THE TRACY WETLANDS: A CASE STUDY OF TWO PASSIVE MINE DRAINAGE TREATMENT SYSTEMS IN MONTANA

Michael T. Hiel and Francis J. Kerins, Jr.[1]

Abstract.--Two man-made wetland systems were constructed in Montana to experiment with and assess applicability of Passive Mine Drainage Treatment technologies to the state. The wetland systems, designated the Large Tracy Wetland and the Small Tracy Wetland treat flows of .95 and .15 liters per second, respectively. Both wetlands were constructed during the summer of 1986 and utilize a peat substrate planted predominantly with Typha latifolia for metals removal and limestone gravel and aeration structures for pH buffering. The large wetland has approximately 418 square meters of surface area. The inflow to this system has metals concentrations in excess of 280 mg/L Al and 1.5 mg/L Mn. The small wetland has approximately 111 square meters of surface area. The inflow to this system has metals concentrations in excess of 143 mg/L Fe, 46 mg/L Al and mg/L Mn. Construction costs for the Large and Small Wetland were $\$67/m^2$ and $\$140/m^2$, respectively. Both wetlands were relatively ineffective in improving the water quality of the acid mine drainage. Low system retention times and minimal contact between the peat and acid mine drainage are primary reasons for the ineffectiveness of the systems.

INTRODUCTION

The Abandoned Mine Reclamation (AMR) Bureau of the Montana Department of State Lands (DSL) has identified more than 50 sites in Montana where acid mine drainage from abandoned mining facilities has significantly impacted the local environment. Passive mine drainage treatment techniques provide a potentially useful and economical means for mitigation of acid mine drainage impacts at many of these sites.

Two man-made wetland treatment systems were designed and constructed in Montana to treat acid mine drainage from abandoned coal mines. These wetlands, designated the Large Tracy Wetlands and the Small Tracy Wetlands, are located near the town of Tracy in the Sand Coulee drainage ten miles southeast of Great Falls in Cascade County. The wetlands were constructed during July and August of 1986.

This report presents design criteria and construction costs for both wetland systems. In addition, inflow and outflow water quality data, soil chemistry data, and plant tissue chemistry data are presented.

SITE DESCRIPTION

The Large Wetland treats a flow of .50 to .95 liters per second (11,520 to 22,000 gpd). This flow has a pH of 2.7, and total iron, total

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[1] Michael T. Hiel is Reclamation Specialist, Mont. Dept. of State Lands, Helena, MT, and Francis J. Kerins, Jr. is a Mining Engineer, Robert Peccia & Associates, Helena, MT.

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aluminum, total manganese, and sulfate concentrations of 284 mg/L, 178 mg/L, 1.51 mg/L and 2618 mg/L, respectively.

The Large Wetland system includes a peat layer planted with cattails and sedges for metals removal, a limestone gravel channel for the neutralization of mineral acidity, and several aeration structures. A limestone-soil mix was used as a substrate throughout the system and in the construction of baffles to provide sinuosity.

The Small Wetland treats a flow of .38 to .50 liters per second (8,500 to 12,000 gpd). This flow has a pH of 3.1, and total iron, total aluminum, total manganese and sulfate concentrations of 148 mg/L, 46.7 mg/L, 1.2 mg/L, and 1560 mg/L, respectively.

The Small Wetland includes a peat layer, a limestone gravel channel, aeration structures, and a limestone-soil substrate. This wetland was also planted with cattails and sedges.

SITE LOCATION, HISTORY AND HYDROLOGY

The Great Falls area is a semiarid environment with a total precipitation of 38 cm (15 inches) per year. Seventy percent (70%) of the annual precipitation occurs during the months of April through September. The annual mean temperature is 7.2°C (45°F), with extremes from 37.8°C to -31.7°C (100°F to -25°F). Temperature and rainfall have a significant effect upon hydrology and soil characteristics.

