PROGRESS REPORT ON THE OLD BEVIER PASSIVE TREATMENT WETLAND, MACON COUNTY, MISSOURI[1]

Kwang "Min" Kim[2] and Paul T. Behum, Jr.

Abstract. The Old Bevier Aerobic Wetland in Macon County, Missouri, was constructed between 1990 and 1991 by the Missouri Department of Natural Resources' Land Reclamation Program for the purpose of treating acid mine drainage (AMD). The principal source of the AMD is from an underground mine that operated during the 1920's through 1950's, which was partially exposed during surface mining in the 1950's. Limestone bedding of an AMD collection system provided alkalinity similar to an anoxic limestone drain (ALD). Because the original aerobic wetland failed when a critical dilution water supply became unavailable, the total acidity of the AMD overwhelmed the limited neutralization ability of the aerobic wetland. The aquatic vegetation deteriorated and treatment became ineffective. The Missouri Land Reclamation Program with the assistance of the Office of Surface Mining, Mid-Continent Regional Coordinating Center rehabilitated the Old Bevier Aerobic Wetland in 2001, incorporating newer technologies to improve the performance. The new system, Old Bevier II treatment facility, consists of a 2-stage vertical flow pond (VFP) with associated oxidation cells and aerobic wetlands. This paper discusses the performance of this passive AMD treatment system, updating an earlier report. The new treatment system has operated with nearly continuous net alkaline discharge and a high iron removal rate. Also discussed are measures to improve AMD collection and treatment by the facility.

Additional Key Words: Acid Mine Drainage, Vertical Flow Pond, Anoxic Limestone Drain, Aerobic Wetland, Anaerobic Wetland, and Water Sampling.

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[1] Paper presented at the 2004 National Meeting of the American Society of Mining and Reclamation and the 25th West Virginia Surface Mine Drainage Task Force, Morgantown, WV, April 18-22, 2004. Published by ASMR, 3134 Montavesta Rd., Lexington, KY 40502

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Proceedings America Society of Mining and Reclamation, 2004 pp 1034-1055
DOI: 10.21000/JASMR04011034
https://doi.org/10.21000/JASMR04011034

Introduction

The Old Bevier II AMD in Macon County, Missouri, is located 11.2 kilometers (7 mi.) southwest of the city of Macon (Fig. 1). The project area is within the watershed of the East Fork of the Little Chariton River and the extensively mined Bevier-Ardmore Mining District.

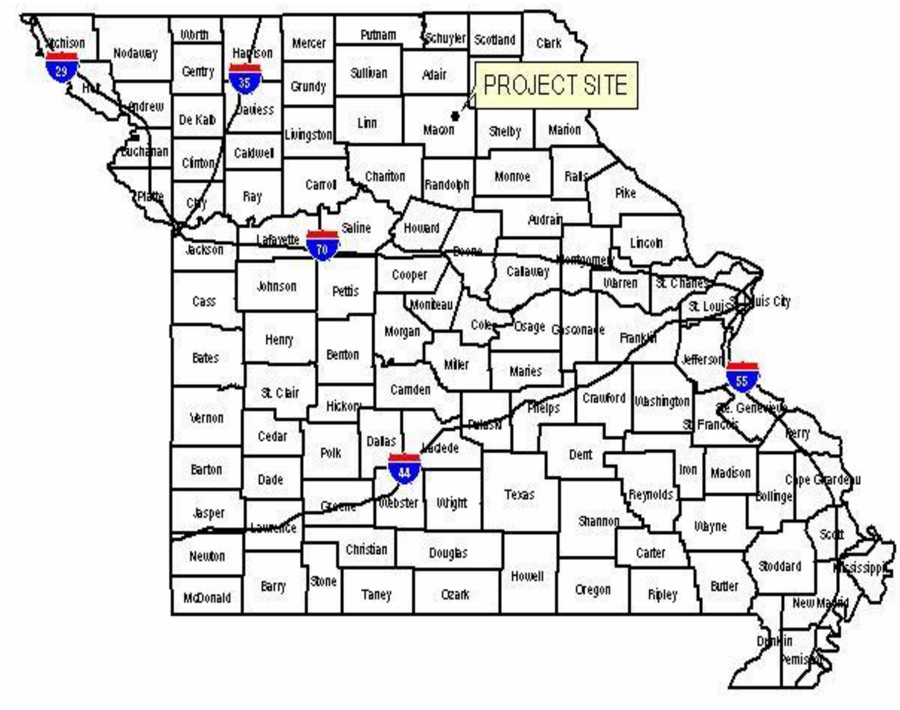

Figure 1. Old Bevier II Project Site Location Map.

This district is historically the most important coal-producing field in Missouri (Hinds, 1912). The extraction of coal began around 1859 in the field with Macon County coal production totaling 39 million metric tons (43 million short tons) between 1889 and 1964 (Gentile, 1967). Room-and-pillar mining was extensive in the 1920's through the early 1950's, followed by area-type surface mining. The Bevier-Wheeler coal bed, composed of the upper, thicker Bevier and a lower, thinner Wheeler coal bed, was the principal target of the mining. At the project site, the overlying 45.7-cm (18-inch) thick Mulky coal was also removed from surface mines (Gentile, 1967). The abandoned underground workings in the Bevier area generate, store, and transmit acid mine drainage (AMD). Unlike many locations in the Midwest these coal beds lie above drainage in the Bevier-Ardmore area. As pre-1977 underground mines, the Bevier-Wheeler seam workings would normally be designed as free-draining facilities. The surface mining operations also “day lighted” some of the old workings and now convey the acid water to a series of seeps along the drainage channels. A number of small coal waste piles (gob) and acid-forming materials exposed by the surface mining generate additional AMD at the site. Several unnamed tributaries of the East Fork of the Little Chariton River are devoid of aquatic life and the river water is degraded by iron, manganese and sulfate from the mine area. Ground water level fluctuations and seasonal flushing of AMD from the underground works during seasonal rainfall events lead to variations in the quality and quantity of water in these streams.

