REMEDIATION OF ABANDONED MINE SITES USING CONSTRUCTED WETLANDS: A COLORADO PERSPECTIVE[1]

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Abstract: In recent years, constructed wetlands have been used to remediate acid mine drainage which has resulted from both coal and metal mining activities. These wetlands are used in conjunction with other engineered components to create a passive mine drainage treatment system (PMDT). Passive systems are designed to remediate mine drainage using minimum capital expenditures and little to no operational and maintenance costs. The Colorado Division of Minerals and Geology (DMG) is responsible for the design, construction, and operation of constructed wetlands in Colorado. Only 5 systems are in existence at this time, located in terrain varying from gentle foothills to remote, sub-alpine mountains. The design of a wetland system is based on a multitude of factors such as site terrain and access, mine drainage composition, and in the Rocky Mountain region, altitude. The salient design issues associated with each wetland system will be presented and discussed. The impact of altitude, climate, terrain, and other physical site constraints on each wetland design will be discussed. In addition, chemical issues critical to the design of each wetland such as pH and alkalinity will be presented. Finally, the performance of each wetland system will be examined.

Additional Key Words: passive mine drainage treatment system, anoxic limestone drain, sulfate reducing wetlands.

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Introduction

Acid mine drainage is probably one of the leading factors having a negative impact on the water quality in colorado today. Pollution from an estimated 20,000 abandoned mines has rendered 25 watersheds and 1300 stream miles incapable of supporting aquatic life (Colorado Nonpoint Assessment Report, 1988). Many of the mine sites responsible for the pollution are located in inaccessible, mountainous terrain. In addition, many of the mines have been inactive for decades. The mining operators abandoned or sold the sites long ago.

The need for a low-cost, low-maintenance method of effectively treating these sites is clear. The actual method is not so apparent. In recent years, the concept of passive mine drainage treatment systems was developed to address the unique conditions found at remote mountain sites. These man-made facilities are designed to remediate mine drainage without the costly maintenance encountered in active treatment systems (Holm and Lewis, 1988). Passive mine drainage treatment systems rely on the geochemical and bacterial reactions which occur naturally in wetlands to remediate the drainage (Holm and bishop, 1985). Successful design of the treatment system involves maximizing the particular chemical reactions which will most effectively treat the mine drainage in question.

The design of a constructed wetland is dependent upon many factors, including site topography, accessibility, spatial constraints, and water quality (pH, alkalinity, dissolved oxygen, acidity, metals concentrations). The purpose of this paper is to present several examples of constructed wetlands as applied to the following inactive mine sites in Colorado: Gamble Gulch, East Willow Creek, Boston Mine, Marshall No. 5, and Pennsylvania Mine.

Gamble Gulch

The Gamble Gulch site is located 2 miles southwest of Rollinsville, Colorado, at an elevation of approximately 8,600 feet. Acidic mine drainage is seeping from the Tip top or Perigo Mine, which was a metals mining operation.

The PMDT at the Gamble Gulch site consisted of 7 peat bogs, which were approximately 40 feet wide and 60 feet long. The first cell was 8 feet deep and the six following cells were 3 feet deep. The cells were designed to remediate mine drainage both aerobically and anaerobically. The wetland system reduced metals the first year as follows: 71% Al, 89% Fe, 28% Mn, 87% Cu, 55% Zn, and 67% Ni. However, by the second year, metals removed decreased to less than 10% as all the exchange sites on the peat were filled.

Unfortunately, the system never functioned as intended. The treatment capacity of this system was greatly limited by the low hydraulic conductivity of the peat substance. Much of the mine drainage which flowed into the cells merely flowed across the surface of the peat, leaving the PMDT virtually untreated. Vandalism several years ago resulted in damage to the retention dams which held the peat in place, which essentially destroyed the treatment system.

