Restoration and Reclamation Review
Student On-Line Journal
Vol.2, No.7, Spring 1997
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Constructed Wetlands for Treating Acid Mine Drainage

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Introduction

The mining industry has felt the burden of both negative environmental criticism and strong governmental regulations. In the past, mineral extraction and processing has been a source of many contaminants entering our water, soil, and air. They have also been responsible for many vast lands of infertile and unproductive landscapes. In order to reduce these pollutants and restore environmental productivity to mined lands, the Surface Mining Control and Reclamation Act of 1977 was passed. This act required reclamation standards for mining operations (Majer 1989). Since that time, the mining industry has made many advancements toward the goal of higher environmental quality and sustainability.

Acid mine drainage (AMD) has been considered one of the industries toughest problems to solve. Most water remediation techniques are timely and costly, and AMD can continue over a period of many years, therefore requiring treatment of AMD to continue until well after the land has been abandoned by mining activities. Constructed wetlands have been considered a possible solution to the long-term remediation of acid mine drainage. Studies have revealed positive results regarding the use of creating wetlands to remediate a human induced pollutant (Fennessy & Mitsch 1986; Perry & Kleinman 1991; Snyder & Aharrah 1985; Kadlec 1985). Constructed wetlands to treat acid mine drainage may provide a continuous, low-cost and effective solution to a growing problem for mining industries today.

What is AMD?

Acid mine drainage occurs when sulfide oxidation in rock reacts with water and air creating hydroxide, sulfate, and hydrogen ions (Durkin & Hermann 1994). The mineral that is responsible for this reaction, for both coal and metal mining situations, is pyrite (Wildeman *et al*. 1991). Mining activities expose this mineral to weathering air, water, and microbial processes. The exposure causes the contaminated waters to have increased acidity, and elevated concentrations of heavy metals, sulfate, and other total dissolved solids. Contaminants that are of particular concern have been acidity, iron, manganese, and aluminum (Perry & Kleinman 1991). A second source of acid mine drainage is by chemosynthetic bacteria including *Thiobacillus ferooxidans*, *T. thiooxidans*, and *Ferrobacillus ferroxidans*. These bacteria are known to catalyze the oxidation of pyrite (Fennessy & Mitsch 1989).

How does a wetland remove AMD?

Wetlands have several functions that aid in the removal of metals in drainage and ameliorate AMD. These characteristics are required for certain processes to occur: adsorption and ion exchange, bioaccumulation, bacterial and abiotic oxidation, sedimentation, neutralization, reduction, and dissolution of carbonate minerals (Perry & Kleinmann 1991). The contaminants caused by AMD of concern are sulfate, manganese, iron, and heavy metal concentrations.

Wetland processes which reduce these concentration are of particular interest and will be discussed in more detail.

Processes within natural wetlands have been found to remediate contaminants within AMD: imitation of these processes can work similarly in constructed wetlands. Wetlands have organic-rich substrates which exchange dissolved metals. This exchange occurs between the dissolved metals and abundant humic and fulvic acids contained within the substrate (Wildeman *et al*. 1991). Wetland sediments are generally anaerobic below a thin oxidized surface layer and contain organic carbon for microbial growth (Gambrell & Patrick 1978). The anoxic zone of the sediments provide conditions which favor microbial and chemical reducing processes, transforming iron and sulfates to hydrogen and sulfides (Fenessy & Mitsch 1989). Soluble metals are converted to insoluble forms by the anoxic conditions of wetland sediments (Fennessy & Mitsch 1989). Settling of suspended solids occurs from water velocity control of the wetland vegetation (Brooks 1984). Snyder and Aharrah (1985) verified *Typha* wetlands as effective removers of iron and manganese. Kleinmann (1985) recorded data that states iron concentrations dropped from 20-25 mg/L to

1 mg/L, manganese concentrations dropped from 30-40 mg/L to 2 mg/L in a *Typha* wetland. *Sphagnum* spp. has also shown significant effect on concentrations of iron, manganese, sulfate, and other mineral concentrations (Kleinmann 1985; Wieder *et al*. 1985). Plant roots will retain arsenic and other metals (Sobolewski 1997). Plants also generate microenvironments that assist in the reduction and oxidation processes (Wildeman *et al*. 1991). Certain bacteria, such as those in the generas *Desulfovibrio* and *Delsulfotomaculuum*, employ sulfate in anaerobic respiration (Mitsch & Gosselink 1986). These are but a few of the many examples of how a wetland can treat AMD, and therefore by employing our knowledge in wetland construction, simulate these processes for AMD remediation.

