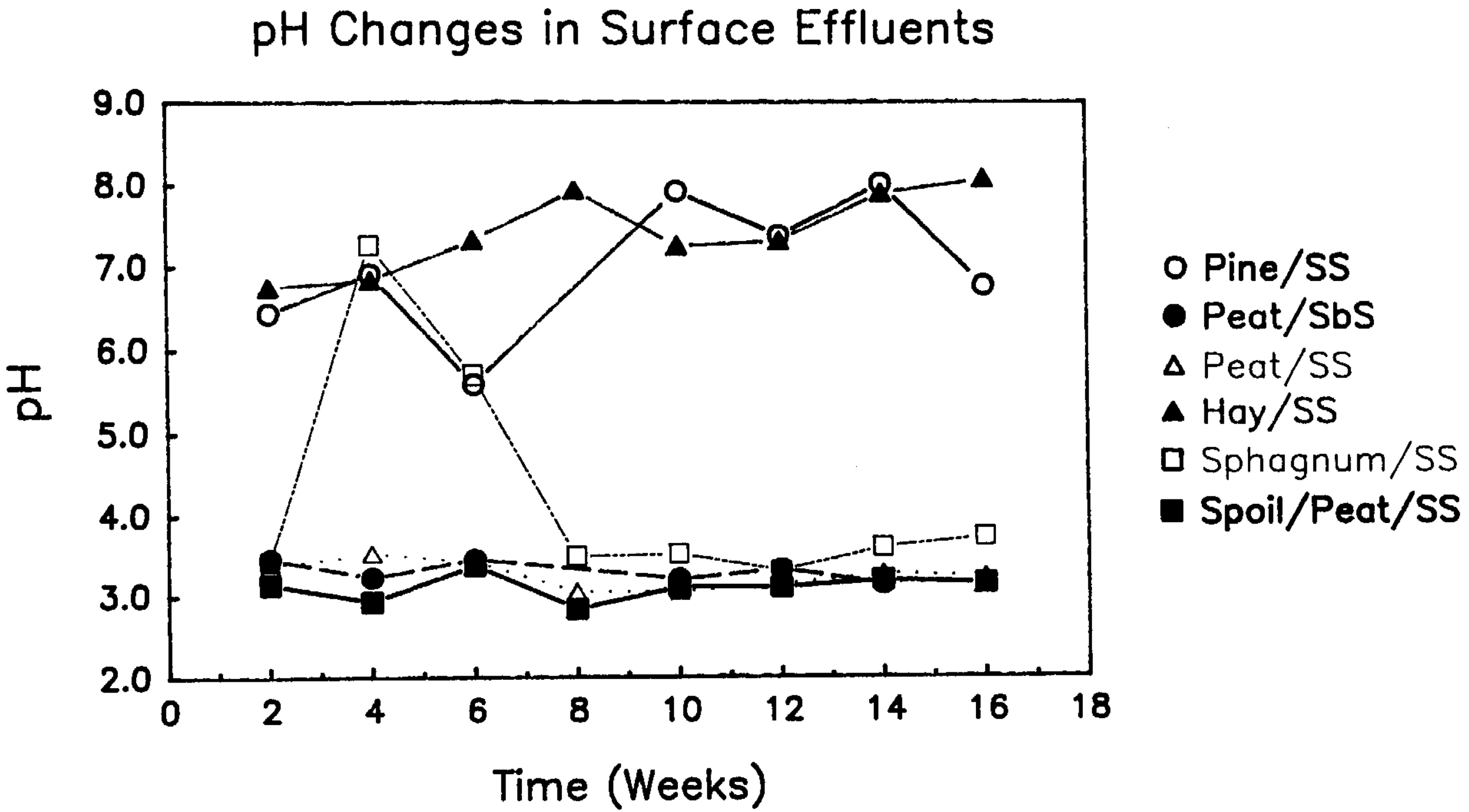
pH Changes in Surface Effluents
pH
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
0
2
4
6
8
10
12
14
16
18
Time (Weeks)
○ Pine/SS
● Peat/SbS
△ Peat/SS
▲ Hay/SS
□ Sphagnum/SS
■ Spoil/Peat/SS

FIG. 2

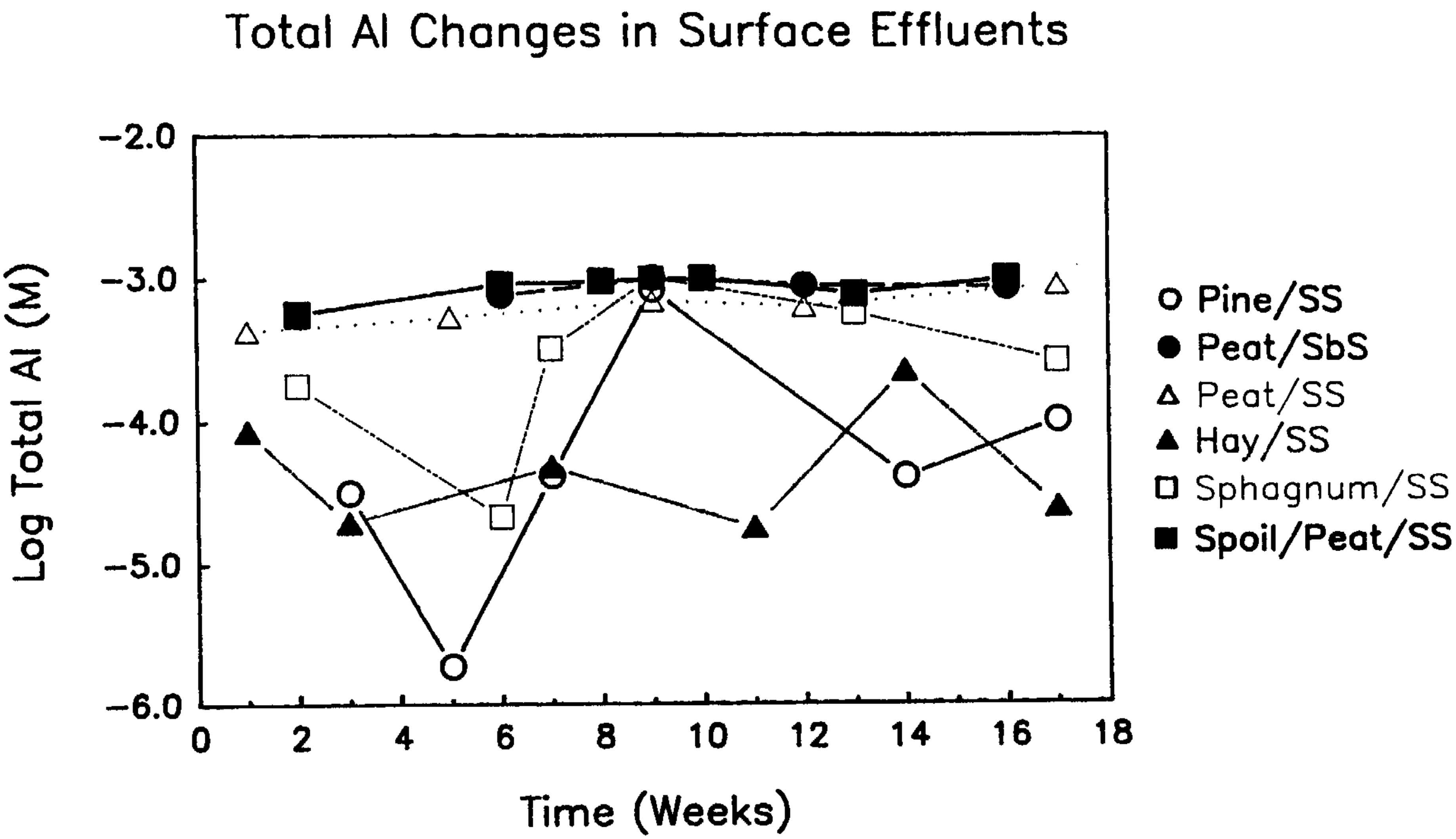
Total Al Changes in Surface Effluents
Log Total Al (M)
−2.0
−3.0
−4.0
−5.0
−6.0
0
2
4
6
8
10
12
14
16
18
Time (Weeks)
○ Pine/SS
● Peat/SbS
△ Peat/SS
▲ Hay/SS
□ Sphagnum/SS
■ Spoil/Peat/SS

FIG. 3

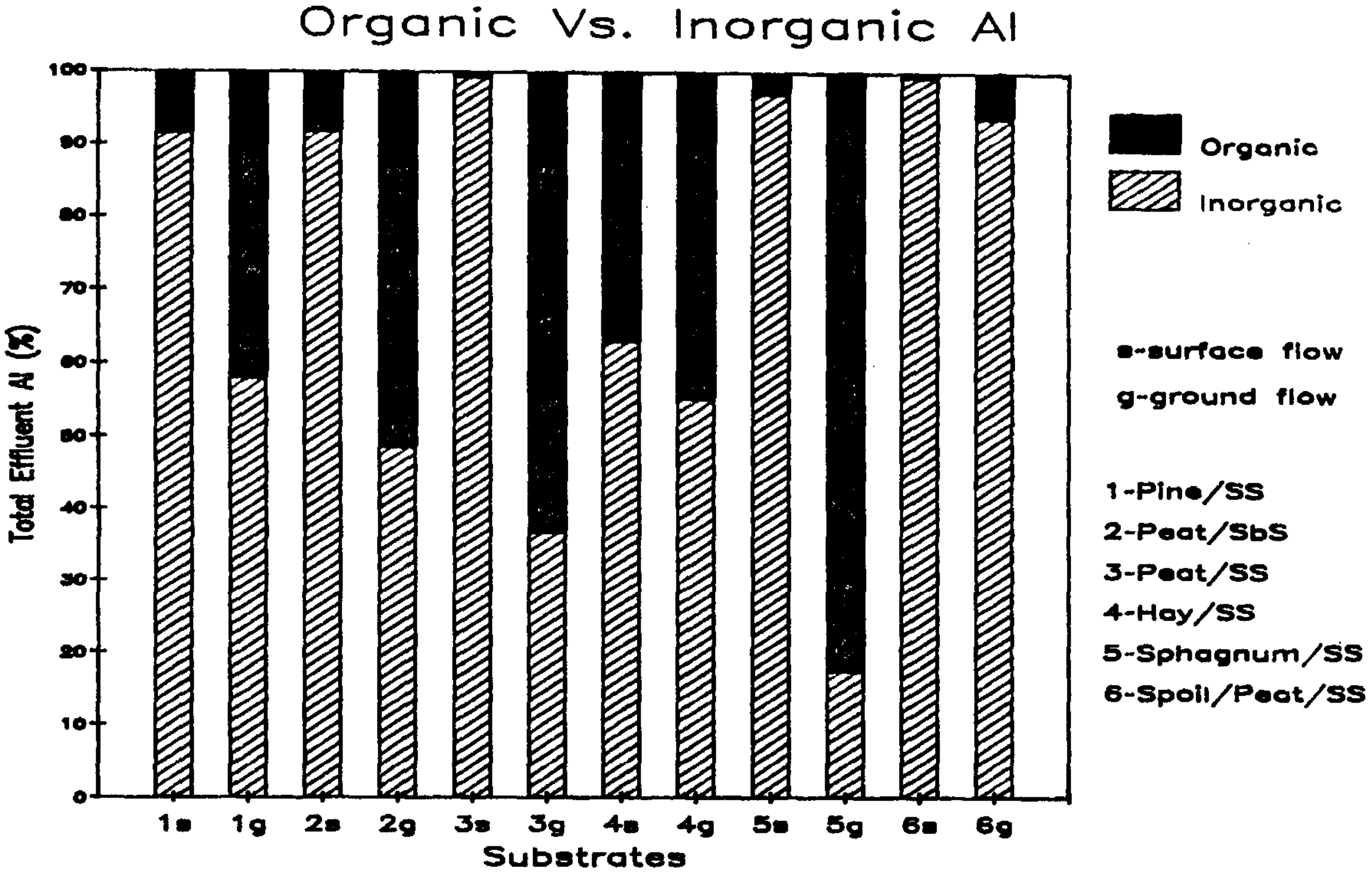
Organic Vs. Inorganic Al
Total Effluent Al (%)
0
10
20
30
40
50
60
70
80
90
100
1s
1g
2s
2g
3s
3g
4s
4g
5s
5g
6s
6g
Substrates
Organic
Inorganic
s-surface flow
g-ground flow
1-Pine/SS
2-Peat/SbS
3-Peat/SS
4-Hay/SS
5-Sphagnum/SS
6-Spoil/Peat/SS

FIG. 4

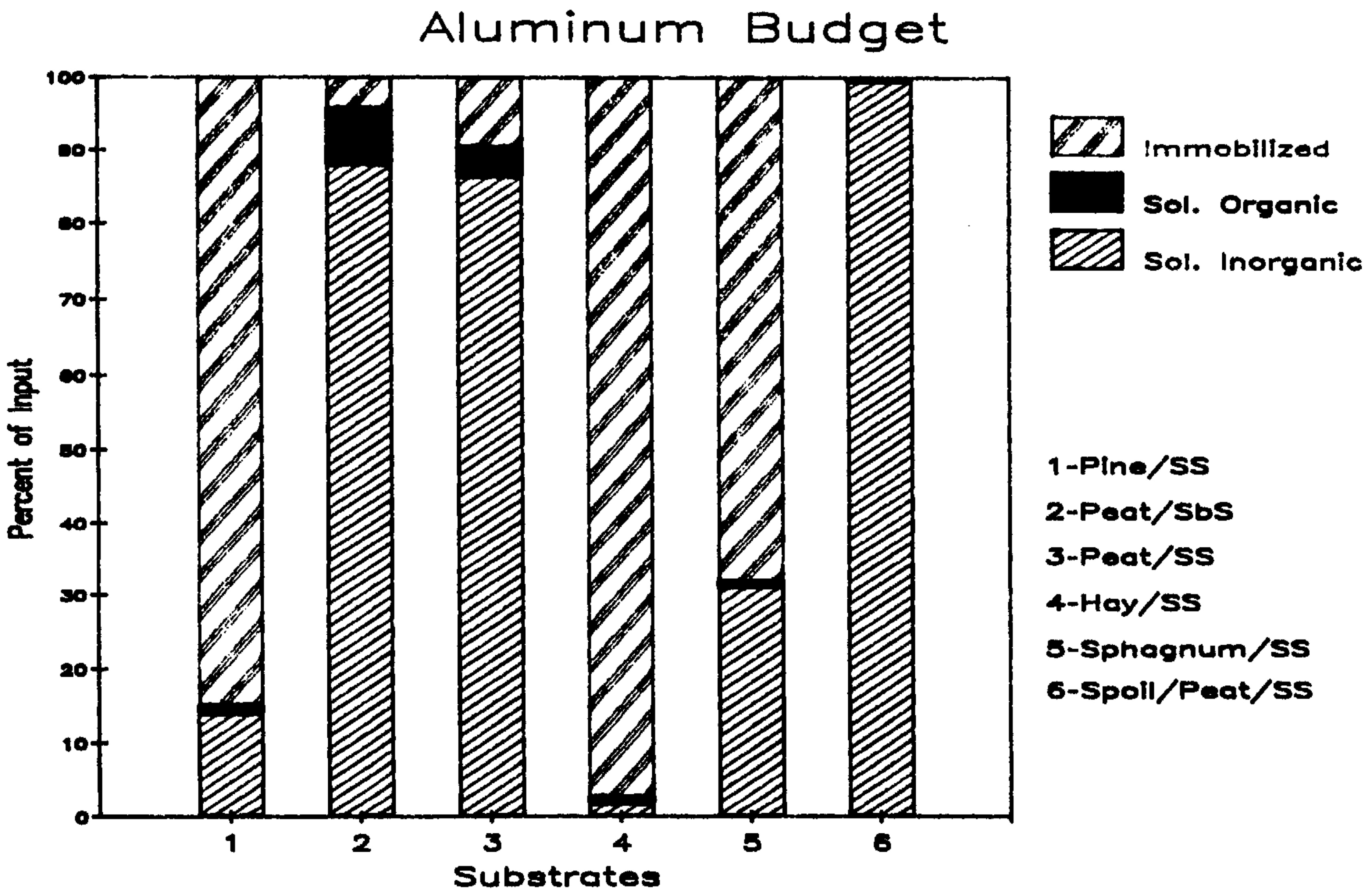
Aluminum Budget
Percent of Input
0
10
20
30
40
50
60
70
80
90
100
1
2
3
4
5
6
Substrates
Immobilized
Sol. Organic
Sol. Inorganic
1-Pine/SS
2-Peat/SbS
3-Peat/SS
4-Hay/SS
5-Sphagnum/SS
6-Spoil/Peat/SS

FIG. 5

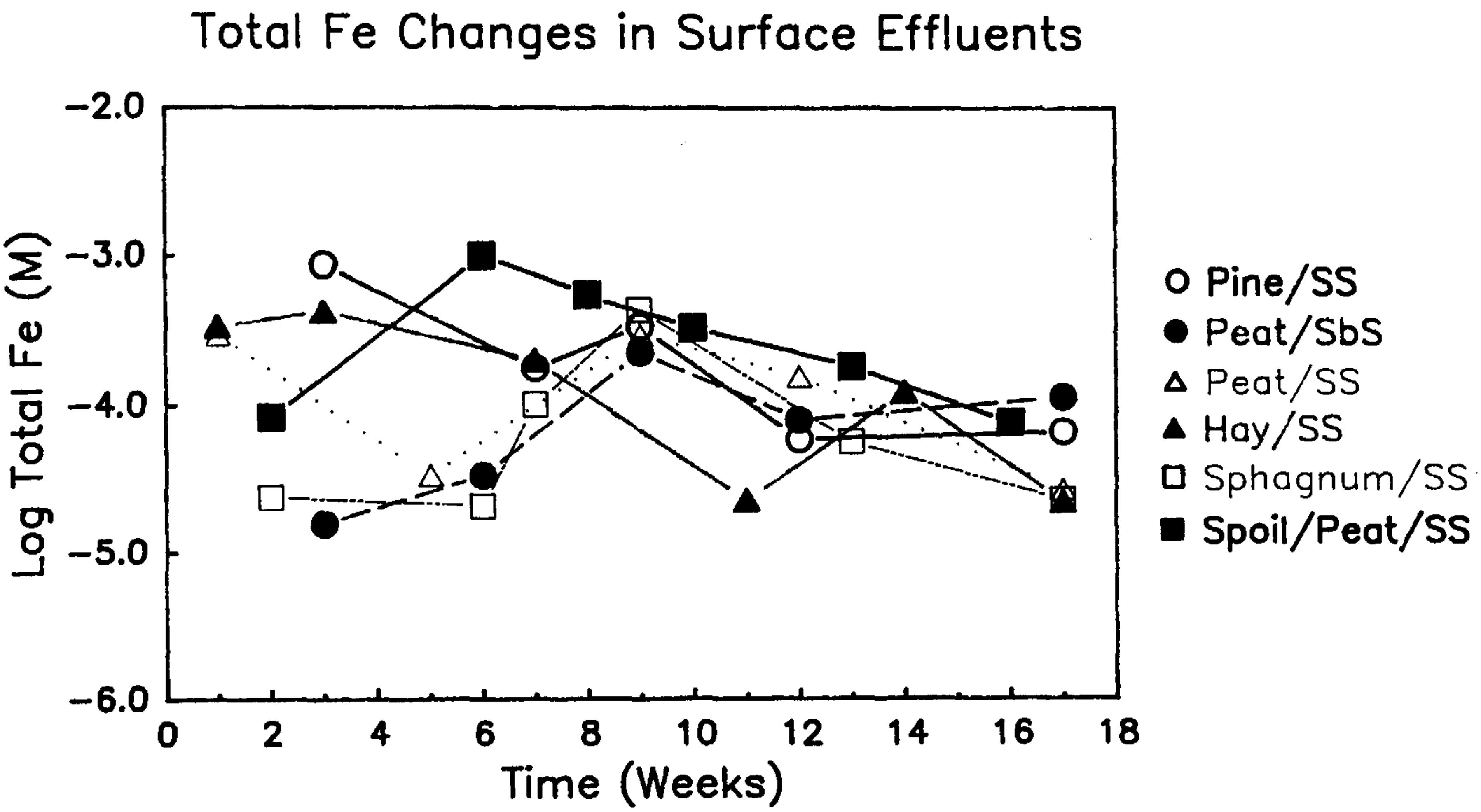
Total Fe Changes in Surface Effluents
Log Total Fe (M)
−2.0
−3.0
−4.0
−5.0
−6.0
0
2
4
6
8
10
12
14
16
18
Time (Weeks)
○ Pine/SS
● Peat/SbS
△ Peat/SS
▲ Hay/SS
□ Sphagnum/SS
■ Spoil/Peat/SS

FIG. 6

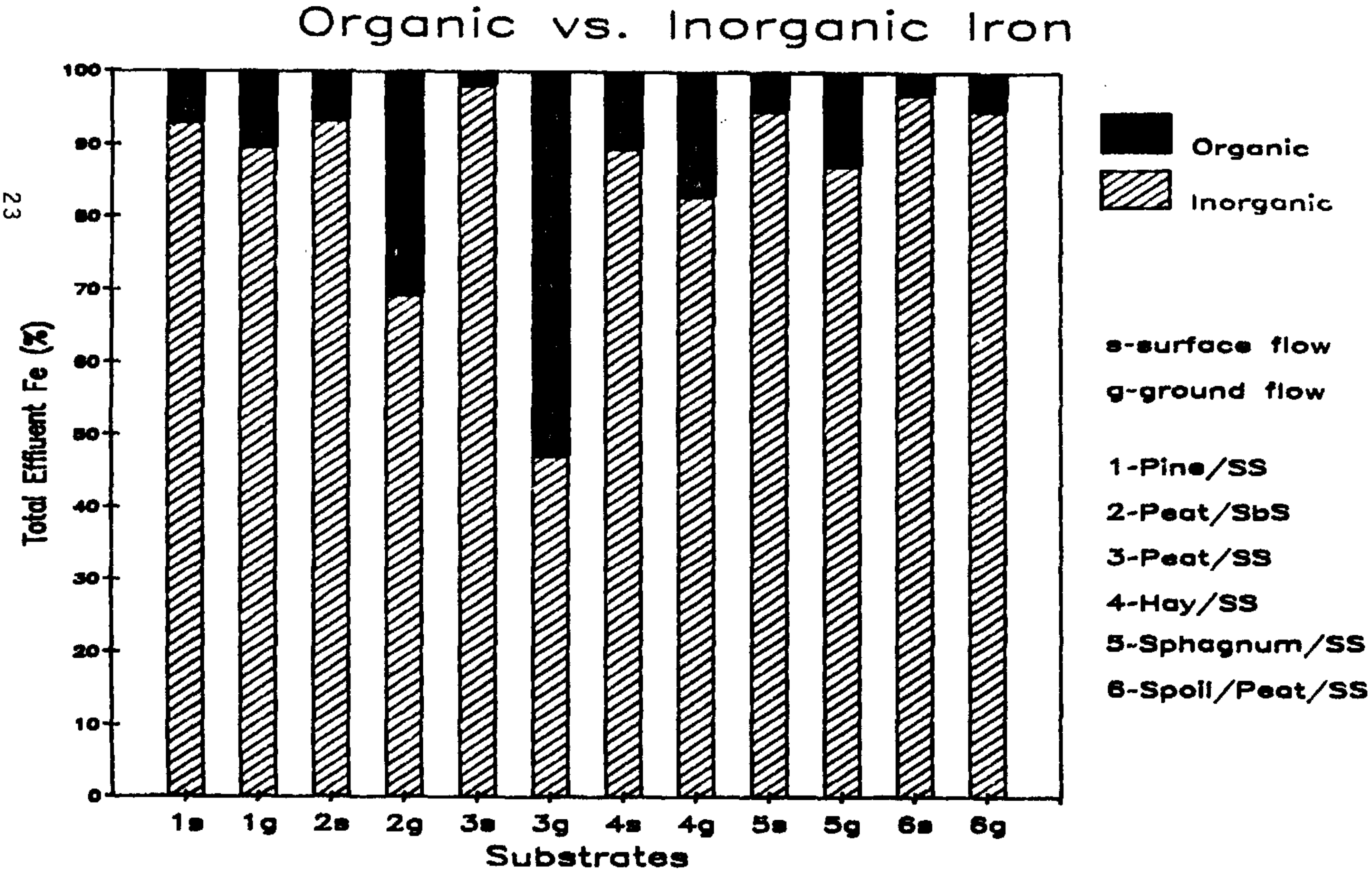
Organic vs. Inorganic Iron
Total Effluent Fe (%)
0
10
20
30
40
50
60
70
80
90
100
1s
1g
2s
2g
3s
3g
4s
4g
5s
5g
6s
6g
Substrates
Organic
Inorganic
s-surface flow
g-ground flow
1-Pine/SS
2-Peat/SbS
3-Peat/SS
4-Hay/SS
5-Sphagnum/SS
6-Spoil/Peat/SS

FIG. 7

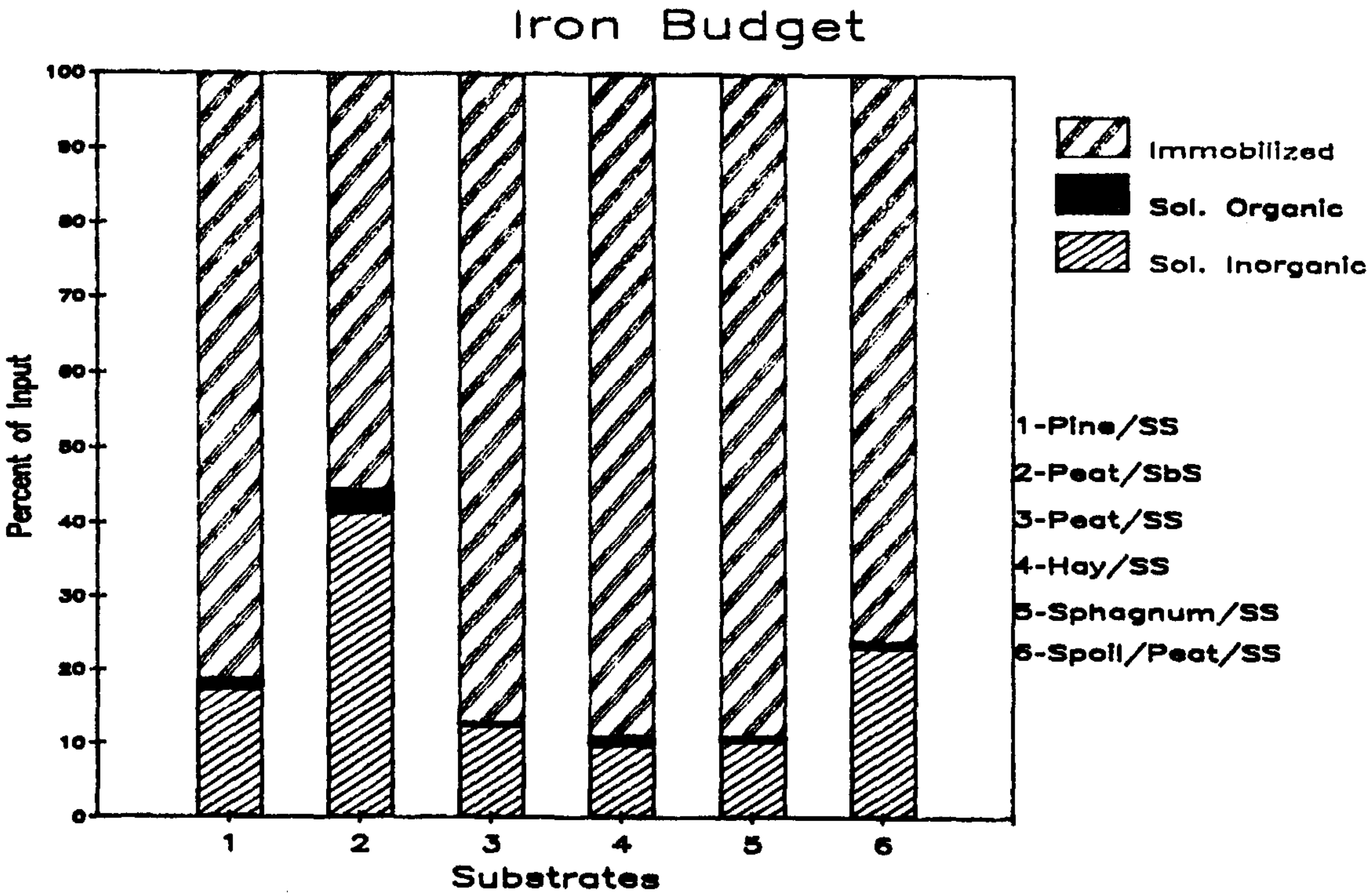
Iron Budget
Percent of Input
0
10
20
30
40
50
60
70
80
90
100
1
2
3
4
5
6
Substrates
Immobilized
Sol. Organic
Sol. Inorganic
1-Pine/SS
2-Peat/SbS
3-Peat/SS
4-Hay/SS
5-Sphagnum/SS
6-Spoil/Peat/SS

FIG. 8

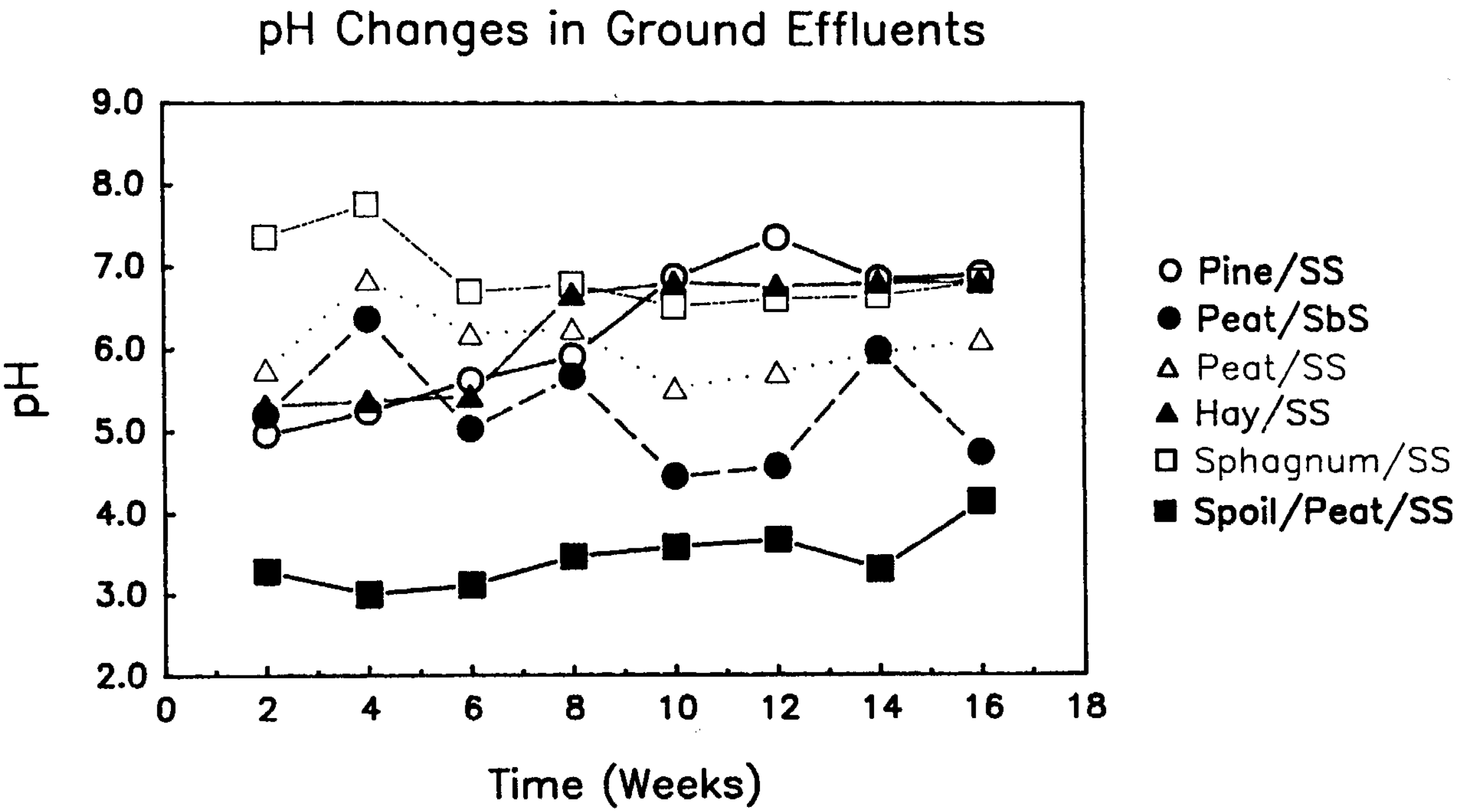
pH Changes in Ground Effluents
pH
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
0
2
4
6
8
10
12
14
16
18
Time (Weeks)
○ Pine/SS
● Peat/SbS
△ Peat/SS
▲ Hay/SS
□ Sphagnum/SS
■ Spoil/Peat/SS