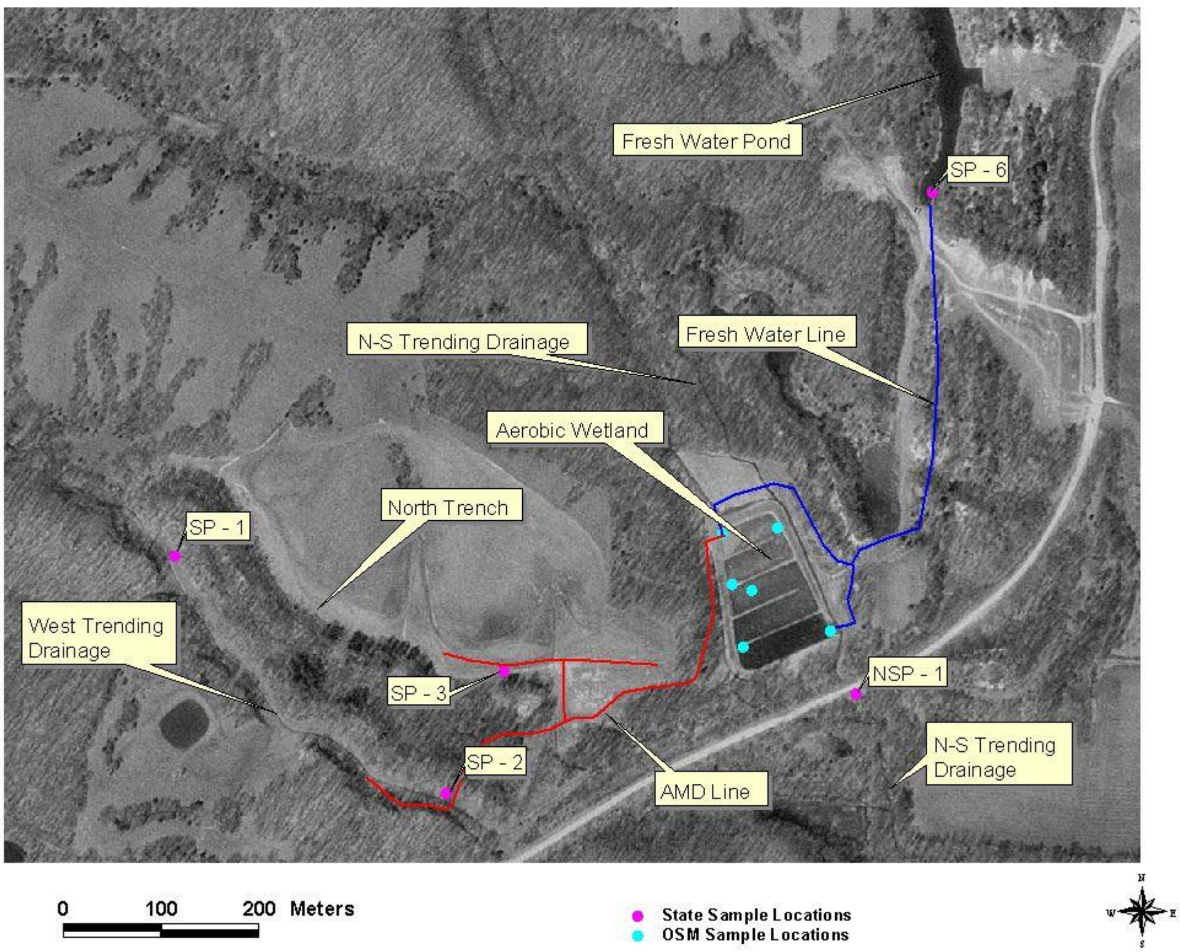

Figure 2. Water Sample Locations Before the 2001 Rehabilitation.

The original Old Bevier reclamation activity began on March 12, 1990, and was completed on April 30, 1991, at a total cost of $932,089 U.S. The project reclaimed 18.6 hectares (46 acres) of abandoned mine lands, including 1.2 hectares (3 acres) of gob, 121.9 meters (400 feet) of dangerous highwalls, and one vertical opening. An aerobic wetland, with its associated collection and dilution pipelines, was constructed at the project site to treat AMD (Fig. 2). Multiple intermittent seeps, in part fed by underground mine workings, occur along the base of exposed highwalls, coal outcrops, and spoil ridges. The west-trending drainage (Fig. 2) was surface mined along the contour. Mine pits were advanced into the slopes of the west-trending drainage until the overburden reached a thickness of 9.1 to 12.1 meters (30 to 40 feet). A final cut was at the northern edge of this disturbance (North Trench) in the 1991 project and reclaimed to create a swale that parallels the original valley (Fig. 2). The final pit (North Trench in Figure 2) apparently intercepted underground workings and is the principal source of AMD. Flow from this area was sampled at SP-3 (Fig. 2 and Table 1). To the south, AMD flows from an outcrop of the Bevier coal. A pre-reclamation water sample of this AMD (Site SP-2) revealed elevated concentration of iron, manganese, and sulfate (Table 1, Fig. 2). A French drain in the North Trench collects seepage and directs the AMD, along with water from a second French drain in the west-trending drainage, into the original Old Bevier wetland. These AMD collection French drains were embedded with limestone which acts like anoxic limestone drain (adds alkalinity). The AMD going into the wetland contains average alkalinity of 180 mg/L.

Original Old Bevier Constructed Wetland

The original aerobic wetland was about 1.2 hectares (3.0 acres) in size and consisted of five cells (see Fig. 2). AMD treatment by the original aerobic wetland began on June 3, 1991. Emergent vegetation rapidly grew and covered most of the water surface during the first summer. The key part of the original design for passive treatment included intake of alkaline fresh water from a nearby fresh water pond to increase pH and boost alkalinity. The fresh water line is highlighted with blue line in Figure 2. Although the wetland was designed to function as an anaerobic wetland it operated primarily as an aerobic wetland. Designed for a 3.78-liters-per-second [60 gallons-per-minute (GPM)] flow, the wetland was supplied by about 1.89 liters-per-second (30 GPM) of AMD from the two AMD-collection pipelines with the remainder from the fresh water source. The system also included an additional 30 GPM of fresh water at the system discharge (Fig. 2).

