PERFORMANCE DATA ON TYPHA AND SPHAGNUM WETLANDS CONSTRUCTED TO TREAT COAL MINE DRAINAGE

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ABSTRACT

The construction of ecological systems to treat acid mine water is a recently developed ameliorative technology. In a study of systems constructed prior to 1986 in the Appalachian bituminous coal region, two plants were frequently found as dominant vegetation: <u>Sphagnum</u> (moss) and <u>Typha</u> (cattails). Systems were designed to mimic natural ecosystems dominated by one or the other vegetation type, or a combination of the two in the same plot or sequential plots. Data analysis of individual plots indicates that systems which include both cattails and moss show the greatest difference between inflow and outflow metal and acidity concentrations. Iron, manganese, and suspended solids concentrations were lowered to the greatest extent in these systems, and pH showed the largest increase (decrease in hydrogen ion concentration). However, net acidity was higher in effluent, and sulfate concentrations were essentially unchanged. Sphagnum-dominated constructed wetland plots were noteworthy for their long turnover times (156 hours) and the increased concentrations of manganese in effluent water. Typha-dominated wetland plots showed shortest turnover times (median of 19.1 hours), slight modification of pH, and no impact on suspended solids load. In relation to contact time, <u>Typha</u> systems showed the highest average concentration change per contact hour, more than 10 times that of <u>Sphagnum</u> dominated systems. Volume to flow path length ratios were found to be comparable for all three system vegetation types.

INTRODUCTION

Constructed ecosystems using wetland vegetation types have become increasingly popular as an alternative water treatment method for effluent from mined sites. They are also being considered for use on sites classified as hazardous waste sites due to high trace metal concentrations, particularly in the Rocky Mountain region. Although such ecosystems have been constructed the bituminous coal region of the Appalachians since 1983 primarily on an experimental basis, little information has been assembled on the relative and long-term effectiveness of the various designs, and particularly of the vegetation types used.

The objective of this paper is to address the question of relative effectiveness of ecosystem designs which incorporate the most common vegetation types found. It was expected at the onset of this study that large differences between design specifications and effectiveness would be apparent from surveying those systems which had been constructed prior to 1986 (i.e. systems which had time to become established). Recommended design criteria cannot, however, be extrapolated from this dataset, due to the nonstandardization of water sampling techniques and analysis methods. Systems with highest apparent treatment efficiencies identified from the survey are currently under further investigation; selected systems will be studied over the next 20 months to determine removal mechanisms, rates, and regulating factors.

METHODS

During 1986, data were collected from state agencies, system designers and constructors, and coal companies that were involved with constructed ecosystem water treatment projects in Maryland, Ohio, Pennsylvania, and West Virginia. Descriptive summaries of this dataset are presented in Girts and Kleinmann (1986) and Erickson et al. (1987). Early in 1987, information gathering for sites constructed prior to 1986 was completed; ambiguous data were verified and additional chemical data were collected. Data were summarized as physical and design features of each individual plot, and mean inflow and outflow chemical analysis results. Of particular interest were pH, net acidity, and total iron, manganese, aluminum, sulfate, and suspended sediment concentrations. Data were analyzed using statistical analysis software (SPSS); analyses conducted included descriptive statistics and correlation analysis.

RESULTS AND DISCUSSION

Before evaluating the relative efficiencies of the three vegetation system types, it was necessary to examine differences in inflow water chemistry. If raw water chemistry differs between the systems, apparent contrasts in treatment efficiency may be attributable to the original chemical environment rather than the system effectiveness.

Median chemical concentrations of influent are presented for the three system types in Table 1. In general, the Sphagnum and Typha intermingled systems receive circumneutral or alkaline water with low iron and aluminum concentrations. Manganese and sulfate concentrations are, however, comparable to the other system types. The Sphagnum and Typha monoculture (one plant type only) influents differ primarily in the lower pH, higher net acidity, iron, aluminum, and sulfate concentrations found in the Sphagnum influent. Data are more complete for Typha and mixed vegetation systems; however, samples representing Sphagnum influent chemistries were nearly all collected by the Bureau of Mines and so were collected and analyzed using identical techniques.

