EFFICIENCY OF A SCALE MODEL VERTICAL FLOW AND AEROBIC WETLAND SYSTEM IN TREATING ACID MINE DRAINAGE[1].

Fred J. Brenner[2], Kimberly D. Kosick, Shaun Busler, Corrie A. Gardner,
and Carol Tippie.

Abstract: The efficiency of a scale model vertical flow wetland (VFW) and aerobic wetland system in treating acid mine drainage was monitored over a two year period. The vertical flow system was constructed using a mixture of mushroom compost and limestone and the aerobic wetland was a cattail (*Typha latifolia*) dominated system constructed with mushroom compost as the planting medium. Water samples were collected weekly and analyzed for pH, acidity, alkalinity, iron, manganese, iron and manganese oxidizing bacteria. There was nearly a three unit increase in pH (3.73-6.65) along with a 83% reduction in acidity from an average of 300 mg/L to 50mg/L (83%) and corresponding net alkaline discharge of between 40-9 mg/l. The average iron concentrations were reduced from 32 to 4 mg/l (88%), but only an average of 2 mg/L (11%) of manganese was removed with all manganese reductions occurring in the aerobic wetland. The efficiency of the system varied seasonally, as well as between years, and the reductions in iron and manganese concentrations were correlated with bacterial activity within the systems. The majority of reduction in acidity in the VFW occurred within the upper 45 cm of the substrate, whereas alkaline addition and metal removal occurred between 45 and 90 cm of substrate depth. The efficiency of the systems decreased in the second year of operation. The efficiency of the scale model was similar to systems currently treating acid mine drainage in northwestern Pennsylvania.

Key Words: passive treatment, bacteria, iron and manganese reduction

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[2] Fred J. Brenner is Professor of Biology, Grove City College, 100 Campus Drive, Grove City, PA 16127. Kimberly D. Kosick, Shaun Busler, Corrie A.Gardner, and Carol Tippie were senior Biology majors at Grove City College, 100 Campus Drive, Grove City, PA 16127

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Introduction

Constructed aerobic wetlands have been used for over four decades for the treatment of acid mine drainage (Kleinmann *et al.*, 1983; Burris *et al.*, 1984; Gerber *et al.*, 1985). Many of these early systems were based on observations of natural *Sphagnum* wetlands receiving mine drainage,

but almost all of these constructed *Sphagnum* based wetlands ceased to be effective in improving water quality after several months. As a result of early work, almost all acid mine drainage treatment wetlands are currently being planted with cattails (*Typha latifolia*) since they have been shown to be tolerant of a wide range of water conditions (Sencidiver and Bhumbla 1988, Samuel *et al.*1988, Brenner *et al.* 1993, 1995). Although numerous wetlands were constructed during the last three decades, little research has been undertaken to understand the mechanisms operating within these constructed wetland systems.

The most accepted theory for the removal of metals by constructed wetlands involves oxidation and hydrolysis resulting in the precipitation of metals (Hedin 1989). Wieder and Lang (1986) reported that 93 and 27 percent of iron and manganese accumulation, respectively, was in oxidized forms. In drainages with a pH less than 6, the abiotic oxidation rates are slower and oxidizing bacteria become an important component of these treatment wetlands (Kleinmann and Crerar, 1979, Brenner *et al.* 1995). These chemoautotrophic and chemoheterotropic bacteria have been reported to increase the oxidation of ferrous iron, thereby enhancing the formation of iron precipitates (Brenner *et al.* 1993, 1995). Brenner *et al.* (1995) reported that a greater amount of iron oxidizing bacteria occurred in association with cattail rhizomes than elsewhere in the substrate, suggesting increased iron oxidization in the rhizosphere. But this increase in oxidation associated with the rhizosphere may be due to a combination of plant induced oxygenation and iron bacteria (Sencindiver and Bhumbia,1988, Brenner *et al.* 1995). In addition to iron oxidizing bacteria, manganese oxidizing bacteria and fungi have been shown to be the primary source of manganese removal from AMD in constructed wetlands (Brenner *et al.* 1995, Robbins *et al.* 1999).