Table 1. Water Quality at the Old Bevier South Site Associated with the 1991 Reclamation*

Parameter**	SP-2 AMD from Southern Seeps: 1988	SP-3 AMD from Northern Seeps: 1988	AMD at Wetland Inlet: July 1991	SP-6 Dilution Water: East Site Last Cut Pit: 1991	SP-1 West Drainage: 1988 Data	Treated AMD at the Wetland Outlet: July 1991
pH	3.20	2.60	3.20	8.1	7.7	3.3
Total Alkalinity	pH < 4.3	pH < 4.3	pH < 4.3	103	168	pH < 4.3
Total Acidity	1,200	769	625	-57	-96	180
Dissolved Oxygen	6.3	5.5	NT	8.7	9.2	NT
Total Iron	502	90	299	0.36	1.18	18.10
Total Manganese	13.0	13.7	15.5	0.10	0.99	31.2
Total Aluminum	NT	NT	NT	NT	NT	NT
Sulfate	3,463	3,238	3,060	393	406	3,300
Total Dissolved Solids	5,174	4,564	4,620	824	773	4,070

* Samples were collected by the Land Reclamation Program in 1988 through December, 1991.

** All values are in mg/L except pH which is in Standard Units, NT = Not Tested.

Wetland Failure

Two consecutive years of drought severely limited the availability of dilution water from the fresh water pond. Subsequently, the pipeline from this pond was damaged. Because alkaline dilution water was not available to neutralize influent AMD, wetland cells 3 through 5 became acidic, discharging water with pH 3 or less. The low pH harmed aquatic vegetation and slowed metals removal. Although the wetland was losing its capacity to remove iron as the years passed, the iron removal rate remained significant in the upper two cells due to near neutral pH maintained by the alkalinity in the inlet AMD. The alkalinity is being added by the limestone embedded AMD collection system in the North and West French drains. However, most of the alkalinity in the inlet water was being consumed by the acidity generated by the iron oxidation, and pH of the water dropped to 3 or less in wetland cells 3 through 5. Also, the wetland had almost no contribution in adding alkalinity and removing other pollutants in the water. The original treatment facility required rehabilitation due to failure of the dilution water source, exhaustion of some of the carbon content in the compost, and accumulation of iron precipitate.

Hydrologic Investigation and Initial Construction Activity

By early 1998, the LRP/OSM-MCRCC project team decided to conduct a comprehensive hydrologic study at the constructed wetland site to better understand the nature of the AMD and gather the scientific and engineering data necessary to transform the Old Bevier Aerobic Wetland into an improved passive treatment system.

Water Sampling and Analysis

Although some historical AMD water data were available, there was uncertainty about methods employed for field measurements and analyses. Also, there were little or no data on some critical parameters such as aluminum. Systematic water sampling was performed over a two-year period during 1998 and 1999 (Behum and others, 2001). The parameters selected to characterize the AMD were those suggested by Hyman and Watzlaf (1995) and Wildeman and others (1997) and include dissolved metals (iron, aluminum, and manganese) and sulfate. The important measurements of both ferric and ferrous iron were also taken during this sampling effort. Total and ferrous dissolved iron concentrations were determined in the field with a portable colorimeter. Dissolved ferric iron values were calculated by subtracting ferrous iron from the total dissolved iron. Additional field measurements included temperature, pH, redox potential (Eh), specific conductivity, salinity, dissolved oxygen (DO), and, where the pH was > 4.5 S.U., total alkalinity. Either electrochemical or titration methods were used for these field tests. Calculated total acidity (Hyman and Watzlaf, 1995) corresponded well with total acidity as measured in the laboratory. Water samples were collected consistent with 19th Edition Standard Methods (APHA and others, 1995).

Jar Tests

A vertical flow pond (VFP) was considered as for use in remediation of the wetland. The design of the VFP depended upon the alkalinity-producing potential of the locally available limestone. A modified version of the jar test method (Watzlaf and Hedin, 1993) was used to evaluate the limestone. An 18.9-liter (5-gallon) plastic carboy was filled with limestone from a nearby quarry. The limestone was then completely saturated with Old Bevier AMD and the carboy placed in a cooler with some ice to maintain a temperature similar to the ground water. Samples were then drawn over the next several days and the total alkalinity was measured (Hach digital titration method). Data were plotted on a chart to show the rate of alkalinity generation (Behum and others, 2001). Two replicates of the test were run to ensure data consistency. The tests showed that the potential increase in alkalinity using this limestone and AMD combination was 160 to 190 mg/L.

Phase I Construction Activities and Temporary Chemical Treatment

To best characterize water quality, the AMD should be collected and analyzed in the same chemical state as found in the field. Anoxic water may be sampled from a well, a wet-type mine seal, or an existing AMD collection pipeline as was the case at the Old Bevier site. However, the outlet of the drainage collection system in the original wetland was inaccessible because it was submerged under water and buried in iron flocculent. A valve-controlled tap in the collection pipe was installed during Phase I construction. From the tap, a 10.2 cm (4- inch) PVC pipe conveys flow for temporary bypass treatment. It provides a means to collect AMD, the characterization of which is critical to the redesign effort, and allows a standpipe connection for water head measurement. The Phase I activity also involved construction of an all-weather access road and facility area near the southwest corner of the original wetland. A commercially-available treatment device known as an *Aquafix* system[3] (Aquafix Water Treatment Systems, Kingwood, WV) chemically treated the AMD, which was diverted during wetland construction.

New Passive Treatment Options

Following the hydrologic investigations, Missouri LRP and OSM-MCRCC considered options for improving passive treatment at the site. The data (Table 2) suggested three approaches to rehabilitate the wetland. These options included:

[3] Use of this commercial product name is intended to identify the type of technology applied and does not imply endorsement by the Office of Surface Mining nor the Missouri Department of Natural Resources.

Table 2. Old Bevier II Project: AMD Loading and Dilution Estimates.