The Sand Coulee drainage, consisting of approximately 500 sq. km (195 sq. mi.) in the upper Missouri River basin, is adversely impacted by acid mine drainage (AMD) from 22 discharging abandoned coal mines. This is the largest concentration of abandoned discharging coal mines west of the Mississippi River. Approximately 230 sq. km (90 sq. mi.) of the drainage contains abandoned coal mines discharging acid mine water.

The coal in this area occurs within the upper part of the Mission Formation (Jurassic) and is exposed along outcrops in the valley of Sand Coulee Creek and its tributaries. The topography is gentle with the exception of drainages incised into the plateau leaving a dissected and irregular terrain above the drainage areas. The Sand Coulee drainage lies in the Great Falls-Lewistown Coal Field, which is a large deposit of sub-bituminous coal. Unlike Eastern Montana Tertiary coal deposits, the coal in this area is higher in grade (11,118 btu/lb), and higher in sulfur content (0.5 - 5.5%) (Silverman and Harris, 1967). Thickness of the coal seam varies from .3 m to 3.6 m (one to twelve feet).

This coal was the target of the mining activity beginning in the 1880's. The last large-scale mine closed in 1952. During the period from 1885 to 1955 the coal mined from the Great Falls-Lewistown Coal Field exceeded 36 million tons. This amounted to about 23 percent of the total coal produced in Montana during that period. Coal mined from the Great Falls-Lewistown area from 1955 to 1965 was less than 1 percent of the total coal produced in Montana and since 1965 there has been no commercial coal production (Westech/Hydrometrics, 1982).

The geology of the area consists primarily of Cretaceous, Jurassic and Mississippian sedimentary rocks; the coal occurs in the Jurassic rocks. The Cretaceous Kootenai Sandstone and Flood Sandstone are aquifers most consistently used for water for domestic wells and springs in the area. Water from these aquifers leaks into the abandoned mines in the underlying formations.

The presence of large, abandoned underground coal mines in the area has apparently produced a large change in the regional ground water flow system. The underdraining of the basal Kootenai Sandstone aquifer by the abandoned mines has diverted the ground water flow, which most likely discharged to the Sand Coulee drainage prior to mining (Osborne, 1987).

The two mine discharges dealt with in this project are from the old Pierce Mine. Although a relatively small mine, the mine discharges have had a significant impact on the adjacent agricultural lands. For 40 years the discharges had been flowing into prime bottom land rendering .08 to .12 sq. km (20 to 30 acres) unsuitable for agricultural purposes. The problem persisted until even after several attempts by the landowner to seal the mine opening and reroute the flow of the discharge. In the fall of 1984, the Montana Abandoned Mine Reclamation Bureau (AMRB) completed a project which installed a drainage pipeline system. This pipeline collected drainage from both mines into a main pipeline and discharged directly into Sand Coulee Creek. Subsequent to the wheat field drying out, the soils have been amended and a wheat crop is once again growing. In solving the problem of flooding of the fields with acid mine drainage no attempt was made to treat the problem of acid mine drainage until this project in 1986.

WETLAND DESIGN

The sites chosen for construction of the experimental wetlands offered several advantages, including:

1. Two different controlled flows of less than one liter per second in proximity to each other;

2. Two flows having different pH's and metal concentrations;

3. Easy access to the sites during all seasons; and

4. A topography at the sites which provided some freedom in the design of the wetlands.

The larger flow where the Large Wetland was constructed has been monitored since 1970. The smaller flow where the Small Wetland was constructed has been monitored since 1986.

Design criteria for the wetlands were established following communication with people involved in the construction of similar systems in other states and a review of literature concerning wetlands construction techniques. The principal sources of information were the Colorado Inactive Mine Land Program (Holm, 1986) and a set of notes prepared by Kleinmann et al. (1986) for a course entitled, "Constructing Wetlands for the Treatment of Mine Water."