As a result of the poor performance of this system, the depth of future PMDTs was limited to 4 or 5 feet. The 10 foot thickness of peat was too great to allow for efficient flow through the treatment cells. In addition, the peat was thought to have experienced some hydraulic compaction, due to the great saturated thickness of material. As a result, peat is generally not recommended for use in constructed wetlands.

East Willow Creek

The East Willow Creek site is located 2 miles north of Creede, Colorado at an elevation of approximately 9,500 feet. The site was a metals mining operation.

The PMDT at the East Willow Creek consisted of 3 wetland cells, having depth varying from 3 to 5 feet. A bulkhead seal was placed over the mine adit, and mine drainage was permitted to flow from the adit into the wetlands cells. All of the cells were lined with compacted soil and 30 mil PVC.

Cell 1 was 50 feet long by 30 feet wide and 5 feet deep. This cell was filled with clean hay substrate. Cell 2 was slightly larger (50 feet long by 40 feet wide by 4 feet deep and was filled with wood chips. The final cell, Cell 3, was 140 feet long by 40 feet wide by 4 feet deep. The substrate material in Cell 3 consisted of a mixture of hay, wood chips, and mushroom compost manure.

Water quality data indicated that the mine drainage characteristics changed very little after flowing through Cell 1 and Cell 2. The hay and the wood chips did not appear to be very effective at remediating the mine drainage. In addition, the low density material became suspended in the water and flowed out of the cells. The mushroom compost substrate, however, appeared to be quite effective at treating the mine drainage. Testing showed the following reductions in dissolved metals concentrations; cadmium 98%, lead 97%, aluminum 91%, cobalt 91%, copper 85%, iron 84%, zinc 65%, nickel 62% and manganese 15%. Also, there was very little change in pH from the mine vs Cell 1 vs Cell 2. However, the pH rose from 4.3 to 6.0 in Cell 3.

Boston Mine

The Boston Mine is located 5 miles northwest of Durango, Colorado, at an elevation of approximately 8,000 feet. The boston mine is a former coal mining operation.

The PMDT at the Boston Mine consists of a drainage collection system, an anaerobic wetland cell, and a crushed rock-filled polishing trench. The drainage collection system consisted of a rock and gravel french drain which intercepted mine drainage from a seep area and channeled it into the rest of the treatment system.

The wetland cell designed to function anaerobically and was 120 feet long by 30 feet wide by 3 feet deep. The bottom of the wetland cell was covered with 15 tons of crushed limestone, to add alkalinity to the highly acidic waters. An underdrain of 2 inch diameter perforated PVC piping embedded in pea gravel, was placed over the crushed limestone. Finally, mushroom compost substrate was placed on top of the underdrain.

The rock-filled polishing trench was approximately 1500 feet long, 1 foot wide, and 1 foot deep. The trench was designed to provide a place for manganese to precipitate.

The performance of the Boston mine system was not as good as had been expected. Metal removal has been acceptable, but hydraulic conductivity has been severely reduced by the large amount of iron in the mine drainage. In addition, it was difficult to maintain a steady flow through the system. Nonetheless, the pH of the drainage was increased from 2.5 to 5.8 after flowing through the PMDT. Testing showed the following reductions in dissolved metals concentrations; cadmium 88%, copper 96 %, iron 91%, zinc 91%, and manganese 66%.

Marshall No. 5

The Marshall No. 5 tunnel is located approximately 4 miles south of boulder, Colorado at an elevation of approximately 5,600 feet. The area had been mined extensively for coal from the mid 1800s until 1963 (Holm and Jones, 1985) The abandoned mine discharges a significant amount of acidic waters which are laden with a variety of metals (3600 ug/l iron, 900 ug/l manganese, and 50 ug/l Zinc). The drainage from the Marshall No. 5 tunnel is considered to be perennial, and has been determined to vary from 17 to 70 gallons per minute (Guertin et al., 1985).