Treatment efficiency parameters for Sphagnum-dominated, Typha-dominated, and mixed vegetation sites are presented in Table 2. While the-ratios of inflow volume to minimum flow path length (MFPL) are similar for all three constructed ecosystem types, turnover times vary greatly, with nearly a week required to completely replace the water volume of Sphagnum systems in contrast to less than a day for water replacement in Typha systems. Such a wide range is in part an artifact of the assumption that the substrate in Typha systems allows no subsurface flow, while 60% of the total substrate volume underlying Sphagnum systems is pore space through which water can flow. Although the peat-imitating substrate in the latter systems is probably more dense than naturally accumulated peat (particularly at the sites where hay is used), the Typha substrate is probably somewhat porous (no porosity estimates are currently available). These observations would tend to result in shorter turnover times for Sphagnum plots and longer turnover times for Typha sites; a difference would still exist, however, as the median substrate thickness was found to be 18 in. in Typha systems and 30 in. in sphagnum systems.

All ecosystem types show lowered concentrations of most chemical constituents at the outflow sampling point (Table 2). Only one parameter showed increased effluent concentrations for each system type: manganese in Sphagnum systems, suspended solids in Typha systems, and net acidity in Sphagnum and Typha combined systems. The lower relative effectiveness of Sphagnum in manganese removal in comparison to iron removal has been noted in other studies (Wieder et al. 1985, Gerber et al. 1985), and recent trends in design and maintenance have focused on enhancing manganese removal ability in Typha systems. The lower effluent manganese concentrations in comparison to inflow concentrations found in Typha systems (Table 2) may reflect increasing awareness of the problem and incorporation in early wetland designs. The combined vegetation wetland types showed the greatest difference between inflow and outflow manganese contributions, implying that chemical processes within the systems are unique and not simply an additive function of Sphagnum and Typha system chemical processes.

Higher suspended solids concentrations in effluent from Typha systems (Table 2) as opposed to influent concentrations were found. Only one sample estimate was available from a Sphagnum system, with little change in concentrations with flow through -the wetland (3% decrease). Again, the wetlands of combined vegetation types demonstrate the greatest decrease in suspended solids of all system types.

Water flow through Sphagnum and Typha combined systems resulted in increased net acidity. At the same time, the hydrogen ion concentrations decreased to the greatest extent proportional to inflow concentrations of all three system types. These apparently contradictory results in the combined systems may be due to: 1) acidity from high concentrations of metal-bound humic acids, with the metals not detected in colorimetric tests; or 2) the fact that observed inflow pH in these systems is circumneutral and high alkalinities were common (Table 1). As no attempt has been made to study humic acids or to measure dissolved organic carbon in these systems, the likelihood of #1 cannot be assessed. Alkalinity of water saturated with respect to carbonate is given as 100 mg/L at 1 atm, 250C (Stumm and Morgan 1981). With calcium carbonate alkalinity of more than 100 mg/L at over 50% of these sites, these influent waters appear to be supersaturated with respect to alkalinity. Equilibrium forces alone would result in apparent lowering of alkalinity and/or generation of acidity. Also, a lower absolute decrease in hydrogen ion concentration would appear as a higher proportional decrease at higher pH ranges. Further research, however, is planned to clarify this apparent anomaly.

Iron concentrations, which were affected more by wetland treatment than any other parameter measured, showed the greatest decrease between influent and effluent waters in the Sphagnum and Typha combination systems. Decreases were comparable between Sphagnum and Typha constructed monocultures. In contrast, sulfate concentrations were altered the least of parameters measured in these systems, with Sphagnum dominated systems showing a 12% decrease in outflow over inflow concentrations. Typha-dominated and mixed vegetation systems showed minimal (1-4%) change.