During the last decade, vertical flow wetlands (VFWs) have been used to treat AMD, but the mechanisms operating within these systems are not completely understood. Based on the initial design of these systems proposed by Kepler and McCleary (1994), VFWs provide net alkalinity through the dissolution of limestone and sulfate reduction, resulting in the precipitation of iron and aluminum in the substrate. Brenner (2001a,b) reported that VFWs are effective in removing over 90% of the iron and aluminum, but they are not as effective in manganese removal. Demchak (1998) indicated that the efficiency of some of these systems began to decline after 18-24 months due to a reduction in limestone and iron accumulation in the substrate with similar results occurring in scale models of these systems (Brenner, 2001a,b). When these scale models were dissected, iron precipitates had accumulated in the upper third of the substrate and the efficiency of the systems in both alkaline addition and metal removal had declined in the second year of operation (Brenner, 2001a,b). Demchak (1998) also reported that overall effectiveness varied seasonally, especially as the systems aged. In theory, these systems function anaerobically. However, in a recent study, Brenner (2001a,b) reported that iron, manganese and sulfate bacteria were isolated from these systems under both anaerobic and aerobic conditions, suggesting the occurrence of both oxidative and reduction processes operating in VFWs.

The object of the current study was to evaluate the efficiency and the role of bacteria in the treatment of AMD in a scale model VFW and aerobic wetland system over a two year period. The model systems were based on the design of a VFW and aerobic wetland system operating at the Jennings Environmental Center in Butler County, PA.

Methods

In the spring of 1998, a scale model VFW and aerobic wetland was constructed at the Jennings Environmental Education Center, Butler County, Pennsylvania (Fig. 1). The system was designed proportionally to a system treating an acidic discharge on the property. The scale model was designed for an average flow of 2.1 L/min. with an average acidity of 300 mg/l and average iron and manganese concentrations of 32 mg/L and 18 mg/L, respectively. The VFW was constructed using a 1 m tall x 1.5 m diameter fiberglass septic tank using substrate consisting of a mixture of 45 cm of mushroom compost and # 9 (0.94 cm) limestone at a ratio of 1 compost:1.4 limestone by weight.. The water distribution system consisted of over and underdrains constructed of 2.5 cm PVC pipes. Sampling ports were installed at depths of 30, 45 and 90 cm. A 2.42 x 1.21 x 0.3 m deep aerobic wetland was constructed, using treated 1.5 cm thick plywood. The substrate consisted of clean river gravel overlain by a mixture of 30 cm of mushroom compost and # 9 limestone (0.94 cm) at a 1 compost:1.4 limestone by weight. The water distribution system was installed in the river gravel using 2.5 cm PVC pipe and sampling ports were installed at the influent, 1.2 m and at the effluent. Samples were collected weekly from the influent, effluent and each sampling port. Samples were analyzed for acidity, alkalinity, iron, and manganese according to the procedures described in the 18th edition of Standard Methods for Analysis of Water and Waste Water (Greensburg *et al.* 1992). Samples were analyzed for total iron and manganese by atomic absorption and by spectrophotometric procedures. Samples for bacteriological analysis were collected in 150 ml polypropylene bottles and cultured aerobically and anaerobically on iron and manganese medium. One ml of each sample was cultured aerobically and anaerobically on iron isolation medium and manganese agar at 20 C for 5 to 7 days as described in the 18th edition of Standard Methods for Analysis of Water and Waste Water (Greensburg *et al.* 1992).