Loading (g/day) = Concentration* x Flow Rate x Conversion Factor (5.45)				
	Constituent	**(mg/L)**	**L/sec(GPM)**	**Loading (g/day)**
Inlet AMD	Total iron	450	1.893(30)	73,575
	Manganese	15	1.893(30)	2,452
	Net Acidity	580	1.893(30)	94,830
	Sulfate	3,400	1.893(30)	555,900
East Lake Dilution Source	Total iron	0.29	2.524(40)	62
	Manganese	0.10	2.524(40)	21
	Net Alkalinity	90	2.524(40)	19,620
	Sulfate	358	2.524(40)	77,935
West Lake Dilution Source (proposed)	Total iron	1.2	2.524(40)	257
	Manganese	1.0	2.524(40)	215
	Net Alkalinity	150	2.524(40)	32,700
	Sulfate	406	2.524(40)	88,508
Resultant : AMD + East Lake + Proposed West lake	Total iron	123	6.94(110)	73,894
	Manganese	4.5	6.94(110)	2,690
	Net Acidity	70.91	6.94(110)	42,510
	Sulfate	1,205	6.94(110)	722,343
Resultant : AMD + East Lake only	Total iron	193	4.417(70)	73,637
	Manganese	6.50	4.417(70)	2,474
	Net Acidity	197	4.417(70)	75,210
	Sulfate	1,661	4.417(70)	633,835

* "Lake" Samples collected in 1988 by the Land Reclamation Program. "Inlet AMD" is an average of state and OSM values collected as of the 1999 dilution option studies and approximately represent the inlet quality prior to reconstruction.

Option 1

Construct Two Dilution Water Impoundments and Rehabilitate the Aerobic Wetland - An adequate amount of suitable alkaline dilution water could be obtained by constructing a new 7,402 cubic meter (6 acre-foot) impoundment in the unnamed west side drainage. This supply would supplement flow from a rebuilt pipeline from the East Site freshwater impoundment (Fig. 2). Table 2 provides the loading calculations used in this evaluation. As in the original design, this plan has dilution water alkalinity offsetting AMD acidity. An aerobic wetland would provide a favorable environment for the precipitation of metals contained in the AMD/alkaline water mixture. The new dilution water source would be located upstream from the surface mining area and was expected to have relatively good water quality (Tables 1 and 2). Note that both dilution sources have elevated sulfate (>300 mg/L), which would contribute to sulfate loading (Tables 2).

Option 2

Dilution Pond and VFP Construction with Aerobic Wetland Rehabilitation - This option only uses dilution water from the new 7,402 cubic meter (6 acre-foot) impoundment as an alkalinity source (Table 2, West Lake Dilution Source) to partially offset the AMD acidity. However, additional alkalinity is required (compare acidity loading from the inlet to the AMD load of the outlet, Table 2). A VFP could provide the remaining alkalinity requirement. The VFP is a deepwater pond with piping that drains the AMD/dilution water mixture downward through a layer of compost, through an alkalinity source (a bed of limestone), and out through collection pipes and water level control structure. The critical step is the removal of dissolved oxygen by the deep water and compost. This shift in the redox potential to a reducing environment prevents iron precipitation in the limestone bed. Without the compost and deep water layer, iron accumulation would reduce the life of the system. A downstream aerobic wetland would then provide a favorable environment for precipitation of metals.

Option 3

Two-Stage VFP and an Anaerobic Wetland Treatment - Option 3 does not require the use of dilution water to partially offset the acidity. Instead, alkalinity is generated in a two-stage VFP. Because of the high acidity of the untreated AMD (Tables 1 and 2), additional alkalinity may be required. An anaerobic wetland, operating in series with the VFP, produces this alkalinity from limestone and bacteria-mediated sulfate reduction reactions within its thick compost layer.

Design of the new treatment system

During the review of design options, the LRP was concerned that, due to site topography, a dilution pond would have to be located remote from the treatment system in a heavily wooded area. This would require a long pipeline, as had been employed for the original treatment system. This design had proved to be troublesome. Also, project costs would have increased from clearing, grubbing, and earthwork associated with dam and impoundment construction in a wooded area. Therefore, the LRP decided to implement Option 3, a two-stage VFP system with associated wetlands and oxidation ponds. The design for Option 3 calls for the final treatment cell to be an anaerobic wetland. A hybrid aerobic/anaerobic cell was actually constructed with a

30-cm (1-foot) thick layer of organic matter covering a 30-cm (1-foot) thick limestone bed. This cell is submerged under 15 cm (6 inches) of water. This paper generally refers to this hybrid final cell as an Aerobic Wetland #3.

The project design relied on certain assumptions. These assumptions are based on criteria presented by Watzlaf and Hyman (1995), Skovan and Clouser (1998), Skousen and others (1998), and from project designs by the Pennsylvania Department of Environmental Protection, Bureau of Abandoned Mine Reclamation (Eric Cavazza, Personal Communication, 1999).
The design criteria are:

$$\textit{Iron Removal Rate} = 10\ gram/m^2/day \tag{1}$$

$$\textit{Mass of Limestone Needed} = M_1 + M_2 \tag{2}$$

Where:
M_1 (mass of limestone gravel needed to achieve water retention time) = $Q * L_d * R_t / V_d$
M_2 (mass of limestone gravel dissolved during effective life of system) = $Q * A_g * T_l / A_p$
Q = flow rate
L_d = limestone gravel density
R_t = water retention time
V_d = limestone gravel porosity
A_p = alkalinity productivity (fraction of limestone that is $CaCO_3$)
T_l = effective life of system
A_g = expected alkalinity concentration to be generated (160 mg/l was used based on the Phase I study's modified Jar Tests).

Because the concentrations of aluminum and manganese are insignificant compared to the total iron concentration, iron is the limiting factor. Therefore, the iron removal rate was used to size the aerobic wetland cell. The oxidation ponds were sized to provide least 24 hours of water retention time and to store iron floc for the project life. Manganese and sulfate levels were also relatively high. However, cost and space limitations of the project prevented inclusion of specific structures for manganese or sulfate removal. Such facilities could have included a large anaerobic wetland for sulfate reduction and/or a limestone bed inoculated with manganese-removing bacteria.