FIG. 9

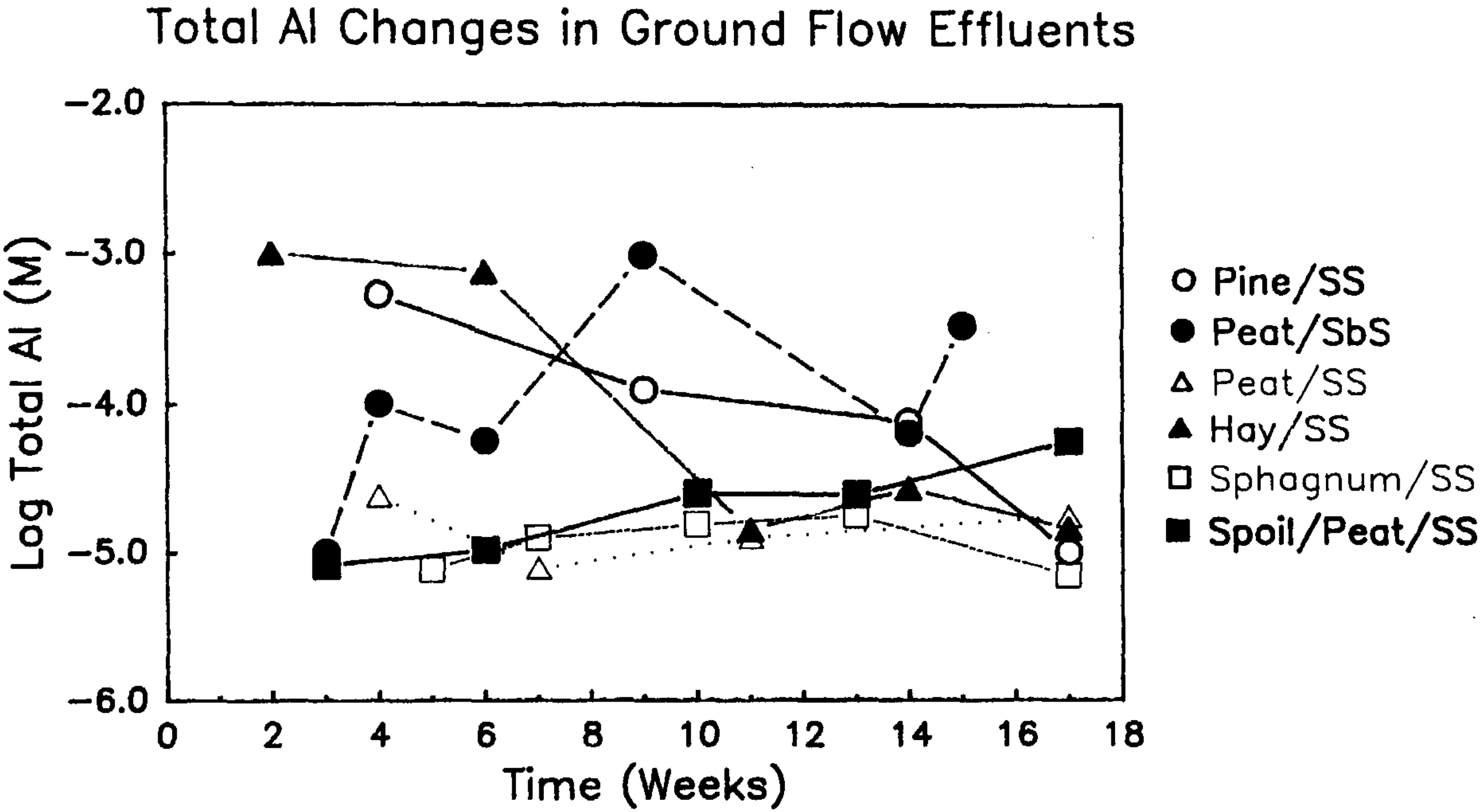
Total Al Changes in Ground Flow Effluents
Log Total Al (M)
−2.0
−3.0
−4.0
−5.0
−6.0
0
2
4
6
8
10
12
14
16
18
Time (Weeks)
○ Pine/SS
● Peat/SbS
△ Peat/SS
▲ Hay/SS
□ Sphagnum/SS
■ Spoil/Peat/SS

FIG. 10

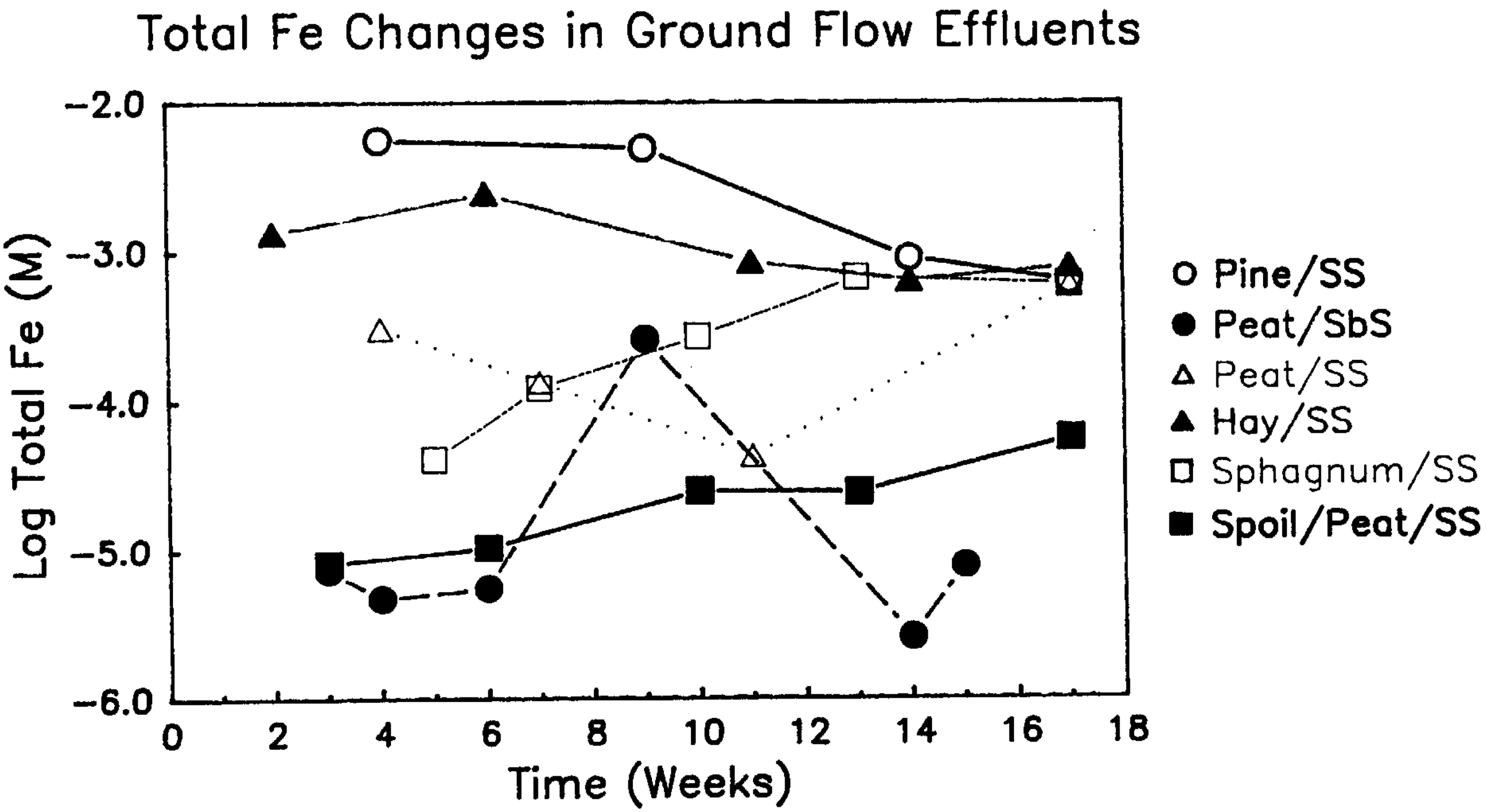
Total Fe Changes in Ground Flow Effluents
Log Total Fe (M)
−2.0
−3.0
−4.0
−5.0
−6.0
0
2
4
6
8
10
12
14
16
18
Time (Weeks)
○ Pine/SS
● Peat/SbS
△ Peat/SS
▲ Hay/SS
□ Sphagnum/SS
■ Spoil/Peat/SS

FIG. 11

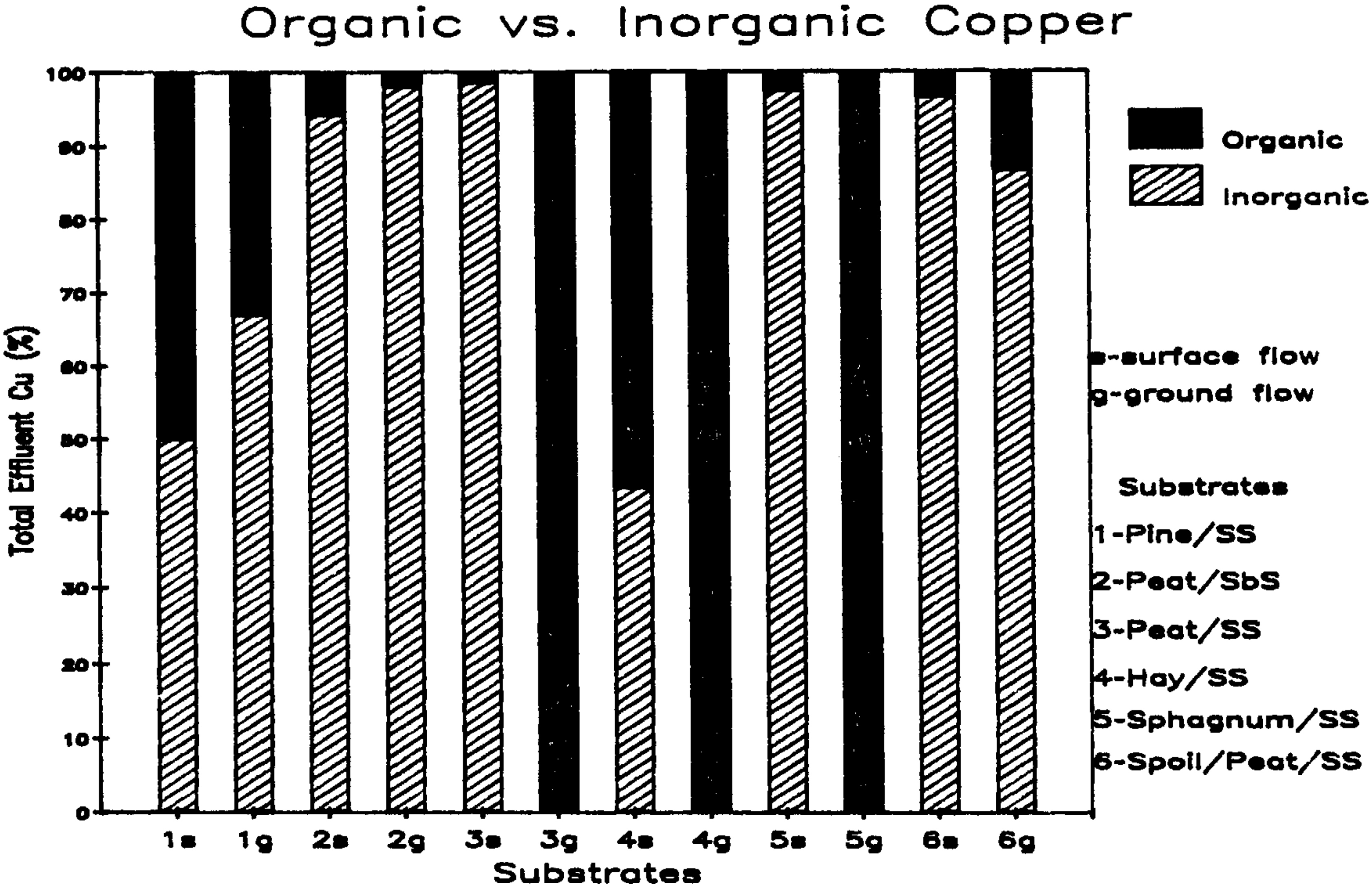
Organic vs. Inorganic Copper
Total Effluent Cu (%)
0
10
20
30
40
50
60
70
80
90
100
1s
1g
2s
2g
3s
3g
4s
4g
5s
5g
6s
6g
Substrates
Organic
Inorganic
s-surface flow
g-ground flow
Substrates
1-Pine/SS
2-Peat/SbS
3-Peat/SS
4-Hay/SS
5-Sphagnum/SS
6-Spoil/Peat/SS

FIG. 12

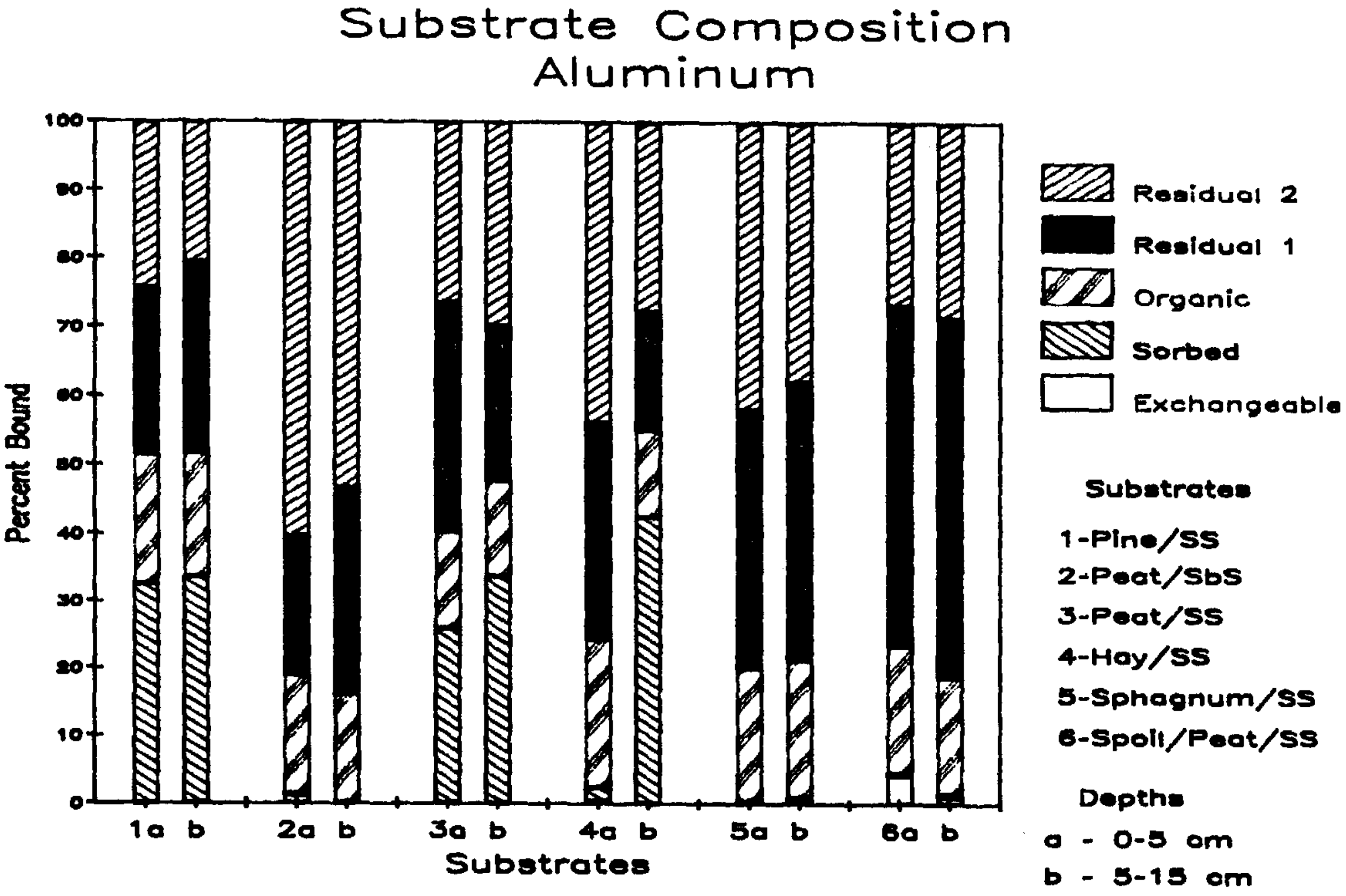
Substrate Composition
Aluminum
Percent Bound
0
10
20
30
40
50
60
70
80
90
100
1a
b
2a
b
3a
b
4a
b
5a
b
6a
b
Substrates
Residual 2
Residual 1
Organic
Sorbed
Exchangeable
Substrates
1-Pine/SS
2-Peat/SbS
3-Peat/SS
4-Hay/SS
5-Sphagnum/SS
6-Spoil/Peat/SS
Depths
a - 0-5 cm
b - 5-15 cm

FIG. 13

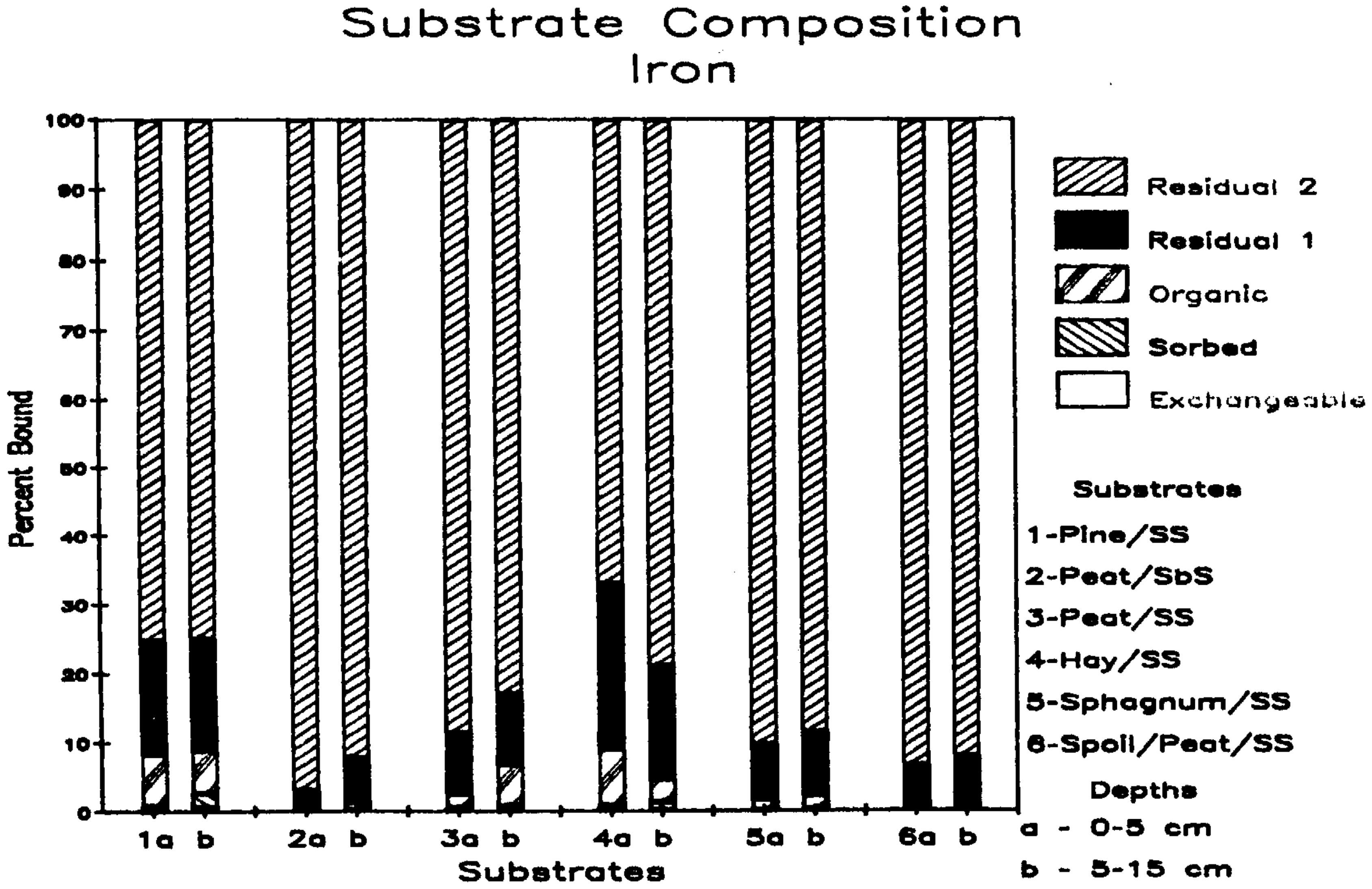
Substrate Composition
Iron
Percent Bound
100
90
80
70
60
50
40
30
20
10
0
1a b
2a b
3a b
4a b
5a b
6a b
Substrates
Residual 2
Residual 1
Organic
Sorbed
Exchangeable
Substrates
1-Pine/SS
2-Peat/SbS
3-Peat/SS
4-Hay/SS
5-Sphagnum/SS
6-Spoil/Peat/SS
Depths
a - 0-5 cm
b - 5-15 cm

FIG. 14

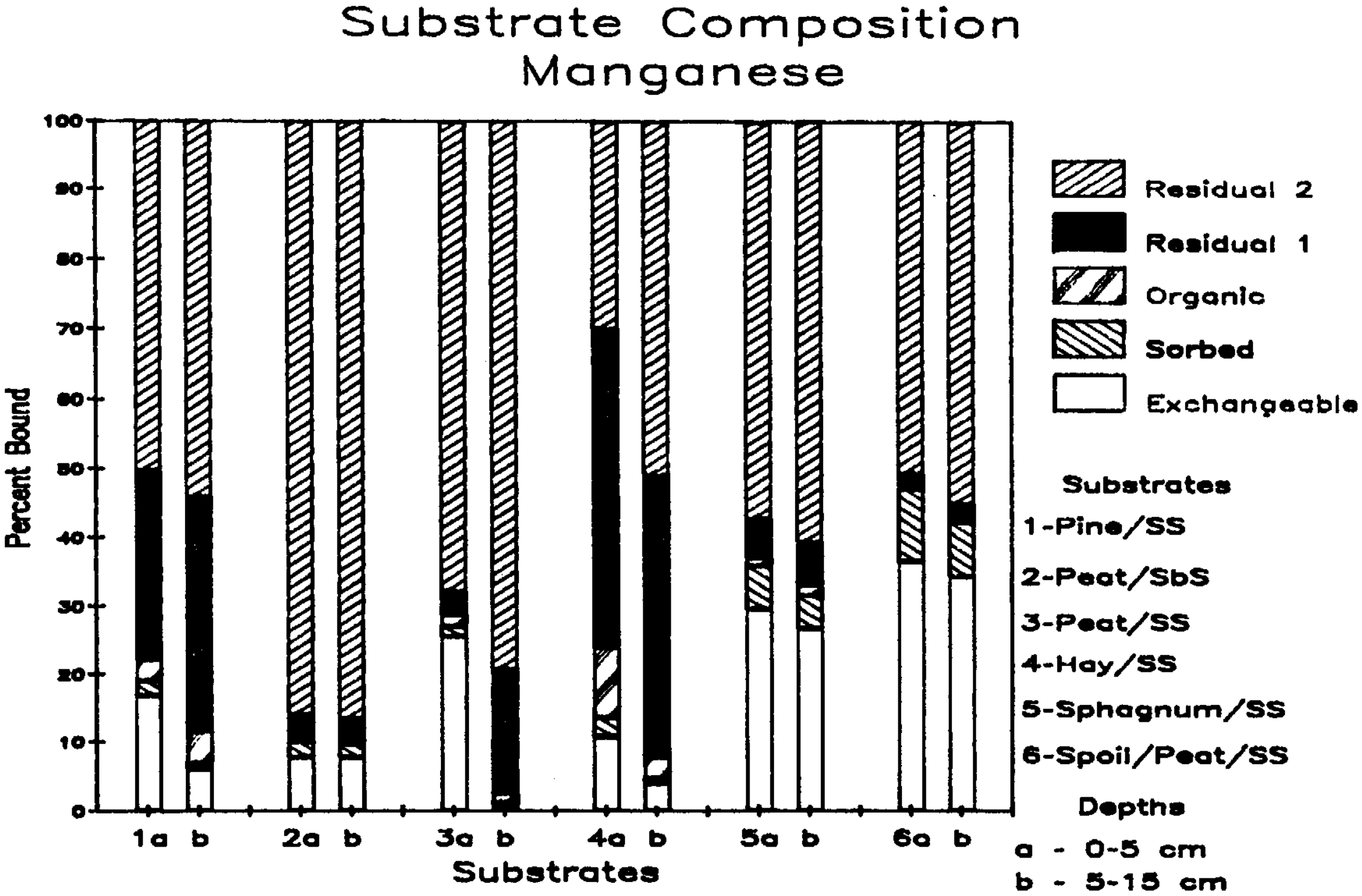
Substrate Composition
Manganese
Percent Bound
100
90
80
70
60
50
40
30
20
10
0
1a
b
2a
b
3a
b
4a
b
5a
b
6a
b
Substrates
▨ Residual 2
■ Residual 1
▨ Organic
▧ Sorbed
☐ Exchangeable
Substrates
1-Pine/SS
2-Peat/SbS
3-Peat/SS
4-Hay/SS
5-Sphagnum/SS
6-Spoil/Peat/SS
Depths
a - 0-5 cm
b - 5-15 cm

FIG. 15

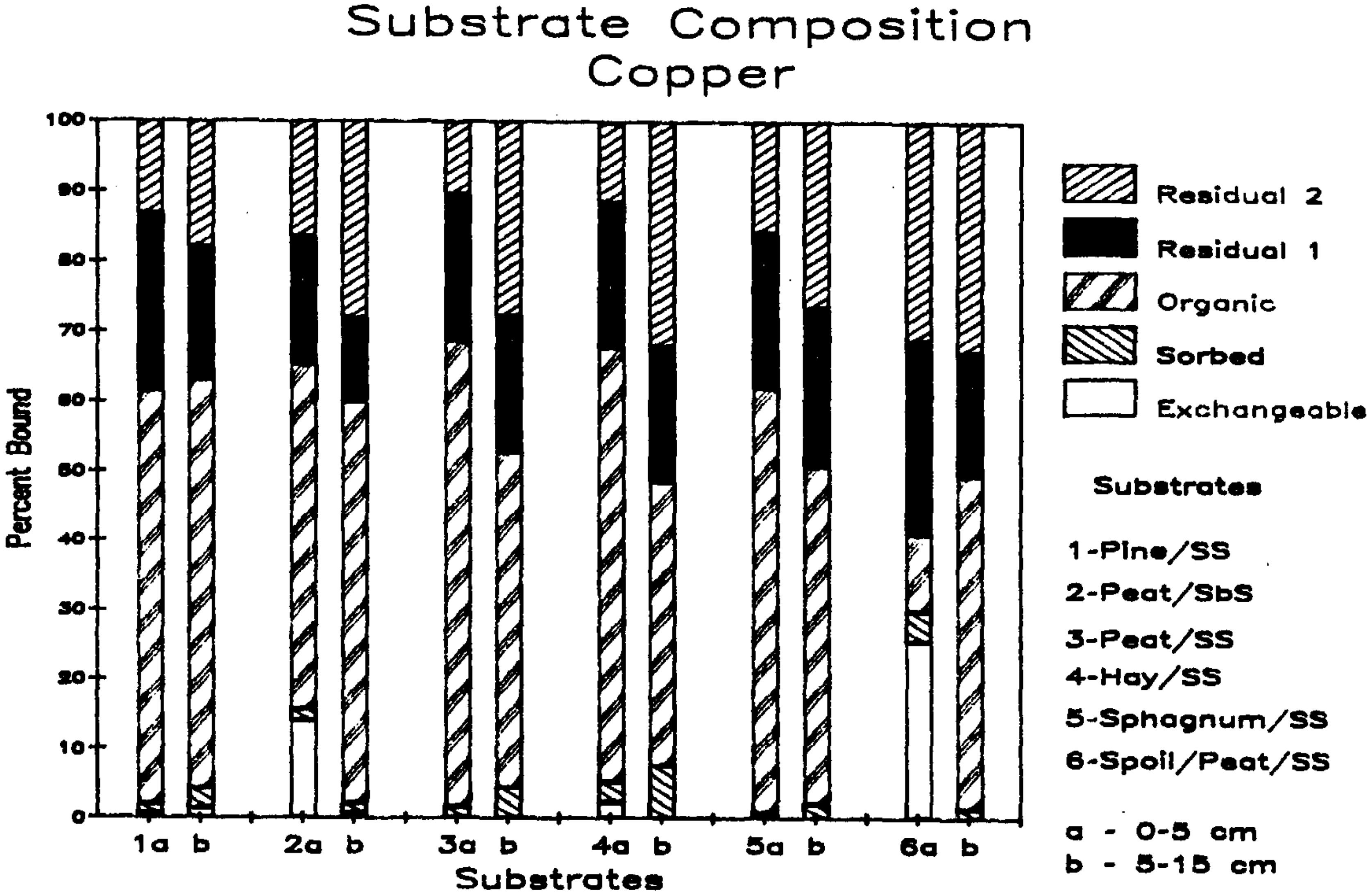
Substrate Composition
Copper
Percent Bound
100
90
80
70
60
50
40
30
20
10
0
1a b
2a b
3a b
4a b
5a b
6a b
Substrates
Residual 2
Residual 1
Organic
Sorbed
Exchangeable
Substrates
1-Pine/SS
2-Peat/SbS
3-Peat/SS
4-Hay/SS
5-Sphagnum/SS
6-Spoil/Peat/SS
a - 0-5 cm
b - 5-15 cm

FIG. 16

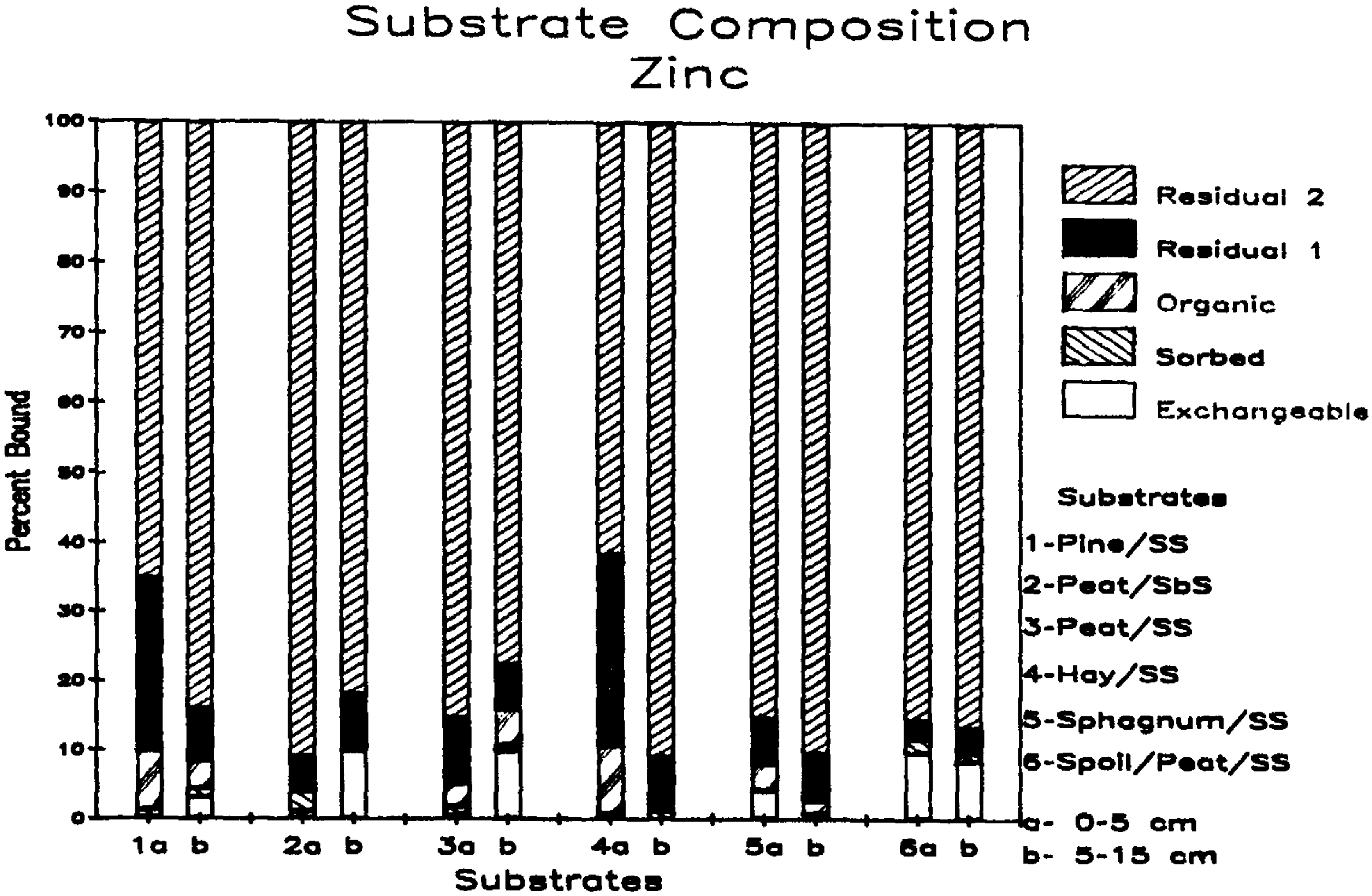
Substrate Composition
Zinc
Percent Bound
100
90
80
70
60
50
40
30
20
10
0
1a
b
2a
b
3a
b
4a
b
5a
b
6a
b
Substrates
Residual 2
Residual 1
Organic
Sorbed
Exchangeable
Substrates
1-Pine/SS
2-Peat/SbS
3-Peat/SS
4-Hay/SS
5-Sphagnum/SS
6-Spoil/Peat/SS
a- 0-5 cm
b- 5-15 cm

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Table 18. Ground Flow Effluent Composition of *Sphagnum* and Surface Soil Substrate at 0.25 Liter/Hour Flow Rate.