The intent of the wetland design was to provide a three-stage treatment facility: man-made peat wetlands planted with cattails and sedges, limestone-filled drainage channels, and aeration structures. The peat wetland planted with cattails and sedges provides an ion exchange facility for the removal of heavy metals. The limestone-filled channel provides a source of alkalinity for neutralization of the low pH drainage. The aeration structures provide a means for the exsolution of carbon dioxide to the atmosphere thereby reducing the concentration of carbonic acid (Guertin et al., 1985).

The primary criteria used for the design of the wetlands included:

1. Sizing the wetland to allow for treatment of the quantity of water expected during all seasons and following precipitation events. A surface area of 294 $m^2/L/s$ (200 ft^2/gpm) was considered a minimum size (Kleinmann, 1986).

2. Minimizing water velocities and maximizing retention time in the system.

3. Providing water depths varying from 5 cm to 46 cm (2 in. to 18 in.) in the system.

4. Providing optimum wetlands soils for emergent hydrophytes (such as Typha) composed of decomposed organic matter (peat) with some mineral soil content. The minimum depth of the peat was .3m (1 ft.).

5. Avoiding "short-circuiting" of the wetland by the formation of flow channels.

6. Providing for placing cattail sod mats over approximately 40 percent of the surface area of the wetlands.

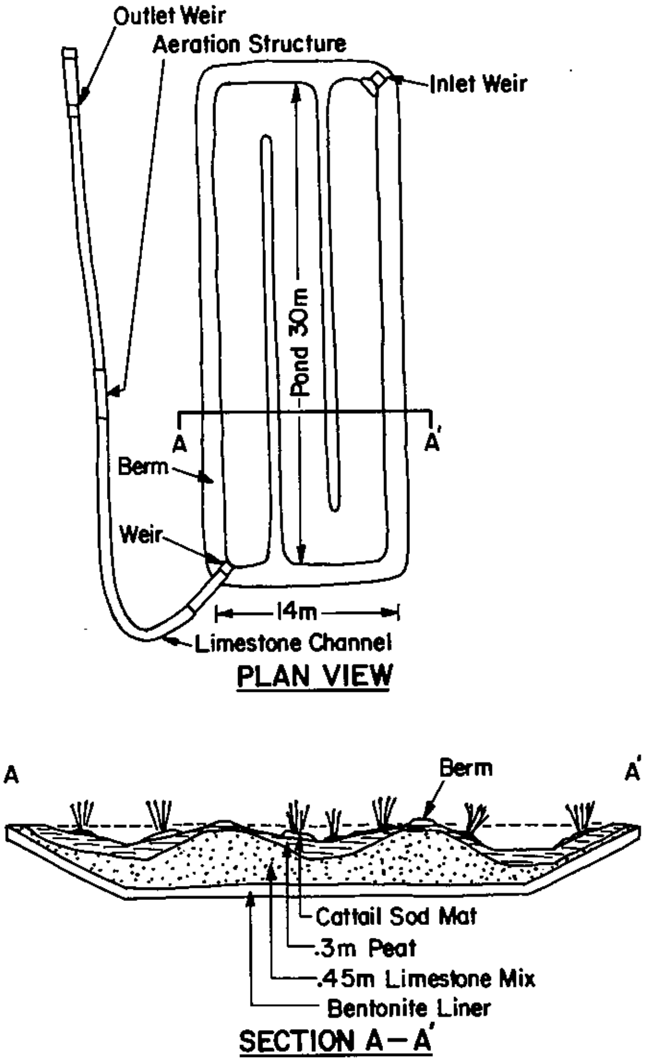
7. Providing a crushed limestone-filled channel downstream of the wetland for moderation of pH.

8. Providing aeration structures along the limestone channel.

DESCRIPTION AND CONSTRUCTION

The Large Wetland was designed as a rectangular impoundment with the approximate dimensions of 30 meters (100 ft.) by 14 meters (45 ft.) (Figure 1). This impoundment was baffled by a berm extending 28 meters (93 ft.)