Table 3. Design Parameters: Untreated AMD Quality and Contaminant Load.

Parameter	**Value**	**Units**	**Comments**
pH	5.8	S.U.	typical value
Eh (estimated)	73	mv	typical value
DO	0.48	mg/L	average values
Total Fe	450	mg/L	average value
D. Fe	400	mg/L	average value
D. Fe+3	20	mg/L	by subtraction
D. Fe+2	380	mg/L	average value
Al	0.4	mg/L	average value
Mn	15.0	mg/L	average value
Acidity	760	mg/L	average value
Alkalinity	180	mg/L	average value
Net Acidity	580	mg/L	by subtraction
Sulfate	3400	mg/L	average value
Flow 1	1.89	L/sec.	(30 GPM) from existing AMD line, average value
Flow 2	0.63	L/sec	(10 GPM) est. added from Western extension
Flow 3	0.32	L/sec	(5 GPM) est. to be collected seep adjacent to the wetland
Total Flow @ Inlet	2.52	L/sec	(40 GPM) @ 1st thru 5th cells
Total Flow w/ Seep	2.84	L/sec	(45 GPM) @ 6th and last cells

Contaminant Load Calculations

Acid loading = 2.52 L/sec * 60 sec/min * 60 min/hr * 24 hr/d * 580 mg/L * 1 g/1000 mg = 126,282 g/d

Fe loading = 2.52 L/sec x 60 sec/min x 60 min/hr x 24 hr/day x 450 mg/L x 1 g/1000 mg = 98,133 g/d

Mn loading = 2.52 L/sec x 60 sec/min x 60 min/hr x 24 hr/day x 15 mg/L x 1 g/1000 mg = 3,270 g/d

SO_4 loading = 2.52 L/sec x 60 sec/min x 60 min/hr x 24 hr/day x 3,400 mg/L x 1 g/1000 mg = 741,254 g/d