Table 19. Surface Flow Effluent Composition of *Sphagnum* and Surface Soil Substrate at 0.5 Liter/Hour Flow Rate.

Table 20. Ground Flow Effluent Composition of *Sphagnum* and Surface Soil Substrate at 0.5 Liter/Hour Flow Rate.

Table 21. Surface Flow Effluent Composition of Peat Moss, Mine Spoil and Surface Soil Substrate at 0.25 Liter/Hour Flow Rate.

Table 22. Ground Flow Effluent Composition of Peat Moss, Mine Spoil and Surface Soil Substrate at 0.25 Liter/Hour Flow Rate.

Table 23. Surface Flow Effluent Composition of Peat Moss, Mine Spoil and Surface Soil at 0.5 Liter/Hour Flow Rate.

Table 24. Ground Flow Effluent Composition of Peat Moss, Mine Spoil and Surface Soil at 0.5 Liter/Hour Flow Rate.

Table 25. Organically Bound Metals in Effluents of 0.25 Liter/Hour Surface Flow

Table 26. Organically Bound Metals in Effluents of 0.25 Liter/Hour Ground Flow

Table 27. Organically Bound Metals in Effluents of 0.5 Liter/Hour Surface Flow

Table 28. Organically Bound Metals in Effluents of 0.5 Liter/Hour Ground Flow

Table 29. Means and Standard Deviations of Influent Concentrations

Table 30. Exchangeable Cation Concentrations in Substrates Treated at 0.25 Liter/Hour Flow Rate.

Table 31. Exchangeable Cation Concentrations in Substrates Treated at 0.5 Liter/Hour Flow Rate.

Table 32. Sorbed Cation Concentrations in Substrates Treated at 0.25 Liter/Hour Flow Rate.

Table 33. Sorbed Cation Concentrations in Substrates Treated at 0.5 Liter/Hour Flow Rate.

Table 34. Organic Cation Concentrations in Substrates Treated at 0.25 Liter/Hour Flow Rate.

Table 1. Surface Flow Effluent Composition of Pine Needle and Surface Soil Substrate at 0.25 Liter/Hour Flow Rate.

Sampling Week	pH	Al	Ca	Mg	Na	K	Fe	Mn	Cu	Zn	SO_4
		m Moles									
1	6.81	.021	28.50	6.98	1.06	0.67	0.030	0.33	0.0011	0.011	20.68
2	6.43	.016	10.25	15.97	0.93	0.65	0.21	0.62	0.0009	0.0023	28.89
3	6.65	.029	56.0	20.17	3.39	3.10	0.93	3.55	0.0003	0.0010	31.51
4	6.91	.012	8.19	6.56	0.80	0.57	0.36	0.40	0.0007	0.001	8.41
5	7.02	.018	10.375	7.33	0.95	0.67	0.29	0.54	0.0020	0.005	3.83
7	5.59	.034	4.26	1.58	0.59	0.33	0.17	0.19	0.0006	0.012	8.04
9	3.90	.787	2.75	3.15	0.60	0.26	0.31	0.16	0.0296	0.033	9.49
10	7.92	.011	3.00	4.67	0.99	0.45	0.020	0.014	0.0028	0.0004	7.34
11	7.47	.017	4.58	4.37	0.62	0.32	0.007	0.080	0.0009	0.0004	8.27
12	7.37	.139	2.55	4.06	0.57	0.27	0.056	0.16	0.0046	0.009	7.81
13	7.38	.122	3.05	6.75	0.56	0.27	0.055	0.17	0.0038	0.0076	7.87
14	8.01	.041	2.54	4.54	0.92	0.43	0.025	0.011	0.0026	0.0041	6.61
15	7.27	.356	2.76	3.71	0.58	0.26	0.114	0.12	0.0115	0.0144	6.72
16	6.76	.054	2.52	5.58	0.52	0.25	0.003	0.12	0.0009	0.005	7.17
17	8.15	.103	3.02	3.96	0.73	0.33	0.065	0.072	0.0034	0.0038	5.60

Table 2. Ground Flow Effluent Composition of Pine Needle and Surface Soil at 0.25 Liter/Hour Flow Rate.

Sampling Week	pH	Al	Ca	Mg	Na	K	Fe	Mn	Cu	Zn	SO_4
		m Moles									
2	4.96	0.21	39.60	6.13	1.70	2.43	2.14	2.51	0.0023	0.0050	16.76
3	5.26	0.19	32.5	9.54	1.61	4.17	3.72	2.76	0.0011	0.0056	15.39
4	5.24	0.52	51.75	10.62	2.00	5.17	5.71	3.79	0.0014	0.0049	30.36
5	5.44	0.63	74.19	10.02	1.20	3.0	7.76	3.10	0.0007	0.0032	19.52
6	5.62	0.11	41.75	7.05	1.22	3.91	8.69	3.09	0.0003	0.0010	14.57
7	5.86	0.41	51.8	5.90	0.88	2.96	6.87	2.80	0.0015	0.0015	11.76
8	5.91	0.06	74.96	5.36	1.00	2.30	7.18	2.73	0.0025	0.0009	4.57
9	5.94	0.11	47.0	8.17	0.31	0.59	5.20	2.29	0.0006	0.0006	4.72
10	6.87	0.02	20.12	6.15	1.04	1.46	1.31	0.87	0.0007	0.0007	4.00
11	7.27	0.04	15.42	6.81	1.14	1.37	0.25	0.01	0.0003	0.0003	2.94
12	7.35	0.02	4.25	4.33	1.14	1.30	0.49	0.05	0.0004	0.0007	4.27
13	7.42	0.04	4.70	4.29	1.13	1.42	0.65	0.10	0.0007	0.0012	4.30
14	6.85	0.06	10.0	5.17	1.16	1.50	0.88	0.33	0.0006	0.0026	1.76
15	7.73	0.01	3.31	3.96	1.10	1.37	---	---	---	---	1.35
16	6.91	0.02	5.13	4.02	1.13	1.38	0.32	0.02	0.0006	0.0007	1.52
17	7.14	0.02	5.69	4.54	1.06	1.16	0.58	0.21	0.0003	0.0003	1.69

Table 3. Surface Flow Effluent Composition of Pine Needle and Surface Soil Substrate at 0.5 Liter/Hour Flow Rate.

Sampling Week	pH	Al	Ca	Mg	Na	K	Fe	Mn	Cu	Zn	SO_4
					m Moles						
1	4.70	0.63	5.22	7.79	0.95	0.45	0.41	0.35	0.017	0.042	26.26
2	4.62	0.22	5.92	11.06	0.84	0.50	0.009	0.38	0.015	0.038	24.95
3	4.35	0.47	5.25	9.54	0.70	0.38	0.018	0.34	0.029	0.065	22.65
4	7.01	0.016	22.62	10.60	1.23	0.85	0.73	0.41	0.002	0.0010	5.15
5	7.07	0.008	5.28	7.08	0.53	0.25	0.04	0.21	0.0004	0.0012	5.94
6	7.50	0.01	4.90	7.50	0.46	0.33	0.02	0.15	0	0.0007	3.50
7	4.48	0.26	4.23	1.87	0.46	0.21	0.18	0.18	0.012	0.023	8.66
8	7.21	0.011	6.35	4.37	0.70	0.30	0.16	0.24	0.0014	0.0044	4.45
9	6.72	0.038	3.35	2.73	0.46	0.22	0.08	0.21	0.0007	0.0084	7.82
10	6.77	0.033	6.75	4.37	0.54	0.18	0.09	0.37	0.0033	0.009	12.27
11	7.12	0.017	7.67	3.48	0.49	0.24	0.009	0.24	0.0003	0.0012	5.52
12	7.13	0.08	5.40	6.62	0.65	0.33	0.16	0.22	0.0025	0.0035	3.53
13	6.91	0.012	3.95	4.35	0.52	0.26	0.01	0.22	0.0009	0.0058	7.79
14	6.84	1.37	2.87	5.25	0.43	0.20	0.33	0.19	0.031	0.049	7.62
15	6.83	0.42	3.99	5.02	0.49	0.28	0.14	0.22	0.016	0.023	9.56
16	4.97	0.06	3.49	3.87	0.47	0.24	0.002	0.19	0.018	0.027	10.66
17	3.98	0.67	3.32	5.27	0.47	0.23	0.067	0.18	0.02	0.027	10.88

Table 4. Ground Flow Effluent Composition of pine Needle and Surface Soil Substrate at 0.5 Liter/Hour Flow Rate.

Sampling Week	pH	Al	Ca	Mg	Na	K	Fe	Mn	Cu	Zn	SO_4
						m Moles					
2	5.50	0.75	51.40	8.33	1.43	2.41	3.78	2.71	0.0003	0.0009	9.03
3	5.71	0.20	48.94	10.31	1.23	1.67	6.18	2.89	0.0003	0.0006	4.06
4	5.55	0.16	32.34	11.80	1.20	1.56	6.95	2.81	0.0003	0.0007	4.23
5	6.15	0.12	51.38	10.53	1.19	--	6.64	2.73	0.0003	0.0007	3.98
6	6.35	0.098	35.50	8.42	1.00	2.13	3.58	2.25	0.0003	0.0003	3.73
7	6.79	0.03	34.06	8.17	1.08	1.40	1.84	0.73	0.0001	0.0003	3.90
8	6.80	0.03	32.25	8.50	1.08	1.34	2.69	1.27	0.0007	0.0009	4.06
9	6.86	0.04	26.00	6.75	0.93	1.18	1.05	0.36	0.0003	0.0004	4.00
10	6.94	0.024	16.00	5.12	0.79	0.90	0.76	0.47	0.0004	0.0009	3.44
11	6.86	0.016	19.27	7.52	0.85	0.94	0.71	0.10	0.0003	0.0003	3.02
12	6.85	0.021	7.85	5.46	0.88	0.97	0.92	0.38	0.0003	0.0003	3.00
13	6.90	0.019	9.40	5.31	0.86	0.95	1.02	0.45	0.0003	0.0003	2.89
14	6.93	0.021	9.83	7.79	0.86	0.96	0.90	0.28	0.0003	0.0018	1.06
15	7.22	0.018	7.39	5.58	0.77	0.91	0.68	0.20	0.0004	0.0003	1.25
16	6.97	0.014	8.64	6.31	0.78	0.91	0.60	0.11	0.0003	0.0009	1.21
17	6.87	0	5.99	3.27	0.66	0.69	0.39	0.31	0.0003	0.0003	1.59

Table 5. Surface Flow Effluent Composition of Peat Moss and Subsoil Substrate at 0.25 Liter/Hour Flow Rate.

Sampling Week	pH	Al	Ca	Mg	Na	K	Fe	Mn	Cu	Zn	SO_4
		m Moles									
1	3.99	0.14	2.92	3.87	1.15	0.58	0.23	0.21	0.017	0.036	12.59
2	3.45	0.57	3.97	9.37	0.91	0.50	0.018	0.27	0.027	0.042	19.89
3	3.41	0.87	4.87	10.33	1.13	0.69	0.016	0.32	0.033	0.042	17.88
4	3.22	2.00	4.76	6.87	--	0.21	0.027	0.33	0.047	0.067	19.21
6	3.45	0.76	1.55	4.21	0.45	0.25	0.031	0.16	0.025	0.036	9.03
7	2.76	1.14	3.22	1.82	0.35	0.16	0.32	0.11	0.034	0.032	8.04
9	2.82	0.99	1.60	1.96	0.30	0.16	0.26	0.11	0.035	0.032	8.14
10	3.20	0.92	1.87	3.94	0.33	0.33	0.18	0.15	0.027	0.034	9.33
11	3.21	0.95	3.40	3.19	0.35	0.31	0.057	0.15	0.026	0.034	9.16
12	3.32	0.90	1.78	2.85	0.36	0.37	0.088	0.15	0.026	0.034	9.10
13	3.20	0.91	2.10	3.69	0.35	0.24	0.25	0.12	0.029	0.036	8.95
14	3.13	0.82	2.06	3.12	0.33	0.25	0.12	0.13	0.027	0.051	8.46
15	3.15	0.80	1.78	3.94	0.32	0.27	0.11	0.08	0.028	0.039	8.56

Table 6. Ground Flow Effluent Composition of Peat Moss and Subsoil Substrate at 0.25 Liter/Hour Flow Rate.

Sampling Week	pH	Al	Ca	Mg	Na	K	Fe	Mn	Cu	Zn	SO_4
		m Moles									
2	5.20	0.009	5.60	1.81	1.61	0.99	0.003	0.17	0	0.0012	11.73
3	5.41	0.009	6.80	2.25	1.13	0.90	0.007	0.22	0	0.0006	14.01
4	6.36	0.011	9.65	2.62	1.43	0.71	0.005	0.26	0	0.0015	16.64
5	5.65	0.087	9.81	4.42	1.26	0.40	0.012	0.38	0.0011	0.0083	20.91
6	5.03	0.066	8.37	7.19	1.22	0.26	0.005	0.41	0.0058	0.012	23.67
7	5.50	0.021	18.87	5.77	1.43	0.22	0.012	0.66	0.0003	0.0049	33.06
8	5.67	0.015	15.54	9.06	2.21	0.22	0.008	0.72	0.0001	0.0040	41.19
9	3.48	0.98	6.85	9.94	1.20	0.36	0.27	0.33	0.029	0.039	19.20
10	4.45	0.45	6.15	6.71	1.17	0.43	0.077	0.36	0.012	0.027	16.81
11	4.49	0.24	9.24	6.00	1.64	0.36	0.025	0.38	0.011	0.025	9.97
12	4.57	0.37	7.40	8.71	2.13	0.41	0.033	0.50	0.0088	0.023	19.20
13	4.57	0.31	7.90	10.13	2.18	0.39	0.026	0.51	0.0074	0.023	20.39
14	5.99	0.06	11.52	13.67	3.50	0.30	0.003	0.51	0.0006	0.0086	33.14
15	4.58	0.34	7.57	11.65	2.02	0.44	0.007	0.35	0.0082	0.024	26.31
16	4.74	0.08	9.31	12.57	2.80	0.40	--	--	--	--	24.19

Table 7. Surface Flow Effluent Composition of Peat Moss and Subsoil Substrate at 0.5 Liter/Hour Flow Rate.

Sampling Week	pH	Al	Ca	Mg	Na	K	Fe	Mn	Cu	Zn	SO_4
		m Moles									
1	3.39	0.86	2.80	3.85	1.04	0.51	0.083	0.24	0.028	0.040	13.97
2	3.34	1.03	3.77	8.81	0.86	0.47	0.024	0.26	0.032	0.042	15.68
3	3.09	1.84	3.92	8.46	0.84	0.51	0.048	0.28	0.046	0.063	16.80
4	2.91	1.44	4.76	8.81	0.90	0.42	0.094	0.28	0.054	0.065	18.40
5	5.65	0.60	3.43	3.23	0.45	0.26	0.075	0.17	0.022	0.034	9.38
6	5.03	0.12	1.80	4.19	0.54	0.31	0.016	0.23	0.019	0.036	9.14
7	3.01	1.06	3.00	1.67	0.31	0.25	0.18	0.14	0.033	0.032	7.86
8	3.05	1.08	3.30	3.20	0.40	0.30	0.28	0.18	0.037	0.035	8.50
9	2.80	0.93	1.70	2.12	0.33	0.17	0.27	0.12	0.038	0.034	8.69
10	3.22	0.85	1.75	3.47	0.30	0.20	0.32	0.14	0.029	0.033	8.85
11	3.37	1.03	3.48	--	0.39	0.37	0.020	0.20	0.026	0.036	17.19
12	3.23	0.94	2.45	3.75	0.39	0.26	0.075	0.18	0.027	0.036	9.77
13	3.29	1.08	2.08	4.37	0.47	0.33	0.058	0.21	0.028	0.038	10.94
14	3.28	0.89	2.09	3.98	0.42	0.31	0.038	0.16	0.027	0.036	9.62
15	3.12	0.82	1.79	4.71	0.36	0.20	0.059	0.10	0.027	0.040	9.14

Table 8. Ground Flow Effluent Composition of Peat Moss and Subsoil Substrate at 0.5 Liter/Hour Flow Rate.

Sampling Week	pH	Al	Ca	Mg	Na	K	Fe	Mn	Cu	Zn	SO_4
		m Moles									
2	5.29	0.0074	6.55	2.91	1.15	1.00	0.0046	0.20	0.0001	0.0007	13.61
3	5.63	0.0096	5.37	1.96	1.74	0.88	0.0039	0.21	0	0.0007	11.37
4	6.27	0.016	8.30	2.97	1.48	0.76	0.0032	0.30	0	0.0004	15.36
5	5.95	0.007	12.77	4.27	0.17	0.65	0.0083	0.45	0	0.0006	18.56
6	5.83	0.0077	8.37	5.00	1.87	0.53	0.0080	0.55	0	0.0007	22.78
7	5.80	0.0055	14.36	3.77	1.33	0.37	0.0119	0.57	0.0001	0.0010	25.44
8	5.73	0.0029	17.97	8.50	2.20	0.34	0.0155	0.73	0.0001	0.0009	25.91
9	5.83	0.0088	17.37	7.58	2.35	0.25	0.0158	0.90	0.0003	0.0013	28.34
10	6.05	0	13.55	9.62	2.22	0.27	0.0100	0.62	0.0003	0.0026	30.77
11	6.06	0.0098	19.29	10.57	2.53	0.30	0.0021	0.53	0.0003	0.0030	29.96
12	6.02	0.0081	12.45	13.47	2.75	0.34	0.0092	0.62	0.0003	0.0027	28.67
13	6.12	0.0051	12.15	10.80	2.95	0.35	0.0142	0.61	0.0003	0.0023	28.53
14	6.08	0.0077	11.69	11.60	2.58	0.37	0.0142	0.54	0.0022	0.0024	29.0
15	6.17	0.0062	11.21	10.48	2.58	0.36	0.0135	0.54	0.0006	0.0020	28.15
16	6.17	0.0044	10.57	13.77	2.91	0.36	0.0025	0.46	0.0003	0.0016	29.62

Table 9. Surface Flow Effluent Composition of Peat Moss and Surface Soil Substrate at 0.25 Liter/Hour Flow Rate.

Sampling Week	pH	Al	Ca	Mg	Na	K	Fe	Mn	Cu	Zn	SO_4
		m Moles									
1	4.19	0.51	5.0	8.12	1.14	0.25	0.29	0.32	0.016	0.039	17.68
2	3.37	0.86	10.15	11.04	1.78	0.33	0.059	0.49	0.025	0.065	27.31
3	3.67	1.31	8.65	11.37	1.43	0.27	0.036	0.48	0.028	0.065	25.75
4	3.53	1.75	10.61	10.60	1.40	0.25	0.12	0.45	0.035	0.066	24.53
5	3.34	0.62	4.53	4.29	0.60	0.16	0.033	0.19	0.018	0.034	11.46
6	3.42	0.57	2.70	4.21	0.59	0.15	0.015	0.19	0.017	0.034	10.82
7	3.04	0.98	3.48	2.01	0.35	0.13	0.026	0.15	0.026	0.035	8.26
8	3.05	0.89	3.44	3.25	0.39	0.17	0.36	0.15	0.026	0.035	8.26
9	3.05	0.76	2.65	2.74	0.50	0.22	0.26	0.21	0.020	0.035	10.45
10	3.05	0.78	1.97	3.83	0.38	0.22	0.28	0.15	0.026	0.035	9.97
11	3.28	0.52	4.29	4.14	0.48	0.27	0.038	0.17	0.017	0.035	10.38
12	3.14	0.72	2.20	3.44	0.39	0.18	0.16	0.15	0.022	0.033	9.68
13	2.90	0.96	3.90	5.46	0.84	0.24	0.30	0.30	0.020	0.038	15.50
14	3.27	0.69	3.20	4.58	0.58	0.26	0.033	0.18	0.022	0.031	11.12
15	3.36	0.71	2.87	5.10	0.58	0.23	0.018	0.17	0.022	0.034	11.26
16	3.23	0.80	2.44	4.04	0.50	0.20	0.024	0.12	0.024	0.033	11.64
17	3.26	0.99	3.06	4.33	0.63	0.19	0.029	0.16	0.023	0.040	11.19

Table 10. Ground Flow Effluent Composition of Peat Moss and Surface Soil Substrate at 0.25 Liter/Hour Flow Rate.

Sampling Week	pH	Al	Ca	Mg	Na	K	Fe	Mn	Cu	Zn	SO_4
		m Moles									
2	5.75	0.0077	9.75	1.65	1.91	0.12	0.20	0.34	0	0.0003	15.53
3	6.16	0.0079	11.25	1.80	2.00	0.084	0.22	0.38	0	0.0003	16.45
4	6.84	0.0070	13.05	2.16	2.13	0.028	0.29	0.50	0	0.0003	19.34
5	6.42	0.0083	14.75	2.81	1.99	0.014	0.18	0.56	0	0	21.78
6	6.18	0.0083	11.25	4.12	2.74	0.011	0.30	0.60	0	0.0001	23.62
7	6.23	0.0077	17.37	1.92	1.39	0.0033	0.13	0.59	0.0001	0.0003	25.14
8	6.24	0.011	18.22	5.08	2.33	0.0041	0.35	0.60	0.0001	0.0001	27.44
9	6.08	0.010	16.75	9.06	3.78	0.019	0.0051	0.54	0.0003	0.0006	35.45
10	5.52	0.031	10.45	7.17	3.26	0.14	0.047	0.30	0.0011	0.0075	29.80
11	5.75	0.0085	16.49	8.00	2.97	0.086	0.042	0.42	0.0006	0.0043	21.05
12	5.72	0.030	10.30	9.62	3.06	0.071	0.088	0.52	0.0009	0.0029	27.05
13	6.02	0.017	11.80	9.48	3.05	0.063	0.17	0.62	0.0004	0.0013	20.86
14	5.95	0.012	11.10	8.31	2.80	0.074	0.26	0.63	0.0006	0.0010	25.36
15	5.93	0.023	10.84	11.42	2.56	0.081	0.35	0.64	0.0011	0.0012	26.71
16	6.11	0.0055	10.47	9.85	2.41	0.075	0.015	0.59	0.0004	0.0012	24.40
17	6.23	0.017	11.04	9.46	2.14	0.080	0.62	0.66	0.0006	0.0018	8.59

Table 11. Surface Flow Effluent Composition of Peat Moss and Surface Soil Substrate at 0.5 Liter/Hour Flow Rate.

Sampling Week	pH	Al	Ca	Mg	Na	K	Fe	Mn	Cu	Zn	SO_4
		m Moles									
1	4.27	0.55	4.60	6.48	0.93	0.26	0.30	0.32	0.018	0.040	17.20
2	3.19	1.04	4.75	10.58	0.88	0.26	0.058	0.27	0.041	0.064	19.05
3	3.03	1.99	4.12	11.15	0.73	0.26	0.092	0.27	0.045	0.066	20.42
4	3.17	2.06	8.05	10.60	0.99	0.26	0.056	0.44	0.044	0.067	23.47
5	3.20	0.66	3.34	3.27	0.39	0.14	0.036	0.13	0.020	0.033	8.52
6	3.32	0.59	1.47	3.77	0.43	0.15	0.11	0.15	0.020	0.033	8.91
7	3.09	1.00	3.31	1.97	0.34	0.12	0.15	0.15	0.027	0.035	7.69
8	3.07	1.02	3.34	3.12	0.37	0.13	0.48	0.14	0.027	0.035	7.54
9	2.87	1.02	2.47	2.91	0.50	0.17	0.25	0.20	0.025	0.035	11.53
10	3.42	0.81	2.30	4.25	0.43	0.26	0.40	0.18	0.023	0.036	11.20
11	3.08	0.94	3.85	4.21	0.45	0.29	0.12	0.18	0.027	0.038	11.26
12	3.20	0.83	2.10	3.69	0.35	0.19	0.093	0.13	0.024	0.033	9.10
13	3.29	0.69	2.05	3.83	0.39	0.19	0.054	0.15	0.022	0.034	9.41
14	3.28	0.70	2.94	3.87	0.36	0.18	0.021	0.12	0.023	0.031	8.71
15	3.27	0.73	2.43	4.71	0.40	0.20	0.032	0.11	0.021	0.035	9.18
16	3.28	0.78	1.97	3.56	0.38	0.18	0.028	0.098	0.021	0.034	9.01
17	3.15	0.82	1.89	4.60	0.39	0.15	0.12	0.09	0.028	0.035	9.01

Table 12. Ground Flow Effluent Composition of Peat Moss and Surface Soil Substrate at 0.5 Liter/Hour Flow Rate.

Sampling Week	pH	Al	Ca	Mg	Na	K	Fe	Mn	Cu	Zn	SO_4
					m Moles						
2	5.58	0.0059	7.70	1.40	2.39	0.14	0.015	0.23	0.0003	0.0006	13.01
3	5.85	0.0079	6.50	1.51	2.39	0.13	0.033	0.26	0.0001	0.0003	11.03
4	6.85	0.0083	10.15	1.57	2.35	0.13	0.26	0.34	0.0003	0.0007	14.53
5	6.35	0.0094	11.79	2.48	1.53	0.12	0.41	0.38	0.0001	0.0001	14.68
6	6.18	0.0118	8.00	2.89	2.29	0.11	0.63	0.42	0.0001	0.0003	16.66
7	6.33	0.0074	14.96	1.89	1.26	0.087	0.57	0.43	0.0001	0.0003	15.75
8	6.35	0.0081	11.55	3.00	1.82	0.074	0.38	0.39	0.0001	0.0001	14.98
9	5.87	0.015	15.75	3.09	1.56	0.024	0.018	0.56	0.0003	0.0001	26.41
10	4.60	0.35	6.25	4.51	1.18	0.26	0.31	0.21	0.010	0.023	15.65
11	5.63	0.12	12.16	4.77	1.86	0.15	0.067	0.21	0.0034	0.012	17.82
12	5.50	0.13	10.25	5.79	2.65	0.088	0.060	0.26	0.0034	0.0087	20.60
13	5.89	0.065	12.20	6.96	2.74	0.081	0.032	0.25	0.0015	0.0052	21.74
14	5.99	0.027	12.51	7.79	2.70	0.049	0.015	0.19	0.0009	0.0041	24.86
15	5.92	0.021	12.32	9.85	2.77	0.063	0.0085	0.16	0.0003	0.0041	26.88
16	5.81	0.015	11.97	10.27	2.70	0.025	0.0030	0.16	0.0004	0.0038	27.50
17	5.80	0.029	14.19	8.75	2.81	0.033	0.035	0.16	0.0012	0.0063	26.32

Table 13. Surface Flow Effluent Composition of Hay and Surface Soil Substrate at 0.25 Liter/Hour Flow Rate.

Sampling Week	pH	Al	Ca	Mg	Na	K	Fe	Mn	Cu	Zn	SO_4
						m Moles					
1	5.39	0.085	5.47	7.14	0.76	3.74	0.30	0.36	0.011	0.033	16.66
2	6.74	0.021	10.30	13.83	1.00	7.08	0.20	0.61	0.0014	0.0015	20.31
3	6.28	0.022	12.55	11.60	1.06	8.46	0.46	0.79	0.0007	0.0010	10.74
4	6.83	0.11	5.97	10.61	1.00	8.44	0.63	0.26	0.021	0.031	8.28
5	7.84	0.022	1.82	7.35	1.22	10.82	0.23	0.026	0.0006	0.0010	6.78
6	7.31	0.011	2.67	6.69	0.77	3.90	0.070	0.064	0.0003	0.0007	6.63
7	7.01	0.054	4.07	4.55	0.60	3.51	0.21	0.022	0.0019	0.0023	6.80
8	7.93	0.021	2.70	4.43	0.91	6.00	0.13	0.061	0.0025	0.0029	6.80
9	7.31	0.024	1.35	3.62	0.93	7.46	0.15	0.030	0.0014	0.0023	6.65
10	7.24	0.029	2.90	3.92	0.73	5.00	0.23	0.12	0.0082	0.0063	3.97
11	8.04	0.018	4.33	3.31	0.53	2.85	0.024	0.075	0.0011	0.0016	2.21
12	7.30	0.077	2.90	3.60	0.62	4.01	0.13	0.091	0.0080	0.0075	2.80
13	8.19	0.065	2.70	3.56	0.66	4.08	0.026	0.075	0.0034	0.0040	3.57
14	7.89	0.23	3.13	4.79	0.55	3.62	0.14	0.099	0.0065	0.0075	4.21
15	7.84	0.17	2.89	4.17	0.52	3.23	0.065	0.099	0.0061	0.0092	5.07
16	8.06	0.028	2.28	3.46	0.55	3.54	0.011	0.080	0.0028	0.0030	5.27
17	8.57	0.023	2.89	4.06	0.61	3.87	0.024	0.034	0.0036	0.0026	6.25

Table 14. Ground Flow Effluent Composition of Hay and Surface Soil Substrate at 0.25 Liter/Hour Flow Rate.

