EVALUATION OF A CONSTRUCTED WETLAND FOR TREATMENT OF ACID MINE DRAINAGE IN SOUTHEASTERN OHIO

by

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Abstract. Acid Mine Drainage (AMD) is formed from the reaction water, oxygen, and pyrite left from past mining. AMD can occur in surface streams, or seep from underground sources. One area affected by AMD is the Black Fork sub-watershed near Crooksville, Ohio. Black Fork is one of the four main contributors to Moxahala Creek, which has been identified as one of the most acidic watersheds in Ohio. One remediation strategy was to implement a treatment wetland for an identified seep flowing into Black Fork. The wetland was designed and constructed by the Ohio Department of Natural Resources, Division of Mines and Reclamation. The seep is routed through an anoxic limestone channel to add alkalinity. The water then enters a settling pond before flowing into one of twelve vegetated wetland cells. The water flows into an effluent channel and is discharged into Black Fork through two separate culverts. Monthly samples have been taken since March, 1999, to evaluate flow rates and water quality. Measurements of flowrate, pH, conductivity, oxidation-reduction potential, acidity, iron, sulfate, and other metals were taken before and after vegetation developed to evaluate the effectiveness of the addition of biomass. The wetland currently removes 65% of the acidity, 85% of the iron load, and up to 15% of the sulfate load, and lowers the pH by 1.5 to 2.0 units. This report provides recommendations to improve the efficiency of the treatment.

Additional Key Words: Anoxic Limestone Drain, Residence Time.

Introduction

Acid mine drainage (AMD) is a form of water pollution that stems from mining. The three major components needed to form AMD are pyrite, water, and oxygen. Pyrite, FeS_2, is a mineral that is associated with coal deposits and can be found in spoil from mining operations. As pyrite oxidizes it generates acidity and soluble iron. The iron precipitates and coats the receiving stream as a result of rainwater or groundwater running over or through the spoil or abandoned underground mines and colors the streambed yellow or orange-red.

AMD impacts the environment in many different ways. Iron precipitation inhibits aquatic food supplies, clogs gills, and covers spawning beds. This precipitation flowing throughout the streams also increases the turbidity, obscuring sunlight. High concentrations of precipitate can destroy plant life. The acidity of the water can corrode culverts, pipes, pumps, bridge abutments, locks, and dams.

There are three general chemical reactions that characterize AMD. Equation 1 below represents ferrous iron is being generated and oxidized slowly in acidic water, though iron-oxidizing bacteria catalyze this process. Since pH is the negative log of H^+, as the hydrogen ion concentration increases, the pH decreases. The pH of the affected water is often less than 3.0. When ferrous iron oxidizes, it remains in solution at a low pH as seen in equation 2. Equation 3 occurs when the pH is greater than approximately 3.5, which can be achieved when AMD is diluted by flowing into an unpolluted stream, thereby raising the pH. The higher the pH, the faster the precipitate will form. The reaction represented by equation 3 also creates hydrogen ions, which in turn causes the pH to decrease (Stuart, et al. 1999).

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$$2\,FeS_2 + 7\,O_2 + 2\,H_2O \rightarrow 2\,Fe^{2+} + 4\,SO_4^{2-} + 4\,H^+ \quad (1)$$

$$4\,Fe^{2+} + O_2 + 4\,H^+ \rightarrow 4\,Fe^{3+} + 2\,H_2O \quad (2)$$

$$Fe^{3+} + 3\,H_2O \rightarrow Fe(OH)_3 + 3\,H^+ \quad (3)$$

In the past, most treatment technologies used for AMD remediation were categorized as active treatment. This typically involved the addition of chemicals to the water for neutralization. Recently there has been a movement toward passive treatment, however, which requires substantially less involvement from those treating the water as well as lower operational and maintenance costs (Skousen 1998). Passive treatment systems such as wetlands are engineered to assist nature in attenuating the pollution.

Wetlands treat water physically and biologically. Wetlands slow the flow, which allows sediments to settle out. They also usually have vegetation growing in an organic layer of material. Bacteria that thrive in this environment remove contaminants as a result of their metabolic activity. Subsurface flow also filters out some particles in the water (Sanders 1998).

Since the use of wetlands as treatment systems is a fairly new treatment strategy, exact design parameters have not been established. Therefore, an evaluation of a constructed treatment wetland in the Black Fork sub-watershed to determine its actual contaminant removal effectiveness was desired.

Objective

The objective of this study was to evaluate a constructed wetland, which has been in use for five years for treatment of a seep affected by acid mine drainage. In order to evaluate the effectiveness of the system the acidity, iron, and sulfate removal efficiencies needed to be determined.