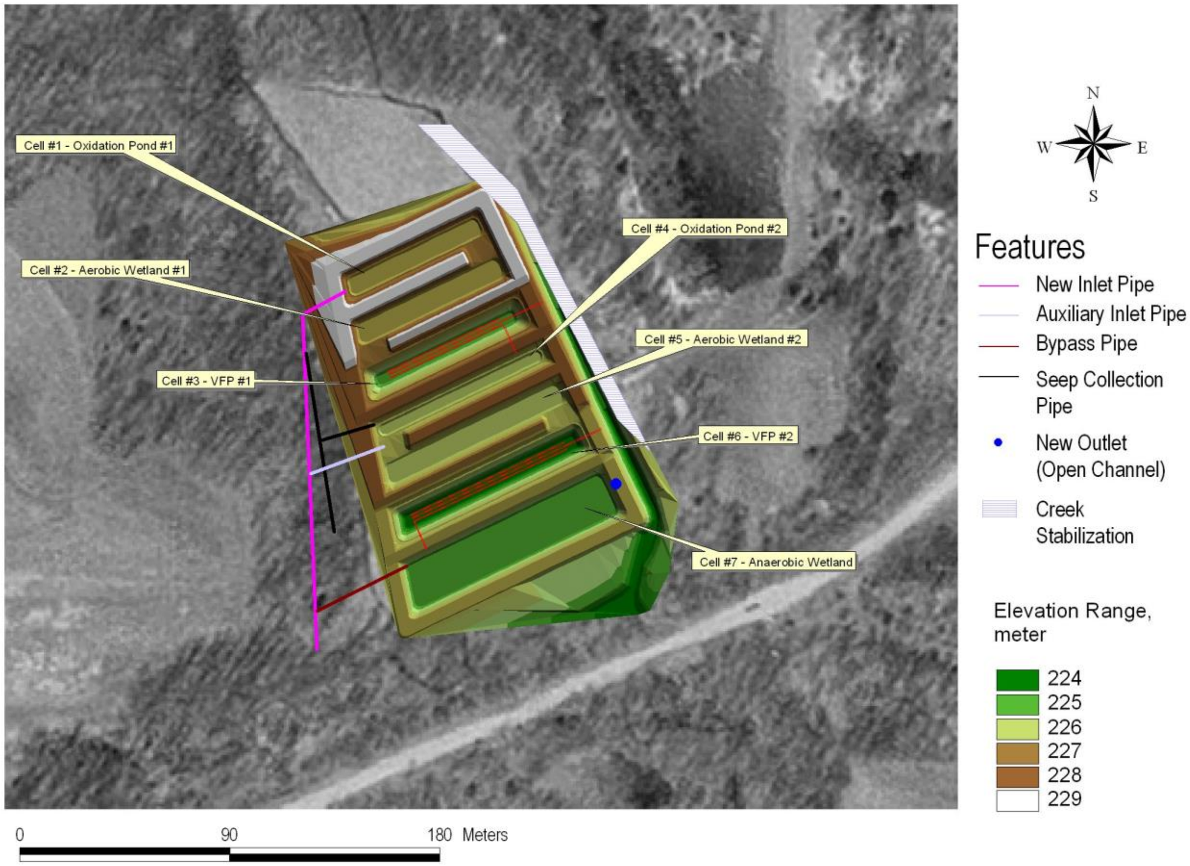

Figure 3. Topographic Model of the Old Bevier II Project

The VFP cells, designed for a 20-year effective life, contain a 1.3-meter (4-foot) thick layer of limestone in VFP #1 and a 0.91-meter (3-foot) thick layer in VFP #2. The limestone layers are designed to have a 15.2 cm (6-inch) thick bedding of 4 to 5 cm (1.5 to 2 inch) fine aggregate and rest filled with 10 to 12.5 cm (4 to 5 inch) coarse aggregate. Overlying the limestone beds are a 0.46-meter (1.5-foot) thick layer of organic matter and then a 0.61-meter (2-feet) of water. Because of the limited amount of elevation head available at this site the latter two layers are slightly thinner than the standard VFP design. Most of the organic matter is mushroom compost shipped from the Miami, Oklahoma area. The VFP units are constructed with 15.2 cm (6-inch) and 20.3 cm (8-inch) Schedule 80 PVC under drain piping and AgriDrain Corporation's (Adair, IA) *Inline Water Level Control Structures* [4]. A single 20.3 cm (8-inch) Schedule 80 PVC pipe and control valves composed a flushing capability to each VFP unit as suggested by Skovan and Clouser (1998) and Eric Cavazza, PADEP-BAMR (personal communication, 1999). The retention time in VFP #1 is 15 hours and VFP #2 is designed for 12 hours. The aerobic wetlands are designed with 0.46 meter (1.5-foot) thick layer of compost, which is mostly composed of a manufactured product from Chamness Technologies (Eddyville, IA). The aerobic wetland cells are also designed for a 12-hour retention time. Water depth of aerobic wetland cells is variable, ranging about 6.35 mm (0.25 inches) to 30.5 cm (12 inches) thick. Underlying Aerobic Wetland #3 is a 15.2 cm (0.5-foot) thick limestone layer. A small anoxic limestone drain (ALD) was constructed along the western edge of the reconstructed wetland to collect AMD seepage, with outlets into cell #4 (Oxidation Pond #2) and cell #7 [Aerobic Wetland #3 (cell #7); see the black line in Figure 3]. This ALD is designed with a 12-hour retention time, and the size of rocks used is 12.5 to 15 cm (5 to 6 inch) coarse aggregate. The water retention times in VFPs and ALD are permanent, meaning that the system design accounted the limestone loss by dissolution throughout the 20 year system design life.

Phase II Construction

The Old Bevier II facility was constructed between the summer and fall of 2001. The new system has been processing AMD since early October, 2001. Seven treatment cells, starting from the system inlet, are: Oxidation Pond #1, Aerobic Wetland #1, VFP #1, Oxidation Pond #2, Aerobic Wetland #2, VFP #2, and Aerobic Wetland #3 (Fig. 3). In the spring of 2002, MO LRP planted some cattails and other hydrophilic plants in the aerobic cells. During the warm months in 2003, the wetlands were fully covered with vegetation (Fig. 4).

[4] Use of this commercial product name is intended to identify the type of technology applied and does not imply endorsement by the Office of Surface Mining nor the Missouri Department of Natural Resources.

Figure 4. View of VFP #2 (left) and Aerobic Wetland #2 (center) - Photograph by OSM-MCRCC May 2003.

System Evaluation

Post-construction water samples were collected October 2001 through July 2003 and analyzed both by OSM-MCRCC and a commercial laboratory (Table 4). Water analyses indicate the system is operating as expected with a high iron removal rate during warm months, followed by reduced performance during the winter. Based on the average values from seven rounds of water sampling since the end of construction, the new system is removing more than 95 percent of the total iron from the inlet AMD. The removal rates for manganese and sulfate are lower (Table 4).

Table 4. AMD Water Quality at the Old Bevier II Project Site Following Rehabilitation*

Parameter	Inlet	Oxidation Pond 1 Outlet	Aerobic Wetland 1 Outlet	VFP #1 Outlet	Oxidation Pond 2 Outlet	Aerobic Wetland 2 Outlet	VFP #2 Outlet	Aerobic Wetland: System Outlet	Units
Median pH	5.92	6.02	3.10	6.23	4.70	3.29	6.42	6.62	s.u.
pH Range	5.60 ~ 6.25	3.07 ~ 6.27	2.89 ~ 6.32	5.96 ~ 6.6	3.34 ~ 6.6	2.97 ~ 6.8	6.2 ~ 6.73	3.57 ~ 7.27	s.u.
Alkalinity Median***	186	88	0	164	0	0	139	69	mg/L
Alkalinity Range***	164 ~282	0 ~ 200	0 ~ 84	131 ~ 198	0 ~ 150	0 ~ 90	76 ~ 184	0 ~ 152	mg/L
Lab Alkalinity	217							132	mg/L
$Acidity_{cal}$ Median**	753	599	447	454	191	95	132	26	mg/L
$Acidity_{cal}$ Range[2]	360~ 1164	452 ~ 770	297 ~ 731	273 ~ 690	70 ~ 354	57 ~ 297	56 ~ 265	15 ~ 166	mg/L
Lab (net) Acidity	683	470	680	440	390	79	35	20	mg/L
Median Sulfate***	1800	1875	1950	1925	2000	1500	1650	1560	mg/L
Sulfate Range***	1350 ~3000	1300 ~ 3040	1300 ~ 3160	1000 ~2600	1100 ~ 2650	400 ~ 2200	900 ~2360	1050 ~ 2200	mg/L
Lab Sulfate	2900							2070	mg/L
Median T. Fe***	408	316	234	197	101	13.0	50.6	12.2	mg/L
T. Fe Range***	162 ~ 514	178 ~ 364	85 ~ 352	128 ~ 289	32 ~ 175	9.5 ~ 103	24 ~ 111	3.3 ~ 66	mg/L
Lab T. Fe	474	434	439	328	246	22.8	115	71.9	mg/L
Cumulative Fe removal	0.0	21	48	46	74	91	84	93	%
Median D. Mn	9.1	9.6	8.3	9.1	7.8	8.6	8.9	8.3	mg/L
D. Mn Range	8.0 ~ 13	7.1 ~ 11	6.8 ~ 12	7.1 ~ 11.0	6.1 ~ 10.0	7.0 ~ 10.5	7.0 ~ 12.8	7.0 ~ 11.3	mg/L

* Samples were collected by OSM-MCRCC 9/26/01, 10/22/01, 1/23/02, 2/21/02, 9/25/02, 5/27/03, 7/23/03, and 12/17/03. On 9/26/01, the water level in cell #6 was below the discharge level, and cell #7 was dry. Lab samples were collected on 1/23/02. Metals and sulfate values were determined using HACH DR890 colorimeter except lab value; field alkalinity was measured using HACH digital titration.

