Abstract. Five wetlands, each 6 m wide and 30 m long and containing 30 cm of an organic substrate (Sphagnum peat to which limestone and fertilizer were surface-applied on a quarterly basis, Sphagnum peat, sawdust, straw/manure, spent mushroom compost), were exposed to controlled inputs of acid coal mine drainage (AMD; pH 2.89, soluble Fe, Mn, and SO$_4^{2-}$ concentrations of 119, 19, and 3132 mg L$^{-1}$, respectively) at a mean flow rate of 8513 L da$^{-1}$ for 111 weeks, beginning in July of 1989. All wetlands were net sources, rather than sinks, for base cations (Ca$^{2+}$, Mg$^{2+}$, Na$^+$, K$^+$). The Sphagnum peat wetland was the least effective in treating the AMD, retaining 35% of the soluble Fe influx, but not retaining substantial H$^+$ soluble Mn, soluble Al, SO$_4^{2-}$, or acidity. The straw/manure and mushroom compost wetlands were the most effective in treating the AMD, retaining 53 and 67% of the H$^+$ influx, 80 and 78% of the soluble Fe influx, 7 and 20% of the soluble Mn influx, 54 and 53% of the soluble Al influx, 15 and 11% of the SO$_4^{2-}$ influx, and 57 and 63% of the acidity influx. For these two wetlands especially, treatment effectiveness was substantially diminished during the cold winter months of January through March. Moreover, from March through July of the final year of the study, treatment effectiveness was minimal with outflow pH and concentrations of soluble Fe, Mn, Al, SO$_4^{2-}$ and acidity that were similar to inflow values. Decreases in treatment effectiveness over time appeared to be related to a decrease in the ability to counter the substantial acid load entering the wetlands in the AMD. Lime or limestone dissolution and bacterial dissimilatory sulfate reduction may have contributed substantially to pH improvement and acidity consumption in the straw/manure and mushroom compost wetlands, but after 2 years the cumulative input of acidity apparently had overwhelmed biotic and abiotic alkalinity generating mechanisms, as reflected in a progressive decrease in both substrate pH and abiotic acid neutralization capacity (ANC) over time, especially in the surface substrates. Also over time, effluent H$^+$ and acidity concentrations became more like influent and H$^+$ and acidity concentrations. Although samples of wetland interstitial water were not collected for chemical analysis, as substrate pH and ANC decreased and as influent and effluent water chemistry became more similar, it is likely that wetland interstitial water became progressively more acidic, potentially inhibiting bacterial processes that could contribute to effective treatment, favoring dissolution rather than formation of insoluble metal precipitates, and thereby contributing to the eventual failure of the wetlands to effectively treat the AMD. In general, when constructed wetlands are used to treat particularly acidic (pH < 4) AMD, if abiotic and biotic alkalinity generation cannot balance the influent acid load, long-term effective treatment will not be achieved.

1. Introduction

Coal and metal mining have had considerable impact on aquatic environments in the United States. The physical movement of large quantities of soil and rock during the mining process has the potential to produce a considerable sediment load to streams. Further, when the mining activity exposes pyrite-bearing strata to oxygen and water, oxidation of the pyrite can lead to the generation of acid mine drainage (AMD). Although the chemistry of AMD is highly variable, it is generally characterized by depressed pH (with values below 3.0 on occasion), elevated
concentrations of dissolved metals (especially Fe, but also Mn, Al, and other metal cations as well), and elevated concentrations of SO4^{2-} (Appalachian Regional Commision, 1969; Barton, 1978; USEPA, 1982; Proudan et al., 1982). Prior to the enactment of the Federal Surface Mining Control and Reclamation Act (SMCRA) in 1978 (Public Law 95-87), of the 16 800 km of streams in the Appalachian Region alone that were continuously or intermittently affected by mine drainage, 9120 km had been acidified (Appalachian Regional Commission, 1969; Kim et al., 1982).

In the post-SMCRA era, however, Federal regulations require all water discharged from surface coal mines in the United States to meet specified water quality for pH (between 6 and 9), dissolved Fe (< 7 mg L^{-1} for any individual sample; < 4 mg L^{-1} for a monthly average), dissolved Mn (< 4 mg L^{-1} for any individual sample; < 2 mg L^{-1} for a monthly average), and suspended solids (< 70 mg L^{-1} for any individual sample; < 35 mg L^{-1} for a monthly average). Despite inspection and enforcement powers of Federal and/or state regulatory agencies, and substantial penalties for failure to comply with discharge water quality criteria, AMD continues to be a widespread environmental problem (Herlihy et al., 1990).

Treatment of AMD on active coal mines is well within technological capabilities. Addition of neutralizing agents such as soda ash (Na_{2}CO_{3}), lime (CaO or Ca(OH)_{2}), limestone (CaCO_{3}), caustic (NaOH), or anhydrous ammonia (NH_{3}) to AMD effectively raises the pH to levels where Fe and Mn become insoluble, settling out in a pond prior to discharge. Such treatment, especially for high volume and/or severe chemistry incidences of AMD, can be quite costly (Kim et al., 1982). In light of these costs, field observations of the improvement of AMD upon passage through naturally occurring wetlands and the suggestion that constructed wetlands might provide a “low cost, low maintenance” alternative to conventional chemical treatment (Huntsman et al., 1978; Wieder and Lang, 1982; Kleinmann et al., 1983; Baker et al., 1991) sparked considerable enthusiasm in the coal and consulting industries. Although hundreds of wetlands have been constructed to treat AMD (Hellier, 1989; Wieder, 1989; Kleinmann et al., 1991), treatment effectiveness continues to be both variable and generally unpredictable. While considerable information about effluent water quality is available from extant constructed wetland treatment systems, it is infrequent that influent water chemistry and/or hydrologic fluxes are measured with an intensity equal to that typically seen for effluent water chemistry. As such, our understanding of the mechanisms of AMD amelioration, and of the limitations and potentials for wetland treatment, has lagged behind implementation of the wetland treatment option.

In 1989 a field study was initiated in which 5 constructed wetlands were exposed to controlled and measured quantities of AMD over a 2-yr period. In this paper, temporal changes in inflow and outflow water chemistry, along with hydrologic fluxes, are reported for all 5 wetlands. In addition to providing quantitative measures of treatment effectiveness, the information presented in this paper provides the background for subsequent papers which will report the results from concurrently conducted studies of diel changes in the Fe^{3+}/Fe^{2+} chemistry of inflow and outflow