Site Description

One of the seeps affecting the Black Fork sub-watershed was in Morgan County, approximately four miles south of Crooksville, Ohio, near Tropic Township. To abate the acid seep, the Ohio Department of Natural Resources – Division of Mines and Reclamation (ODNR-DMR) designed and constructed the "Tropic Wetland" in 1994 (Figure 1). The process is as follows: the AMD seep first enters an anoxic limestone drain (ALD). The flow then travels through an eight-inch pipe into a sedimentation pond. The flow is then routed into one of twelve wetland cells. Each cell flows into a collection channel before exiting from one of two outlets to Black Fork. There is a small pond in one area of the collection channel, which could allow for more acidity, iron, and sulfate removal.

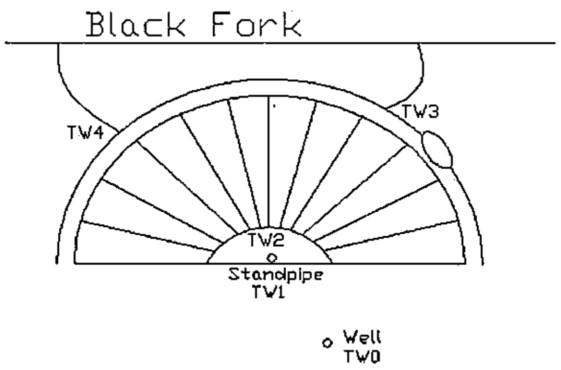

Figure 1. Tropic Wetland Sketch

The entire wetland covers approximately nine acres, with an average depth of 1.5 to 2.0 feet. The cells originally had a base of peat, which is an organic material, mixed with lime in order to provide a desirable habitat for biological growth and to add alkalinity to the water. Corrugated fiberglass sheets were placed between the cells to discourage short-circuiting (Stuart, et al. 1998). A sparse stand of volunteer cattails was the only vegetation present. Since the wetland's construction, sediment has filled several of the cells, and these cells are no longer submerged. Some of the baffles were also destroyed during winter freeze/thaw cycles.

Methodology

Field Procedures

Monthly sampling of the wetland by Ohio University was originally performed in 1996 for a period of one year. In March of 1999, a regular sampling program was re-established, and samples from the wetland continue to be taken every four to six weeks. The sampling locations used for this report were: TW0, a well sampling the seep before it enters the ALD; TW1, the inlet to the sedimentation pond; TW2, a discharge from the sedimentation pond before the flow enters one of the wetland cells; and TW3 and TW4, the outlets to Black Fork (Figure 1). Flow measurements were taken at the inlet to the sedimentation pond and at each of the two outlets to Black Fork.

The pH, oxidation-reduction potential (ORP), and conductivity were measured at each of the five locations using handheld probes. The pH is an indicator of hydrogen acidity, the ORP indicates the oxidation state of the water, and the conductivity is directly related to the total dissolved solids in the water. Water from each location was then placed in a cup to which a small amount of hydrogen peroxide, H_2O_2, was added. This completed the AMD reaction if the sample had not yet fully oxidized. The pH and ORP were measured once again. By measuring the ORP, it could be seen if the water was fully oxidized. After being oxidized, the pH reading was more representative of the anticipated hydrogen acidity further downstream.

Two samples were taken at each field location, one 500mL sample, which was preserved with nitric acid, and one 1L sample, which was unpreserved. The preserved sample at TWO was filtered before filling the bottle in order to remove any sediment or minerals that could oxidize before laboratory analysis was done. The oxidation of these materials would have misrepresent the actual water quality of the well sample, since the well environment was oxygen deficient.

Laboratory Procedures

Field samples were sent to an analytical laboratory operated by ODNR-DMR. Samples were analyzed for pH, total acidity, carbonate alkalinity, bicarbonate alkalinity, hydroxide alkalinity, phenolphthalein alkalinity, total alkalinity, conductivity, total dissolved solids, total suspended solids, total solids, sulfate, chloride, total calcium, total magnesium, total sodium, total potassium, total iron, ferrous iron, total manganese, total aluminum, and hardness. Twice a year, during periods of high and low flow, the water samples were additionally analyzed for total zinc, phosphate, copper, chromium, arsenic, barium, cadmium, lead, mercury, selenium, silver, cobalt, boron, total nickel, total molybdenum, and bromide.