Sampling Week	pH	Al	Ca	Mg	Na	K	Fe	Mn	Cu	Zn	SO_4
					m Moles						
2	5.31	1.04	47.26	10.44	1.14	43.79	1.33	2.16	0.0004	0.0046	14.45
3	5.39	1.46	40.06	12.83	1.19	39.18	1.33	2.46	0.0009	0.0043	18.94
4	5.37	0.84	32.25	11.62	1.13	43.33	2.36	2.50	0.0003	0.0016	14.77
5	5.42	1.68	52.98	12.03	1.06	40.51	7.82	3.16	0.0004	0.0012	10.51
6	5.43	3.16	54.37	9.00	1.17	38.85	2.71	2.76	0.0004	0.0018	10.51
7	5.65	0.063	35.60	9.54	0.60	22.56	4.15	2.39	0.0011	0.0043	6.80
8	6.67	0.050	18.04	16.93	1.04	31.28	2.79	1.06	0.0012	0.0016	3.54
9	6.98	0.046	17.22	8.33	1.17	21.02	0.95	0.29	0.0011	0.011	5.06
10	6.81	0.014	9.65	5.52	0.98	13.85	0.86	0.33	0.0007	0.0003	3.39
11	6.74	0.014	11.84	5.31	0.93	13.82	0.48	0.11	0.0003	0.0003	3.11
12	6.77	0.023	7.65	5.54	0.96	12.62	0.72	0.29	0.0003	0.0003	1.50
13	7.23	0.022	4.75	5.75	0.93	11.72	0.70	0.28	0.0006	0.0003	3.41
14	6.81	0.027	7.83	6.60	0.90	11.90	0.64	0.26	0.0004	0.0003	1.13
15	6.87	0.016	7.20	7.60	0.86	11.62	0.66	0.27	0	0.0001	1.30
16	6.83	0.013	6.11	5.37	0.86	11.46	0.62	0.25	0.0003	0.0001	1.21
17	6.81	0.014	4.96	4.58	0.81	10.92	0.73	0.24	0.0003	0.0003	1.31

Table 15. Surface Flow Effluent Composition of Hay and Surface Soil Substrate at 0.5 Liter/Hour Flow Rate.

Sampling Week	pH	Al	Ca	Mg	Na	K	Fe	Mn	Cu	Zn	SO_4
		m Moles									
1	4.85	0.035	4.25	5.89	0.72	2.49	0.37	0.29	0.020	0.045	4.66
2	4.45	0.48	3.70	11.87	0.67	1.04	0.64	0.29	0.035	0.053	16.70
3	4.55	0.69	4.82	10.62	0.70	2.31	0.59	0.40	0.0036	0.036	17.80
4	6.25	0	6.20	8.21	0.90	2.33	0.39	0.44	0.0003	0.020	18.50
5	6.97	0.050	6.35	5.19	0.62	5.38	0.099	0.43	0	0.0007	17.95
6	6.82	0.044	2.97	6.69	0.43	2.61	0.31	0.23	0.0003	0.0050	3.50
7	6.41	0.041	4.60	2.96	0.49	2.59	0.26	0.25	0.0003	0.0032	3.66
8	8.05	0.11	3.95	3.67	0.67	5.00	0.11	0.071	0.0026	0.0046	7.80
9	7.27	0.063	3.25	3.11	0.55	4.23	0.094	0.099	0.0006	0.0018	3.66
10	7.33	0.024	2.85	3.00	0.46	3.69	0.10	0.12	0.0060	0.0084	2.88
11	8.08	0.0066	3.76	2.94	0.43	2.20	0.0055	0.0021	0.0009	0.0004	4.84
12	7.60	0.10	2.20	3.60	0.48	2.35	0.087	0.097	0.0044	0.0061	4.83
13	7.25	0.17	2.25	3.50	0.41	2.10	0.045	0.12	0.0071	0.011	5.65
14	6.85	0.15	2.59	3.85	0.36	1.76	0.058	0.024	0.0053	0.0049	5.83
15	7.98	0.079	2.66	3.46	0.41	2.51	0.050	0.040	0.0020	0.0026	5.54
16	8.14	0.015	2.32	3.52	0.44	2.55	0.008	0.0012	0.0012	0.0003	5.77
17	6.96	0.15	2.45	3.77	0.43	1.79	0.048	0.12	0.0069	0.0092	6.62

Table 16. Ground Flow Effluent Composition of Hay and Surface Soil Substrate at 0.5 Liter/Hour Flow Rate.

Sampling Week	pH	Al	Ca	Mg	Na	K	Fe	Mn	Cu	Zn	SO_4
		m Moles									
2	5.39	0.10	48.40	8.75	1.09	70.51	2.07	2.14	0.0007	0.0038	3.97
3	5.43	0.28	48.20	9.94	1.07	47.69	2.05	2.23	0.0004	0.0041	17.80
4	5.33	0.74	41.10	11.50	1.15	41.95	6.65	2.52	0.0007	0.0021	16.08
5	5.38	0.098	48.60	10.60	1.09	36.20	8.27	2.64	0.0004	0.0024	18.11
6	5.43	2.48	54.00	11.71	0.96	43.20	5.32	2.56	0.0003	0.0015	13.97
7	5.68	0.054	43.38	9.40	1.11	28.72	1.89	2.08	0.0003	0.0015	4.36
8	6.62	0.043	30.12	11.33	0.96	27.49	1.09	1.13	0.0003	0.0015	5.18
9	6.98	0.044	12.80	10.08	0.90	23.43	0.83	0.27	0.0003	0.0018	5.50
10	7.02	0.018	6.75	4.14	0.57	9.61	0.47	0.16	0.0009	0.0006	2.88
11	7.36	0.0081	8.08	3.21	0.56	9.08	0.10	0.048	0.0006	0.0003	2.95
12	7.18	0.016	3.30	3.58	0.58	8.75	0.39	0.23	0.0003	0.0003	1.31
13	7.43	0.011	3.65	3.58	0.57	8.64	0.38	0.24	0.0004	0.0003	2.93
14	6.86	0.012	6.31	4.06	0.53	8.49	0.40	0.23	0.0002	0.0001	1.10
15	6.92	0.011	5.69	4.85	0.53	8.96	0.40	0.24	0.0002	0.0003	1.17
16	7.46	0.009	2.03	4.10	0.56	7.89	0.054	0.0065	0.0002	0	1.13
17	6.72	0.036	5.46	4.14	0.58	8.74	0.59	0.25	0.0009	0.0012	1.35

Table 17. Surface Flow Effluent Composition of <u>Sphagnum</u> and Surface Soil Substrate at 0.25 Liter/Hour Flow Rate.

Sampling Week	pH	Al	Ca	Mg	Na	K	Fe	Mn	Cu	Zn	SO_4
		m Moles									
1	3.75	0.94	3.32	0.64	0.82	0.28	0.42	0.26	0.037	0.059	16.63
2	3.42	0.95	4.25	9.73	0.73	0.26	0.023	0.30	0.036	0.051	18.23
3	3.46	0.18	4.97	8.06	0.77	0.27	0.033	0.36	0.013	0.031	17.43
4	7.26	0.17	6.55	9.29	1.04	0.35	0.053	0.40	0.0082	0.012	19.18
5	5.68	0.017	3.98	2.58	0.51	0.21	0.038	0.20	0.0061	0.023	8.92
6	5.70	0.026	2.10	4.96	0.53	0.22	0.023	0.18	0.0046	0.018	8.68
7	4.31	0.36	4.01	2.58	0.44	0.13	0.101	0.21	0.015	0.029	8.76
8	3.49	0.65	2.85	2.88	0.42	0.15	0.055	0.21	0.020	0.037	8.44
9	2.88	1.01	1.77	2.17	0.35	0.14	0.43	0.13	0.033	0.038	8.84
10	3.52	0.64	3.05	4.32	0.39	0.21	0.18	0.23	0.021	0.066	10.52
11	3.41	0.49	4.37	3.79	0.42	0.24	0.040	0.25	0.016	0.035	9.62
12	3.30	0.63	2.25	3.73	0.41	0.23	0.83	0.19	0.019	0.025	9.18
13	3.61	0.59	2.85	4.71	0.49	0.23	0.060	0.24	0.016	0.025	9.41
14	3.60	0.36	2.83	4.52	0.50	0.23	0.025	0.22	0.0082	0.019	12.60
15	3.48	0.42	2.78	3.79	0.48	0.21	0.016	0.19	0.013	0.021	9.51
16	3.73	0.32	3.03	6.35	0.56	0.23	0.0098	0.20	0.011	0.017	9.88
17	3.55	0.30	3.02	4.44	0.60	0.18	0.027	0.21	0.013	0.021	10.68

Table 18. Ground Flow Effluent Composition of <u>Sphagnum</u> and Surface Soil Substrate at 0.25 Liter/Hour Flow Rate.

Sampling Week	pH	Al	Ca	Mg	Na	K	Fe	Mn	Cu	Zn	SO_4
		m Moles									
2	7.35	0.0081	2.80	2.65	0.69	0.19	0.010	0.020	0.0006	0.0004	3.27
3	7.16	0.0081	3.17	2.94	0.71	0.19	0.0057	0.054	0.0006	0.0003	3.27
4	7.75	0.0074	3.37	1.44	0.93	0.20	0.010	0.003	0.0006	0.0003	3.19
5	7.07	0.0081	12.34	2.17	0.97	0.17	0.037	0.17	0.0004	0.0003	3.27
6	6.69	0.0137	6.37	3.08	1.06	0.18	0.15	0.15	0.0006	0.0003	3.27
7	6.75	0.0129	11.17	2.10	0.87	0.13	0.14	0.18	0.0009	0.0003	3.33
8	6.78	0.037	8.60	2.77	0.82	0.11	0.63	0.24	0.0004	0.0006	3.33
9	6.85	0.072	7.85	2.71	0.77	0.079	0.64	0.22	0.0004	0.0009	3.41
10	6.51	0.014	5.35	3.87	0.85	0.12	0.28	0.46	0.0009	0.0029	15.39
11	6.58	0.0103	15.82	5.73	0.89	0.069	0.47	0.54	0.0003	0.0001	14.49
12	6.60	0.019	10.45	5.31	1.00	0.075	0.10	0.56	0.0003	0	13.27
13	6.77	0.017	12.40	5.04	1.05	0.076	0.68	0.56	0.0003	0	12.37
14	6.64	0.012	11.03	5.04	1.07	0.079	0.60	0.55	0.0004	0.0001	9.70
15	6.74	0.0088	11.04	5.44	1.09	0.078	0.60	0.53	0.0003	0.0003	12.52
16	6.82	0.0048	10.12	5.33	1.10	0.078	0.01	0.27	0.0003	0	11.13
17	6.73	0.0085	10.52	4.46	1.10	0.076	0.62	0.51	0.0001	0	11.62

Table 19. Surface Flow Effluent Composition of <u>Sphagnum</u> and Surface Soil Substrate at 0.5 Liter/Hour Flow Rate.

Sampling Week	pH	Al	Ca	Mg	Na	K	Fe	Mn	Cu	Zn	SO_4
		m Moles									
1	4.59	0.43	4.80	5.54	0.85	0.28	0.16	0.28	0.020	0.047	16.95
2	3.20	1.35	3.80	9.81	0.71	0.23	0.066	0.27	0.046	0.060	18.19
3	4.09	1.17	4.55	8.58	0.75	0.23	0.013	0.34	0.030	0.043	17.72
4	4.62	0.47	7.67	8.71	0.97	0.21	0.028	0.34	0.016	0.032	17.10
5	4.42	0.45	3.44	2.31	0.44	0.19	0.0098	0.16	0.019	0.031	8.44
6	4.56	0.18	2.25	2.15	0.42	0.19	0.0082	0.19	0.011	0.026	9.01
7	3.16	1.01	3.45	2.15	0.36	0.17	0.093	0.16	0.033	0.039	8.70
8	3.25	1.17	2.00	2.38	0.44	0.24	0.39	0.16	0.030	0.039	8.93
9	3.07	0.69	1.90	2.37	0.35	0.17	0.23	0.15	0.026	0.035	8.47
10	3.24	0.99	1.82	3.63	0.33	0.23	0.29	0.14	0.031	0.070	10.02
11	3.29	0.85	3.63	3.40	0.36	0.18	0.049	0.18	0.026	0.039	9.46
12	3.34	0.93	2.20	3.27	0.42	0.18	0.062	0.18	0.026	0.037	10.03
13	3.33	1.02	2.00	3.52	0.36	0.17	0.074	0.16	0.026	0.036	9.17
14	3.30	0.77	2.35	4.42	0.38	0.18	0.027	0.16	0.024	0.045	9.39
15	3.33	0.86	2.25	4.56	0.38	0.18	0.030	0.15	0.027	0.045	9.43
16	3.41	0.86	2.33	5.00	0.41	0.18	0.012	0.12	0.024	0.038	9.66
17	3.27	0.90	2.28	4.23	0.44	0.16	0.036	0.11	0.030	0.042	10.30

Table 20. Ground Flow Effluent Composition of <u>Sphagnum</u> and Surface Soil Substrate at 0.5 Liter/Hour Flow Rate.

Sampling Week	pH	Al	Ca	Mg	Na	K	Fe	Mn	Cu	Zn	SO_4
		m Moles									
2	6.54	0.0085	10.55	1.55	0.69	0.14	0.018	0.18	0.0015	0.0012	3.87
3	6.75	0.0081	6.82	1.45	0.68	0.13	0.027	0.11	0.0007	0.0009	3.33
4	7.12	0.0185	6.81	4.12	0.86	0.12	0.26	0.13	0.0011	0.0003	3.48
5	6.95	0.0088	11.72	1.40	0.90	0.099	0.078	0.18	0.0009	0.0013	17.57
6	6.67	0.0077	5.75	2.71	0.93	0.10	0.029	0.29	0.0015	0.002	3.61
7	6.78	0.0081	10.34	1.32	0.79	0.049	0.037	0.21	0.0003	0.0001	1.38
8	6.83	0.0070	8.35	1.97	0.79	0.035	0.23	0.20	0.0001	0.0003	2.65
9	6.88	0.0074	9.40	2.17	0.71	0.014	0.23	0.20	0.0003	0.0001	3.84
10	6.37	0.0237	16.87	3.94	1.02	0.042	0.24	0.77	0.0009	0.0040	29.50
11	6.41	0.0103	25.81	8.85	1.13	0.021	0.24	0.80	0.0004	0.0015	28.56
12	6.35	0.0137	18.12	6.52	1.20	0.017	0.33	0.84	0.0004	0.0016	29.50
13	6.94	0.0129	18.25	7.33	1.24	0.010	0.27	0.85	0.0006	0.0015	30.64
14	6.35	0.010	21.56	9.90	1.26	0.015	0.21	0.83	0.0007	0.0010	30.87
15	6.42	0.0077	21.56	9.42	1.30	0.010	0.18	0.76	0.0003	0.0009	32.00
16	6.45	0.0048	19.34	10.04	1.41	0.011	0.0067	0.72	0.0003	0.0004	28.27
17	6.41	0.0077	19.85	8.62	1.47	0.0064	0.16	0.75	0.0004	0.0004	30.64

Table 21. Surface Flow Effluent Composition of Peat Moss, Mine Spoil and Surface Soil Substrate at 0.25 Liter/Hour Flow Rate.

Sampling Week	pH	Al	Ca	Mg	Na	K	Fe	Mn	Cu	Zn	SO_4
					m Moles						
1	3.21	1.34	3.25	6.79	0.86	0.27	0.11	0.26	0.039	0.067	20.47
2	3.13	1.23	5.32	11.33	1.00	0.27	0.091	0.42	0.044	0.084	17.96
3	2.91	2.37	4.65	11.84	0.94	0.25	0.105	0.39	0.048	0.080	21.88
4	2.92	2.97	6.35	10.87	0.96	0.32	0.12	0.44	0.054	0.092	36.76
6	3.37	0.75	7.37	13.93	2.78	0.17	1.07	0.89	0.0012	0.034	39.64
7	2.88	1.05	3.52	5.64	0.45	0.16	0.43	0.21	0.035	0.047	11.03
8	2.83	1.05	2.20	3.09	0.46	0.24	0.50	0.16	0.028	0.038	11.14
9	2.81	0.86	1.62	2.25	0.37	0.16	0.43	0.13	0.026	0.035	10.75
10	3.10	0.98	2.10	3.97	0.35	0.20	0.31	0.14	0.025	0.036	10.36
11	3.01	0.99	3.44	4.06	0.39	0.21	0.20	0.14	0.017	0.036	10.37
12	3.09	0.89	2.35	4.81	0.48	0.31	0.17	0.16	0.016	0.036	10.94
13	3.17	0.87	1.95	3.81	0.46	0.29	0.17	0.15	0.016	0.035	10.13
14	3.18	0.99	1.99	4.71	0.44	0.31	0.080	0.10	0.015	0.078	12.32
15	3.16	0.99	1.91	4.04	0.38	0.22	0.11	0.087	0.021	0.035	9.93
16	3.14	1.02	1.92	5.35	0.46	0.30	0.068	0.096	0.019	0.035	10.23

Table 22. Ground Flow Effluent Composition of Peat Moss, Mine Spoil and Surface Soil Substrate at 0.25 Liter/Hour Flow Rate.

Sampling Week	pH	Al	Ca	Mg	Na	K	Fe	Mn	Cu	Zn	SO_4
		m Moles									
2	3.28	1.39	8.05	14.53	2.61	0.20	0.20	0.80	0.0007	0.028	9.02
3	3.48	0.85	6.65	13.54	2.35	0.26	1.38	0.98	0.0011	0.029	31.44
4	3.00	0.84	11.05	15.47	2.30	0.25	0.94	0.98	0.0006	0.029	34.46
5	2.97	0.81	12.62	12.47	1.61	0.21	0.96	0.92	0.0003	0.031	34.65
6	3.11	0.99	1.85	5.60	0.55	0.18	0.11	0.17	0.032	0.041	12.07
7	3.35	0.82	13.49	11.93	1.23	0.10	1.51	0.89	0.0007	0.035	12.37
8	3.46	0.69	8.25	11.06	1.09	0.06	0.77	0.74	0.0004	0.035	31.81
9	2.98	0.82	8.60	10.75	1.15	0.033	0.77	0.72	0.0009	0.035	31.23
10	3.58	0.86	7.87	9.02	1.10	0.12	0.27	0.41	0.0069	0.036	18.54
11	3.66	0.75	7.65	11.03	1.13	0.14	0.34	0.40	0.0039	0.036	19.27
12	3.67	0.59	6.60	11.20	1.21	0.17	0.44	0.42	0.0026	0.038	20.97
13	3.90	0.81	6.15	14.20	1.79	0.18	0.37	0.41	0.0039	0.037	24.93
14	3.30	0.79	6.63	11.52	1.28	0.22	0.15	0.33	0.0019	0.049	27.82
15	3.74	0.86	7.31	12.58	1.70	0.22	0.10	0.36	0.0022	0.046	26.04
16	4.14	0.87	6.43	16.73	1.79	0.24	0.040	0.33	0.0026	0.043	27.46
17	3.69	0.93	7.57	16.30	1.64	0.27	0.79	0.32	0.0023	0.049	27.61

Table 23. Surface Flow Effluent Composition of Peat Moss, Mine Spoil and Surface Soil at 0.5 Liter/Hour Flow Rate.

Sampling Week	pH	Al	Ca	Mg	Na	K	Fe	Mn	Cu	Zn	SO_4
		m Moles									
1	3.21	1.37	2.85	0.68	0.77	0.27	0.17	0.24	0.047	0.063	16.92
3	3.01	2.30	5.70	11.71	1.11	0.30	0.081	0.47	0.042	0.081	16.86
4	2.91	2.34	5.85	13.57	1.13	0.31	0.13	0.48	0.055	0.089	28.50
5	3.25	0.83	3.55	4.31	0.48	0.18	0.085	0.17	0.027	0.039	11.47
7	2.94	0.88	3.13	4.81	0.41	0.15	0.20	0.15	0.028	0.037	9.81
8	2.84	0.94	2.07	3.04	0.43	0.16	0.34	0.15	0.029	0.089	9.58
9	2.73	0.79	1.60	2.37	0.36	0.15	0.83	0.12	0.022	0.033	9.19
10	3.17	0.92	1.65	4.00	0.33	0.22	0.35	0.13	0.024	0.035	9.32
11	3.08	0.87	3.18	3.10	0.36	0.26	0.14	0.14	0.015	0.032	9.21
12	3.13	0.89	1.75	3.83	0.36	0.23	0.13	0.13	0.022	0.031	9.36
13	3.12	0.85	1.85	4.27	0.37	0.24	0.24	0.13	0.019	0.033	9.48
14	3.13	0.75	1.86	3.56	0.36	0.25	0.063	0.088	0.018	0.033	11.42
15	3.13	0.88	1.76	4.62	0.37	0.27	0.068	0.088	0.017	0.035	9.18
16	3.17	0.87	1.66	3.73	0.39	0.29	0.042	0.086	0.014	0.029	9.89
17	3.13	0.97	2.01	4.27	0.47	0.29	0.046	0.094	0.020	0.037	9.02

Table 24. Ground Flow Effluent Composition of Peat Moss, Mine Spoil and Surface Soil at 0.5 Liter/Hour Flow Rate.

Sampling Week	pH	Al	Ca	Mg	Na	K	Fe	Mn	Cu	Zn	SO_4
		m Moles									
2	3.35	0.72	6.75	11.87	2.39	0.26	0.60	0.69	0.0006	0.026	27.82
3	3.42	0.65	9.75	9.54	2.39	0.26	1.09	0.71	0.0004	0.029	29.69
4	3.23	0.58	10.40	15.27	2.52	0.21	1.32	0.68	0.0006	0.028	33.08
5	3.03	0.69	14.06	11.37	1.82	0.15	0.51	0.64	0.0004	0.029	30.87
6	3.42	0.39	6.87	15.47	1.83	0.098	0.73	0.55	0.0004	0.025	27.82
7	3.55	0.38	7.95	9.27	1.13	0.048	0.75	0.54	0.0003	0.024	27.31
8	3.84	0.31	7.10	8.46	1.48	0.024	0.88	0.44	0.0003	0.023	24.25
9	2.94	0.26	5.35	6.60	1.26	0.075	1.30	0.35	0.0019	0.019	18.16
10	3.67	0.46	3.85	5.31	0.74	0.15	0.43	0.26	0.0030	0.033	14.01
11	3.67	0.42	5.71	6.83	0.86	0.15	0.36	0.28	0.0011	0.034	14.49
12	3.61	0.44	4.30	8.10	0.89	0.19	0.31	0.26	0.0009	0.034	14.42
13	3.65	0.53	4.10	9.77	0.99	0.18	0.46	0.27	0.0009	0.036	15.42
14	3.30	0.52	4.25	9.50	0.97	0.23	0.14	0.21	0.0009	0.040	17.11
15	3.51	0.59	4.44	9.23	1.10	0.26	0.25	0.25	0.0004	0.038	15.86
16	3.58	0.46	4.61	10.87	1.13	0.29	0.034	0.21	0.0004	0.036	17.05
17	3.61	0.62	4.43	7.87	1.34	0.32	0.091	0.22	0.0003	0.042	18.13

Table 25. Organically Bound Metals in Effluents of 0.25 Liter/Hour Surface Flow

Substrate	Sampling Week	Al	Fe	Mn	Cu	Zn
				m Moles		
Pine Needles and Surface Soil	3	0.0110	0.5700	0.1500	0.0011	0.0008
	7	0.0410	0.0470	0.0014	0.0004	0.0022
	9	0.2700	0.0019	0.0001	0.0006	0.0001
	12	0.0120	0.0039	0.0	0.0023	0.0007
	17	0.1400	0.0210	0.0090	0.0017	0.0003
Peat Moss and Subsoil	6	0.0360	0.0050	0.0018	0.0006	0.0007
	9	0.1200	0.0330	0.0140	0.0046	0.0042
	15	0.0660	0.0073	0.0045	0.0015	0.0016
Peat Moss and Surface Soil	1	0.0520	0.0360	0.0005	0.0011	0.0007
	5	0.1600	0.0028	0.0043	0.0006	0.0008
	9	0.0220	0.0170	0.0007	0.0001	0.0001
	17	0.0053	0.0005	0.0	0.0003	0.0002
Hay and Surface Soil	1	0.0300	0.0820	0.0072	0.0046	0.0072
	3	0.0120	0.1600	0.0070	0.0006	0.0001
	7	0.0140	0.0720	0.0020	0.0014	0.0006
	14	0.0660	0.0350	0.0045	0.0036	0.0022
	17	0.0084	0.0025	0.0005	0.0020	0.0001
Sphagnum and Surface Soil	2	0.0250	0.0019	0.0089	0.0014	0.0016
	6	0.0120	0.0078	0.0085	0.0014	0.0011
	7	0.0090	0.0094	0.0018	0.0006	0.0001
	9	0.0130	0.0026	0.0003	0.0006	0.0001
	17	0.0084	0.0014	0.0001	0.0003	0.0
Mine Spoil, Peat Moss, and Surface Soil	2	0.0450	0.0007	0.0150	0.0001	0.0021
	8	0.0290	0.0092	0.0027	0.0002	0.0006
	16	0.0047	0.0019	0.0003	0.0006	0.0

Table 26. Organically Bound Metals in Effluents of 0.25 Liter/Hour Ground Flow

Substrate	Sampling Week	Al	Fe	Mn	Cu	Zn
		m Moles				
Pine Needles and Surface Soil	4	0.5100	3.8000	0.0023	0.0011	0.0
	9	0.0930	1.2200	0.0170	0.0009	0.0005
	14	0.0710	0.1100	0.0050	0.0007	0.0002
	17	0.0098	0.0590	0.0069	0.0009	0.0001
Peat Moss and Subsoil	3	0.0058	0.0007	0.0	0.0006	0.0001
	4	0.0650	0.0007	0.0	0.0003	0.0
	6	0.0530	0.0019	0.0010	0.0012	0.0012
	9	0.0320	0.0064	0.0029	0.0006	0.0009
	14	0.0080	0.0005	0.0680	0.0006	0.0010
	16	0.0436	0.0021	0.0032	0.0001	0.0001
Peat Moss and Surface Soil	4	0.0210	0.1400	0.0110	0.0006	0.0001
	11	0.0120	0.0180	0.0021	0.0004	0.0
	17	0.0110	0.3300	0.0860	0.0007	0.0008
Hay and Surface Soil	6	0.2500	1.6300	0.0190	0.0014	0.0002
	11	0.0054	0.0420	0.0009	0.0006	0.0001
	17	0.0062	0.1200	0.0050	0.0007	0.0002
Sphagnum and Surface Soil	5	0.0084	0.0058	0.0010	0.0004	0.0
	10	0.0061	0.1900	0.0450	0.0007	0.0002
	17	0.0070	0.0800	0.0083	0.0007	0.0
Mine Spoil, Peat Moss, and Surface Soil	6	0.0096	0.0023	0.0014	0.0007	0.0004
	13	0.0230	0.0030	0.0007	0.0002	0.0001
	17	0.0580	0.0041	0.0001	0.0002	0.0001

Table 27. Organically Bound Metals in Effluents of 0.5 Liter/Hour Surface Flow

Substrate	Sampling Week	Al	Fe	Mn	Cu	Zn
				m Moles		
Pine Needles and Surface Soil	3	0.1400	0.0320	0.0023	0.0026	0.0007
	5	0.0060	0.0030	0.0003	0.0009	0.0
	9	0.0150	0.0044	0.0001	0.0009	0.0001
	16	0.0056	0.0	0.0014	0.0012	0.0002
	17	0.0071	0.0030	0.0	0.0001	0.0
Peat Moss and Subsoil	3	0.0064	0.0032	0.0	0.0	0.0
	5	0.0480	0.0014	0.0003	0.0006	0.0001
	9	0.0660	0.0310	0.0140	0.0050	0.0037
	15	0.0200	0.0012	0.0027	0.0009	0.0008
Peat Moss and Surface Soil	5	0.0110	0.0035	0.0012	0.0003	0.0
	9	0.3300	0.0080	0.0067	0.0011	0.0016
	17	0.0380	0.0051	0.0061	0.0017	0.0017
Hay and Surface Soil	3	0.2100	0.1600	0.0074	0.0006	0.0007
	4	0.0095	0.0980	0.0043	0.0004	0.0017
	8	0.0220	0.0230	0.0016	0.0031	0.0008
	12	0.0710	0.0058	0.0010	0.0025	0.0004
	17	0.0750	0.0260	0.0012	0.0031	0.0012
Sphagnum and Surface Soil	3	0.0730	0.0017	0.0110	0.0012	0.0013
	6	0.0390	0.0017	0.0049	0.0014	0.0023
	9	0.0057	0.0050	0.0003	0.0004	0.0001
	17	0.0075	0.0008	0.0007	0.0003	0.0003
Mine Spoil, Peat Moss, and Surface Soil	5	0.0110	0.0025	0.0003	0.0001	0.0
	9	0.0350	0.0220	0.0056	0.0009	0.0014
	17	0.0065	0.0016	0.0003	0.0	0.0001

Table 28. Organically Bound Metals in Effluents of 0.5 Liter/Hour Ground Flow

Substrate	Sampling Week	Al	Fe	Mn	Cu	Zn
		m Moles				
Pine Needles and Surface Soil	4	0.2900	8.1800	0.0067	0.0006	0.0001
	6	0.0170	1.0900	0.0034	0.0003	0.0003
	12	0.0098	0.0660	0.0080	0.0004	0.0001
	17	0.0390	0.0690	0.0080	0.0003	0.0
Peat Moss and Subsoil	3	0.0130	0.0005	0.0030	0.0003	0.0
	9	0.0095	0.0033	0.0089	0.0004	0.0
	16	0.0140	0.0007	0.0012	0.0004	0.0
Peat Moss and Surface Soil	4	0.0066	0.1300	0.0094	0.0006	0.0009
	8	0.0110	0.1600	0.0032	0.0004	0.0004
	12	0.0250	0.0057	0.0087	0.0007	0.0004
	17	0.0070	0.0025	0.0009	0.0006	0.0
Hay and Surface Soil	6	0.0550	0.8900	0.0400	0.0014	0.0001
	13	0.0059	0.0530	0.0010	0.0006	0.0004
	17	0.0094	0.1300	0.0040	0.0011	0.0004
Sphagnum and Surface Soil	4	0.0065	0.0240	0.0014	0.0	0.0001
	12	0.0048	0.0019	0.0560	0.0001	0.0003
	17	0.0140	0.0030	0.0690	0.0001	0.0
Mine Spoil, Peat Moss, and Surface Soil	5	0.6700	0.1600	0.1000	0.0003	0.0045
	7	0.0300	0.0890	0.0240	0.0	0.0010
	17	0.1500	0.0980	0.0300	0.0001	0.0043

Table 29. Means and Standard Deviations of Influent Concentrations

Substrate	pH	Al	Ca	Mg	Na	K	Fe	Mn	Cu	Zn	SO_4
Pine Needle and Surface Soil	3.38±0.59	1.09±0.54	1.66±0.73	3.79±2.13	0.39±0.18	0.14±0.07	0.38±0.22	0.13±0.06	0.032±0.013	0.045±0.022	10.5±4.20
Peat Moss and Subsoil	3.52±0.80	1.01±0.46	1.56±0.68	3.67±2.07	0.36±0.15	0.13±0.057	0.42±0.21	0.12±0.052	0.032±0.012	0.039±0.016	10.01±3.74
Peat Moss and Surface Soil	3.40±0.59	1.01±0.47	1.61±0.70	3.65±2.12	0.38±0.15	0.14±0.07	0.34±0.18	0.12±0.05	0.031±0.013	0.039±0.016	9.59±4.49
Hay and Surface Soil	3.37±0.60	1.01±0.47	1.52±0.80	3.72±2.65	0.38±0.18	0.13±0.06	0.35±0.22	0.12±0.055	0.031±0.013	0.042±0.016	9.87±4.66
Sphagnum and Surface Soil	3.36±0.58	1.13±0.56	1.69±0.74	3.99±2.50	0.40±0.18	0.15±0.072	0.35±0.16	0.13±.059	0.032±0.012	0.046±0.019	9.11±4.00
Mine Spoil, Peat Moss, and Surface Soil	3.39±0.59	1.06±0.54	1.64±0.69	3.61±2.10	0.38±0.17	0.13±0.063	0.34±0.16	0.12±0.052	0.030±0.013	0.039±0.017	9.59±4.50

Table 30. Exchangeable Cation Concentrations in Substrates Treated at 0.25 Liter/Hour Flow Rate.