A prototype passive treatment system was installed at the Marshall No. 5 tunnel in July 1984. The original system consisted of an aerobic peat bog to remove metals through organic exchange and a limestone channel for neutralization. After approximately one year of operation, total and dissolved iron concentrations were reduced by an average of 96% and 99% respectively after passage through the peat bog (Guerin et al., 1985). The removal mechanisms thought to be responsible for the removal of iron were filtration and adsorption. Total and dissolved zinc concentrations were reduced by an average of 21.4% and 12.3% respectively, while the concentrations of manganese remained unchanged. The pH of the drainage was increased by an average of 1.6 between the adit and the sampling location located farthest downstream. Metal removal rates were less than optimum because the wetland was too small and the hydraulic conductivity of the pear was too low. The system was abandoned after one year and no more water samples were collected.

A new treatment system was constructed at the site in 1993. The new system consisted of the following components: an anoxic limestone drain (ALD), a settling pond, a wetland, and a polishing cell.

The anoxic limestone drain at the Marshall site was constructed by placing an earthfill dam outside the mine opening. The adit is approximately 5 feet high and 10 feet wide. The mine tunnel slopes gently downward as it extends back into the rock. The slope allows for anoxic conditions to exist at some point into the tunnel where the water level intersects the ceiling of the tunnel. Thus, anoxic conditions can exist even during periods of low flow.

The tunnel was back-filled with approximately 73 tons of 1/2" to 2" crushed limestone. The limestone drain began approximately 15 feet behind the adit and extended to 50 feet beyond the adit. A PVC pipe was placed along the full length of the ALD and exited outside the adit. This pipe allowed for the collection of water samples in the mine tunnel before coming into contact with the ALD. A concrete spillway fitted with a steel weir was installed at the adit.

The second stage in the treatment process was a settling pond with the following dimensions: 5 feet deep, 20 feet wide, 30 feet long. The settling pond serves as a retention basin for precipitates and allows control of flow into the rest of the treatment system. A six-inch diameter irrigation gate located at the downstream end of the pond allows the flow rate into the rest of the system to be monitored and adjusted. The downstream end of the irrigation gate connects to a pipe which transmits mine drainage into the next component of the system. The settling pond also has a spillway which channels drainage out of the pond and into an adjacent diversion ditch.

The surface area of the pond is sufficient to allow for precipitation of colloids from inflows as high as of 215 gpm. Typical flow rates out of the adit do not exceed 70 gpm, therefore the pond size is more than adequate to treat typical discharge amounts. Although the design storm does not impact sizing from the remediation perspective, it will control sizing based upon hydraulic stability; the settling pond must be large enough to pass the design storm without overtopping. Water can exit the settling pond through one of two components: a gate valve or a spillway. The gate valve empties into the wetland cell while the spillway channels drainage down a ditch. The spillway used is a combination V-notch and rectangular weir.

The third stage of the treatment system is a wetland with the following dimensions; 4.5 feet deep, 20 feet wide, 40 feet long. The cell is filled with cow manure obtained from a local dairy. The organic cell functions in both an aerobic and anaerobic configuration. The anaerobic portion of the treatment occurs as mine drainage infiltrates downward through the substrate and enters an underdrain. The underdrain consists of a series of 3-inch diameter perforated PVC pipes embedded in pea gravel. The 3-inch diameter pipes connect to a 6-inch diameter pipe near the downstream end of the wetland. The 6-inch pipe exits the wetland through the dam at the downstream end and is connected to a stand pipe. The stand pipe allows for the hydraulic head over the wetland to be controlled.

The final stage of treatment is a shallow wetland or polishing cell with the following dimensions: 2 feet deep, 20 feet wide, 35 feet long. The polishing cell wsw filled with pea gravel and some of the peat from the original wetland. The conditions are primarily aerobic. the purpose of the polishing cell is to increase the oxygen content of the drainage to facilitate the precipitation of any methals remaining in solution. The depth of the shallow wetland was designed to be irregular, having many deep pools (2 ft) surrounded by more shallow areas. The irregularities promote diverse plant growth.