Figure 1—Large Wetland



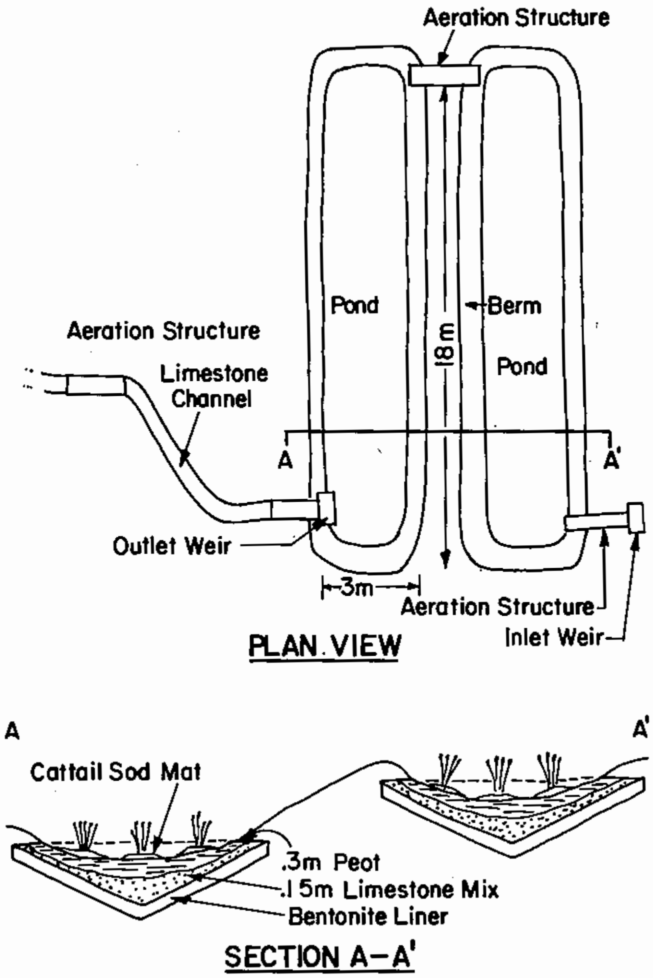
along the length of the wetland from each side of the wetland. This baffling provided sinuosity for the flow through the wetlands and prevented short-circuiting of the flow across the wetlands.

The water level is controlled by a rectangular notch weir at the outlet. The flow from this outlet structure passed over 37 linear meters (124 l.f.) of limestone channel and three aeration structures before exiting the system. Each of the aeration structures had about .45 meters (1.5 ft.) of fall.

The Small Wetland was designed as two parallel linear impoundments connected at one end by an aeration structure, forming essentially a U-shaped wetland (Figure 2). Each of the impoundments is about 18 meters (60 ft.) long and 3 meters (10 ft.) wide. The flow from the outlet structure passed over approximately 12 linear meters (40 l.f.) of limestone channel and two aeration structures before exiting the system.

The soil underlying both wetlands was amended with bentonite to prevent infiltration of the water in the impoundments into the ground. The base of both wetlands and the berms used for baffling in the Large Wetland were made of a limestone-soil mix with a minimum depth of .45 meters (1.5 ft.). A minimum of .3 meters (1 ft.) of peat was placed over the base material. The peat was from an active peat extraction operation located approximately 400 kms (250 miles) southwest of the project site. The species of moss, Polytrichum piliferum and Polytrichum strictum are common to Montana wetland communities and are more often found in drier locations. Cattail sod mats measuring approximately 3.3 sq. meters (36 sq. ft.) were placed on top of the peat, spaced evenly over approximately 40 percent of the area of the wetland. Sedge mats measuring approximately .09 sq. meters (.3 sq. ft.) were placed randomly throughout the wetlands.

Figure 2 — Small Wetland



The cattail and sedge vegetation sod mats were excavated from a wetland source area about 250 meters (835 ft.) from the constructed wetlands. The mats were excavated using a rubber-tired front end loader. The average thickness of these mats was about 15 cm. (.5 ft.). Whole 2.7 meter by 1.2 meter (9 ft. by 4 ft.) mats were placed in the wetlands.