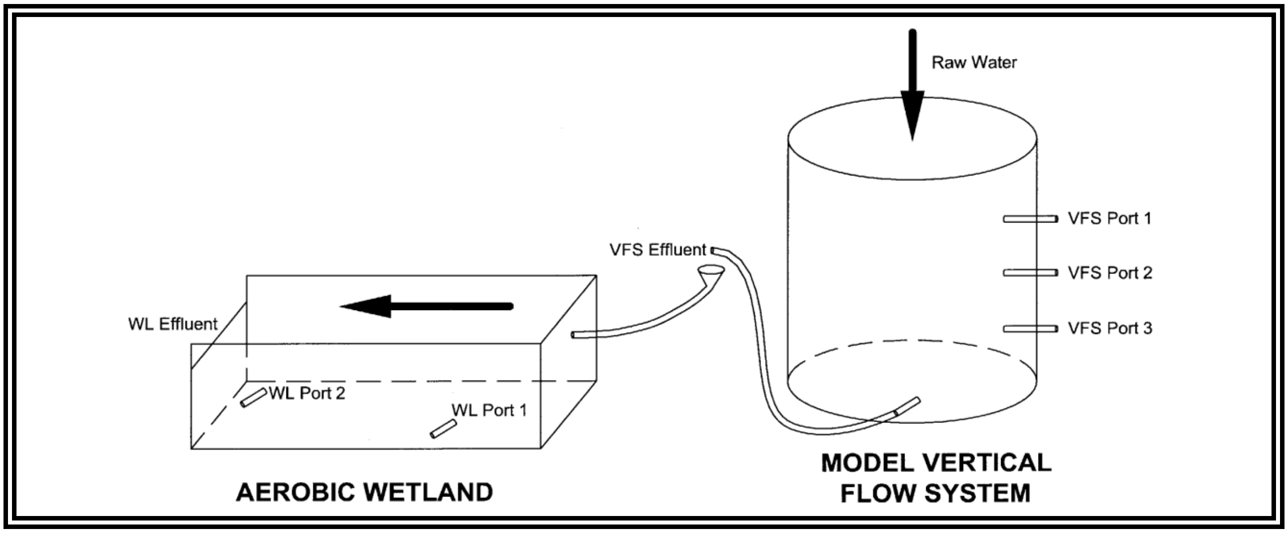

Figure 1. Schematic drawing of the vertical flow and aerobic wetland system at the Jennings Environmental Education Center.

Results and Discussion

The combination of the VFW and the aerobic wetland was effective in removing acidity and reducing metal concentrations in the final discharges, but there was a reduction in the efficiency of the system during the second year of operation. Overall, there was a three unit increase in pH from 3.72 to 6.65 with over 74% of this increase occurring in the VFW. The majority of the increase in pH occurred between the middle 45 cm (sampling port 2) and 90 cm (port 3) substrate depth. Likewise, acidity was reduced from an average of 300 mg/l in the influent to less than 50 mg/l in the final discharge (83%) with over 50% of this reduction occurring in VFW between port 2 (45 cm substrate depth) and port 3 (90 cm substrate depth. The net alkalinity of the final discharge varied between 40 and 90 mg/L with the majority of alkaline addition occurring in the lower 90 cm of substrate in the VFW and in the aerobic wetland. During the second year of operation, there was a 30 and 35% in alkalinity which was probably due, a least in part, to dissolution of limestone in the substrate.

Overall, the combination of the VFW and aerobic wetland was effective in reducing iron concentrations from an average of 32 to 4 mg/L (88.8%) in the final discharge, but the system only removed an average of 2mg/L of manganese (Fig. 2). The efficiency of metal removal