Substrate	Depth (cm)	Ca	Mg	K	Na	Al	Fe	Mn	Cu	Zn
		µg/g								
Pine Needles and Surface Soil	0-5	9585.0	1325.0	163,125.0	370.0	8.25	3.12	212.5	0.75	1.37
	5-15	5595.0	455.0	160,000.0	587.5	21.37	6.00	56.25	0.37	8.37
Peat Moss and Subsoil	0-5	1450.0	500.0	162,500.0	167.5	472.5	17.75	106.25	25.25	3.00
	5-15	6157.5	1265.0	166,250.0	215.0	12.62	0.62	137.5	0.25	31.25
Peat Moss and Surface Soil	0-5	4955.0	1127.5	154,375.0	190.0	34.5	2.00	231.25	0.12	1.87
	5-15	5917.5	772.5	146,250.0	430.0	8.00	1.62	12.5	0	28.5
Hay and Surface Soil	0-5	8800.0	2080.0	177,500.0	235.0	71.37	22.37	156.25	2.37	0.50
	5-15	3592.5	657.5	178,125.0	107.5	14.50	24.87	31.25	0	0
Sphagnum and Surface Soil	0-5	6672.5	1365.0	168,125.0	160.0	3.12	1.50	375.0	0	21.50
	5-15	7920.0	730.0	123,125.0	147.5	7.37	2.87	312.5	0	1.37
Mine Spoil, Peat Moss, and Surface Soil	0-5	1645.0	1140.0	175,000.0	215.0	706.25	126.62	62.5	12.87	30.87
	5-15	4302.5	1375.0	168,125.0	172.5	187.5	20.62	93.75	0	23.00

Table 31. Exchangeable Cation Concentrations in Substrates Treated at 0.5 Liter/Hour Flow Rate.

Substrate	Depth (cm)	Ca	Mg	K	Na	Al	Fe	Mn	Cu	Zn
						μg/g				
Pine Needles and Surface Soil	0-5	5862.5	1875.0	178,750.0	152.5	180.00	44.25	562.5	2.50	136.25
	0-15	4027.5	375.0	159,375.0	150.0	19.75	2.37	168.75	0.37	0.87
Peat Moss and Subsoil	0-5	2660.0	992.5	153,750.0	167.5	265.00	17.25	93.75	8.00	0.25
	5-15	3835.0	707.5	161,875.0	212.5	14.87	0.62	225.0	0.37	32.5
Peat Moss and Surface Soil	0-5	3905.0	1077.5	168,750.0	150.0	76.37	11.87	212.5	0.87	4.25
	0-15	6332.5	790.0	168,125.0	130.0	10.00	0.87	25.0	0	33.25
Hay and Surface Soil	0-5	9225.0	2385.0	182,500.0	187.5	6.50	31.50	400.0	12.5	0.37
	5-15	5202.5	537.5	167,500.0	77.5	6.50	2.37	87.5	0	23.87
Sphagnum and Surface Soil	0-5	5235.0	1297.5	167,500.0	147.5	20.25	1.37	287.5	0	31.12
	5-15	6680.0	937.5	166,875.0	185.0	0.50	0.25	62.5	0	1.25
Mine Spoil, Peat Moss, and Surface Soil	0-5	1732.5	610.0	171,250.0	180.0	571.25	91.50	87.50	15.25	30.75
	5-15	3997.5	1337.5	184,375.0	185.0	226.25	59.00	125.0	0	20.00

Table 32. Sorbed Cation Concentrations in Substrates Treated at 0.25 Liter/Hour Flow Rate.

Substrate	Depth (cm)	Ca	Mg	K	Na	Al	Fe	Mn	Cu	Zn
						µg/g				
Pine Needles and Surface Soil	0-5	555.0	37.5	32,250.0	20.43	10,425.0	203.25	28.87	1.50	5.25
	0-15	225.0	--	28,500.0	11.73	11,737.5	233.62	7.50	0.75	3.37
Peat Moss and Subsoil	0-5	165.0	26.25	27,300.0	6.26	46.5	0.37	30.37	3.00	7.50
	5-15	502.5	60.00	33,900.0	24.40	34.12	0	33.37	0.37	0.75
Peat Moss and Surface Soil	0-5	187.5	33.75	23,850.0	13.87	9,225.0	145.12	13.12	1.50	4.50
	0-15	232.5	12.71	21,900.0	11.25	11,325.0	204.37	3.75	0.75	2.62
Hay and Surface Soil	0-5	615.0	97.50	33.150.0	21.03	384.75	145.87	40.12	3.00	3.37
	5-15	210.0	7.16	21,450.0	7.50	15,825.0	279.0	5.62	1.12	3.37
Sphagnum and Surface Soil	0-5	510.0	105.0	37,050.0	17.58	120.0	31.87	80.62	1.12	0.37
	5-15	502.5	30.0	34,800.0	12.75	251.62	93.37	57.75	0.37	1.12
Mine Spoil, Peat Moss, and Surface Soil	0-5	300.0	60.0	27,900.0	17.58	69.37	7.87	18.00	2.25	6.75
	5-15	367.5	90.0	35,550.0	16.57	69.00	2.25	21.37	0.37	3.37

Table 33. Sorbed Cation Concentrations in Substrates Treated at 0.5 Liter/Hour Flow Rate.

Substrate	Depth (cm)	Ca	Mg	K	Na	Al	Fe	Mn	Cu	Zn
					µg/g					
Pine Needles and Surface Soil	0-5	405.0	45.0	27,000.0	10.65	115.87	22.87	86.62	1.12	18.37
	0-15	165.0	--	19,950.0	6.22	11,737.5	167.25	6.37	0.75	3.37
Peat Moss and Subsoil	0-5	412.5	30.0	31,350.0	14.62	56.25	0.75	54.75	1.12	9.00
	5-15	255.0	71.25	30,000.0	13.50	30.00	0	22.87	0.37	0.75
Peat Moss and Surface Soil	0-5	187.5	37.5	30,450.0	7.87	369.0	101.25	13.87	1.87	6.00
	0-15	247.5	15.15	28,650.0	10.42	13,612.5	192.0	4.12	0.75	3.37
Hay and Surface Soil	0-5	457.5	67.50	23,850.0	14.10	187.12	87.75	62.25	5.25	10.50
	5-15	180.0	5.06	18,150.0	7.05	17,512.50	298.12	6.37	1.50	4.50
Sphagnum and Surface Soil	0-5	382.5	4.50	28,500.0	14.73	107.62	21.37	53.62	1.12	6.00
	5-15	405.0	7.5	32,550.0	14.10	9,787.50	166.12	12.37	0.75	1.87
Mine Spoil, Peat Moss, and Surface Soil	0-5	285.0	7.5	27,900.0	13.98	71.62	2.62	17.62	2.25	6.00
	5-15	352.5	52.5	31,800.0	17.36	67.12	5.25	25.50	0.37	2.62

Table 34. Organic Cation Concentrations in Substrates Treated at 0.25 Liter/Hour Flow Rate.

Substrate	Depth (cm)	Ca	Mg	K	Na	Al	Fe	Mn	Cu	Zn
						µg/g				
Pine Needles and Surface Soil	0-5	557.5	31.5	4187.5	68,687.5	5975.0	1700.0	38.5	64.75	38.25
	0-15	675.0	26.5	4925.0	65,875.0	6250.0	1300.0	42.25	15.25	10.25
Peat Moss and Subsoil	0-5	20.0	1.30	2312.5	94,625.0	6150.0	101.25	2.25	89.75	0.50
	5-15	105.0	2.05	4362.5	83,562.5	5775.0	244.50	7.25	19.50	1.75
Peat Moss and Surface Soil	0-5	200.0	3.10	4400.0	75.937.5	5125.0	422.5	15.00	64.25	10.50
	0-15	582.5	29.00	6062.5	76,750.0	4675.0	1450.0	14.00	8.25	14.75
Hay and Surface Soil	0-5	852.5	40.50	4662.5	98.250.0	4300.0	1547.5	150.25	63.50	47.00
	5-15	227.5	10.67	4375.0	61,125.0	4650.0	692.5	23.25	6.00	1.82
Sphagnum and Surface Soil	0-5	175.0	5.12	4487.5	72,812.5	5025.0	395.0	13.00	82.00	19.00
	5-15	182.5	8.02	4537.5	72,125.0	5425.0	567.5	16.50	8.75	5.00
Mine Spoil, Peat Moss, and Surface Soil	0-5	40.0	1.92	3037.5	78,437.5	3025.0	92.75	0.25	5.50	0.75
	5-15	92.5	2.80	3950.0	70,812.5	2875.0	135.00	0.75	12.75	0.50

Table 35. Organic Cation Concentrations in Substrates Treated at 0.5 Liter/Hour Flow Rate.

Substrate	Depth (cm)	Ca	Mg	K	Na	Al	Fe	Mn	Cu	Zn
						µg/g				
Pine Needles and Surface Soil	0-5	177.5	6.57	3137.5	79,687.5	4600.0	915.0	22.5	106.5	17.75
	0-15	345.0	21.25	4437.5	73,812.5	5500.0	992.5	23.75	19.25	11.00
Peat Moss and Subsoil	0-5	35.0	1.45	2825.0	78,625.0	6450.0	187.75	3.00	96.75	1.25
	5-15	60.0	1.25	3700.0	73,687.5	5875.0	41.75	2.25	12.5	0.50
Peat Moss and Surface Soil	0-5	232.5	3.85	4875.0	83,750.0	5900.0	667.5	15.00	185.50	11.50
	0-15	547.5	30.25	5450.0	74,187.5	7025.0	1392.5	14.75	16.50	15.25
Hay and Surface Soil	0-5	647.5	26.25	3662.5	79,500.0	7675.0	2587.5	100.0	129.5	182.5
	5-15	212.5	5.75	5062.5	78,500.0	4525.0	505.0	27.5	14.25	7.0
Sphagnum and Surface Soil	0-5	130.0	1.72	3750.0	81,312.5	4875.0	252.5	5.75	70.25	9.00
	5-15	220.0	10.02	4837.5	65,812.5	6050.0	695.0	11.0	8.00	6.75
Mine Spoil, Peat Moss, and Surface Soil	0-5	47.5	1.97	2912.5	76,812.5	3575.0	96.5	0.26	62.25	0.50
	5-15	90.0	2.47	3375.0	76,000.0	2775.0	135.0	1.00	11.25	0.75

Table 36. Residual 1 Cation Concentrations in Substrates Treated at 0.25 Liter/Hour Flow Rate.

Substrate	Depth (cm)	Ca	Mg	K	Na	Al	Fe	Mn	Cu	Zn
					µg /g					
Pine Needles and Surface Soil	0-5	4687.5	180.0	1918.75	22,812.5	7775.0	3875.0	350.62	27.62	116.25
	0-15	4790.0	136.25	1981.25	26,687.5	9737.5	3887.5	320.16	5.00	20.75
Peat Moss and Subsoil	0-5	395.0	15.0	1031.25	24,156.25	7400.0	1337.5	53.37	33.25	13.75
	5-15	1922.5	60.0	1918.75	23,593.75	11,187.5	2737.5	60.25	4.12	24.25
Peat Moss and Surface Soil	0-5	2297.5	52.5	1975.0	26,468.75	11,950.0	2200.0	32.62	20.25	32.75
	0-15	5245.0	131.25	1993.75	25,187.5	7625.0	2600.0	228.75	3.37	19.37
Hay and Surface Soil	0-5	6192.5	503.75	1331.25	23,312.5	6300.0	4662.5	671.25	21.37	136.25
	5-15	6025.0	210.00	1581.25	20,656.25	6587.0	3737.5	324.37	2.87	19.75
Sphagnum and Surface Soil	0-5	2611.25	71.25	1875.0	27,812.5	9925.0	2262.5	72.87	30.0	35.12
	5-15	3323.75	70.00	2006.25	27,375.0	11,000.0	2950.0	73.75	4.12	20.5
Mine Spoil, Peat Moss, and Surface Soil	0-5	212.50	10.0	1087.5	24,781.25	8212.5	1525.0	3.62	14.12	8.12
	5-15	545.0	22.5	1518.75	23,125.00	8900.0	1937.5	7.00	4.75	9.75

*As determined by extraction with 0.1 m Na_2 EDTA

Table 37. Residual 1 Cation Concentrations in Substrates Treated at 0.5 Liter/Hour Flow Rate.

Substrate	Depth (cm)	Ca	Mg	K	Na	Al	Fe	Mn	Cu	Zn
						µg/g				
Pine Needles and Surface Soil	0-5	2171.25	4.50	1618.75	26,468.75	9437.5	2525.0	18.75	20.5	30.0
	0-15	3213.75	86.25	1500.0	23,875.0	7112.5	2275.0	123.0	37.5	20.0
Peat Moss and Subsoil	0-5	667.5	16.25	1218.75	24,750.0	10,637.5	1587.5	35.0	16.75	20.12
	0-15	1155.0	28.7	1768.74	23,375.0	10,975.0	2087.5	56.12	3.75	22.37
Peat Moss and Surface Soil	0-5	1540.0	46.25	2231.25	34,593.75	10,337.5	2300.0	24.0	30.12	32.37
	0-15	3483.75	108.75	2925.0	41,406.25	9200.0	2387.5	94.12	3.75	23.5
Hay and Surface Soil	0-5	3138.75	241.25	1293.75	24,375.0	5850.0	3650.0	351.87	75.00	222.5
	5-15	5532.5	158.75	1831.25	20,843.75	7987.5	4037.5	355.0	6.12	26.25
Sphagnum and Surface Soil	0-5	2707.5	60.0	1943.75	24,218.75	9625.0	2312.5	33.37	26.12	33.37
	5-15	4187.5	103.75	1812.5	20,375.0	10,350.0	2587.5	87.87	3.87	19.62
Mine Spoil, Peat Moss, and Surface Soil	0-5	293.75	28.75	1525.0	34,156.25	5637.5	1300.0	4.75	17.12	8.87
	5-15	603.75	22.5	1337.5	22,906.25	9162.5	2187.5	7.62	3.87	9.75

*As determined by extraction with 0.1 M Na_2 EDTA

Table 38. Residual 2 Cation Concentrations in Substrates Treated at 0.25 Liter/Hour Flow Rate.

Substrate	Depth (cm)	Ca	Mg	K	Na	Al	Fe	Mn	Cu	Zn
						μg/g				
Pine Needles and Surface Soil	0-5	7218.75	993.75	1025.0	10,327.5	7737.5	17,387.5	637.5	14.50	300.0
	0-15	6835.0	948.75	1350.0	10,756.25	7150.0	16,150.0	500.0	4.50	225.0
Peat Moss and Subsoil	0-5	947.5	493.75	2400.0	11,516.25	21,325.0	42,950.0	1175.0	30.0	250.0
	5-15	2327.5	547.5	1712.5	11,791.25	19,337.5	37,150.0	1537.5	9.62	262.5
Peat Moss and Surface Soil	0-5	7180.0	987.5	1600.0	11,173.75	9412.5	21,187.5	612.5	9.87	287.5
	0-15	7186.25	960.0	1625.0	9556.25	9987.5	20,575.0	987.5	4.75	225.0
Hay and Surface Soil	0-5	5816.25	815.0	1025.0	9367.5	8612.5	12,987.5	437.5	11.5	300.0
	5-15	6827.5	942.5	1712.5	6338.75	10,250.0	17,737.5	400.0	4.75	250.0
Sphagnum and Surface Soil	0-5	7750.0	990.0	2075.0	14,330.0	10,850.0	24,712.5	725.0	21.12	437.5
	5-15	9577.5	1086.25	1862.5	10,887.5	10,175.0	27,325.0	712.5	5.00	262.5
Mine Spoil, Peat Moss, and Surface Soil	0-5	321.25	847.5	1475.0	13,180.0	4337.5	24,175.0	87.5	15.75	275.0
	5-15	593.75	990.0	1762.5	13,681.25	4750.0	24,162.5	150.0	8.75	237.5

*As determined by extraction with 4 M HNO_3

Table 39. Residual 2 Cation Concentrations in Substrates Treated at 0.5 Liter/Hour Flow Rate.

Substrate	Depth (cm)	Ca	Mg	K	Na	Al	Fe	Mn	Cu	Zn
						μg/g				
Pine Needles and	0-5	6080.0	777.5	912.5	11,167.5	6487.5	17,562.5	750.0	12.37	250.0
Surface Soil	0-15	5487.5	695.0	1600.0	7801.25	6700.0	14,875.0	525.0	3.5	212.5
Peat Moss and	0-5	1396.25	495.0	1462.5	12,772.5	19,962.5	38,900.0	1100.0	15.50	275.0
Subsoil	5-15	1445.0	472.5	2137.5	13,507.5	21,437.5	43,500.0	2100.0	9.75	250.0
Peat Moss and	0-5	6096.25	835.0	1225.0	11,028.75	7162.5	20,950.0	500.0	8.82	262.5
Surface Soil	0-15	7875.0	955.0	1450.0	11,216.25	8700.0	18,837.5	1087.5	4.12	250.0
Hay and	0-5	3948.75	698.75	2725.0	8737.5	7012.5	15,550.0	400.0	26.12	387.5
Surface Soil	5-15	7807.5	1198.75	1937.5	7387.5	11,225.0	22,312.5	575.0	5.75	262.5
Sphagnum and	0-5	7467.5	1070.0	1737.5	11,887.5	10,612.5	24,750.0	437.5	16.12	325.0
Surface Soil	5-15	10,057.5	1338.75	1912.5	11,357.5	10,587.5	23,775.0	1437.5	4.87	250.0
Mine Spoil, Peat Moss,	0-5	263.12	818.75	1512.5	10,340.0	5300.0	22,450.0	87.5	5.00	287.5
and Surface Soil	5-15	448.75	945.0	1475.0	11,058.75	4675.0	23,700.0	137.5	7.87	212.5

*As determined by extraction with 4 M HNO_3

Table 40. Total Cation Concentrations in Substrates Treated at 0.25 Liter/Hour Flow Rate.

Substrate	Depth (cm)	Ca	Mg	K	Na	Al	Fe	Mn	Cu	Zn
						µg/g				
Pine Needles and	0-5	20,109.37	3171.87	1900.0.	133.75	25,000.0	19,687.5	2306.25	93.75	443.75
Surface Soil	0-15	18,093.75	2328.12	1881.25	66.87	23,437.5	18,906.25	1700.0	15.93	156.25
Peat Moss and	0-5	4109.37	1296.87	1606.25	24.37	34,375.0	47,031.25	2593.75	115.62	250.0
Subsoil	5-15	13,937.5	2500.0	1650.0	163.12	35,937.5	46,093.75	2906.25	16.31	187.5
Peat Moss and	0-5	16,546.87	2781.25	1775.0	120.62	28,125.0	21,093.75	1900.0	78.12	356.25
Surface Soil	0-15	16,765.62	2328.12	1462.5	94.37	20,312.5	19,375.0	1937.5	10.37	150.00
Hay and	0-5	19,781.25	4109.37	6250.0	248.12	20,312.5	19,375.0	2806.25	100.0	518.75
Surface Soil	5-15	19,421.87	2796.87	5937.5	45.62	28,125.0	23,281.25	1906.25	14.56	206.25
Sphagnum and	0-5	18,046.87	3062.5	1837.5	95.00	28,125.0	23,437.5	2218.75	125.00	531.25
Surface Soil	5-15	19,593.75	2562.5	1737.5	62.50	21,875.0	38,906.25	2243.75	11.68	181.25
Mine Spoil, Peat Moss,	0-5	3140.62	2312.50	1793.75	174.37	10,875.07	2175.0	428.12	78.12	206.25
and Surface Soil	5-15	5781.25	2703.12	1862.5	177.5	12,500.0	2225.0	531.25	21.37	181.25

*As determined by extraction with HNO_3

Table 41. Total Cation Concentrations in Substrates Treated at 0.5 Liter/Hour Flow Rate.

Substrate	Depth (cm)	Ca	Mg	K	Na	Al	Fe	Mn	Cu	Zn
		µg/g								
Pine Needles and Surface Soil	0-5	15,078.12	3156.25	1743.75	109.06	23,437.5	21,718.75	2050.0	150.0	593.75
	0-15	16,937.5	2218.75	1793.75	19.37	26,562.5	20,468.75	1662.5	3.68	175.00
Peat Moss and Subsoil	0-5	6171.87	1671.87	1562.5	101.25	34,375.0	45,312.5	2293.75	81.25	275.00
	5-15	7515.62	1546.87	1600.0	72.50	32,812.5	53,750.0	4412.5	11.31	168.75
Peat Moss and Surface Soil	0-5	13,859.37	2078.12	1725.0	55.62	21,875.0	17,500.0	1506.25	90.62	387.5
	0-15	19,062.5	2734.37	1562.5	56.25	26,562.5	20,000.0	2062.5	12.18	187.5
Hay and Surface Soil	0-5	16,218.75	3000.0	4950.0	105.0	15,625.0	16,718.75	2262.5	237.5	787.5
	5-15	16,906.25	2328.12	5650.0	26.25	26,562.5	21,718.75	1937.5	20.18	206.25
Sphagnum and Surface Soil	0-5	15,562.5	2625.0	1643.75	86.25	25,000.0	21,562.5	1493.75	81.25	387.5
	5-15	20,406.25	3093.75	1850.0	90.62	28,125.0	22,343.75	2568.75	12.75	187.5
Mine Spoil, Peat Moss, and Surface Soil	0-5	3125.0	2359.37	1893.75	154.37	12,125.0	2287.5	415.62	100.0	212.5
	5-15	5796.87	2734.37	1725.0	141.25	11,250.0	2237.5	550.0	17.87	150.0

Table 42. Exchangeable cations extracted by 1M NH_4OAc (pH 7), and CEC of different substrate depths for fast (F) and slow (S) flow rates.

Substrate	Depth (cm)	Flow Rate	Ca	Mg	K	Na	Al	Fe	Mn	Ca	Zn	CEC
			---------------------c mol_c kg^{-1}									
Pine Needles & Surface Soil	0-5	F	22.78	15.73	0.41	0.41	0.30	0.03	3.13	0.01	0.26	34.85
	5-15	F	20.63	4.14	0.62	0.23	0.07	0.00	1.69	0.00	0.00	32.65
	0-5	S	30.02	13.00	0.74	0.62	0.09	0.00	1.78	0.00	0.03	34.40
	5-15	S	27.98	5.45	0.78	0.36	0.08	0.00	1.20	0.00	0.00	36.10
Peat & Subsoil	0-5	F	9.91	6.06	0.61	0.42	0.13	0.00	1.25	0.00	0.03	29.42
	5-15	F	15.66	5.31	0.74	0.43	0.09	0.00	0.71	0.00	0.00	28.85
	0-5	S	5.09	3.64	0.55	0.25	0.19	0.00	0.51	0.01	0.02	28.19
	5-15	S	21.84	8.86	0.60	0.76	0.10	0.00	0.96	0.00	0.01	32.65
Peat & Surface Soil	0-5	F	12.75	7.45	0.30	0.31	0.19	0.01	1.11	0.00	0.06	41.44
	5-15	F	22.48	6.35	0.14	0.30	0.11	0.01	0.25	0.00	0.00	35.52
	0-5	S	18.81	8.26	0.33	0.51	0.17	0.00	1.49	0.00	0.05	38.50
	5-15	S	26.59	6.43	0.15	0.51	0.12	0.01	0.25	0.00	0.00	38.68
Hay & Surface Soil	0-5	F	22.84	14.90	7.41	0.56	0.12	0.01	3.18	0.02	0.08	30.33
	5-15	F	17.19	5.26	6.66	0.11	0.13	0.00	1.36	0.00	0.00	31.88
	0-5	S	29.06	17.66	11.02	0.63	0.12	0.01	2.20	0.01	0.02	31.50
	5-15	S	18.06	6.23	8.48	0.16	0.13	0.01	0.98	0.00	0.00	32.74
Sphagnum & Surface Soil	0-5	F	19.40	8.91	0.28	0.43	0.18	0.00	1.71	0.00	0.05	33.08
	5-15	F	25.67	5.46	0.28	0.30	0.13	0.01	2.42	0.00	0.00	33.96
	0-5	S	25.14	9.15	0.36	0.41	0.15	0.01	2.42	0.01	0.04	33.21
	5-15	S	26.01	7.10	0.19	0.30	0.13	0.01	0.69	0.00	0.00	32.96
Spoil & Peat & Surface Soil	0-5	F	6.20	5.26	0.36	0.42	0.34	0.01	0.38	0.01	0.03	26.38
	5-15	F	11.79	7.58	0.28	0.49	0.19	0.00	0.62	0.00	0.01	26.49
	0-5	S	5.39	6.03	0.32	0.74	0.39	0.01	0.04	0.01	0.03	25.27
	5-15	S	9.11	7.60	0.25	0.46	0.19	0.00	0.56	0.00	0.02	30.08

PART II

METAL RETENTION PATTERNS IN A WETLAND CONSTRUCTED TO TREAT ACID MINE DRAINAGE IN SOUTHEASTERN KENTUCKY

PART II

INTRODUCTION

During the last few years a new technology for treatment of acid mine discharges has emerged. This technology involves the construction of artificial wetlands with dominant vegetation of *Typha* (cattails), *Sphagnum* (moss), certain algae, and other plant species, which have the potential to treat small flows of acid mine water moving through them (Girts and Kleinmann, 1986; Hammer, 1989). Interest in these systems has steadily increased because of their low cost (1/10 to 1/2 that of conventional treatment), efficiency, and near nonexistent maintenance. Conventional treatments relying on chemical additions and aeration to neutralize and remove metals from acid mine drainage can cost up to $1 million per year for a single site (Erickson et al., 1987). These biological-treatment systems have such a great potential that over 100 experimental wetlands have already been established in Appalachia. These systems are designed to mimic natural wetland ecosystems dominated by a single vegetation type or a combination of two in the same plot or sequential plots.

Recent studies conducted by the U.S. Bureau of Mines (Kleinmann, 1985), Wright State University (Huntsman et al., 1978), and West Virginia University (Wieder, et al., 1982) have indicated significant decreases in iron, manganese, magnesium, sulfate, and acidity in acid mine effluents flowing through artificial wetlands. Treatment efficiency, however, was variable depending on the vegetation, substrate, effluent flow rate and the composition of the acid mine discharge. A survey of preliminary data from wetlands constructed prior to 1986 in Pennsylvania, West Virginia, Ohio, and Maryland (Girts & and Kleinmann, 1986) indicates that iron and hydrogen ion removal efficiencies are high (80 to 96%), while total acidity decreases (titrated to pH 8.3) range from 68 to 76% for inflow-outlfow comparisons. Manganese and sulfates were reduced by 22 to 50%. These results, however include some wetland systems which received additional chemical treatment and therefore, may not be representative of wetland systems alone. Maximum removal efficiencies for hydrogen, sulfate, and iron ions in natural wetlands dominated by Sphagnum and receiving acid mine discharges have been reported to be as high as 98% (Wieder, et al., 1982). In constructed cattail wetlands in Pennsylvania (Girts and Kleinmann, 1986) removal efficiencies were 37%, 58%, 58%, 14% and 47% for hydrogen ions, acidity, iron, manganese and sulfate, respectively. The scarce data available on the efficiency of wetland systems to remove Al from acid mine drainage are at best inconsistent. Of 15 artificial wetland sites with Al influent concentrations between <2 and 100 mg/l, Al removal ranged between 0 and 98% with a median of 75% (Erickson et al., 1987). The highest efficiencies were associated with high pH effluents (6.6), while 32% to 78% removal was observed in the effluent pH range of 3.1 to 6.4.

In none of the above mentioned studies was an attempt made to determine the distribution and speciation of inorganic and organic metal forms in the effluent solutions and substrates. Metal speciations of effluents and analytical characterizations of substrates, however, are important in identifying the mechanisms controlling the metal immobilization processes, the forms of immobilization, and the most effective designs for toxic metal removal.

The objectives of this study were to:

(1) Monitor seasonal influent, effluent and substrate metal composition changes in a constructed acid mine wetland in southeastern Kentucky,

(2) Speciate common toxic metals such as Al, Fe, Mn, Cu, and Zn in effluent solutions and substrates, and

(3) Compare the results with laboratory simulated wetland systems for possible model development capabilities.

MATERIALS AND METHODS

A wetland constructed by the U.S. Forest Service in the spring of 1989 at Jones Branch, McCreary County, Kentucky was selected for this study. This wetland project has a series of small ponds or cells sized according to expected high and low flows from an abandoned coal deep mine, providing 11,000 sq. feet of ponded surface area for treatment. Additional design considerations included site conditions, climate, hydrology, water chemistry, access and expected maintenance needs. According to guidelines developed by the Bureau of Mines (B.O.M.), a final design should be a wetland that provides 200 to 600 square feet of surface area per gallon per minute of flow. The Jones Branch project provides for 480 sq. feet of surface area per gallon at 23 gallons per minute and 150 sq. feet of surface area per gallon at 75 gallons per minute of flow, the projected normal range in flow conditions based on observations. The higher flows, however, are projected to occur as a short term response to high precipitation periods. The wetland as designed therefore should be within B.O.M.'s criteria more than 80 percent of the time. The influent into the constructed wetland is allowed to slowly make its way through the wetland, as flow path length and residence time are critical.

The wetland was constructed by placing a layer of crushed limestone (KY #9's, 3/8 inch) on top of a graded, compacted floor treated with bentonitic clays to minimize seepage. The limestone layer is 9 inches thick. Following this, an 18 inch layer of spent mushroom compost was placed on top of the limestone to provide an organic substrate. After the organic matter was in place and leveled the cattails were planted. The wetland was watered initially with unpolluted water to allow the plants to recover from the stress of being transplanted. Following this, the acid mine drainage was released into the wetland at a rate that would allow the plants to gradually become tolerant of the low pH water.

A diagram of the Jones Branch wetland is shown in Fig. 1. The wetland was sampled twice (February and May, 1990) by our laboratory, while monthly data for the first 6 months of operation (June-December, 1989) were provided by the U.S. Forest Service. The February sampling included effluent and substrate samples, while in May, only effluent samples were taken. The collected solutions were filtered through 0.45 μm filters and analyzed for total Al, Fe, Mn, Zn, Cu, Ca, Mg, Na, and K by atomic absorption spectroscopy (AAS) or colorimetry (Al, Fe) if concentrations were below the AAS detection limits (Page et al., 1982). The solutions were also analyzed for pH, and SO_4^{2-}. These solution parameters have been found to be the major components affecting metal speciations in acid mine drainages (Plankey and Patterson, 1987; Karathanasis et al., 1988). Organically-bound metal species were separated from inorganic metal forms by passing filtered solution subsamples through a chelex 100 ion-exchange resin equilibrated with a synthetic solution containing Ca^{2+}, Mg^{2+}, and H^+ concentrations similar to those encountered in the collected effluents. The collected aliquot was analyzed by AAS or colorimetry and comprised the non-exchangeable metal load, which is organically complexed (Campbell et al., 1983). The concentration of the exchangeable metal load adsorbed by the resin was obtained by subtraction of the organically complexed value from the total filterable metal load.

The substrate samples were collected from the upper 15 cm of selected cells. The natural solution saturating the substrate samples was extracted in the lab by centrifugation and analyzed similarly to the effluent solutions. The distribution of the various metal forms in the substrate samples was determined by a selective sequential extraction procedure (Emmerich et al., 1982) fractionating the metals into exchangeable, adsorbed, organically bound, and residual (carbonate, sulfate, oxyhydroxide) forms. These metal forms were extracted by sequential extractions of 2 g of sample with 25 ml of 0.5 $\underline{M}$ KNO_3, deionized water, 0.5 $\underline{M}$ NaOH, 0.05 $\underline{M}$ Na_2EDTA and 4 $\underline{M}$ HNO_3, respectively. All extracts were analyzed by AAS using standards with extracting reagent matrices.

RESULTS AND DISCUSSION

Surface Effluent Composition

While the June to December data of the U.S. Forest service showed an increasing pH trend from 3.0 in the AMD entering the wetland to about 7.3 in the drainage exiting the wetland, the February and May samplings indicate essentially no pH change between inlet and outlet drainages, with a fluctuation range between 2.7 and 3.3 through the wetland (Fig. 2). The May effluents had somewhat higher pH's (3.0 ± 0.1) than the February-sampled effluents (2.7 ± 0.2), which could be explained by water flow fluctuations (February > 20 gallons/min; May 10 gal/min). Most of the June-December data correspond to lower water flows in the range of 5 to 10 gallons/min.