Results and Discussion

The water quality indicators used in this study to evaluate wetland effectiveness were pH, acidity, total iron, and sulfate. Profiles of the wetland's pH are presented in Figure 2. The pH of the seep at TWO is approximately 5.0. After flowing through the ALD, the water enters the sedimentation pond at TW1 with a pH of about 6.0. The total alkalinity at TWO is zero and at TW1 it is 70 mg/L as $CaCO_3$, indicating that the ALD is effective in adding alkalinity. At TW2, as the water enters the cells the pH remains at about 6.0. However, after flowing through the wetland cells and collection channel, the pH at TW3 and TW4 to about 3.0. This decrease in pH is attributed to hydrogen ion formation in the AMD reactions. When the water first enters the treatment system it has not been in contact with the oxygen in air since its source is an underground seep. However, as it flows through the system, it is oxidized, which completes the AMD reaction, thus lowering the pH of the water.

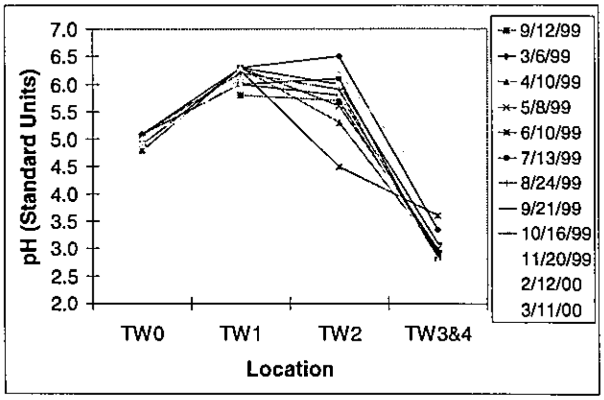

Figure 2. Tropic Wetland pH

Total acidity profiles are presented in Figure 3. The total acidity at TWO is approximately 775 mg/L. At both TW1 and TW2 the acidity is about 450 mg/L, and at the outlets TW3 and TW4 it is reduced to 275 mg/L resulting in overall total acidity reduction of about 65%. As stated above, the hydrogen acidity increases in the water as it flows through the wetland, causing the pH to decrease. However, the total acidity decreases. Acidity consists of hydrogen and mineral acidity. Since the hydrogen acidity has been shown to increase, the decrease in total acidity is attributed to a substantial decrease in mineral acidity.

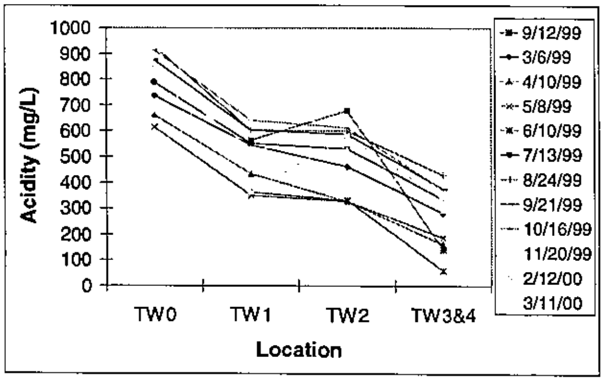

Figure 3. Tropic Wetland Acidity

Iron concentrations throughout the wetland are presented in Figure 4. At TWO and TW1, the total iron concentration is about 400 mg/L. This level is reduced slightly at TW2 to about 360 mg/L. At TW3 and TW4 the iron concentration is significantly lower, approximately 60 mg/L. The overall iron reduction is 85%. Most of this removal is achieved in the wetland cells, where the majority of the oxidation reaction takes place. The result of the removal capabilities of the wetland cells is that some cells have become completely filled with sediment, disallowing flow through them. Sediment accumulation has a significant impact on the productivity of the wetland. First, the sediment covers the layer of organic material, which in combination with the high metal content in the sediments severely hinders vegetation growth. Finally, the detention time is substantially reduced, which reduces the time available for treatment reactions and lowers contaminant removal efficiencies. Observations indicate that flow is currently limited to traveling through only three to five of the twelve wetland cells, substantially reducing overall detention time. The expected reduction in detention time is 60 to 75%.