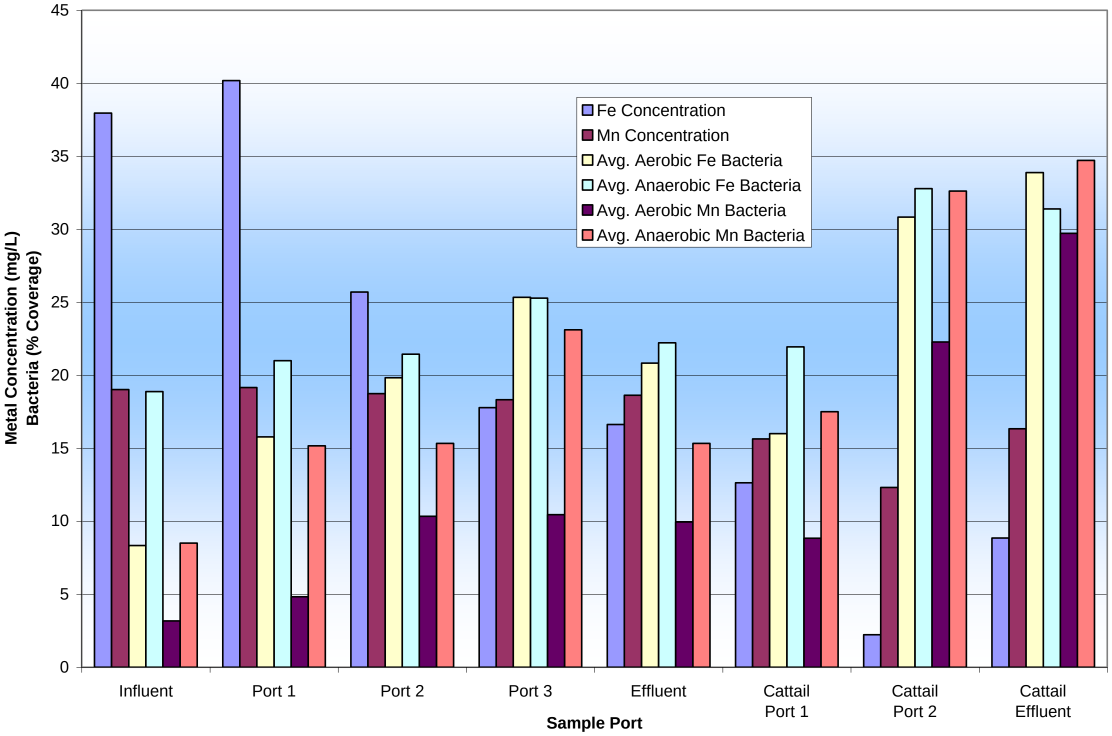

Figure 2. Average metal and bacteria concentrations through vertical flow system and aerobic wetland from 1998 to 2000.

varied seasonally (Fig. 3) and between the two years of operation (Fig. 3). Although, iron concentrations in the influent varied seasonally from an average of 57 mg/L during the winter months (December, January, February) to 26 mg/l in the spring (March April, May), the amount of iron removed was less during the spring than in the other months of the year. During the summer and autumn months, iron concentrations were reduced from 36 to 3 mg/l (92%) compared to 24 mg/L (57-33) (42%) being removed during the winter months. Although lower iron concentrations (26 mg/L) occurred during the spring, the systems also removed less iron (19 mg/L) during this period (which translates into a 73% efficiency of iron removal during these months). The efficiency of iron removal by the VFW decreased during the second year of operation. In the first year, the VFWS removed 34 mg (41-7 mg/L) of iron/L (87%) which decreased to 17 mg/L (46%) during the second year of operation and, in both years, less than 5% of the reduction occurred in the upper 45 cm of the substrate (Fig. 3). Earlier studies (Brenner *et al.* 1993, 1995) report seasonal variations in iron removed and elevated iron concentrations in the effluent from the aerobic wetlands during the winter and early spring. These elevated iron