Wetland Development and Construction

The design of a constructed wetland for the treatment of acid mine drainage varies upon site characteristics. According to Fennessy and Mitsch (1989), the most important design considerations are: biochemical processes, loading rate and retention time, slope, substrate, vegetation, sediment control, morphometry, seasonality, and regulatory issues.

Biochemical processes have to be carefully considered when planning a construction of a wetland to treat acid mine drainage. Conditions which are favorable to chemical and microbial reducing, adsorption, neutralization and precipitation need to be incorporated into the soil, hydrology, vegetation, and site development plan (Fennessy & Mitsch 1989).

The maximum ability for a constructed wetland to treat AMD is determined by the loading rate (Girts & Kleinmann 1986). The retention time is determined by the volume and concentration of AMD, existing effluent standards and the rate of treatment, precipitation, run-off, infiltration, evapotranspiration. All these variables have to be considered when determining the maximum contaminant reduction (Fennessy & Mitsch 1989). According to Wile *et al*. (1985), a hydrologic holding rate of 200 m^3/ha-day and a seven day holding time are believed to be the optimal conditions for wetlands treating wastewater.

Slope is an important factor to consider in wetland design. Brooks (1984) determined a slope of less than 5% maximizes contact by wetland vegetation and substrate, therefore influencing iron and manganese removal. The Environmental Protection Agency recommends a slope of less than 1% will optimize efficiency of wastewater remediation (EPA 1985).

Substrate and vegetation are closely linked, in that the substrate used is dependent upon the desired vegetation (Fennessy & Mitsch 1989). For example, design of *Typha* wetlands often use composted hay and manure on top of a layer of limestone (Girts & Kleinmann 1986). Increased organic matter content of wetland sediments has been shown to influence increased metal adsorption (Fennessy & Mitsch 1989). Limestone and sewage sludge are considered important additives for soil condition manipulation (Joost *et al*. 1987; Topper & Sabey 1986).

Vegetation is an important developmental characteristic for wetland construction due to its important role in AMD remediation, and its influence on other wetland characteristics. Perennial vegetation can be established by placing rhizomes directly into a saturated subsurface zone (Fennessy & Mitsch 1989). The use of local stock is favored because their local adaptability (Fennessy & Mitsch 1989). Two main species used in constructed wetlands are *Typha* spp. and *Shagnum* spp. *Typha* spp. are characteristic of being acid tolerant and thriving under a variety of environmental conditions (Brooks 1984). This versatility and hardiness, along with *Typha* spp. ability to adsorb iron and manganese, make it and excellent vegetative choice for wetlands constructed to remediate mine drainage (Snyder & Aharrah 1985). Studies on *Sphagnum* spp. show significant influence in reducing sulfates, iron, and manganese concentrations (Kleinmann 1985). Perry and Kleinmann (1991) found difficulty in establishing *Sphagnum* spp. due to its sensitivity to the stresses associated with transplanting, abrupt changes in water chemistry, and excessive or insufficient water depth. This establishment problem, along with its having slow generating ability, makes its use in a constructed wetland less viable than *Typha* spp. This does not preclude its consideration, however, because of *Sphagnum* spp. excellent ability to aid in AMD remediation. Future research and development of techniques allowing *Shagnum* spp. use in constructed wetlands could prove critical in this remediation technology.

High sediment loads in AMD make sediment accumulation an important consideration in wetland design and construction. Ponds designed to accumulate sediment can be constructed into the wetland treatment system (Fennessy & Mitsch 1989). These sediment ponds would be constructed prior to the treatment wetland. Sediments then can be dredged from the pond without disturbing the wetland habitat. Kadlec (1985) has found seasonal harvesting of plant biomass to reduce sediment accumulation, although this does raise a concern of affecting levels of important organic matter accumulation in sediments.

Morphometry, or the geometric configuration, can be extremely influential in a constructed wetlands ability to perform AMD remediation. Designs which imitate natural wetlands, such as varied shape and slope, are more aesthetically pleasing, provides better wildlife habitat, and enhances macrophyte establishment (Brooks 1984; EPA 1985). Placement of islands within the wetland system increases habitat diversity and act as natural water flow breaks and diversions (Brooks 1984). Wile *et al*. (1985) determined a more serpentine shape outperformed a rectangular shape in reducing contaminents of AMD.

Seasonality of the locale in which the wetland is to be constructed is an important factor in wetland design, in particular areas where climate fluctuations are great. The bacteria catalyzing AMD creation is as active during cold seasons as does in warmer seasons (McHerren 1985). The dormant season and its effect on the vegetation's ability to remediate AMD is therefore important to consider. *Typha* spp. are subject to a efficiency decline at locales with colder temperatures regime (Fennessy & Mitsch 1989), whereas *Sphagnum* spp. does not face these same restrictions (McHerran 1985).