The Al concentration of the effluents followed the expected relationship with pH (Fig 3). While the June-December, 1989 Al concentrations in the effluent declined as the pH increased from cell to cell, the February and May concentrations remained relatively constant throughout the wetland. Surprisingly, the February effluents showed approximately 4 times lower Al concentrations than the May effluents, apparently due to dilution effects from the higher flow rate. Iron concentrations in the June-December effluents were reduced drastically (~87%), but the removal efficiency appeared to be declining in February (~76%), and May (~18%), probably due to dilution from the high water flow. The May-sampled effluents showed the highest overall Fe concentrations (Fig. 4). Reductions in Zn concentrations were also observed in effluents passing through the wetland. Although outlet Zn concentrations in February and May were at or below the June-December average, input concentrations were also 3.5 times lower, apparently due to dilution effects from higher water flows (Fig. 5).

Manganese concentrations declined by as much as 73% in treated June-December effluents, but remained constant at lower input concentrations in February and May (Fig. 6). Similar patterns were observed for $SO_4^=$ concentrations with no change between input-output concentrations in February and May. Both of these samplings, however, produced $SO_4^=$ concentrations, which were at or below the output $SO_4^=$ levels of the June-December samplings (Fig. 7).

Metal Speciation in Surface and Ground Effluents

Mean concentrations (± SD) of fractionated organic and inorganic metal species in surface effluents of the wetland during the February and May, 1990 samplings are shown in Fig. 8 and 9. More than 95% of the Fe, 99% of the Mn and almost 100% of the Zn present in surface effluents were in inorganic forms (Fig. 10). This indicates the limited affinity of these metals to form organic complexes. In contrast, almost 99% of the Cu and about 40% of the effluent Al were organically bound. This speciation pattern was consistent throughout the wetland, with very little variability among cells. Pathway length (cell 1 to cell 26) and flow rate had a negligible effect on the organic/inorganic proportions of the metal species, although the 4-fold increase of total Al in the May effluents compared to those of February caused a small increase in favor of the inorganic Al fraction (Figures 11 and 12). In all other cases 2-to 3-fold increases of metal concentration in the May effluents did not disturb the organic/inorganic speciation balance. However, flow rates below 10 gallons per minute may disturb this balance by increasing the residence time and providing opportunities for extended interaction of the effluent with the substrate. The latter is supported by the observed increases in organic metal fractions in ground solutions extracted from wetland substrates and especially, that of Al, which approaches 100% (Fig. 13 and 14). The above trends are qualitatively consistent with metal speciations involving different substrates in laboratory-simulated wetland chambers employing much lower flow rates (see part I of this report).

Metal Distribution in the Substrate

Fractionation of various metal forms associated with the mushroom compost substrate of the wetland are shown in Fig. 15-19. The sequentially extracted metal fractions are identified as exchangeable, sorbed, organic, residual 1 (sulfides, sulfates, carbonates), and residual 2 (oxyhydroxides). Generally, the residual metal forms (sulfates, sulfides, carbonates, and oxyhydroxides) were dominant for every metal throughout this wetland except for two cells (1 and 16), in which the exchangeable Mn and Zn species prevailed. Residual metal forms of Fe were especially prominent (> 90%, with > 80% oxyhydroxides), with the organic species being limited to 0-5 %, and the sorbed and exchangeable being almost nonexistent (Fig. 15). Similar, but not as dramatic, were the distribution trends shown by Mn and Zn, with the exception of the two cells (1 and 16) mentioned above, where the exchangeable form ranged between 50 and 60% (Fig. 16 and 17). The highest tendency for organically-bound metal species was shown by Al (20-30%) and Cu (25-40%) (Fig. 18 and 19). There was much smaller affinity by Mn and Zn and the least by Fe to form organic metal complexes (0-15%; Fig. 16, 17, and 15). The distribution of sorbed metals was also limited (0-6%) with more consistent being the presence of Al and Cu species (Fig. 18 and 19). In most cases other than the two cells mentioned above (1 and 16), exchangeable metal forms were limited to < 5%, with sporadically higher values shown primarily by Mn. These trends are consistent with those observed with other substrates used in laboratory simulated wetland systems (section I of this report) and supported the observation, that overall, the majority of the metals passing through wetland systems are immobilized in residual forms. Precipitation of these forms apparently starts before the exchangeable or sorbed sites are completely saturated and proceeds concurrently with exchange or sorption processes.

CONCLUSIONS

Metal concentration and acidity were reduced substantially during the first six months in acid mine drainage effluents treated by a wetland constructed by the U.S. Forest Service in McCreary County, KY. After 8 months of operation, however, and during periods of high flow rages (> 10 gallons/min) the efficiency of the wetland was drastically reduced, apparently due to insufficient size and metal overloading. No major differences were observed during high flow rate periods between input-output metal concentration, although input concentrations varied due to dilution effects. The majority of Fe, Mn, and Zn in surface effluents was present in inorganic metal species. Nearly 100% of Cu and about 40% of the Al, however, was organically bound. Although dilution effects caused the absolute concentrations of organic and inorganic metal species to vary with different flow rates, the organic-inorganic species balance was little affected. Substrate solutions extracted by centrifugation showed increased organic/inorganic metal species ratios, apparently due to extended interaction (increased residence time). A great portion of the metals retained by the substrate was in residual forms (oxyhydroxides, sulfides, sulfates, carbonates). The metals Fe, Mn, and Zn showed the highest tendency for residual retention, while Al and especially Cu showed high affinity for organic retention. Exchangeable and sorbed forms were present in very small concentrations and in many cases were almost negligible.

The above observations suggest that metal distribution and speciation patterns in surface effluents and substrates of field-constructed wetlands and the mechanisms controlling metal retention can be sufficiently modelled by laboratory-simulated wetland chambers, but significant variations can result in wetland efficiency due to flow rate variability and construction design.

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LIST OF FIGURES

Fig. 12. Mean distribution of inorganic and organic metal forms in surface effluents of the Jones Branch wetland expressed on a % basis (May, 1990).

Fig. 13. Mean concentrations (± SD) of organic and inorganic metal forms in substrate solutions of the Jones Branch wetland in February, 1990.

Fig. 14. Mean distribution of inorganic and organic metal forms in substrate solutions of the Jones Branch wetland expressed on a % basis (February, 1990).

Fig. 15. Exchangeable, sorbed, organic, residual 1 (sulfides, sulfates, carbonates), and residual 2 (oxyhydroxides) forms of Fe retained by the mushroom compost substrate of the Jones Branch wetland (February, 1990).

Fig. 16. Exchangeable, sorbed, organic, residual 1 (sulfides, sulfates, carbonates), and residual 2 (oxyhydroxides) forms of Mn retained by the mushroom compost substrate of the Jones Branch wetland (February, 1990).

Fig. 17. Exchangeable, sorbed, organic, residual 1 (sulfides, sulfates, carbonates), and residual 2 (oxyhydroxides) forms of Zn retained by the mushroom compost substrate of the Jones Branch wetland (February, 1990).

Fig. 18. Exchangeable, sorbed, organic, residual 1 (sulfides, sulfates, carbonates), and residual 2 (oxyhydroxides) forms of Al retained by the mushroom compost substrate of the Jones Branch wetland (February, 1990).

Fig. 19. Exchangeable, sorbed, organic, residual 1 (sulfides, sulfates, carbonates), and residual 2 (oxyhydroxides) forms of Cu retained by the mushroom compost substrate of the Jones Branch wetland (February, 1990).

FIG. 1

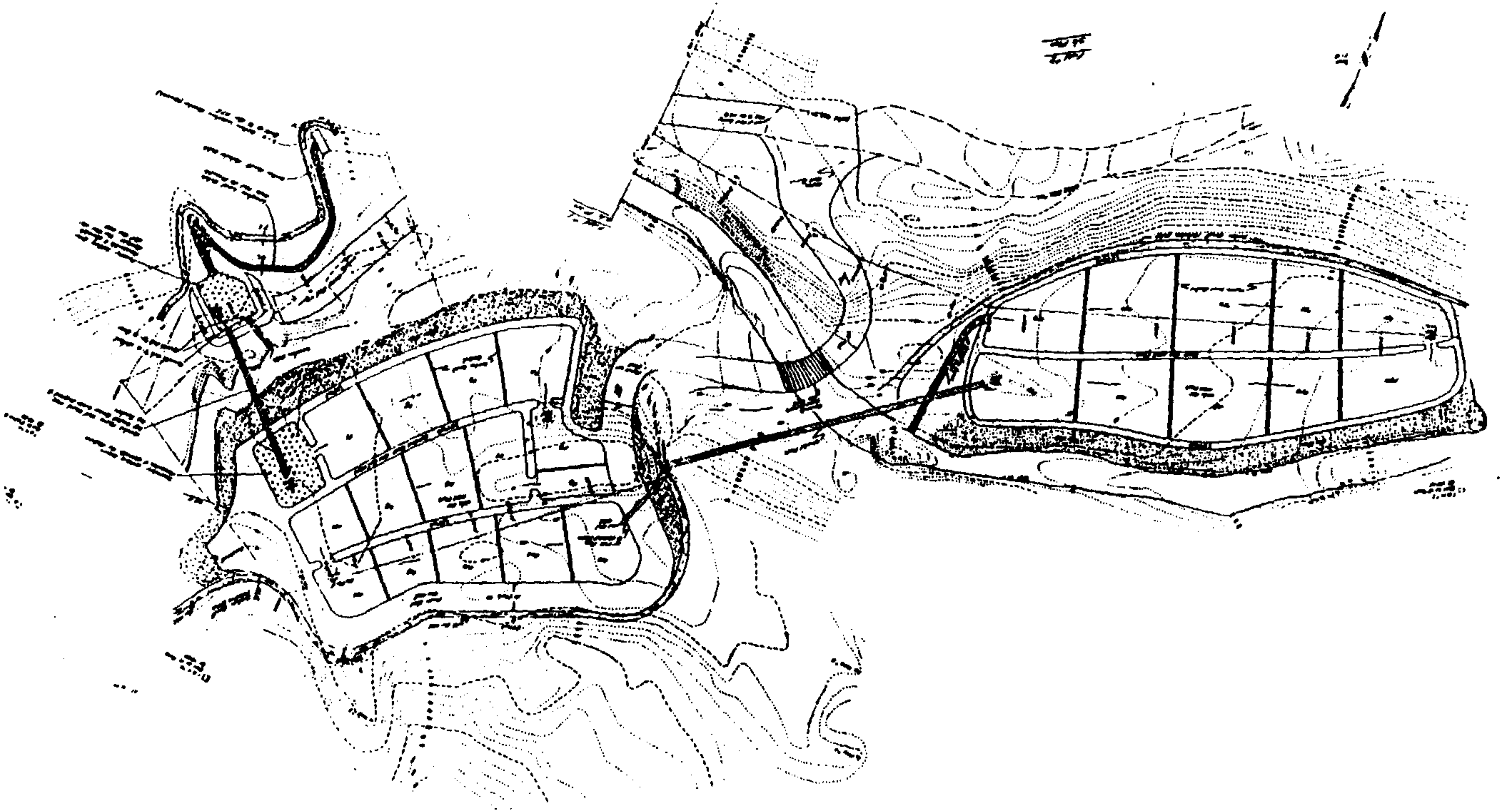
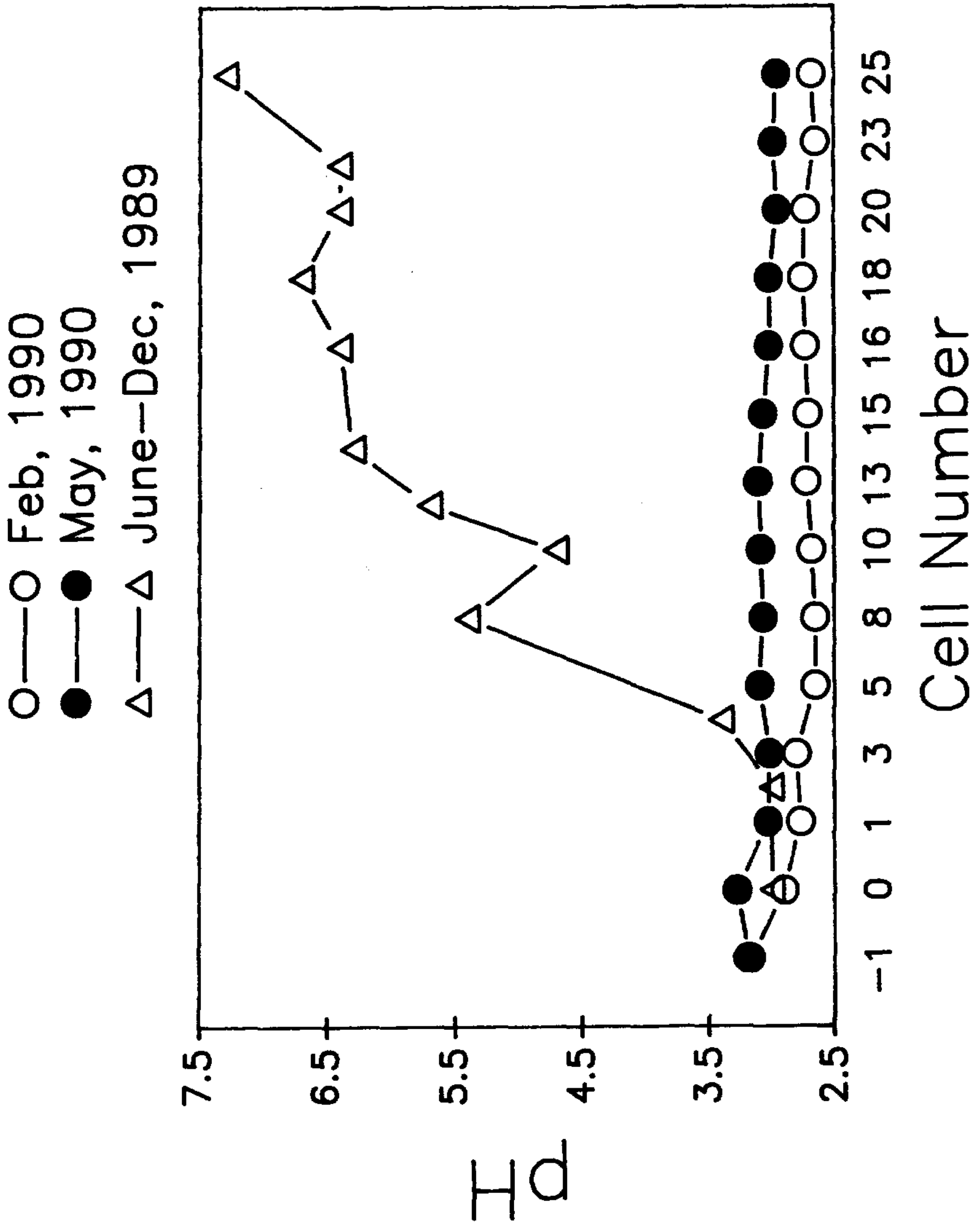


FIG. 2


○—○ Feb, 1990
●—● May, 1990
△—△ June–Dec, 1989
pH
7.5
6.5
5.5
4.5
3.5
2.5
Cell Number
–1
0
1
3
5
8
10
13
15
16
18
20
23
25

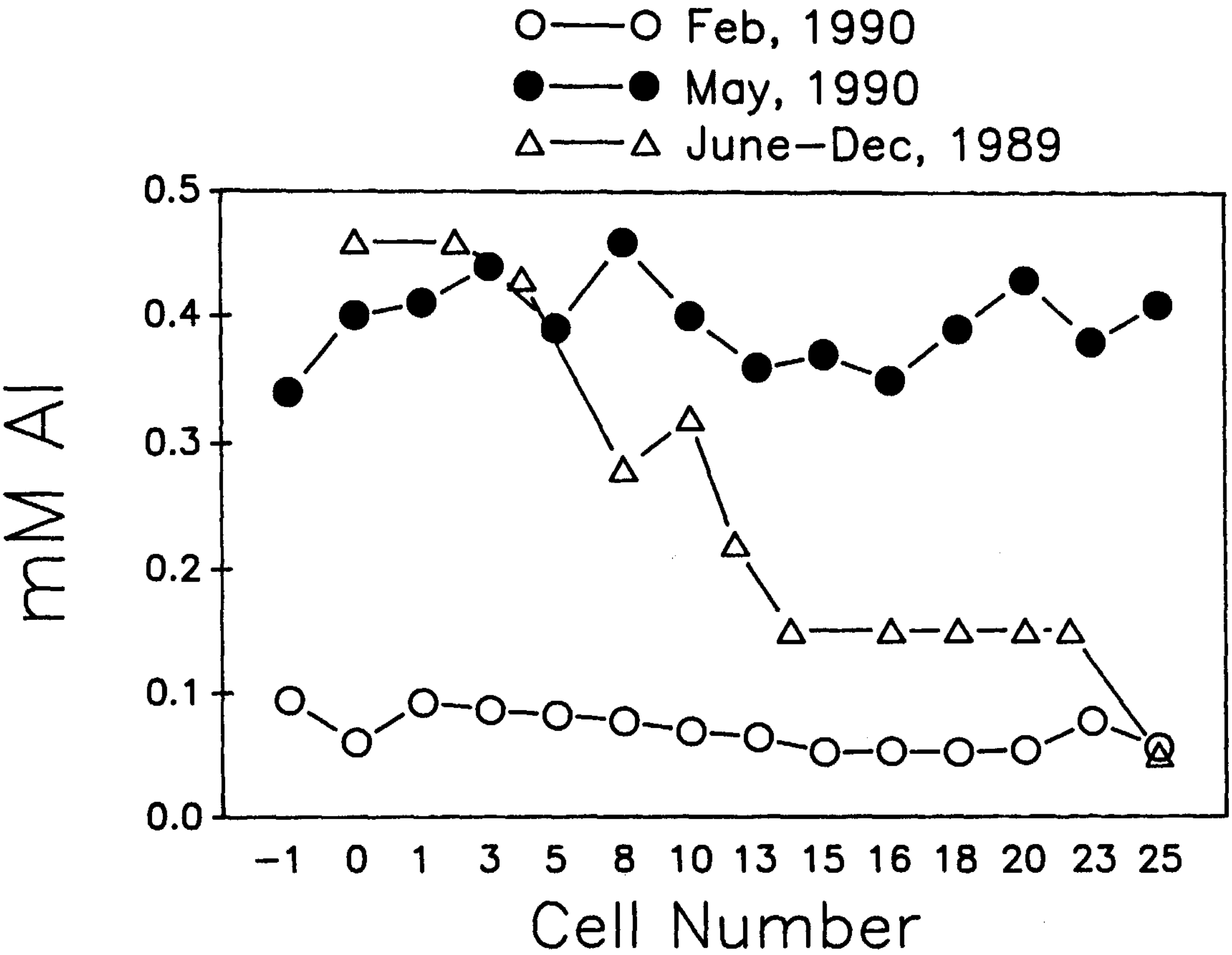
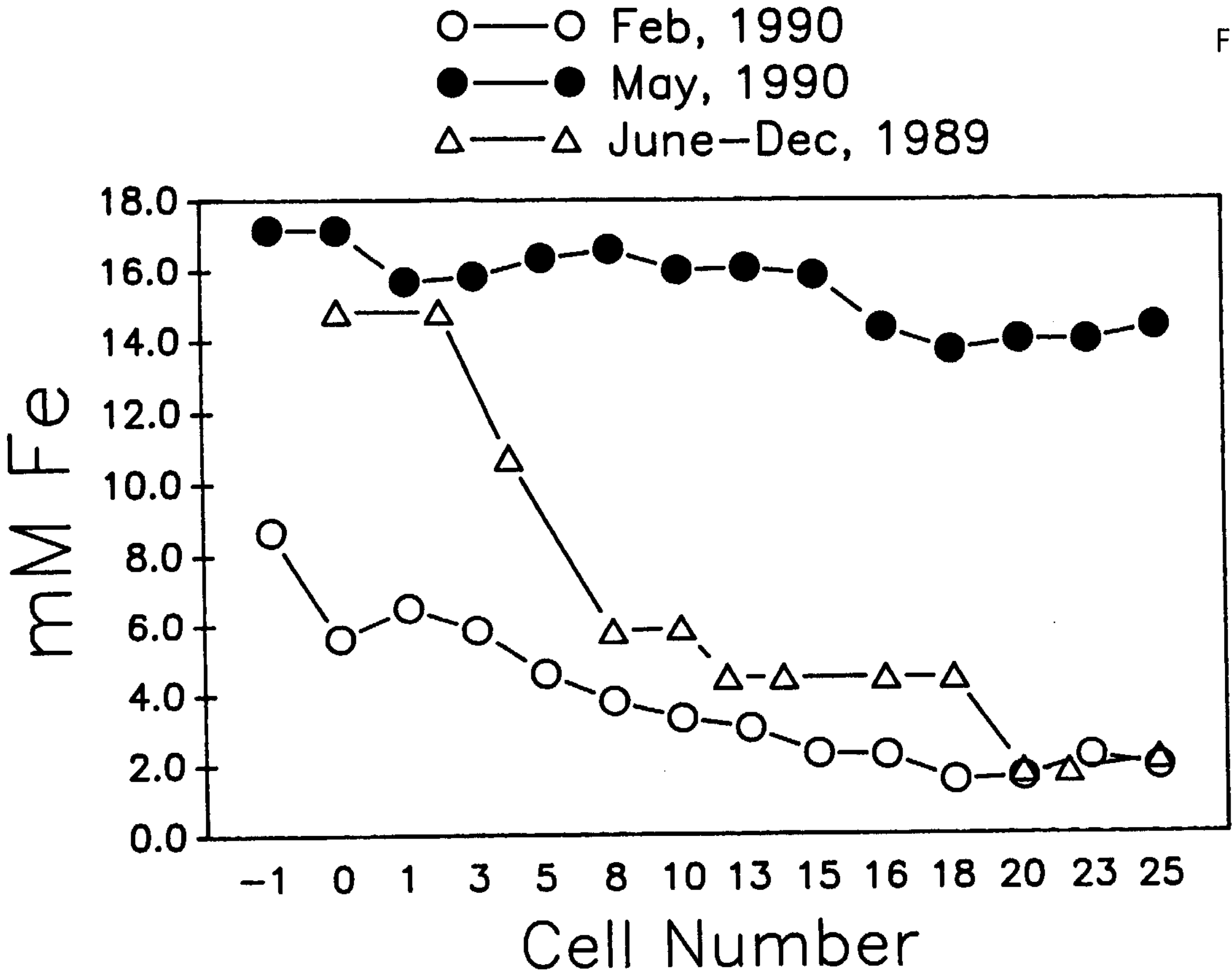

Feb, 1990
May, 1990
June–Dec, 1989
mM Al
0.0
0.1
0.2
0.3
0.4
0.5
–1
0
1
3
5
8
10
13
15
16
18
20
23
25
Cell Number

FIG. 3

FIG. 4


Feb, 1990
May, 1990
June–Dec, 1989
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
mM Fe
–1
0
1
3
5
8
10
13
15
16
18
20
23
25
Cell Number

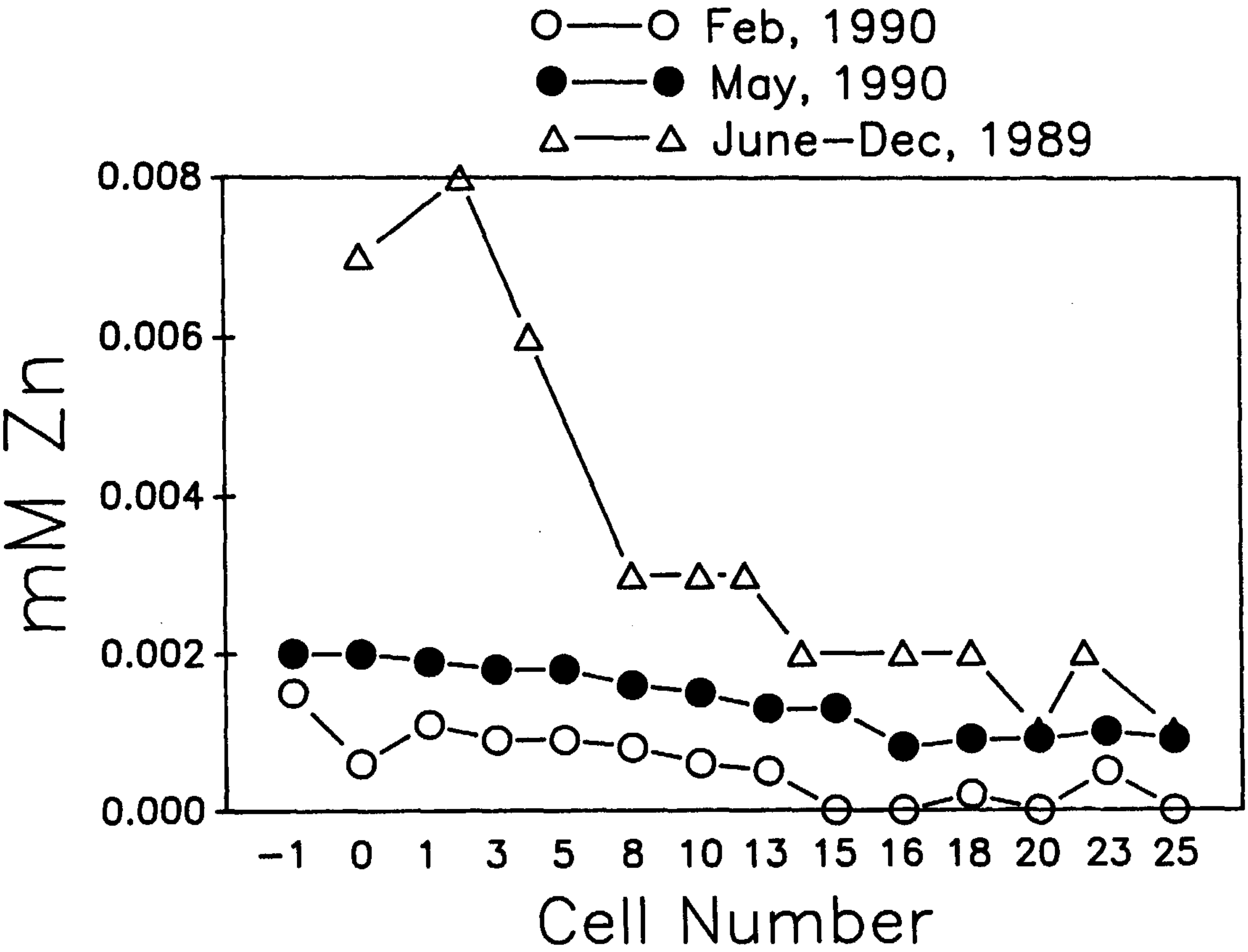

O——O Feb, 1990
●——● May, 1990
Δ——Δ June–Dec, 1989
mM Zn
0.008
0.006
0.004
0.002
0.000
–1
0
1
3
5
8
10
13
15
16
18
20
23
25
Cell Number

FIG. 5

FIG. 6

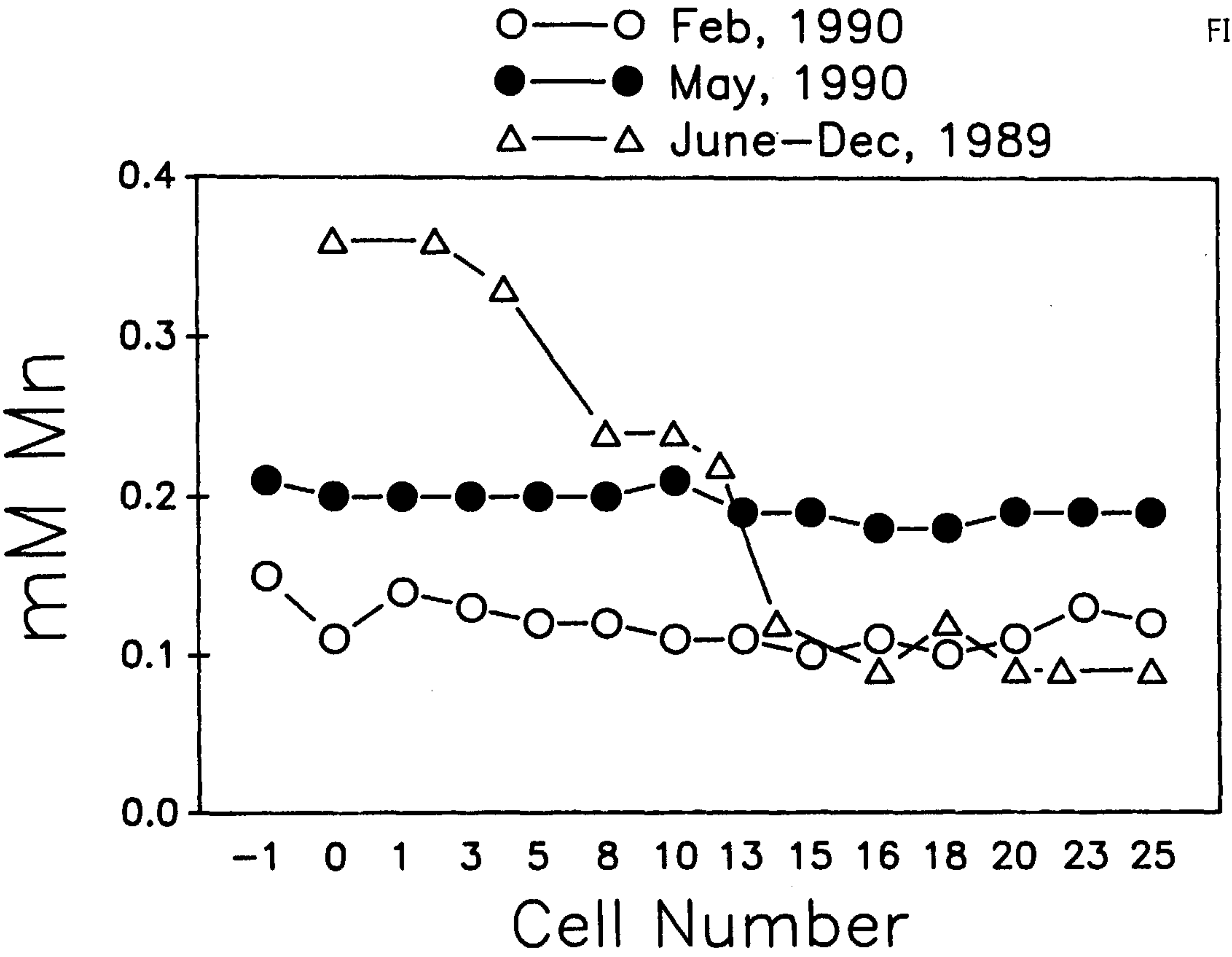
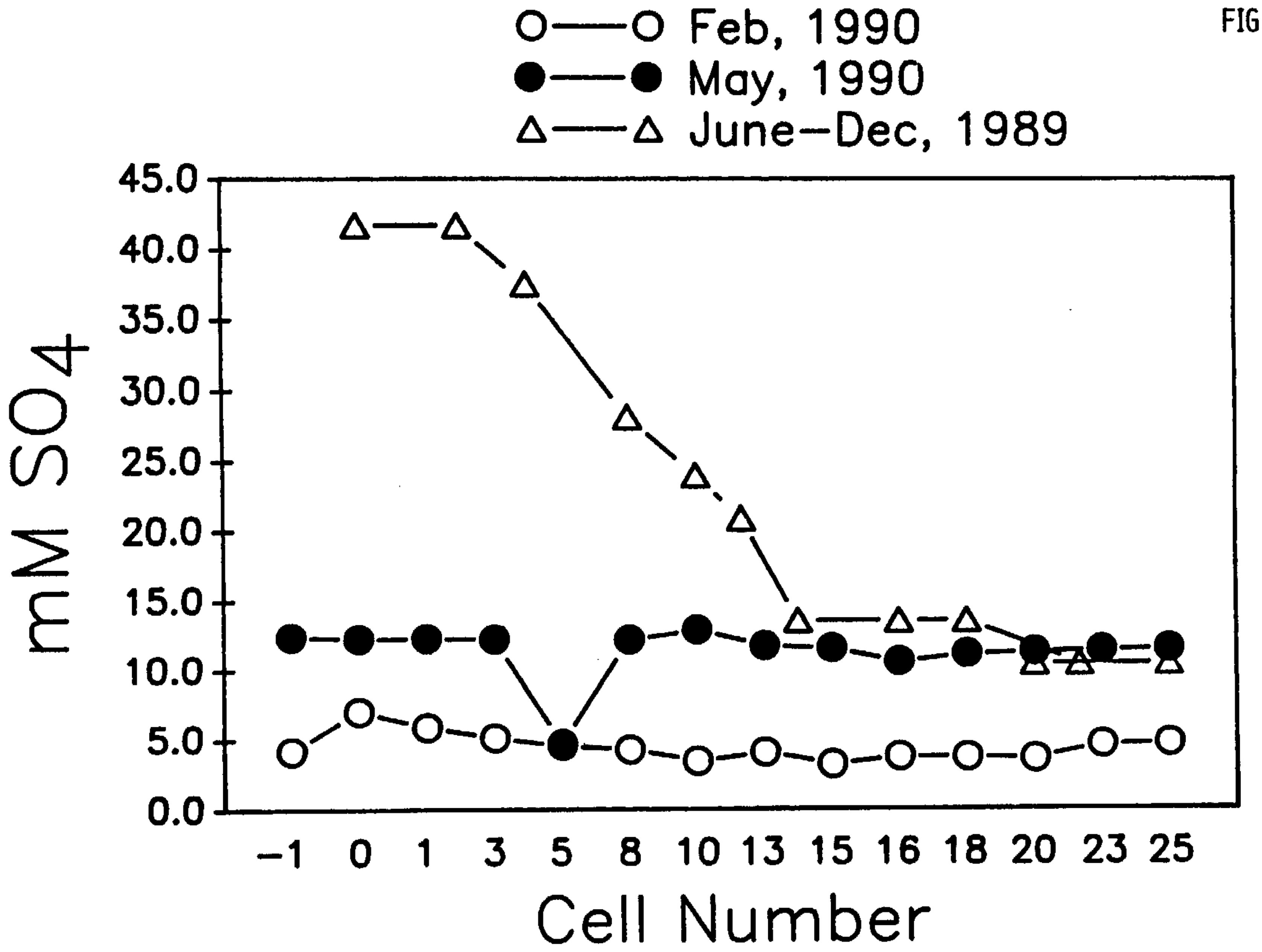