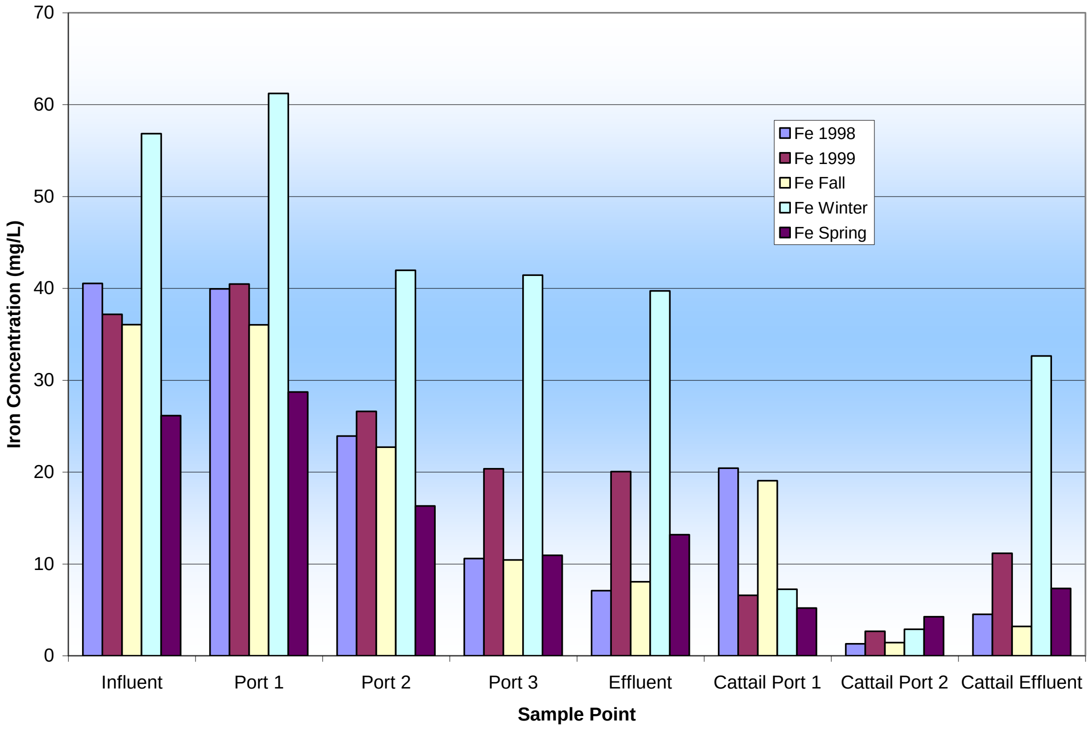

Figure 3. Yearly and seasonal comparison of iron concentrations.

concentrations in the effluent from aerobic wetlands may be due to several factors including the re-dissolving and re-precipitating of iron or the accumulation of iron precipitates and flushing of iron in the discharge.

In contrast to iron, manganese concentrations remained relatively constant throughout the year (18-20 mg/L) (Fig. 4), but manganese removal only occurred at warmer temperatures. During the spring and summer months manganese concentrations were reduced from 20 to 18 mg/l (10%) and from 18 to 15 mg/L (17%), respectively, with only 1 mg/L (5%) being removed during the winter months (Fig. 4). Although there was an initial reduction of iron and manganese in the aerobic wetland, concentrations of both metals increased between the second sampling point and the final discharge with the largest increase occurring during the winter months. These increases in iron and manganese may be due, at least in part, to the re-dissolving and re-precipitation iron and/or the accumulation and flushing of iron in the discharge, the desorbing and resorbing of manganese in the substrate (Brenner *et al.* 1993, 1995).

