TREATMENT OF ACID MINE WATER BY WETLANDS

By Robert L. P. Kleinmann[1]

INTRODUCTION

Wetlands are a potential natural treatment system for small flows of acid mine water. Previous studies of mine water flowing through bogs dominated by Sphagnum moss indicate that such a wetland removes the iron and reduces acidity, without harm to the moss. A group from Wright State University studied a site in the Powelson Wildlife area in Ohio where Sphagnum recurvum was found growing in pH 2.5 water. Iron, magnesium, sulfate, calcium, and manganese all decreased, while pH increased from 2.5 to 4.6 as the water flowed through the bog. A natural outcrop of limestone located at the downstream end provided sufficient neutralization to raise the effluent pH to between 6 and 7 (4).[2]

A similar study was conducted by a West Virginia University group at Tub Run Bog in northern West Virginia (5). They found that acid drainage flowing into the wetland area rapidly improved in quality. In 20 to 50 m, pH rose from 3.05-3.55 to 5.45-6.05, while only 10 to 20 m of flow through the bog was needed to reduce sulfate concentrations from 210-275 mg/L to 5-15 mg/L and iron from 26-73 mg/L to less than 2 mg/L. Overall, they found that the water quality of the bog effluent was equal or superior to that of nearby streams unaffected by mine drainage.

In laboratory experiments it has been shown that 1 kg (wet weight) of S. recurvum can remove up to 92 pct of the influent 50 mg/L of iron in 16.5 L of pH 3.8 synthetic mine water solution (3) by cation exchange. In a natural wetland, bacterial oxidation and sulfate reduction in the organic-rich bottom waters add to the iron removal capability. It has also been demonstrated in the laboratory that S. recurvum can tolerate acid mine drainage with iron concentrations as high as 500 mg/L for 4 weeks. Although the moss was stressed, iron removal by cation exchange continued. In the field, higher evapotranspiration rates and less ideal conditions result in a long-term threshold of less than 150 mg/L.

Such field observations and laboratory studies suggest that a Sphagnum-dominated biological treatment system is feasible. Since discharge from such a biological treatment system will not meet Federal and State pH limitations (pH 6-9) for mine water discharges, it was decided to incorporate a passive limestone neutralization step down-gradient of the moss to raise the pH to at least 6.0. Normally, limestone in mine water would be rendered useless by $Fe(OH)_3$ precipitation, but efficient iron removal by the wetland would eliminate this problem.

PILOT-SCALE EVALUATION OF THE BOG-LIMESTONE SYSTEM

The Bureau of Mines decided that a pilot-scale field test was needed to determine if a bog system could be constructed to treat acid mine water. In September 1981, a contract was initiated with Peer Consultants and Wright State University (subcontractor) to construct a pilot-scale test facility at an actual mine drainage site.

A six-section plexiglass tank was constructed and mounted on a steel flat-bed trailer. Live Sphagnum moss was harvested from the previously studied bog in the Powelson Wildlife area and transplanted

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[2]Underlined numbers in parentheses refer to items in the list of references at the end of this paper.

into the plexiglass chamber, which was then towed to an acid mine drainage site in the Zaleski State Forest in southeastern Ohio. A sketch of the portable bog system (fig. 1) shows how water flows through the divided chambers sequentially. The first five sections were packed loosely with Sphagnum moss (a mixture of S. recurvum v. brevifolium and S. fimbriatum), while the last section was packed with coarsely crushed limestone. Water samples were collected at the intake, at the end of the Sphagnum moss, and at the outlet. The limestone was also analyzed periodically.

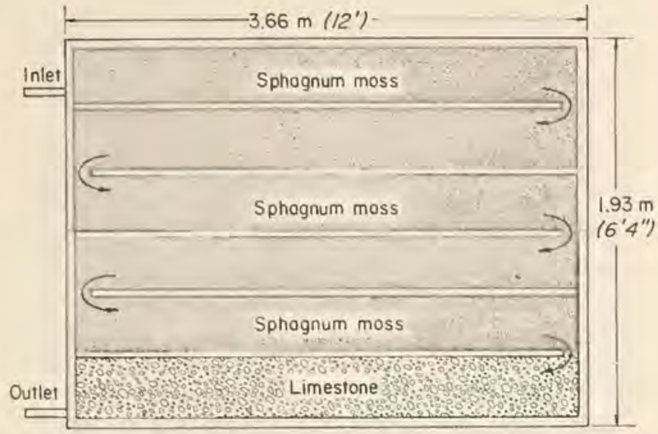

FIGURE 1. - Flow path of acid mine water through the bog-limestone system.