Feb, 1990
May, 1990
June-Dec, 1989
mM Mn
0.0
0.1
0.2
0.3
0.4
-1
0
1
3
5
8
10
13
15
16
18
20
23
25
Cell Number

FIG. 7



Feb, 1990
May, 1990
June–Dec, 1989
mM SO_4
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
–1
0
1
3
5
8
10
13
15
16
18
20
23
25
Cell Number

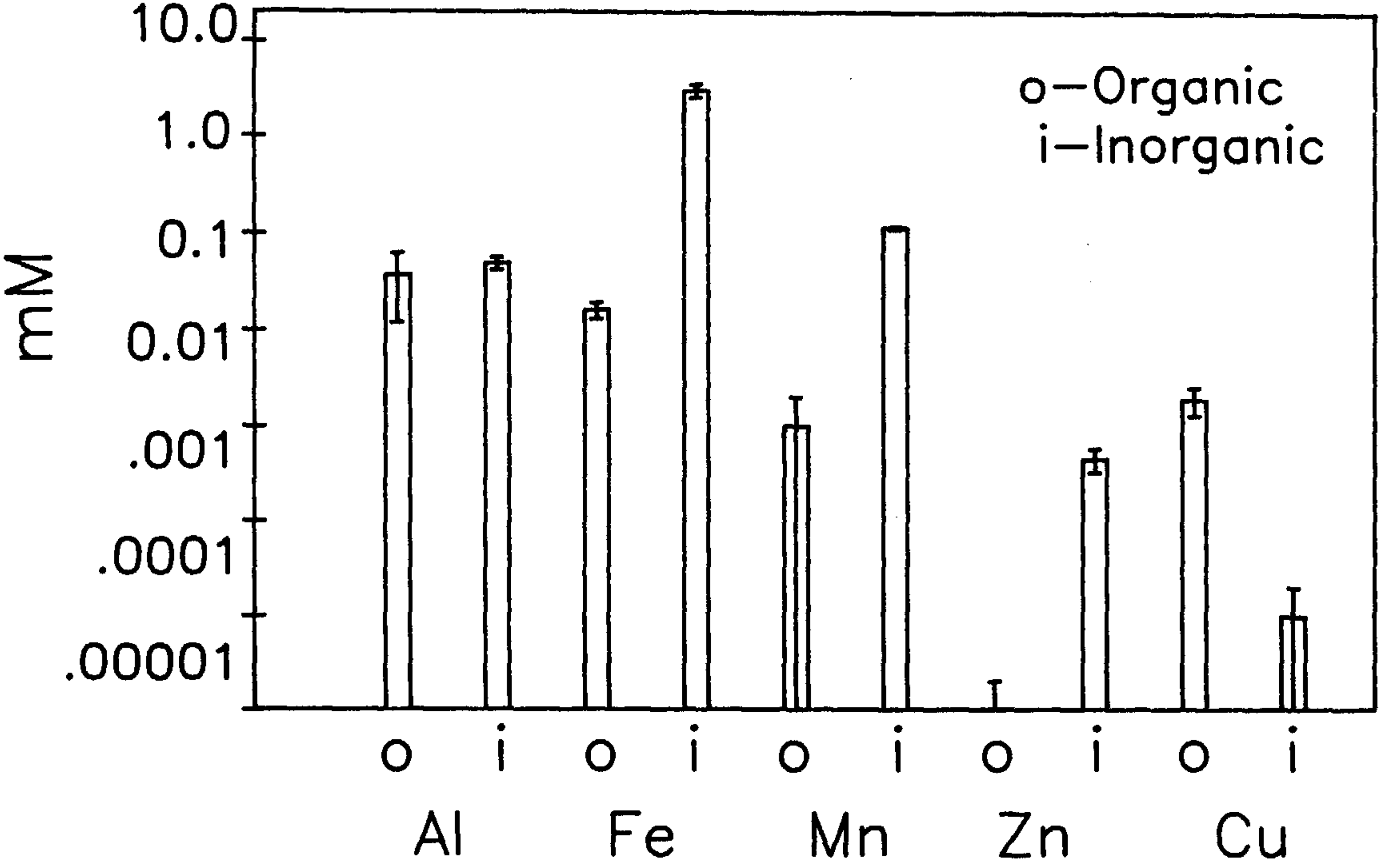
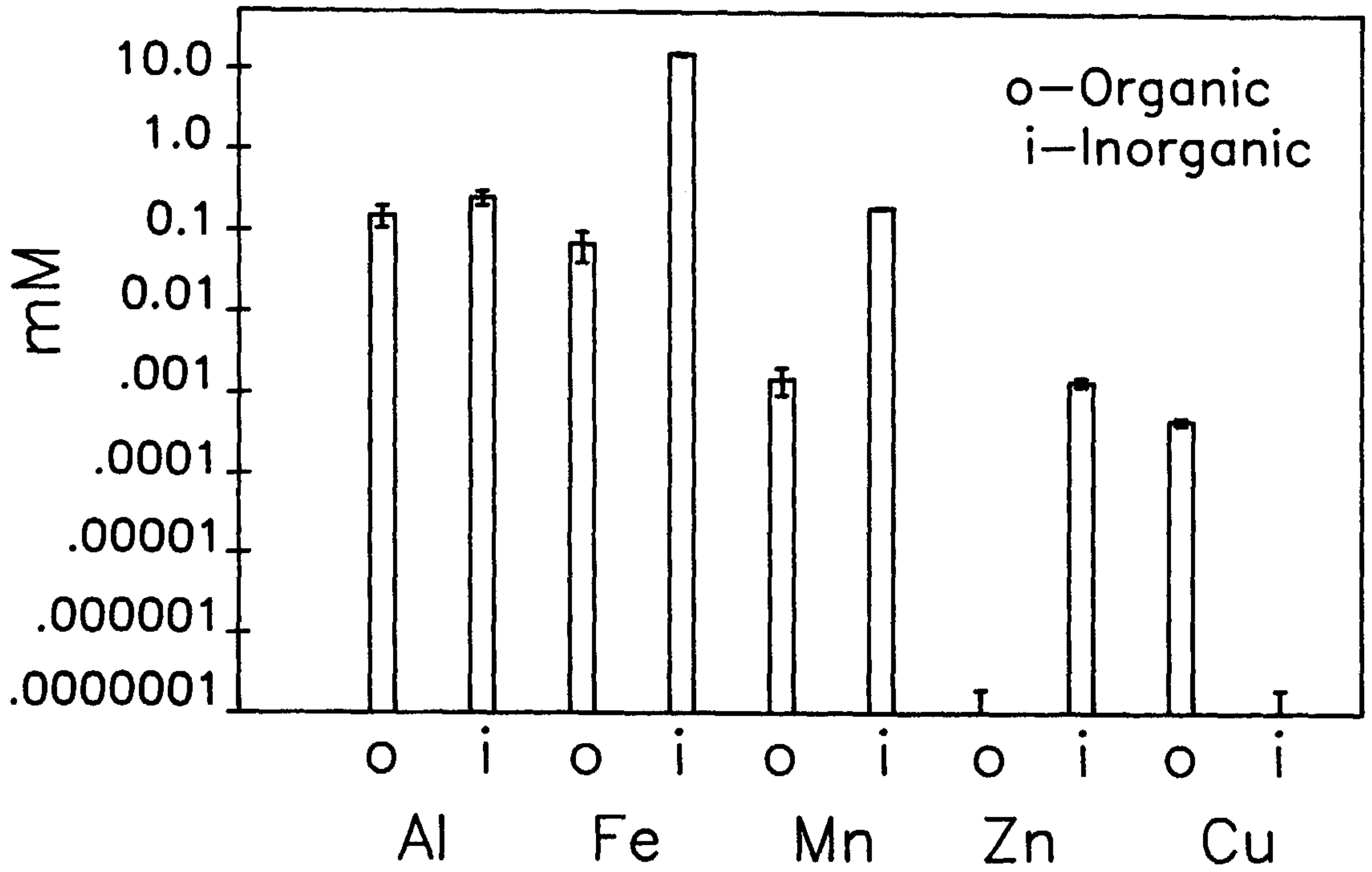


FIG. 8

Metal Speciation in Surface Effluents (Feb, 1990)

FIG. 9



Metal Speciation in Surface Effluents (May, 1990)

FIG. 10

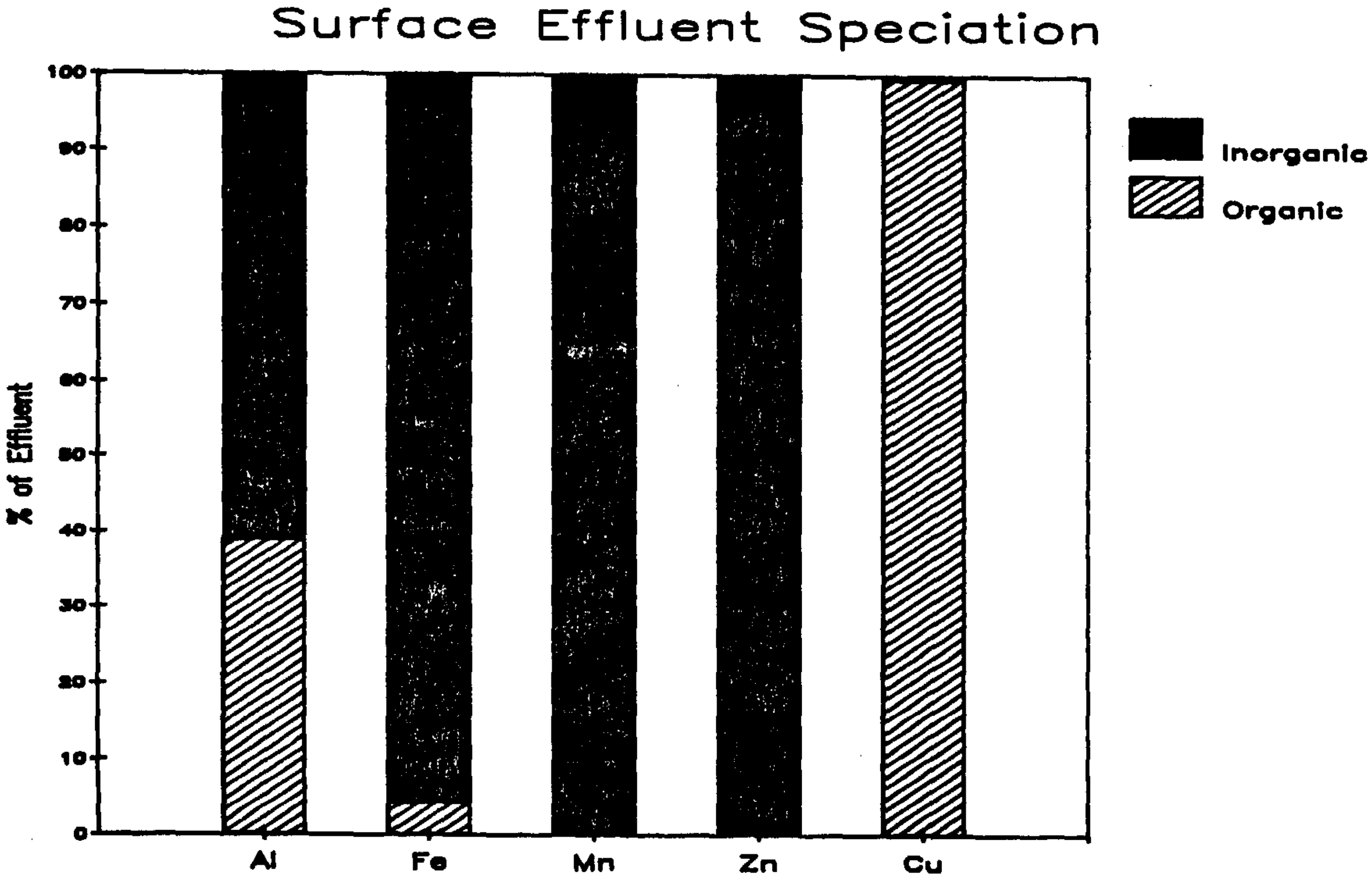

Surface Effluent Speciation
% of Effluent
100
90
80
70
60
50
40
30
20
10
0
Al
Fe
Mn
Zn
Cu
Inorganic
Organic

FIG. 11

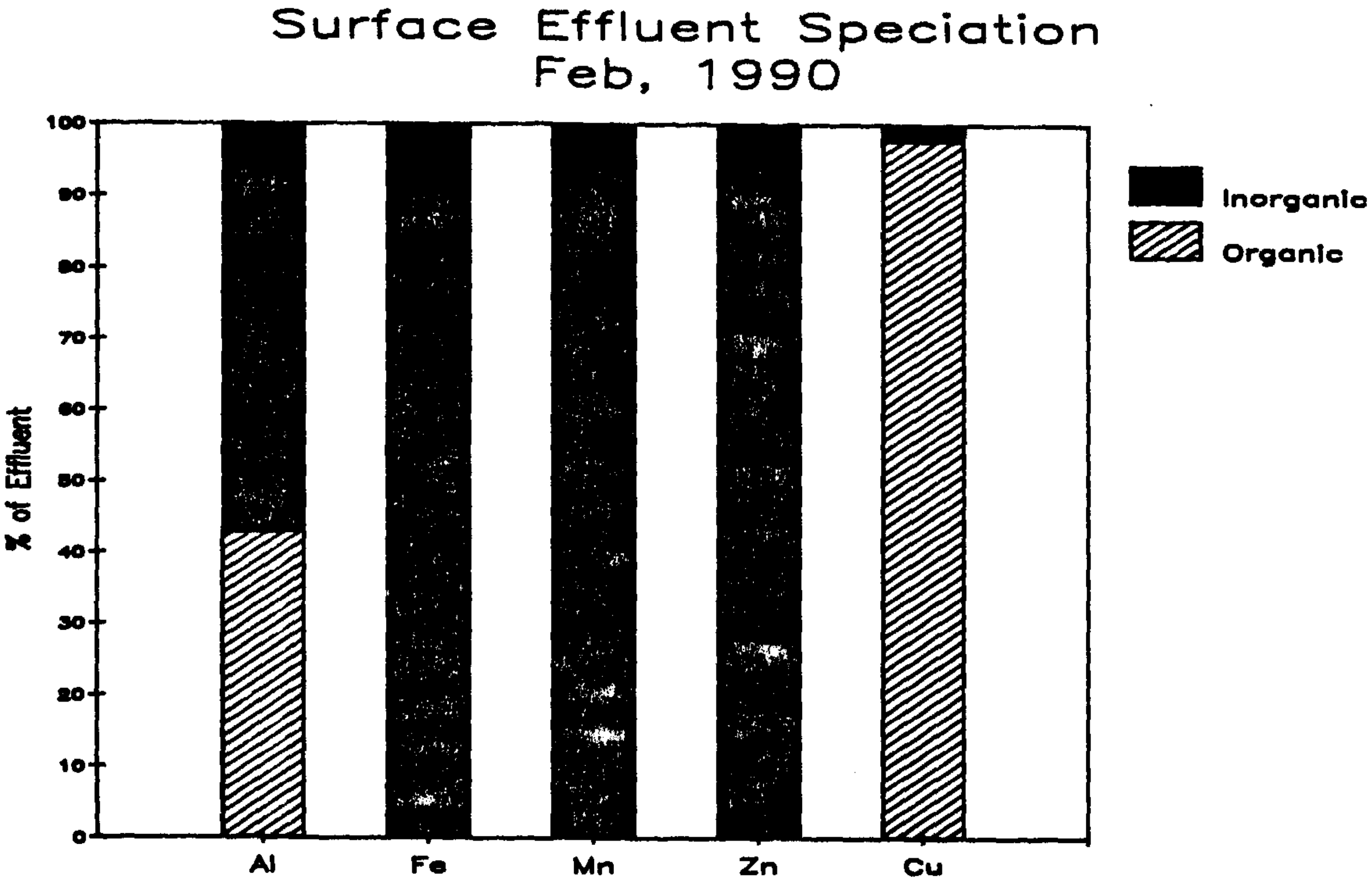

Surface Effluent Speciation
Feb, 1990
% of Effluent
100
90
80
70
60
50
40
30
20
10
0
Al
Fe
Mn
Zn
Cu
Inorganic
Organic

FIG. 12

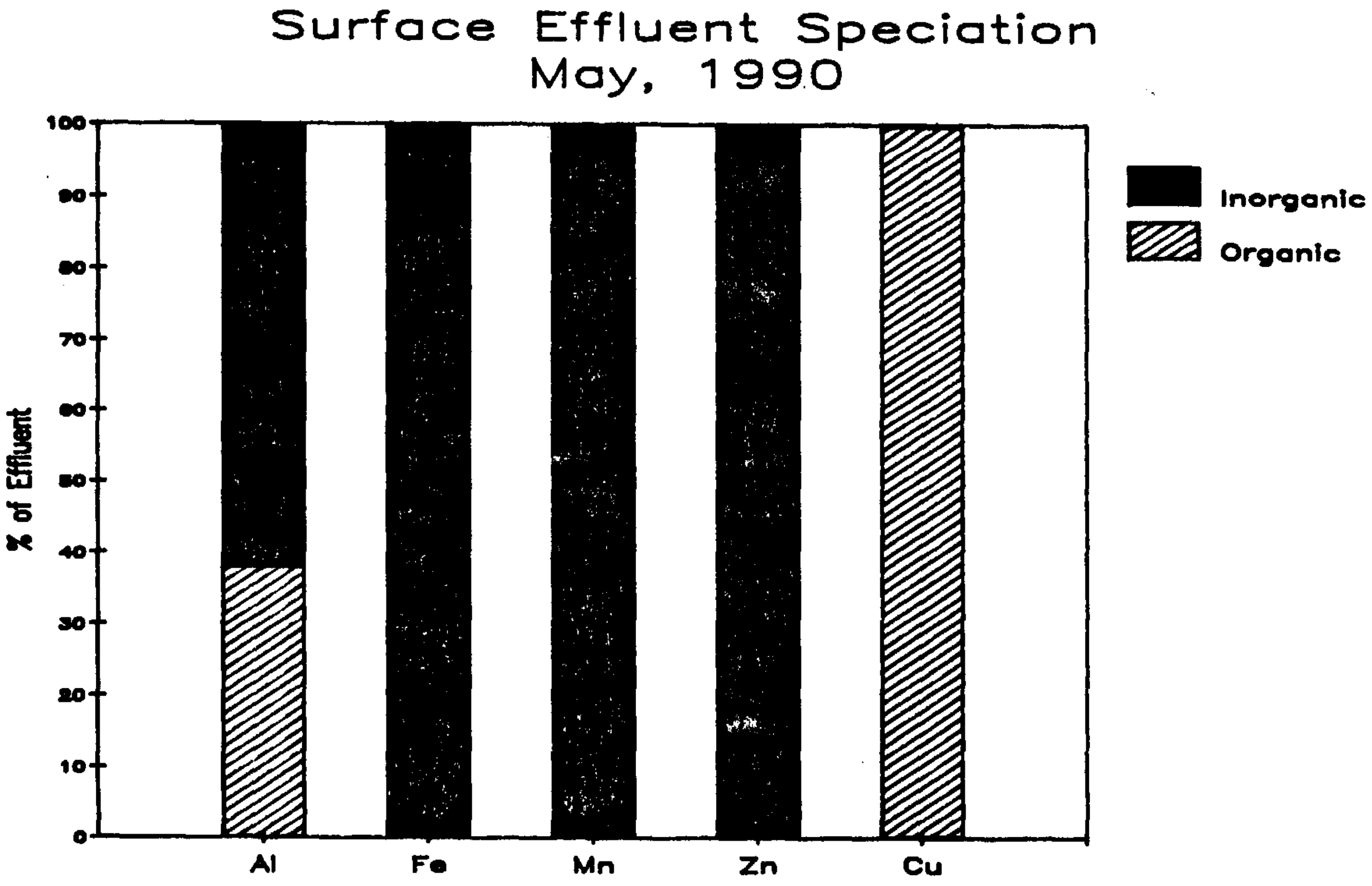

Surface Effluent Speciation
May, 1990
% of Effluent
0
10
20
30
40
50
60
70
80
90
100
Al
Fe
Mn
Zn
Cu
Inorganic
Organic

FIG. 13

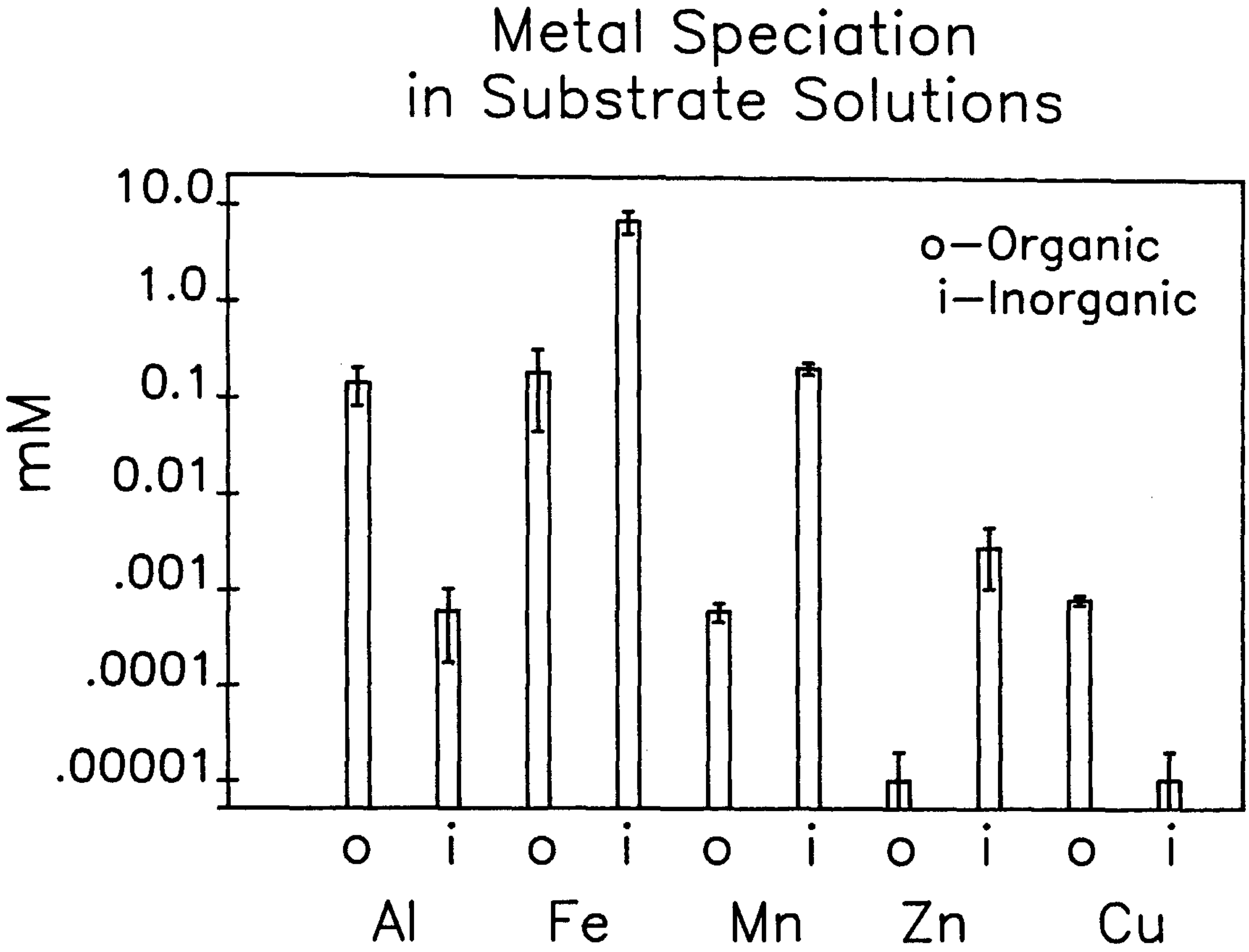

Metal Speciation
in Substrate Solutions
o–Organic
i–Inorganic
mM
10.0
1.0
0.1
0.01
.001
.0001
.00001
o
i
o
i
o
i
o
i
o
i
Al
Fe
Mn
Zn
Cu

FIG. 14

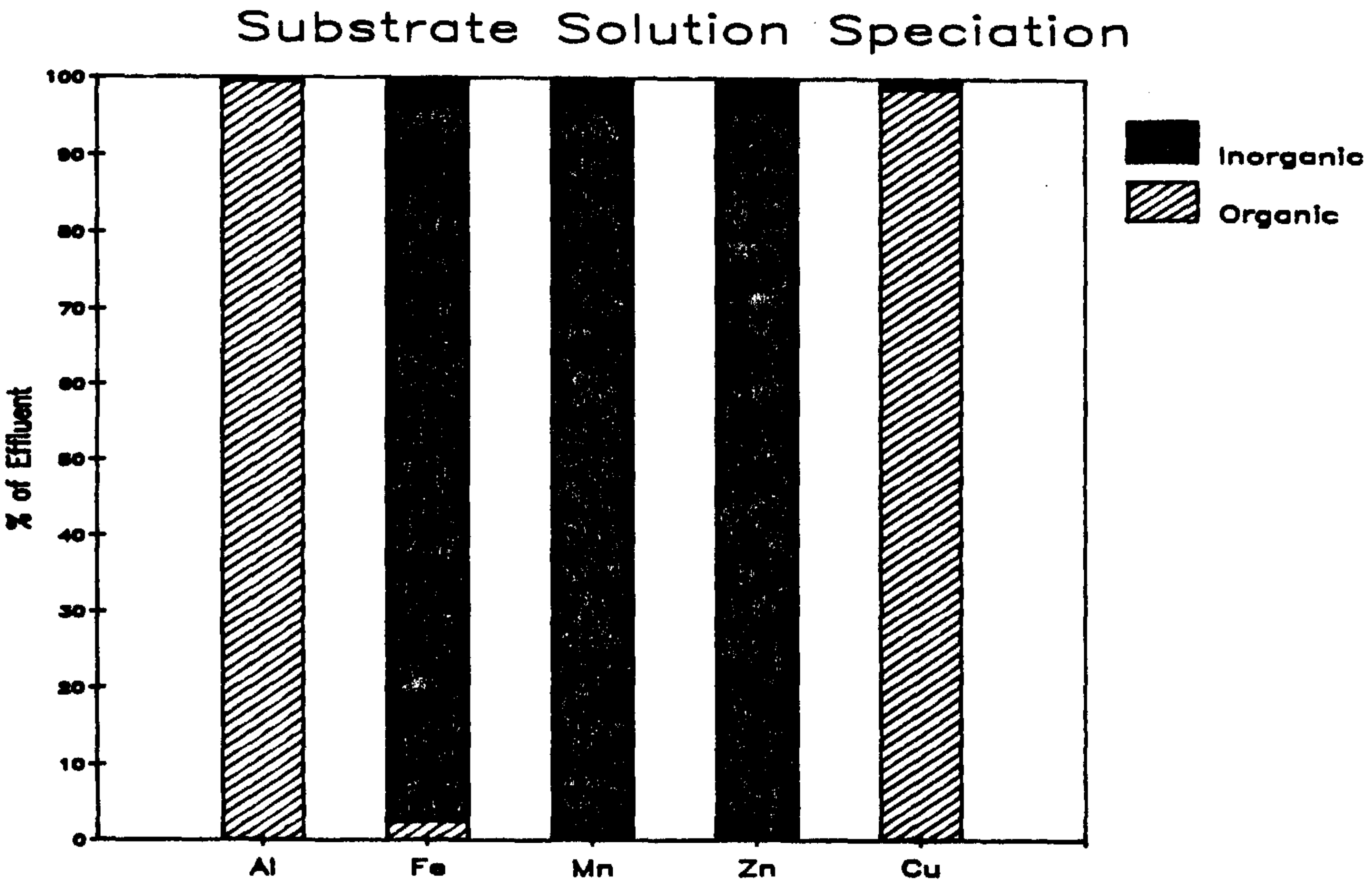
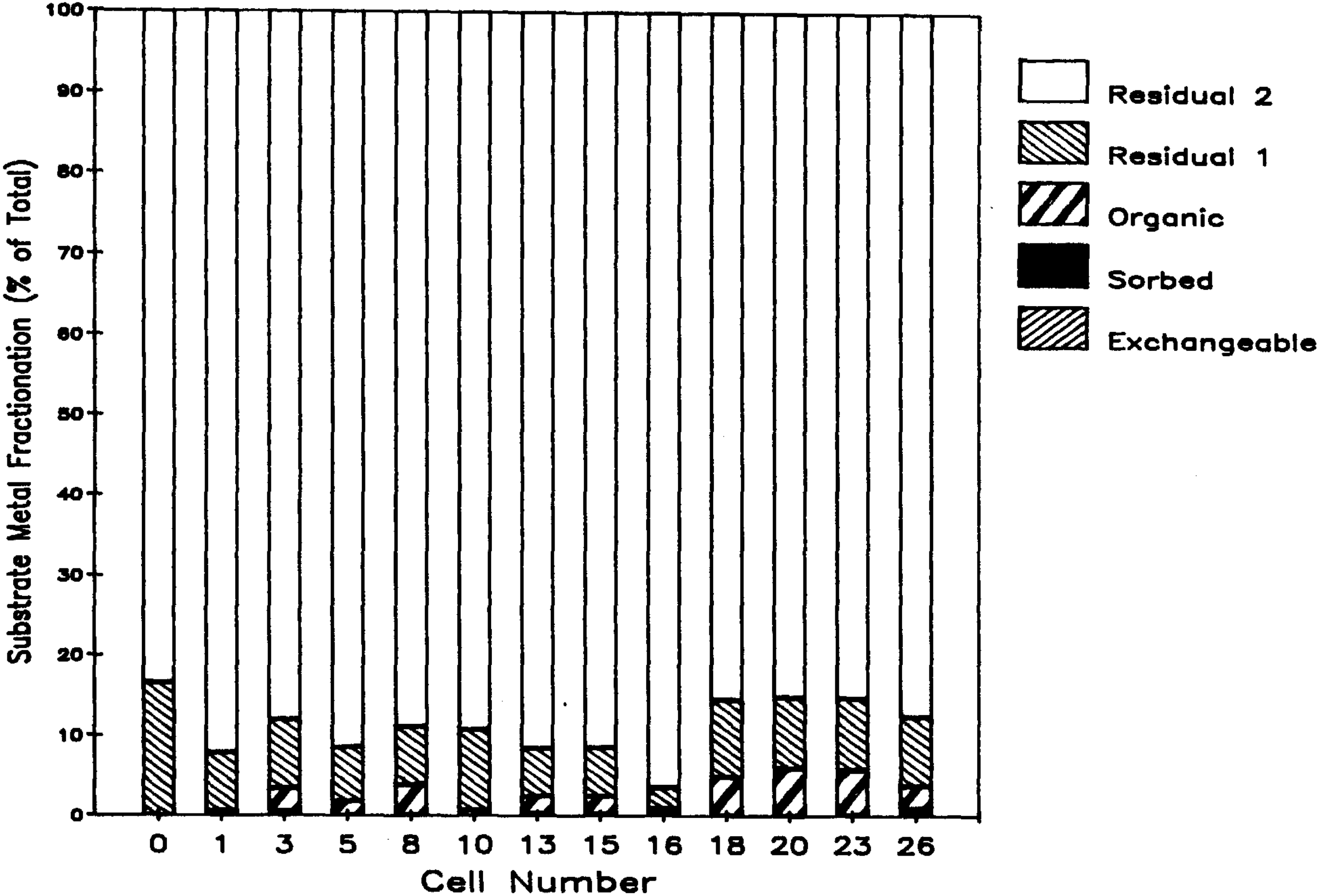