In order to minimize the stress on the transplanted vegetation uncontaminated water was used to partially fill the wetlands prior to inundation with mine drainage. The transplanted vegetation was allowed to adjust to the new environment for one week prior to coming in contact with mine drainage. It is believed that his procedure helps account for the significant "new shoot" growth shown after transplanting the Typha. No plant stress has been observed, and plant growth has been vigorous.

MONITORING

Influent and effluent water quality; metals concentrations in Typha roots, rhizomes and leaves; and metals concentrations in the peat for both systems have been monitored since the end of July 1986. Initially, water sampling was performed on a biweekly basis, but after the first two months a monthly sampling program was adopted. Vegetation and peat sampling was performed on a monthly basis.

Two water samples were collected at the inlet and outlet of each wetland. One of the samples taken from each location was filtered and preserved with acid (HNO_3). The pair of samples from each location was analyzed for total and dissolved aluminum, iron and manganese. The sulfate concentrations, pH, and specific conductance for each pair of samples was also determined. The samples were analyzed utilizing EPA drinking water methods and ICP (Inductively Coupled Argon Plasma) techniques.

The Typha rhizome, root and leaf samples were collected from randomly selected plants in the wetlands. After collecting the samples the rhizomes and roots were dried and any residual peat was carefully removed. Each of the vegetative samples was analyzed for total aluminum, iron, manganese and sulfur. The samples were processed using nitric acid and hydrogen peroxide digestion (EPA method 3050). Analysis of the samples utilized ICP techniques.

The peat samples were collected at locations near the inlet and outlet of each wetland. The samples were collected from the upper 15 cm (.5 ft.) of the peat layer. The samples were analyzed for a number of constituents, including total sulfur, pH and total and extracted iron, aluminum, and manganese. The samples were analyzed utilizing Montana Department of State Lands strip mining soil analysis methods.

PERFORMANCE

Neither the Large Wetland nor the Small Wetland has improved the quality of the water flow through the system to any degree. Table 1 shows a summary of the water quality data for the inlet and outlet of each of the wetlands.

The concentrations of iron, aluminum, and manganese in the rhizomes, roots and leaves of the cattail plants in the two wetlands and the cattail source area used as a control are summarized in Table 2. This data indicates that the Typha is concentrating metals in the system. However, because the potential uptake of metals by Typha is not significant when compared with the actual loading of the system, the vegetation

TABLE 1
Water Quality Summary

	Large Wetland				Small Wetland			
	Inlet		Outlet		Inlet		Outlet	
	Mean	Stan Dev	Mean	Stan Dev	Mean	Stan Dev	Mean	Stan Dev
Total Al	178	17.5	180	17.9	46.7	2.1	45.7	2.1
Total Fe	284	134.9	271	110.6	148.5	37.2	94.1	52.7
Total Mn	1.51	.14	1.67	.23	1.2	0.1	1.3	0.3
Sulfate	2618	285	2683	201	1560	223	1551	218
pH	2.7	.27	2.58	.19	3.1	0.3	2.8	0.4
Specific Conductivity	3349	307	3440	194	2414	246	2559	278

NOTES: 1) All units mg/L except for pH (standard units) and Specific Conductance (u mho/cm).
2) All samples taken between July 10, 1986 and Sept. 30, 1987. Number of samples taken is 21.

TABLE 2
Typha latifolia Analysis Summary

	Total Al		Total Fe		Total Mn	
	Mean	Stan Dev	Mean	Stan Dev	Mean	Stan Dev
Rhizomes						
Control	558	506	590	333	42	31
Large Wetland	1398	1268	4237	1735	164	74
Small Wetland	1400	1478	4806	2325	134	72
Roots						
Control	5171	2368	8093	7584	475	813
Large Wetland	7444	5006	40884	25437	270	151
Small Wetland	4703	2659	34609	29491	241	292
Leaves						
Control	139	100	198	95	275	263
Large Wetland	232	91	287	62	1760	1455
Small Wetland	243	101	286	134	1053	766

NOTES: 1) All units ug/g.
2) All samples taken between Dec. 23, 1986 and Sept. 21, 1987. Number of samples taken is 9.