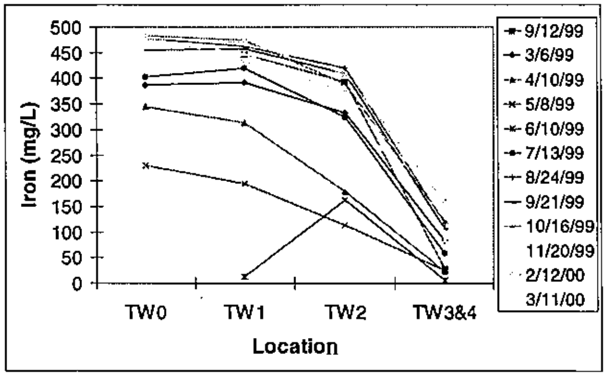

Figure 4. Tropic Wetland Iron

Sulfate profiles are presented in Figure 5. While the previous study suggested 15% sulfate removal, in this study the sulfate levels remain basically constant for any sample event and have an average concentration of 1800 mg/L. This value is typical of minor AMD discharges, however, acceptable stream sulfate concentrations are in the range of 250 mg/L. The high sulfate concentrations and the conservative nature of sulfate (it is less likely to participate in sedimentation reactions) suggest that additional treatment must be employed to target sulfate reduction.

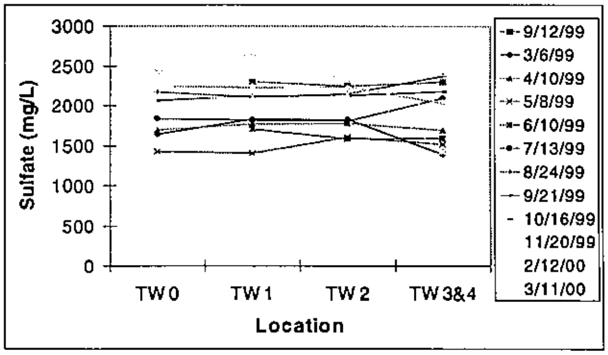

Figure 5. Tropic Wetland Sulfate

Conclusions and Recommendations

The removal of acidity and iron from the seep has been moderately successful. However, the decrease in pH is undesirable, and sulfate removal is suggested. The detention time has been significantly reduced, thus reducing the efficiency of the wetland. Overall, the wetland is providing some attenuation of the negative water quality indicators before the seep enters Black Fork; however, treatment is still insufficient. Also, the quality of the wetland has deteriorated due to sedimentation and breakage of the baffles.

Several modifications could be implemented to address the problems that have occurred in this treatment facility over time. The suggested new design is presented in Figure 6. First, the seep should be temporarily re-routed to allow draining of the wetland. While the wetland is drained, the sedimentation pond could be dredged. The existing sedimentation pond should be increased in size. This would reduce the amount of sedimentation currently taking place in the wetland cells.

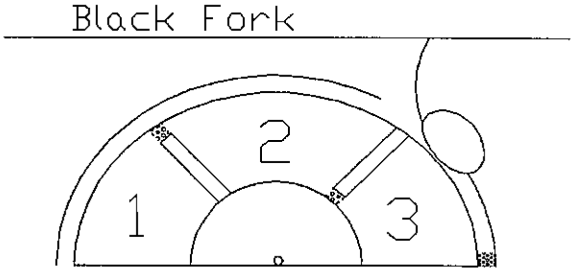

Figure 6. Recommended Redesign of Tropic Wetland. Flow would enter enlarged sedimentation pond at bottom center of figure. It would then proceed to travel through the cells as numbered before flowing through the polishing pond and being discharged.

The major design change suggestion is the conversion of the existing parallel flow configuration to a series or sequential flow configuration. Since the fiberglass baffles were damaged due to weathering, earthen dams could be used to route the flow instead. In the new design, the flow would run from the sedimentation pond into one of the cells. The flow into the adjacent cell would occur at the far end of the first cell. This pattern would be repeated for the desired number of cells. This treatment strategy would minimize the impact of short-circuiting because the water would still be treated in the subsequent cell(s), as opposed to being directly discharged into the receiving stream.

During construction, each cell could be dredged to remove iron precipitate in order to re-expose the original base of organic material mixed with lime. Subsequently, seeding could take place before the affected water is allowed back into the system. Vegetation should be established prior to the introduction of the contaminated water to provide a better chance for plant survival.

A polishing pond should be added before the flow enters the collection channel. The existing pond in this channel could be modified for this purpose. This would allow for removal of trace contaminants. In the anaerobic portion of the pond, sulfidogenic bacteria would either naturally exist or be seeded. These organisms reduce sulfate, which is aqueous, to hydrogen sulfide, which is a gas. The hydrogen gas would exit the water, thereby removing sulfate (Canty 1999).

Finally, the collection channel could be lined with limestone to help raise the pH and add alkalinity to the water just before it enters the receiving stream. In addition to treating the water exiting the wetland, the alkalinity in the water would actually help treat the receiving stream.

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