Preliminary results after several months of operation indicate that the system is functioning well. The pH has increased 43% to near neutral values. The alkalinity of the drainage has significantly increased throughout the system, by almost 10 times. Field inspections identified abundant ferric precipitates surrounding the settling pond and covering the spillway exiting the ALD. The precipitates indicated that the ALD-settling pond system is performing as designed.

Pennsylvania Mine

The Pennsylvania mine is located 8 miles east of Keystone, Colorado along Peru Creek at an elevation of approximately 10,800 feet. This system is the highest altitude PMDT in Colorado. The Pennsylvania mine is an inactive precious metals mining operation which dates back to before the turn of the century. The mine tunnel is draining varying flows of highly acidic, metals-laden water into Peru Creek, rendering it incapable of supporting aquatic life.

The treatment system consists of a limestone injection system, settling pond, and two wetland cells. The system will be capable of handling various dry neutralizing agents. The injection system is a semi-passive acid neutralization technique which uses a unique hydro-powered limestone injection system. Mine drainage flows into a small concrete block building which houses the treatment system. The water flows through a turbine, which releases powdered limestone into the mine drainage, introducing alkalinity and reducing acidity.

The settling pond is located downstream of the limestone injection system. The limestone-enriched mine drainage becomes aerated as it leaves the injection building, causing metals to precipitate as the pH increases. The settling pond provides a place for the precipitates to collect. The injection system/settling pond portion of the PMDT is only utilized during the summer months, when the pH of the mine drainage is low enough to need the limestone pre-treatment. During the winter months, the injection system is by-passed because of the pH of the mine drainage increases to a level which makes limestone pretreatment unnecessary.

Water flows out of the settling pond into the two wetland cells. The wetland cells are designed to function as "bio-reactors," in which sulfate-reducing bacteria act to precipitate metals in an anaerobic environment. Both cells have the following dimensions: 4 feet deep, 40 feet wide, 60 feet long. The cells were lined with 40 mil PVC liner to prevent drainage from seeping out of the wetlands into the surrounding ground. An underdrain, consisting of three-inch diameter PVC pipes embedded in pea gravel, was placed in the bottom of each cell to facilitate flow of water through the cell. Cell 1 was designed to be a down-flow wetland while Cell 2 is an up-flow wetland. Each cell was filled with an organic substrate consisting of various percentages of sand, gravel, and manure, having a minimum organic content of 67%.

The PMDT at the Pennsylvania was constructed in two stages, the second of which was completed in July 1994. Unfortunately, the system has not yet been put into operation due to potential liability and long term maintenance problems associated with the Clean Water Act. The Clean Water Act considers discharging abandoned/inactive mines to be point sources of discharge, which will require NPDES permits. Due to uncertainty regarding long-term liability issues, the treatment system was put on hold.

Conclusions

Passive mine drainage treatment systems appear to be low cost viable solutions to the problem of acid mine drainage remediation. Although the technologies associated with constructed wetlands are still developing, positive results have been obtained. The success of a PMDT is dependent upon chemical and physical design parameters. The authors consider the following subjects to be of great importance with respect to the physical design of a passive mine drainage treatment system:

- hydraulic conductivity of organic substrate material
- changes in substrate permeability over time,
- accurate determination of substrate permeability,
- clogging of substrate by chemical precipitates over time,
- predictable flow rates through organic material,
- maintaining flow through closed pipe conveyances,
- control of hydraulic head in the treatment system,
- maintaining anoxic conditions where required
- sufficient hydraulic capacity to manage a certain flow
- creating the desired flow configuration through the wetland,
- preventing leakage from treatment cells,
- protecting treatment cell structures from erosion.

Cooperative research focusing on the combined influence of chemical and physical design parameters is recommended to gain a more complete understanding of this innovative and promising mine drainage treatment method.