TABLE 3
Soil Analysis Summary

	Control Peat		Large Wetland Peat		Small Wetland Peat	
	Mean	Stan Dev	Mean	Stan Dev	Mean	Stan Dev
Total Al	9595	1665	12872	1726.1	15413	4606
Total Fe	6918	2358	29009	18364	60839	68291
Total Mn	113	50	160.6	242.7	98.4	74.7

NOTES: 1) All units in ug/g.
2) Number of samples for control peat is 2. Number of samples for Large and Small Wetland peat is 10.

TABLE 4
Construction Costs

Wetlands Construction Costs - 1986	Large Wetland (Dollars)	Small Wetland (Dollars)
Site Development/Inflow Control Facilities	$5,510	$4,125
Wetland Construction	5,655	2,335
Materials (in place)		
- Water	780	375
- Bentonite	975	750
- Limestone Gravel	4,260	1,470
- Peat	6,760	3,380
- Vegetation Sod Mats	440	220
Wetland Flow Control/Aeration Structures	3,430	2,940
Total	$27,810	$15,595
Wetland Surface Area (m^2)	418	111
Wetland Surface Area ($ft.^2$)	4,500	1,200
Wetland Cost/Area ($dollars/m^2$)	66.53	139.89
Wetland Cost/Area ($dollars/ft^2$)	6.18	13.00

would provide only a minor contribution to the total metal retention of a functioning system.

The peat has also concentrated metals in the system. Total aluminum, iron and manganese concentrations for both wetlands and the control peat are shown in Table 3.

Because the removal of the metals in both systems was unsuccessful, the limestone gravel in the channels downstream of each wetland became armored in less than two weeks. Although no specific tests were made, visual indications suggest that metals precipitation and pH buffering decreased after the armoring process was complete.

It was also observed that detention times in the systems were much shorter than was desired. Dye tests showed that the detention times were approximately seven hours and three hours for the Large and Small Wetlands, respectively. These low retention times are due primarily to the relative impermeableness of the peat once it is saturated.

WETLANDS CONSTRUCTION COSTS

Construction of the Large and Small Wetlands occurred during the months of July and August in 1986. Because of the relatively good access to the project sites many different pieces of equipment were used during construction, including bulldozers, backhoes, smooth-drum rollers, water trucks, motor graders, tractor-trailers, and rubber-tired front end loaders. Use of specialized equipment allowed for the volumes of material incorporated into the system to be easily handled and placed, and for work to be completed in less than four weeks.

Table 4 shows a breakdown of the costs for the construction of the Large and Small Wetlands. The breakdowns show that material costs made up the largest portion of the construction costs. The peat was the largest cost material item because it was necessary to haul it approximately 400 kms (250 miles) to the project site.

CONCLUSION

Two passive treatment systems constructed in Montana during 1986 have been ineffective in removing heavy metals from acid mine drainage. There seems to be two primary reasons for the ineffectiveness of these systems. Firstly, both systems were undersized, which resulted in very low retention times and limited the contact between the AMD and the primary heavy metal removal medium, the peat moss. Secondly, the systems designs did not force the AMD to flow through the peat at any location. The designs maximized the length of the flow paths through each system, but most of the flow through the systems was above the AMD-peat interface.

Improvements in the performance of these systems would probably be realized if the retention time was increased and provisions were made to force the AMD to flow through the peat. Expansions were made to both systems during the summer of 1987. These expansions significantly increased the size of each system and provided for flow of the AMD through the peat. A report on the performance of these expansions will be made at a future date.

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