** Calculated from pH and dissolved metal values using the formula:

Metal Acidity (calc.) = 50[2 Fe2+/56 + 3Fe3+/56 + 3Al/27 + 2Mn/55 +1000(10-pH)].

*** Lab values are not included.

Overall, the system is discharging net alkaline water during the warm months (March through November). In winter (December, January, and February), a slightly net acidic water may be discharged.

The project included a collection system to intercept small seeps from underground mines immediately west of the treatment cells. This water flows through a small ALD, and then because of elevation constraints of the seep outlets, flows directly into VFP #2 (cell #6). The collection system appears to capture only a small amount of AMD, and although discharge from the ALD is small, the increase in contaminant levels of the lower cells is measurable. This explains why the average total iron concentration in the VFP #2 (cell #6) effluent is higher than the average iron concentration in the Aerobic Wetland #2 (cell #5) discharge (Table 4, Fig. 6). Additional AMD seepage may be occurring into VFP #2 (cell #6, Fig. 5 and 6).

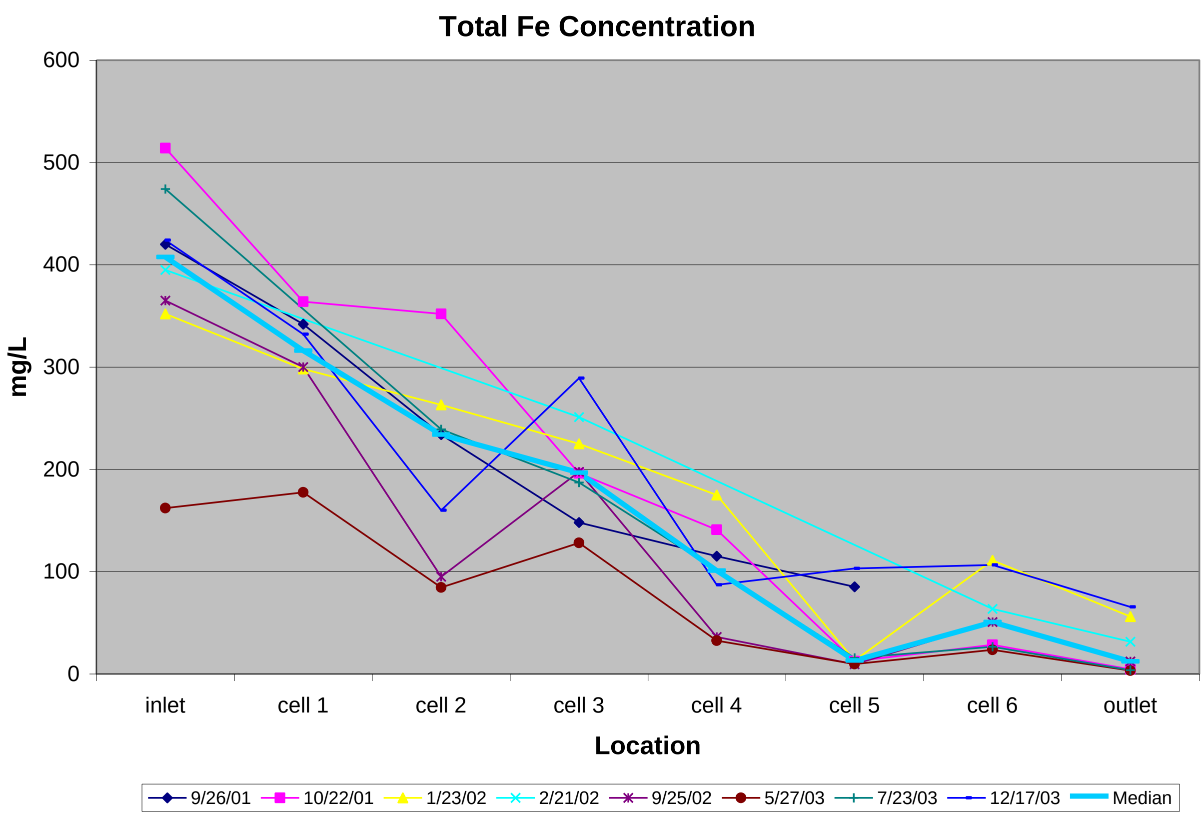

Figure 5. Changes in Total Iron within the Old Bevier II Passive Treatment System.