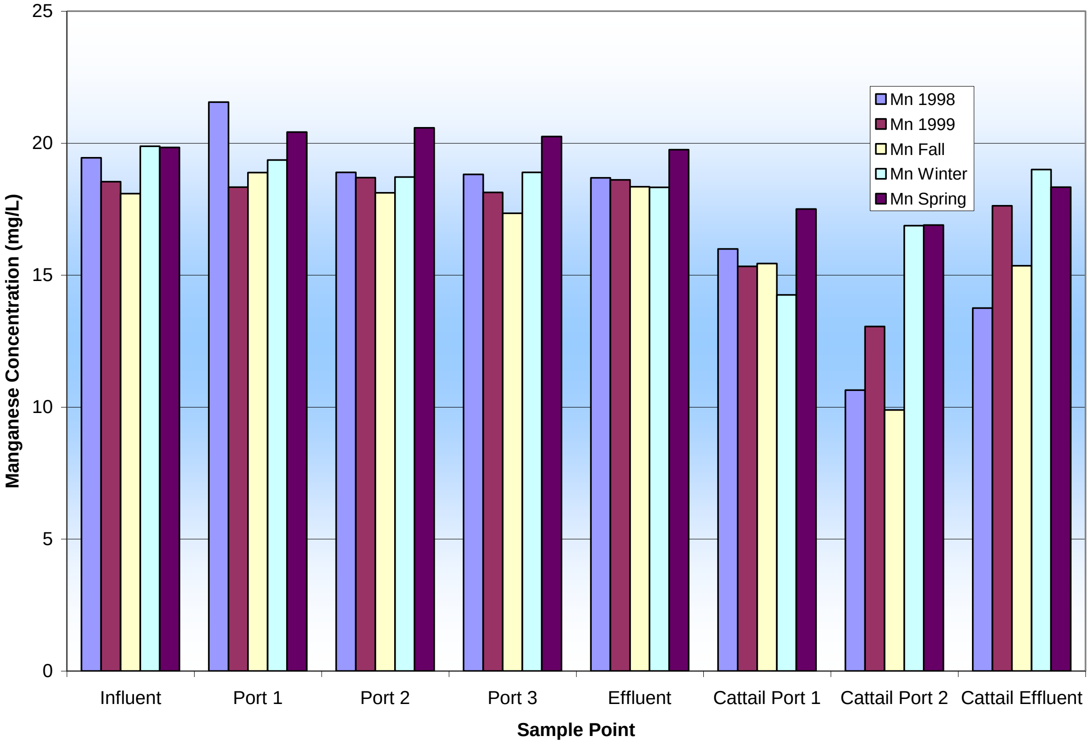

Figure 4. Yearly and seasonal comparison of manganese concentrations.

Overall, the bacteriological activity within the VFW, and aerobic wetland was inversely correlated with the iron (aerobic, r = -0.795, P<0.01; anaerobic, r = -0.796, P<0.01) and manganese concentrations (aerobic, r = -0.657, P<0.05; r = -0.730, P<0.01) (Fig. 5), but seasonal variations occurred in bacteriological activity in both systems, as well as between the two years (Table 1). Except for the spring months (March, April, May) when anaerobic bacteria were positively correlated with iron concentrations, both aerobic and anaerobic bacteria were inversely correlated with iron concentrations during the remainder of the year. Likewise, manganese concentrations were positively correlated with aerobic and anaerobic bacteria during the spring and, except for anaerobic bacteria during the winter months, manganese concentrations were inversely correlated with bacteriological activity during the other months of the year. During, the first year of operation, iron concentrations were inversely correlated with aerobic bacteria (r = -0.839, P<0.01), but there was not a significant correlation between anaerobic bacteriological