Regulatory issues can hinder the use of constructed wetlands to remediate AMD due to uncertainty of the ability of wetlands to remediate effluent to meet standards on a consistent basis, or whether they can be maintained to retain biological control (Fennessy & Mitsch 1989).

Other Methods of Treatment

Most efforts for remediating AMD problems have been directed toward treating the symptoms rather than controlling the source of the problem. Control of AMD can be accomplished by removing one or more of the factors in the AMD generating process: either air, water, or presence of pyrite. Steps which can be taken to control AMD are as follows: waste segregation and blending, base additives, covers and caps, bactericides, collection and treatment of contaminants, and bioremediation (Durkin & Herrmann 1994).

Waste segregation and blending requires the mixing of acid-generating rocks with enough rock of neutralizing potential (Durkin & Herrmann 1994). The ability to perform this mixing procedure require the ability to mix rock, which may not exist in some mined areas, and presents a need for a very accurate calculation of the acid-generating potential of the remaining rocks. Alkaline materials can also be added to the sulfite rock to buffer against reactions (Durkin & Herrmann 1994). Again, very careful calculations have to be made and may need several re-applications over several years. Soil, clay, and synthetic covers can be placed over the acid-generating rock to reduce infiltration of air and water (Durkin & Herrmann 1994). These capping procedures are costly and not completely effective in stopping the interaction of water, air, and pyrite rock. Chemicals can be used that reduce bacteria that catalyze the acid-generation of AMD (Durkin & Herrmann 1994). Chemical additives can have other complications with their use, such as vegetative effects caused by a chemical additive, and, again may require several re-applications. Microorganisms, which remove metals from mine drainage, can be added to AMD afflicted areas (Durkin & Herrmann 1994). This process can provide positive results, but may not be effective in treating large amounts of AMD. Drainage can be collected and treated using passive or active treatment systems (Durkin & Herrmann 1994). An active treatment system, as in using base additives to precipitate metals out of the solution, remove resulting sludge, and releasing treated water, is a very expensive procedure and sludge disposal can add more concern of environmental contamination.

Most of these other treatments are not long-term solutions to the problems generated by AMD. They can also be very costly and time consuming, requiring careful monitoring and repeated applications. The possibility of incorporating some of these treatments into a constructed wetland plan can improve efficiency of the wetland's ability to remediate AMD. The use of a passive treatment system, such as a constructed wetland, is a cost effective and self-perpetuating solution to the problem resulting from acid-generating rocks (Fennessy & Mitsch 1989; Sobolewski 1997; Perry & Kleinmann 1991).

Concerns

Many concerns exist regarding the metal accumulation of sediments and uptake of plants. This possible accumulation in vegetation could be an entrance of heavy metals into the food chain. Pascoe *et al*. (1994) and Dollhopf *et al*. (1988) found no such results. Neither plants nor mammals living in a wetland receiving AMD accumulated toxic elements. Reptilian populations have also been studied and the results were similar (Lacki *et al*. 1992). Other reports have shown negative impacts on microorganism and insects, such as the caddisfly (*Limnephilius indivisus*). A report by Ustis and Foote (1991) showed the caddisfly to have greater mortality in a wetland impacted by AMD. There are still a number of areas that have not been properly researched and documented. Much more needs to be known before one can say that constructed wetlands for the treatment of AMD have absolutely no effect on the plant and animal communities that depend upon it.

A second concern is that assume these wetlands will last forever without anticipating that they could create serious impacts in the environment in the future. Concerns have been raised about whether the wetland will be able to sustain the continuous drainage emitted into it. The construction of the wetland system must include monitoring to ensure that it does not become saturated and begin to once again leak toxic substances back into the environment. Specific regulations regarding the use of constructed wetlands to treat AMD will be important step for the future of this technology.

Critique

The creation of wetlands to remediate acid mine drainage is a important reclamation technique that should continue to be examined in further detail and recognized as a possible solution for the long-term treatment of AMD. Certain areas, such as construction design specifications, should be more closely examined before it can be considered a ideal solution. Some of these areas of research should include the effects such wetlands can have on plants and animals living within these aquatic systems, and a better understanding of natural wetland processes and the methods to mimic these processes and conditions which provide the best circumstances for wetland AMD removal. The research to date provides us an exciting look at how reclamation techniques can provide habitat that is beneficial to wildlife and humans, in conjunction with remediating a possible hazardous solution.

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