Aluminum concentration data were often not available, particularly for the Sphagnum and Typha mixed plots. Comparable concentration decreases of approximately 20% were seen in the monoculture vegetation systems. In terms of overall effectiveness at lowering metal and acidity concentrations, evaluated as the average percent concentration decrease per unit contact hour, the Typha-dominated system (at 0.91%/hr) is 10 times as effective as the Sphagnum-dominated system (at 0.092%/hr). The combined vegetation sites show an intermediate efficiency at 0.50%/hr. As noted before, the difference between the monocultural systems may be lessened with quantification of residence time through inflow/outflow budgets or substrate porosity estimates. Also, these contrasting efficiencies must be viewed against the background of differing inflow concentrations, which were lowest for the combined vegetation systems.

Correlation analysis was applied to the untransformed chemical data sets; outliers were removed from the dataset. Table 3 summarizes the correlations which were found to be significant ($p<0.05$). As is common among acid waters, strong positive associations ($r>0.70$) were found among inflow aluminum, net acidity, and sulfate concentrations. Similarly, pH and aluminum, and pH and net acidity were negatively correlated ($r=-0.43$ and $r=-0.55$, respectively). An association between manganese and sulfate concentrations was also evident. These characteristics are related to the solubility of aluminum at varying pH, the implication of sulfate as the primary acid-generator in mine water, and the presence of manganese in overburden materials which is released under acidic conditions.

The proportional change in chemical concentrations between inflow and outflow for pH, manganese, sulfate, and suspended solids was found to be associated with inflow chemical concentrations (absolute value of $r=0.37$ to 0.57). However, only in the case of sulfate was the inflow concentration of the parameter correlated with the percent chemical change. Increases in sulfate concentrations were found only in the systems which treated water with sulfate concentrations less than 1000 mg/L. Inflow net acidity was found to be associated with manganese and sulfate concentration changes in the system; highly acid systems showed low changes in manganese concentrations and high changes in sulfate concentrations within the system. Although the inflow net acidity and change in sulfate concentrations is understandable in light of the positive correlation between the acidity and sulfate in inflow waters, the fact that the change in manganese concentrations does not follow the pattern exhibited by sulfate suggests different removal mechanisms and/or rates operating for these two ions within constructed wetlands.

Another acidity related effect, albeit a weak one, is observed for the change in suspended solids concentrations. For this parameter, the lower the pH, the less the change in suspended solids concentrations. This finding may be due to suspension of flocculant in the more acidic system. Alternatively, it may be a secondary effect of the substrate and system design of Typha and Sphagnum mixed vegetation systems which received high pH water, while low pH systems were Typha monocultures (suspended solids data were available for only one Sphagnum system).

Proportional change in pH appeared to be related to influent manganese concentrations; the higher the influent manganese, the lower the change in pH within the system. In such systems, both hydrogen and manganese ions may be competing for association with hydroxides. However, these data are dominated by two systems which show high manganese influent and low change in pH. The majority of systems show low pH change over a wide range of inflow manganese concentrations.

Changes in manganese concentrations, in addition to showing an inverse relationship with inflow acidity, also are inversely related to inflow aluminum concentrations. Inflow aluminum concentration and sulfate concentration changes within the wetland appear to be positively related. sulfate removal is related to inflow sulfate concentrations, and inflow sulfate is related to inflow aluminum and acidity concentrations, changes in manganese and sulfate concentrations within the system are probably all secondary effects of acidity.

Correlations among the proportional change in parameter concentrations after flow through constructed systems agree with the above interpretation. The change in aluminum and net acidity concentrations are closely related (r=0.80). By definition, the change in pH and the change in net acidity are positively related, although loosely due to the alkalinity supersaturation found in some influent. Suspended solids changes are inversely related both to pH changes and aluminum concentration changes; in systems with little change in pH or aluminum concentrations, the change in suspended solids concentrations is great.

CONCLUSIONS

Ecological systems constructed prior to 1986 to treat acid mine water in the Appalachian region can be classified into three different types based on dominant vegetation: Sphagnum-dominated, Typha-dominated, and Sphagnum and Typha interplanted systems. Whether by design or luck, the different s stem types treat water of different chemical compositions: Sphagnum systems with the most acidic inflows and highest metal concentrations, Typha systems with intermediate chemistry, and combined vegetation systems with the most alkaline flows and lowest iron and aluminum concentrations. Chemical concentration changes within the systems were also found to differ, with the combined vegetation systems showing the largest average change by parameter, followed by the Typha and Sphagnum-dominated systems. However, when turnover time is taken into consideration, the Typha systems are associated with the greatest change per unit contact hour, with mixed systems intermediate in effectiveness.