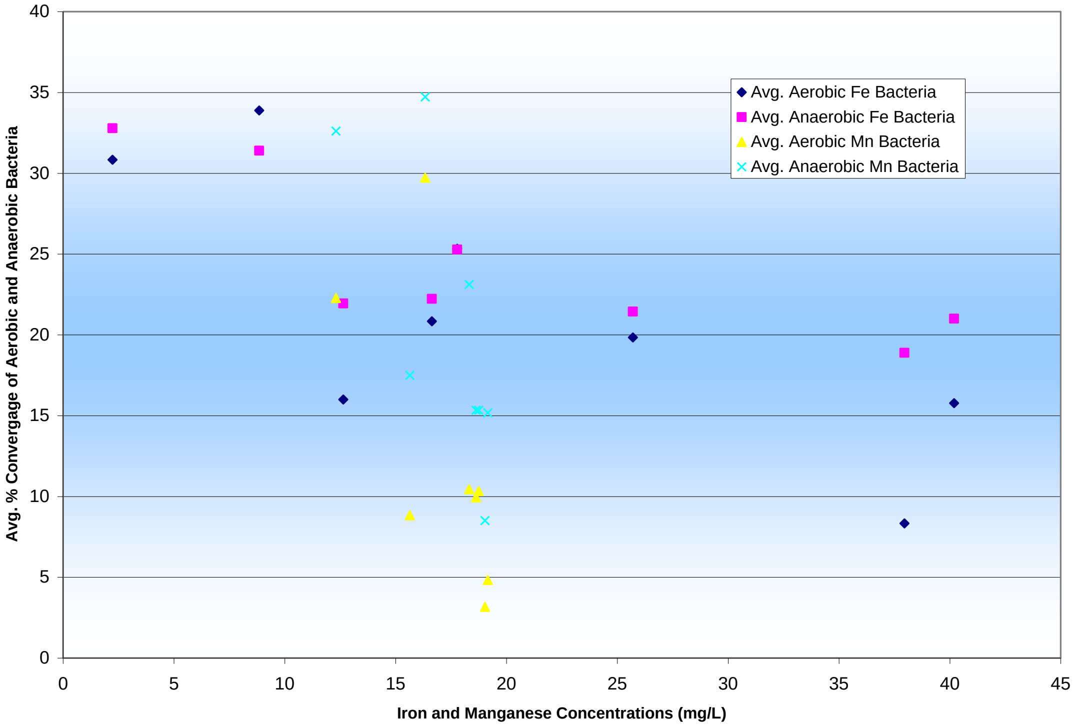

Figure 5. Comparison between average metal concentrations and bacteria levels.

activity and iron concentrations ($r = -0.258$, $P > 0.1$). Whereas during the second year, iron concentrations were inversely correlated with both aerobic ($r = -0.602$, $P<0.05$) and anaerobic ($r = -0.456$, $P<0.05$) bacteria. Manganese concentrations during the first year were inversely correlated with both aerobic ($r = -0.734$, $P< 0.01$) and anaerobic ($r = -0.861$, $P<0.01$) bacteriological activity, but in the second year, manganese concentrations were only inversely correlated with aerobic bacteria ($r = -0.443$, $P<0.05$).

Table 1. Seasonal Yearly Comparisons of Correlation Coefficients Between Bacteriological Activity and Metal Concentrations in a Vertical Flow and Aerobic Wetland System.

	Season			Year		
	Summer-Fall	Winter	Spring	1	2	Overall
Iron						
Aerobic	-0.840**	-0.892**	0.155	-0.839**	-0.602*	-0.901**
Anaerobic	-0.700**	-0.889**	0.371	-0.258	-0.466*	-0.813**
Manganese						
Aerobic	-0.618*	-0.314	0.562*	-0.734*	-0.443*	-0.579*
Anaerobic	-0.730	-0.141	0.487*	-0.443*	-0.272	-0.661

*P<0.05, **P<0.01, ***P<0.001

The season and yearly variations in iron and manganese bacteriological activity appears to be related to the efficiency of iron and manganese reductions of both VFWS and aerobic wetlands. Although the precipitation of iron and manganese oxides continues to be an important aspect of metal reductions in passive treatment systems, bacteriological activity appears to be a major factor in the efficiency of these systems in the removal of iron and manganese from acidic discharges.

Conclusions and Recommendations

There was a three unit increase in pH and removal of 250 mg/L of acidity in the upper 45 cm of the VFW with the majority of the alkaline addition occurring between 45 and 90 cm of the VFW substrate. Although the efficiency of the VFW and aerobic wetland system varied seasonally, as well as between years, overall the system was effective in the removal of iron, but not manganese. The concentrations of both metals, however, were inversely correlated with aerobic and anaerobic bacteria. The results of this study, as well as those of Brenner *et al.* (1993, 1995), suggest chemoauthotrophic and chemoheterotrophic bacteria are important components of both VFW and aerobic wetlands. Although in theory VFWs are designed to function anaerobically, the isolation of both iron and manganese bacteria from these systems suggest that the systems are not completely anaerobic or that these bacteria are functioning facultatively. Previously authors (Brenner *et al.*, 1993, 1995; Hedin *et al.* 1994) have suggested that the removal of manganese in aerobic wetlands is sequential and occurs only after the removal of iron. Brenner and Pruent (1999) reported that manganese concentrations were reduced from 11.3 mg/L to 4.8 mg/L (58%) in a limestone drain, settling pond and aerobic wetland systems with the majority of the iron being removed by the limestone drain/settling pond and manganese removal occurred in the aerobic wetland. These along with the current study suggest that increasing the pH and alkalinity via either VFWs or limestone drains will improve the efficiency of aerobic wetlands to removal manganese from AMD.

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