The acid source water for the bog system was an adjacent stream badly contaminated by acid mine drainage. Water was already being pumped from the stream by the U.S. Geological Survey sampling station at the site. A portion of this pumped water was used for our project. Flow rates through the bog during the initial 8 weeks of the test (June-July 1982) ranged from 1.4 to 19.8 gal/h owing to problems with the pumping equipment and inundation of the bog by heavy rainfall. This was subsequently stabilized by increasing the diameter of the inlet tube and inclining the inlet side of the trailer 1.8 in above the outlet side, simulating the natural gradient observed at the bog in the Powelson Wildlife area. A flow rate of approximately 2 gal/h was used during August and September 1982; after September, flow was increased to approximately 18 gal/h, and then to about 25 gal/h during 1983.

Although at times under stress due to inundation, the Sphagnum moss remained viable throughout the test. Iron was removed from the acid water by the moss so that only minor amounts of visible ferric hydroxide coating occurred on the limestone. Chemical analysis (table 1) confirmed that some coating occurred, but the effect on neutralization was insignificant. Aluminum concentrations, which are not significantly affected by the Sphagnum moss, may prove to be a problem if it turns out that aluminum hydroxide floc armors the limestone.

Dissolved oxygen concentrations indicate that anaerobic conditions did not occur, even at the bottom of the moss mat. Sulfate concentrations were not affected by flow through the bog system, and tests for hydrogen sulfide confirm that little if any sulfate reduction was occurring, presumably owing to the relatively shallow depth (6 in) of the portable bog. Sulfate reduction is an important aspect of acid drainage treatment

TABLE 1. - Results of analysis of limestone samples

Length of exposure to AMD, weeks	Concentration, mg/L				
	Iron	Manganese	Aluminum	Calcium	Magnesium
Unexposed........	1,200	87.8	1,080	194,000	98,500
1................	1,244	76.0	722	204,000	129,000
3................	1,520	79.7	643	207,000	128,000
5................	1,538	83.2	1,050	189,700	142,650
13...............	1,560	103	1,533	200,630	108,770
16...............	1,751	116	1,739	202,130	104,950
19...............	1,784	120	1,526	204,100	103,248
23...............	1,824	128	4,055	201,113	101,128

by a natural bog (5); its general absence in our pilot-scale test implies that our iron removal rates are probably conservative.

Figure 2 shows the effect of the Sphagnum moss on ferrous iron concentrations after the flooding problem was corrected. Ferrous iron oxidation averaged 61 pct and peaked at 97 pct. Total iron concentrations, which include suspended $Fe(OH)_3$ floc, were very erratic, with influent concentrations ranging from 15.9 to 640 mg/L within a week's time. These fluctuations reflect resuspension of $Fe(OH)_3$ floc from the stream bottom during storms; our small bog did not have the detention time to filter out this floc well, although presumably a larger bog would. The Sphagnum bed typically removed 50 to 70 pct of the total iron.

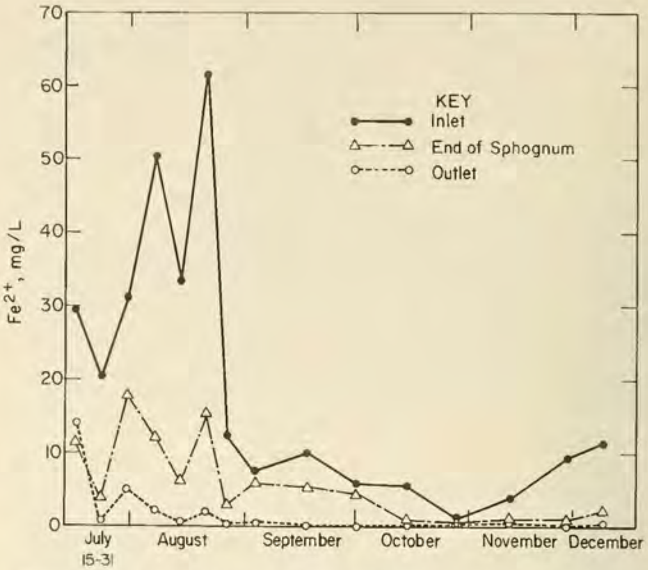

FIGURE 2. - Effect of the Sphagnum moss and limestone on Fe^{2+} concentrations in acid mine water.