Whether these contrasts in apparent treatment are related to inflow concentration differences or the system design, the latter largely dictated by substrate and water level requirements of the vegetation, is not clearcut. Changes in concentrations of hydrogen ion (pH), manganese, sulfate, and suspended solids within the wetland system were found to be associated with inflow chemistry; however, a causative relationship cannot be inferred. We expect that more detailed study of wetland sites using standardized techniques at all sites, examining redox conditions, and calculating hydrologic and chemical budgets will allow isolation of inflow chemistry and system design influences.

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Table 1. Inflow water chemistry treated by constructed wetlands of differing dominant vegetation types (median values). All units are mg/L except pH (in standard units).

	No. of Sites	No. of Samples per Site (Mean)	pH	Net Acidity	Fe	Al	Mn	SO_4	Suspended Solids
Sphagnum	4	1	3.75	1180	41.3	11.4	11.8	1580	--
Typha	19	4	4.30	68	14.9	5.3	16.7	932	12
Sphagnum & Typha	10	4	6.20	-95	9.8	0.25	18.2	1330	10

Table 2. Inflow volume (gpm) to minimum flow path length (ft–MFPL) ratio, turnover time (hr), and percent change in chemical outflow concentrations from chemical inflow concentrations in constructed wetlands of differing dominant vegetation types (median values). Increases in outflow concentrations are indicated by a negative sign (-).

				Concentration Change (%)						
	No. of Sites	Inflow: MFPL	Turnover Time	pH	Net Acidity	Fe	Al	Mn	S04	Suspended Solids
Sphagnum	4	0.11	156	34	14	44	17	-35	12	--
Typha	19	0.15	19.1	20	25	50	24	8	4	-9
Sphagnum & *Typha*	10	0.09	56.9	50	-20	78	--	17	1	44

Table 3. Correlation analysis: significant results.

Inflow Chemistry		r	p
pH	vs. Al	-0.43	0.01726
	vs. Net Acidity	-0.55	0.00085
Al	vs- S04	0.76	0.00001
	vs. Net Acidity	0.96	<0.00001
Mn	vs- S04	0.48	0.00281
S04	vs. Net Acidity	0.72	0.00001

<u>Inflow Chemistry vs % Concentration Change</u>			
pH	vs. dSS	0.38	0.04120
Mn	vs. dpH	-0.56	0.00044
Al	vs. dMn	-0.46	0.01268
	vs. dS04	0.57	0.00189
Net	Acidity vs. dMn	0.50	0.00269
	vs. dS04	0.45	0.00829
S04	vs. dS04	0.43	0.00729
<u>% Concentration Change</u>			
dpH	vs. dSS	-0.45	0.01961
	vs. dNet Acidity	0.39	0.01862
dAl	vs. dNet Acidity	0.80	<0.00001
	vs. dSS	-0.46	0.03533

Table 3. Correlation analysis: significant results.

	r	p
Inflow Chemistry		
pH vs. Al	-0.43	0.01726
vs. Net Acidity	-0.55	0.00085
Al vs. SO_4	0.76	0.00001
vs. Net Acidity	0.96	<0.00001
Mn vs. SO_4	0.48	0.00281
SO_4 vs. Net Acidity	0.72	0.00001
Inflow Chemistry vs % Concentration Change		
pH vs. dSS	0.38	0.04120
Mn vs. dpH	-0.56	0.00044
Al vs. dMn	-0.46	0.01268
vs. dSO_4	0.57	0.00189
Net Acidity vs. dMn	0.50	0.00269
vs. dSO_4	0.45	0.00829
SO_4 vs. dSO_4	0.43	0.00729
% Concentration Change		
dpH vs. dSS	-0.45	0.01961
vs. dNet Acidity	0.39	0.01862
dAl vs. dNet Acidity	0.80	<0.00001
vs. dSS	-0.46	0.03533