Substrate Solution Speciation
% of Effluent
100
90
80
70
60
50
40
30
20
10
0
Al
Fe
Mn
Zn
Cu
Inorganic
Organic

FIG. 15



Fe

Substrate Metal Fractionation (% of Total)
0
10
20
30
40
50
60
70
80
90
100
0
1
3
5
8
10
13
15
16
18
20
23
26
Cell Number
Residual 2
Residual 1
Organic
Sorbed
Exchangeable

FIG. 16

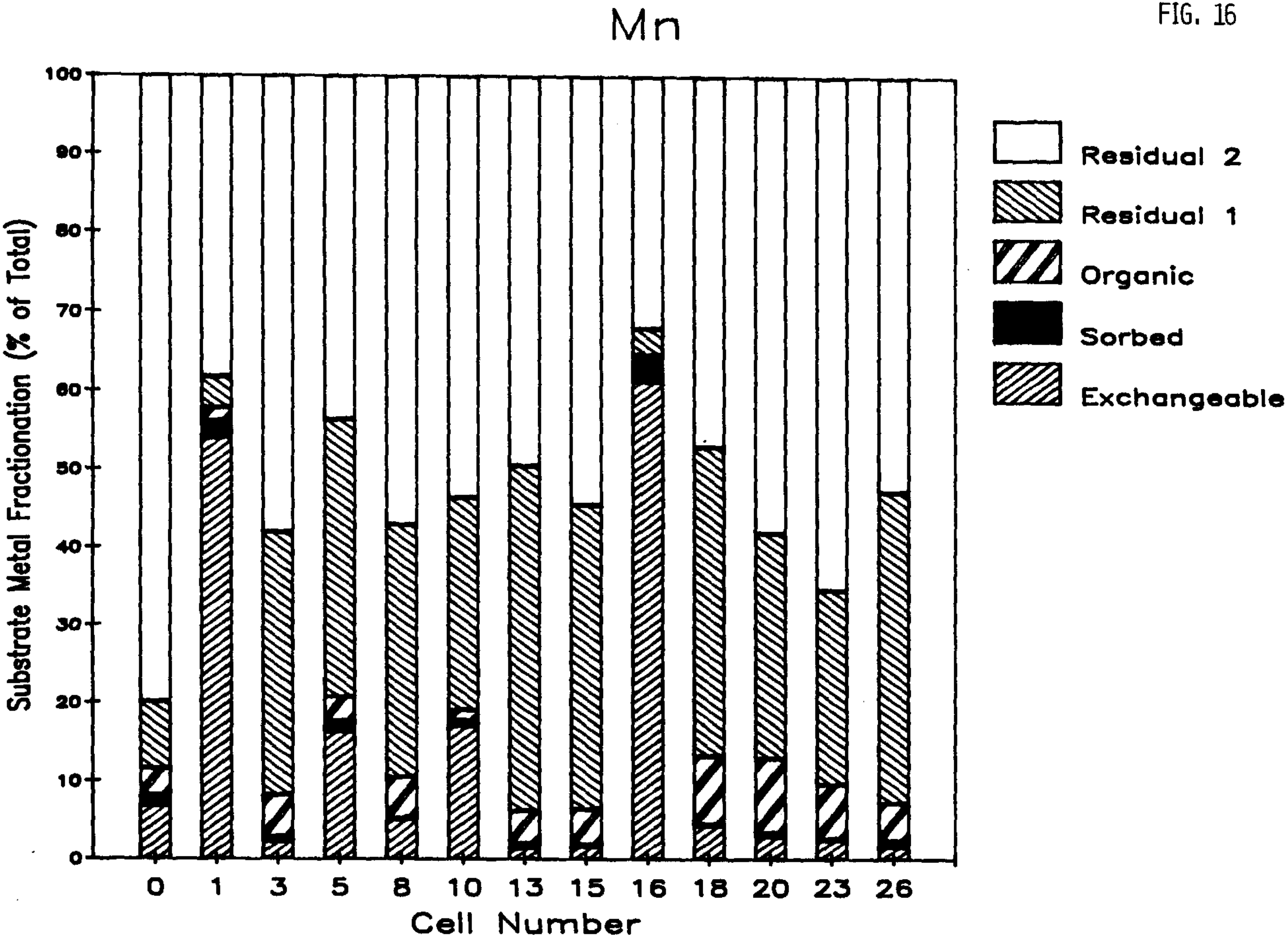

Mn
Substrate Metal Fractionation (% of Total)
100
90
80
70
60
50
40
30
20
10
0
0
1
3
5
8
10
13
15
16
18
20
23
26
Cell Number
Residual 2
Residual 1
Organic
Sorbed
Exchangeable

FIG. 17

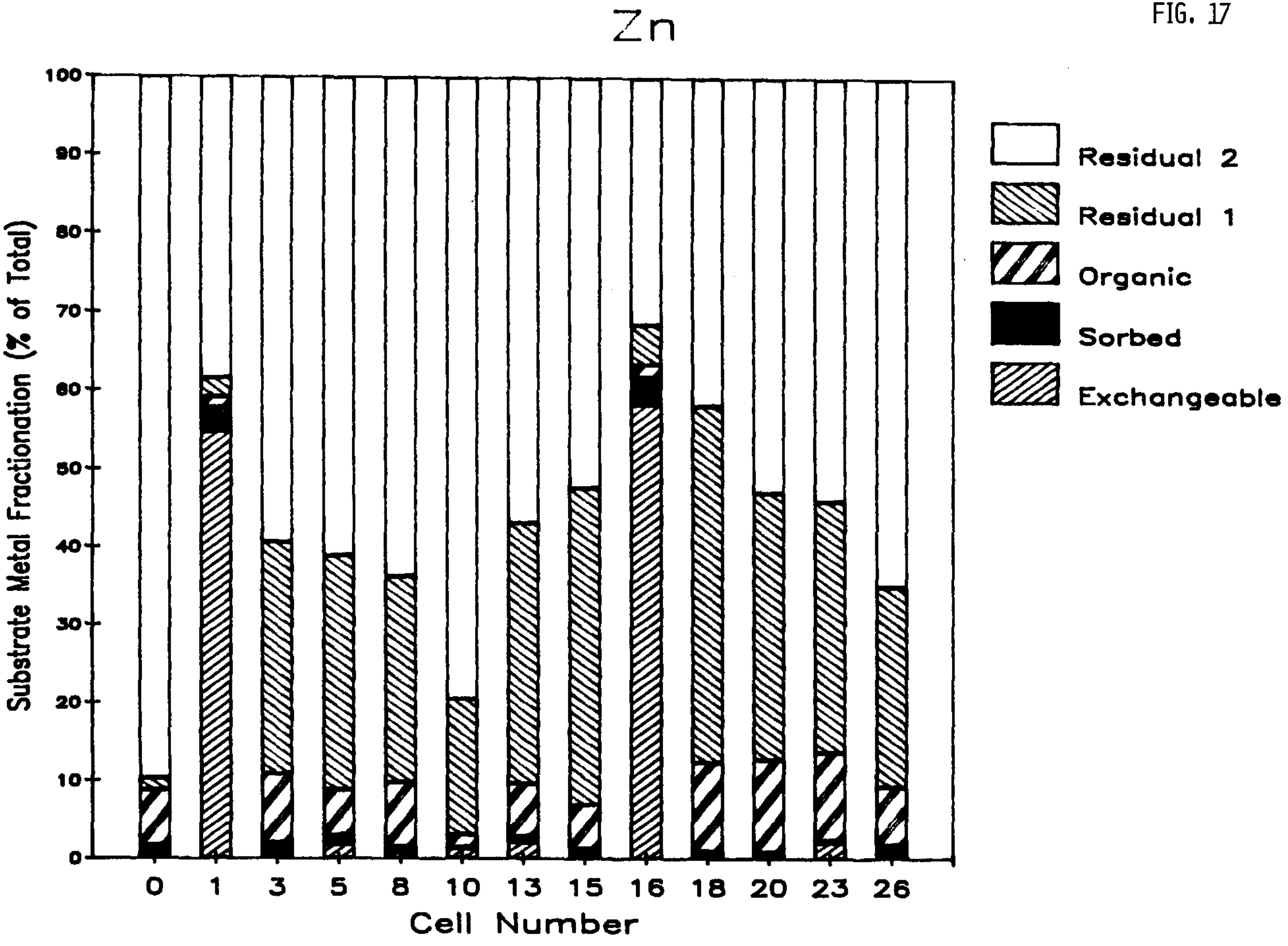

Zn
Substrate Metal Fractionation (% of Total)
100
90
80
70
60
50
40
30
20
10
0
0
1
3
5
8
10
13
15
16
18
20
23
26
Cell Number
Residual 2
Residual 1
Organic
Sorbed
Exchangeable

FIG. 18

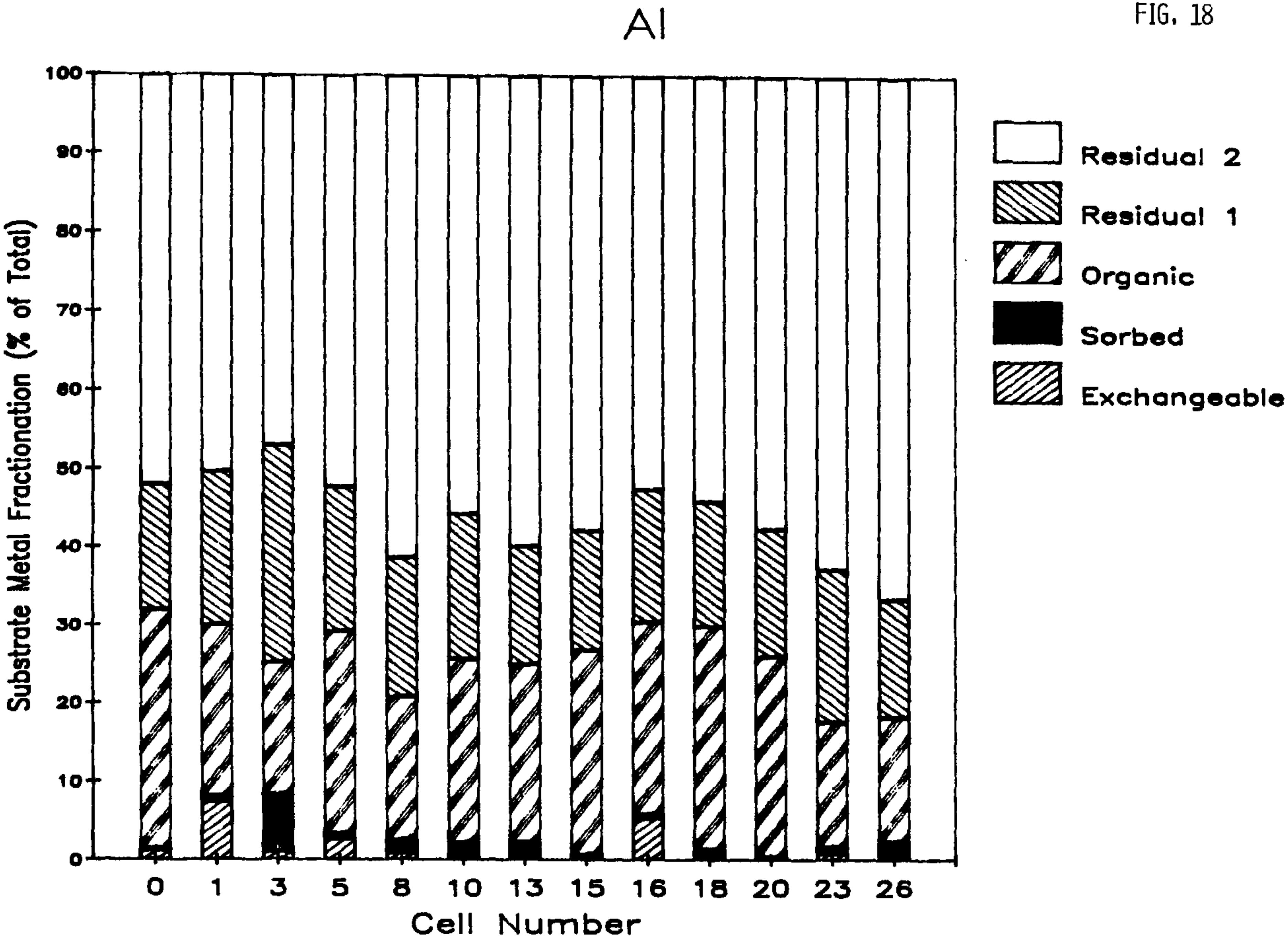
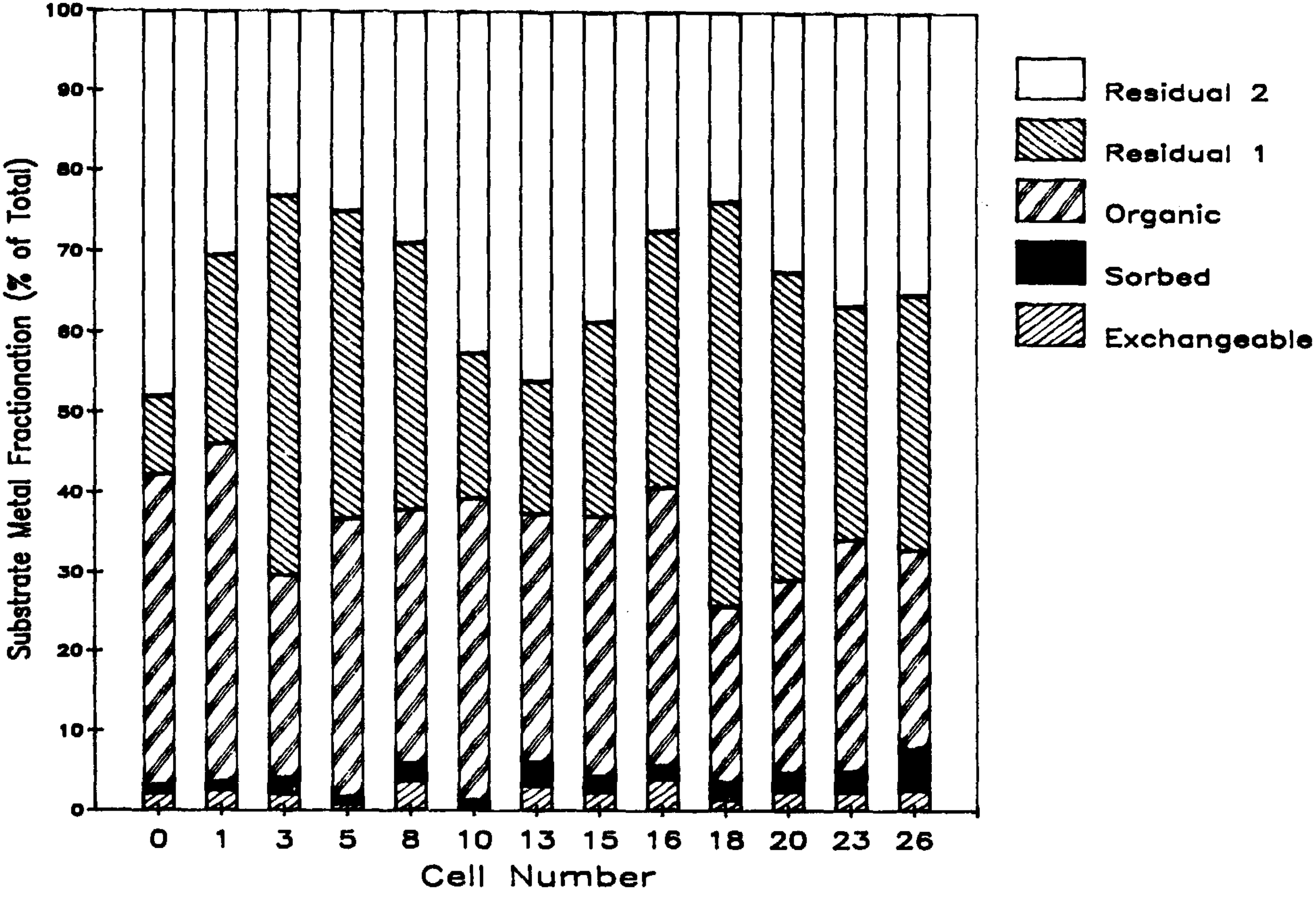

Al
Substrate Metal Fractionation (% of Total)
100
90
80
70
60
50
40
30
20
10
0
0
1
3
5
8
10
13
15
16
18
20
23
26
Cell Number
Residual 2
Residual 1
Organic
Sorbed
Exchangeable

FIG. 19


Cu
Substrate Metal Fractionation (% of Total)
100
90
80
70
60
50
40
30
20
10
0
0
1
3
5
8
10
13
15
16
18
20
23
26
Cell Number
Residual 2
Residual 1
Organic
Sorbed
Exchangeable

LIST OF TABLES

Table 1. Surface water composition (February, 1990) of the Jones Branch wetland established by the U.S. Forest Service in McCreary County, Kentucky.

Cell Number	pH	Ca	Mg	Na	K	Fe	Mn	Cu†	Zn	Al	Cl	SO_4
		mM										
Inlet	3.38	0.034	0.085	0.029	0.021	0.012	0.005	0	0.0005	0.052	0.25	0.064
-1	3.17	3.10	3.02	3.98	0.067	8.65	0.15	0	0.0015	0.094	0.44	4.15
0	2.90	2.04	1.91	2.74	0.085	5.60	0.11	0	0.0006	0.060	0.43	7.02
1	2.77	2.78	2.70	3.57	0.11	6.50	0.14	0	0.0011	0.092	0.47	5.88
3	2.80	2.60	2.52	3.29	0.10	5.85	0.13	0	0.0009	0.086	0.45	5.11
5	2.65	2.46	2.37	2.90	0.10	4.59	0.12	0	0.0009	0.082	0.37	4.51
8	2.65	2.38	2.18	3.06	0.11	3.80	0.12	0	0.0008	0.077	0.39	4.25
10	2.68	2.31	2.04	2.78	0.11	3.31	0.11	0	0.0006	0.069	0.00	3.41
13	2.72	2.41	2.02	2.39	0.15	3.02	0.11	0	0.0005	0.064	0.38	4.05
15	2.71	2.23	1.64	1.86	0.17	2.29	0.10	0	0.00	0.052	0.00	3.18
16	2.73	2.54	1.82	1.98	0.18	2.25	0.11	0	0.00	0.053	0.48	3.73
18	2.75	2.84	1.92	2.03	0.18	1.53	0.10	0	0.0002	0.052	0.52	3.69
20	2.73	2.83	1.92	2.03	0.19	1.62	0.11	0	0.00	0.054	0.48	3.59
23	2.65	3.60	2.51	2.52	0.22	2.21	0.13	0	0.0005	0.077	0.46	4.60
25	2.68	3.70	2.33	2.36	1.40	1.90	0.12	0	0.00	0.056	0.44	4.68

† Below detection limits

Table 2. Composition of substrate solutions (February 1990) extracted by centrifugation from the Jones Branch wetland constructed by U.S. Forest Service in McCreary County, Kentucky.

Cell Number	pH	Ca	Mg	K	Na	Fe	Mn	Cu	Zn	Al	Cl	SO_4
							-mM-					
0	4.05	13.09	4.70	0.18	3.90	13.68	0.23	0.0010	0.0069	0.02	0.25	12.58
1	3.08	3.97	2.93	0.13	3.12	13.80	0.15	0.0006	0.0185	0.11	0.01	8.63
3	4.03	12.57	4.90	0.23	4.63	8.12	0.35	0.0005	0.0008	0	0.05	10.67
5	5.84	11.53	4.82	0.61	4.38	13.34	0.30	0.0005	0.0009	0.002	0.09	12.68
8	6.62	14.61	5.87	3.71	5.09	2.80	0.21	0.0005	0.0009	0.008	0.56	11.45
10	5.52	11.87	4.87	0.74	4.46	17.71	0.43	0.0005	0.0006	0.0015	0.05	14.79
13	6.09	13.52	4.43	2.54	3.71	4.71	0.21	0.0003	0.0008	0	0.82	10.40
15	6.25	12.81	3.85	1.07	4.24	4.88	0.23	0.0003	0.0008	0.0015	0.19	8.85
16	3.38	3.85	2.60	0.19	2.37	14.84	0.15	0.0005	0.0262	0.083	0.04	9.13
18	5.74	11.50	3.83	0.22	3.35	5.67	0.17	0.0003	0.0022	0.004	0.03	9.64
20	6.36	13.23	3.87	1.65	3.56	4.17	0.15	0.0003	0.0008	0	0.06	8.27
23	6.44	12.74	3.70	0.81	3.79	3.16	0.15	0.0002	0.0008	0.003	0.03	8.20
25	6.77	4.35	4.77	3.35	5.02	1.01	0.09	0.0003	0.0009	0	0.20	10.66
Entry Flume	3.55	1.62	1.57	0.07	1.03	8.39	0.09	0.0003	0.0025	0.073	0.01	4.87
Flume 1	3.06	2.17	2.24	0.11	2.92	12.93	0.11	0.0010	0.0023	0.22	0.86	7.41
Flume 2	2.91	2.04	1.93	0.19	1.98	19.06	0.10	0.0017	0.0042	0.14	0.08	9.18

Table 3. Surface water composition (May, 1990) of the Jones Branch wetland established by the U.S. Forest Service in McCreary County, Kentucky.

Cell number	pH	Ca	Mg	Na	K	Fe	Mn	Cu	Zn	Al	Cl	SO_4
		mM										
Inlet	3.75	2.48	2.11	1.99	0.10	6.24	0.08	0	0.0009	0.14	0.18	4.50
-1	3.19	6.20	5.77	6.81	0.90	17.16	0.21	0.0001	0.0020	0.34	0.13	12.36
0	3.28	6.34	5.73	5.76	0.91	17.14	0.20	0	0.0020	0.40	0.14	12.24
1	3.03	6.41	5.85	5.95	0.93	15.68	0.20	0.0001	0.0019	0.41	0.23	12.27
3	3.02	6.34	5.68	6.00	0.92	15.83	0.20	0.0003	0.0018	0.44	0.24	12.22
5	3.10	6.43	5.82	6.06	0.96	16.36	0.20	0.0003	0.0018	0.39	0.24	4.68
8	3.07	6.48	5.70	6.00	0.99	16.61	0.20	0.0003	0.0016	0.46	0.26	12.17
10	3.09	6.41	5.80	6.03	0.98	16.01	0.21	0.0003	0.0015	0.40	0.24	12.86
13	3.11	6.14	5.52	5.81	0.99	16.08	0.19	0.0003	0.0013	0.36	0.24	11.71
15	3.07	6.32	5.57	5.79	1.01	15.86	0.19	0.0003	0.0013	0.37	0.15	11.53
16	3.02	5.90	5.03	5.13	0.95	14.36	0.18	0	0.0008	0.35	0.19	10.56
18	3.02	6.25	5.37	5.39	0.98	13.72	0.18	0	0.0009	0.39	0.23	11.11
20	2.96	6.28	5.40	5.48	1.01	14.02	0.19	0	0.0009	0.43	0.24	11.26
23	2.99	6.39	5.43	5.52	1.04	14.00	0.19	0	0.0010	0.38	0.24	11.39
25	2.96	6.53	5.60	5.62	1.04	14.40	0.19	0	0.0009	0.41	0.23	11.47

Table 4. Exchangeable metal concentrations in substrates of the Jones Branch wetland as determined by 0.5 M KNO_3 extraction (February, 1990).

Cell Number	Fe	Mn	Cu	Zn	Al
			-µg/g-		
0	4.00	3.50	0.25	0.19	70.63
1	272.50	32.13	0.63	33.75	392.50
3	5.50	5.25	0.69	0.38	45.00
5	8.75	32.06	0.25	1.69	162.50
8	7.88	6.69	0.81	0.50	51.88
10	0.56	18.38	0.00	0.56	0.63
13	14.57	3.38	0.50	1.25	15.00
15	3.00	5.00	0.56	0.25	5.63
16	1092.50	47.88	0.81	29.38	350.00
18	6.00	8.44	0.50	0.88	18.75
20	8.25	8.88	1.00	0.63	12.50
23	8.13	7.25	0.69	2.06	38.75
25	18.13	4.44	0.56	0.31	19.38
Entry Flume	445.00	9.75	0.50	1.69	554.38
Flume 1	1120.60	7.75	0.31	2.13	195.00
Flume 2	1055.60	17.44	1.50	3.44	182.50

Table 5. Sorbed forms of heavy metal concentrations in substrates of the Jones Branch wetland as determined by H_2O extraction (February, 1990).

Cell Number	Fe	Mn	Cu	Zn	Al
	- - - - - - - - - - - - - -	- - - - - -μg/g-	- - - - - - - -	- - - - - -	- - - -
0	1.63	0.75	0.13	0.32	19.72
1	13.76	1.38	0.25	1.93	46.58
3	318.38	1.63	0.69	1.61	324.55
5	41.94	2.88	0.25	1.21	50.16
8	58.06	0.75	0.50	0.40	105.71
10	37.38	0.88	0.13	0.09	131.98
13	153.75	1.56	0.50	0.56	105.46
15	200.00	0.88	0.50	0.86	51.50
16	128.06	2.56	0.38	1.79	43.99
18	22.50	0.31	0.75	0.71	63.62
20	51.25	1.50	0.94	0.42	21.14
23	46.06	0.50	0.75	0.41	39.74
25	371.88	2.44	1.13	0.77	157.25
Entry Flume	10.88	0.50	0.75	0.24	26.94
Flume 1	79.94	0.25	0.75	0.07	17.64
Flume 2	95.06	0.75	0.63	0.09	13.62

Table 6. Concentrations of organically bound metals in substrates of Jones Branch wetland as determined by 0.5M NaOH extraction (February, 1990).

Cell Number	Fe	Mn	Cu	Zn	Al
	----------------	----------------	-µg/g-	----------------	----------------
0	33.44	1.75	4.50	2.06	1832.25
1	317.50	0.94	9.94	0.81	1153.50
3	1637.50	12.63	8.31	8.31	733.63
5	1837.50	6.19	9.13	5.31	1521.75
8	1406.25	19.00	6.88	4.75	1089.50
10	338.13	1.50	3.38	0.69	1262.88
13	881.88	9.75	5.06	4.00	1151.25
15	1343.75	14.38	7.81	4.88	1694.50
16	153.94	0.19	7.25	0.81	1599.13
18	1787.50	17.00	7.56	16.19	1674.13
20	2393.75	29.31	9.75	13.31	1498.38
23	1581.25	20.00	8.38	11.13	701.13
25	1061.25	13.69	5.44	4.56	1118.38
Entry Flume	18.44	0.13	0.75	0.56	1449.63
Flume 1	43.81	0.44	0.38	1.19	94.39
Flume 2	55.69	0.06	2.88	0.13	101.38

Table 7. Heavy metal concentrations of residual 1 forms in substrates of Jones Branch wetland as determined by 0.05M Na$_2$EDTA extraction (February, 1990).

Cell Number	Fe	Mn	Cu	Zn	Al
	μg/g				
0	13,037.50	4.38	1.13	0.44	963.88
1	6,384.40	2.38	5.56	1.50	1034.69
3	4,809.40	79.81	15.44	28.13	1211.38
5	6,884.40	70.38	10.00	28.13	1094.63
8	2,681.25	117.31	7.19	15.00	1071.31
10	4,578.10	29.75	1.63	7.25	1020.06
13	2,481.20	104.38	5.00	20.00	776.50
15	3,653.13	123.75	9.19	34.38	1012.06
16	8,387.50	2.56	6.63	2.56	1116.69
18	3,490.60	77.06	17.25	65.00	944.63
20	3,587.50	89.44	15.50	38.13	968.94
23	2,509.40	71.88	11.31	31.88	867.69
25	3,206.30	112.81	6.94	15.63	1077.56
Entry Flume	4,337.50	1.19	0.69	1.38	1939.69
Flume 1	11,375.00	0.31	0.31	0.38	18.44
Flume 2	10,812.50	2.75	1.63	1.06	20.81

Table 8. Heavy metal concentrations of residual 2 forms in substrates of Jones Branch wetland as determined by 4M HNO_3 extraction (February 1990).

Cell Number	Fe	Mn	Cu	Zn	Al
			-µg/g-		
0	65,650.00	41.13	5.56	25.94	3121.88
1	80,800.00	22.75	7.13	23.75	2650.00
3	49,475.00	137.50	7.63	56.25	2038.13
5	94,250.00	86.19	6.56	57.19	3080.63
8	33,100.00	218.44	6.25	36.25	3684.38
10	40,650.00	58.31	3.81	33.13	3034.38
13	38,350.00	117.19	5.19	34.06	3071.88
15	55,525.00	173.44	5.88	44.38	3787.50
16	125,937.00	25.13	5.69	15.94	3515.63
18	31,725.00	91.50	8.19	59.69	3190.63
20	34,700.00	180.31	13.06	59.06	3009.38
23	24,125.00	190.00	7.69	53.44	2793.75
25	32,600.00	150.94	7.69	39.69	4750.00
Entry Flume	60,450.00	27.31	7.25	17.81	7375.00
Flume 1	279,219.00	4.88	5.13	0.00	1415.63
Flume 2	217,031.00	16.19	4.38	4.06	253.73

Table 9. Total heavy metal concentrations in substrates of the Jones Branch wetland as determined by 4M HNO_3 extraction (February, 1990).

Cell Number	Fe	Mn	Cu	Zn	Al
	µg/g				
0	90,500.00	59.81	11.25	32.81	7284.38
1	117,500.00	60.63	41.13	64.69	8762.50
3	62,700.00	281.88	58.00	101.56	6628.13
5	118,906.00	250.63	60.44	102.81	6856.25
8	42,275.00	401.56	38.88	73.44	6931.25
10	52,800.00	139.38	14.75	45.63	6362.50
13	66,800.00	310.00	31.75	73.44	5725.00
15	67,550.00	389.06	54.19	84.06	8712.50
16	171,406.00	63.06	38.56	44.69	7937.50
18	41,275.00	251.25	94.38	151.25	6346.80
20	65,775.00	433.13	100.00	150.63	7459.40
23	40,325.00	363.13	70.94	128.13	6768.75
25	38,350.00	335.00	40.31	72.69	9478.13
Entry Flume	69,450.00	35.13	9.56	19.38	8396.80
Flume 1	333,437.00	8.50	5.81	0.62	1581.25
Flume 2	304,531.00	28.44	10.31	18.44	743.75