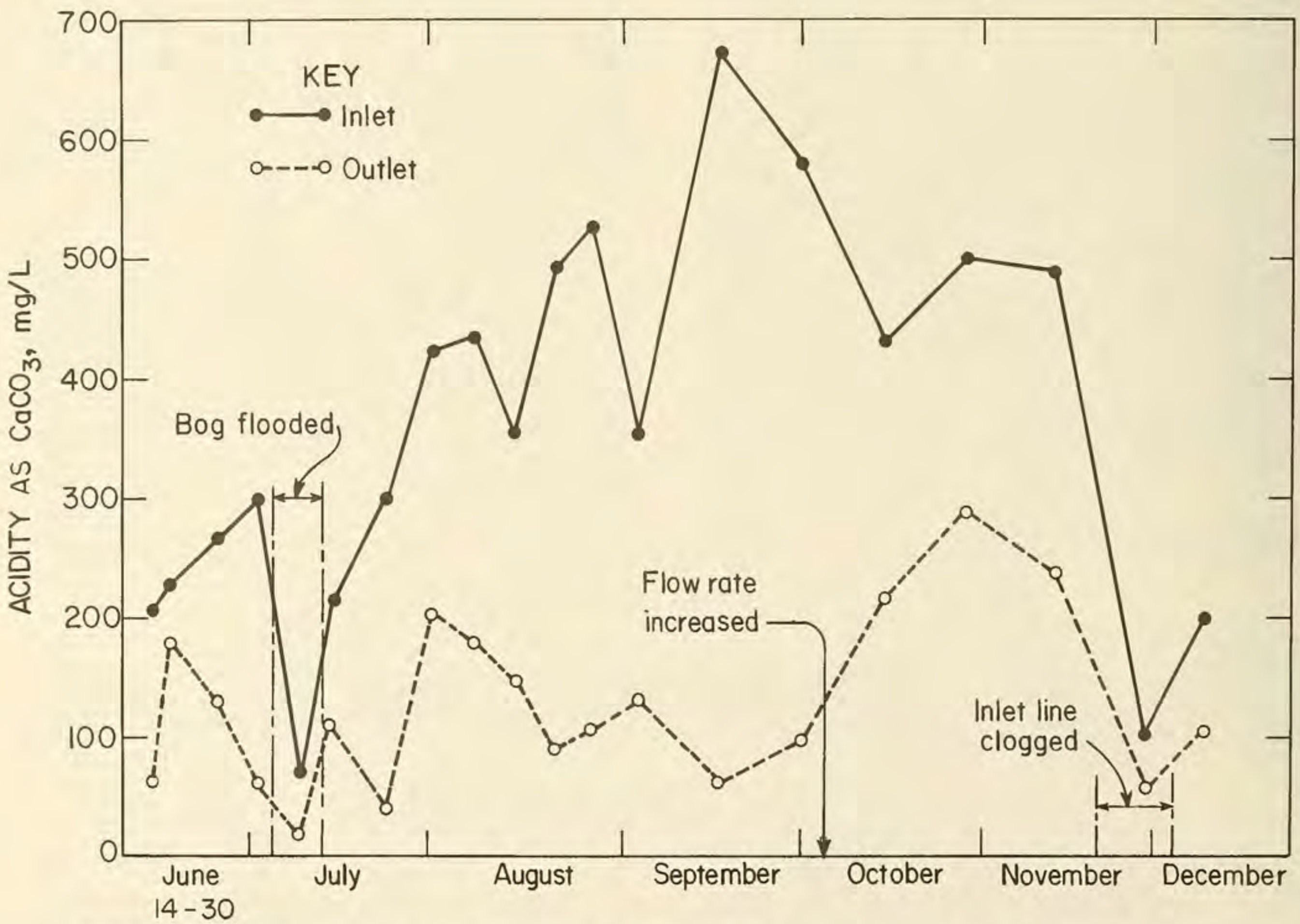

FIGURE 3. - Effect of the bog-limestone system on the titratable acidity of acid mine water.

Acidity was not significantly affected by flow through the Sphagnum mat, but decreased 43 to 90 pct as the water passed through the coarsely crushed limestone (fig. 3). The 90-pct reduction in acidity was observed when the initial acidity of the influent water exceeded 605 mg/L (as $CaCO_3$); the 43-pct reduction was observed when acidity at the inlet was less than 150 mg/L.

Generally, pH increased as acidity decreased. Adsorption of the H^+ ion, although known to be significant in a natural bog (3), did not occur enough in our small system to raise the pH as it flowed through the Sphagnum moss. However, as the water flowed through the limestone bed, pH increased an average of 1.4 and as much as 2.5 units.

A reduction of 88 pct in the ferrous iron concentration in the water was achieved in the moss bed. Initially it was observed that virtually all of the Fe^{2+} reduction occurred as the water passed through the first two chambers containing 24 linear feet (16.5 ft^3) of the moss. During the final month of sampling, after the monitoring sites in the portable bog had been changed, this reduction in Fe^{2+} was found to actually occur after the water has passed through only one chamber of 12 linear feet (8.3 ft^3) of moss. For the entire bog system, at an average flow of 22 gal/h, levels of Fe^{2+} were reduced by 15 mg/L on average at a rate of 5.5 mg/(L·h) or 1.8 mg/L per cubic foot of moss. The removal rate in the first chamber was of course much higher.

FULL-SCALE FIELD EVALUATION OF TREATMENT BY WETLANDS

The Bureau of Mines is now involved in field evaluation of the wetland approach at mine sites in Pennsylvania and West Virginia. The wetlands have been constructed by the respective mining companies for water treatment; the Bureau is facilitating monitoring and evaluation of the sites so that others can learn from these efforts. Four wetland areas constructed during 1984 and two volunteer wetland areas on mined lands are currently being monitored; two additional sites are planned for 1985.

At the volunteer wetland areas, C&K Coal Co. is attempting to enhance already established Typha bogs and to divert additional mine water to the wetland areas for treatment. At the better studied of the two areas, flows range from 30 to 40 gal/min, with an influent pH of 5.5 to 5.8. Influent iron concentration averages 20 to 25 mg/L; manganese ranges from 30 to 40 mg/L. The velocity of the water in the wetland ranges from 0.1 to 1.0 ft/s (as measured in less vegetated areas) over a 150-ft width with a total length of about 85 ft. Effluent water has less than 1 mg/L of iron, less than 2 mg/L manganese, and a near-neutral pH. Manganese removal is attributed to bacterial activity (1-2).

With an understanding of wetlands gained from the pilot-scale test and observation of the volunteer wetland areas, wetland treatment systems have been constructed of Sphagnum alone, and of Sphagnum and Typha together. The vegetation was transplanted from nearby wetlands by personnel of Brehm Laboratory of Wright State University and by Ben Pesavento, of Environment Analytic, who are also responsible for monthly monitoring and sample collection. These initial wetland areas range in size from 750 to 8,500 ft^2, of which 40 to 60 pct is actual wetted area, and treat flows of 2-8 gal/min. Preliminary results are shown in table 2 for the three wetland areas constructed at least 2 months ago. In addition to cation exchange, oxidation, and removal as iron sulfides, these results may partially reflect dilution of iron and manganese in the bog by ground water.

It appears that wetlands can be constructed in acid mine water discharges and that they will improve drainage quality. They require continuous flow, without a lot of variation; long-term maintenance requirements have yet to be determined. They appear to be most appropriate for relatively small flows (less than 10 gal/min) owing to the large

TABLE 2. - Performance of wetlands 2 months after construction or augmentation, milligrams per liter

Mine site	Iron		Manganese	
	Influent	Effluent	Influent	Effluent
Mine 1.................	24	0.5	43.8	16.1
Mine 2.................	8.7	1.2	24.5	15.5
Mine 3.................	24	.6	16	3.8

surface area requirement--we like to allow 200 ft^3 of wetted area per gallon per minute of flow. However, only space limits the extension of this system to greater flows. An attempt will be made to treat acid flows of 50 to 100 gal/min in larger wetland systems, starting with partial treatment in 1985 and, if successful, followed by full-scale tests in 1986.

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