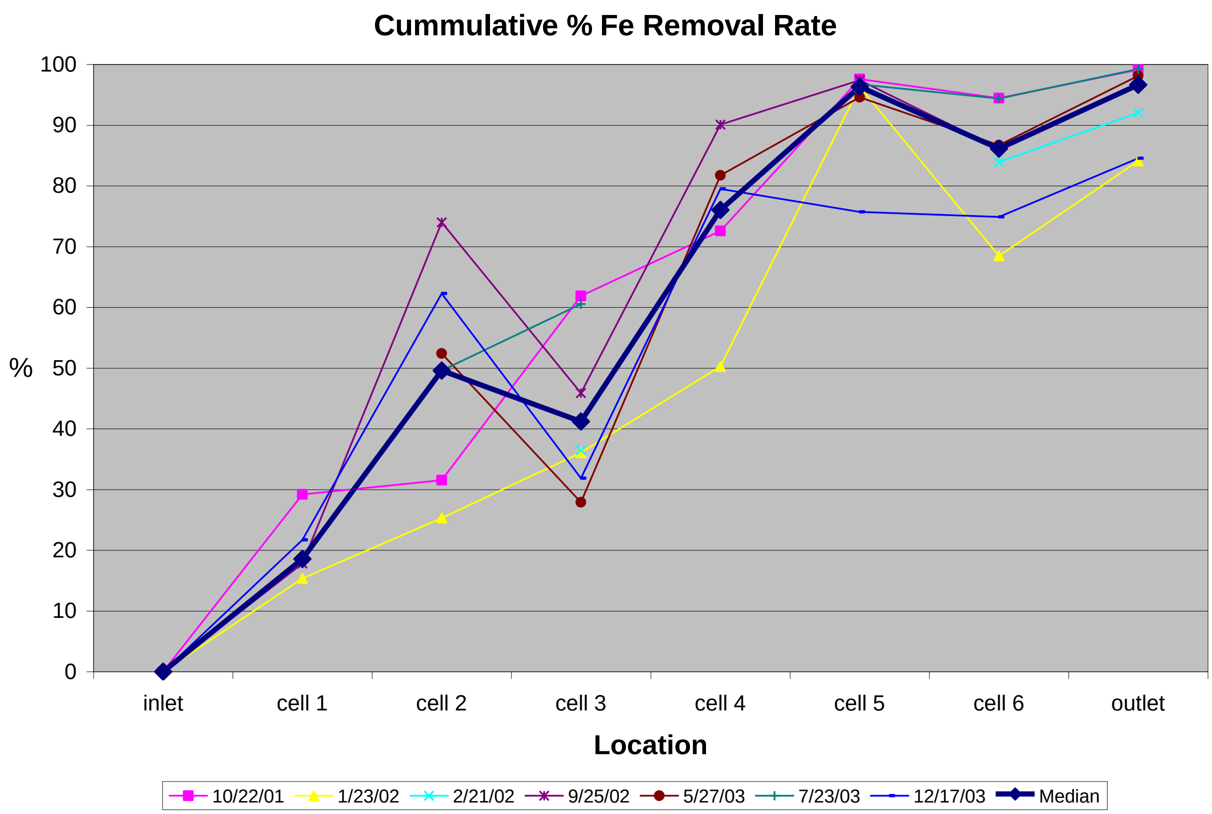

Figure 6. Cumulative Total Iron Removal Rate within the Old Bevier II Passive Treatment System (Note reduced performance in the limited number of winter samples).

Performance of individual treatment cells can be illustrated by plotting key chemical parameters against position along the system flow path (Fig. 5 through 10). The pH levels, which are reduced by metal oxidation and hydrolysis in the oxidation cells and aerobic wetland cells, receive a boost by the VFP cells (Fig. 7). For VFP #1, mean pH increases about 3.0 standard units and for VFP #2 mean pH increases about 3.1 standard units. As designed, the first oxidation pond and aerobic wetland remove iron. Then, after alkalinity is added with VFP #1, additional iron precipitates (Table 4, Fig. 5 and 6). Mean total iron level at the discharge remains high at about 18.5 mg/L. Total alkalinity trends follow pH with reduction as the metal oxidation and precipitation reactions “use up” alkalinity (bicarbonate) and increase from each VFP unit to about a level of 160 mg/L (Fig. 8). Because of the gradual drop in manganese concentration along the flow path, manganese reduction does not appear to be attributed solely to co-precipitation with iron hydroxide (Table 5, Fig. 9). Only about 12 percent of the manganese is removed by this system. A limited amount (18 %) of sulfate removal is occurring. Sulfate is lowered from a mean value of 2,037 mg/L in the inlet to 1,676 mg/L at the system outlet (Table 5, Fig. 10).

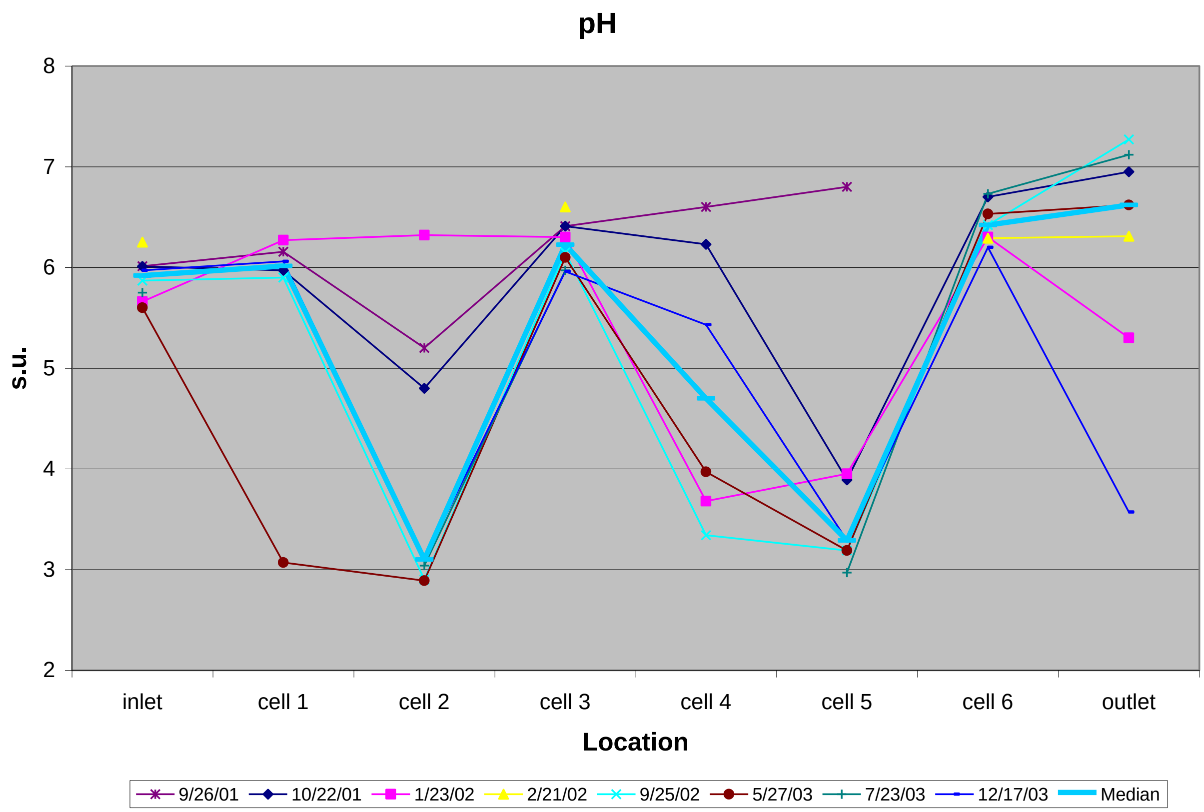

Figure 7. Changes in pH within the Old Bevier II Passive Treatment System.

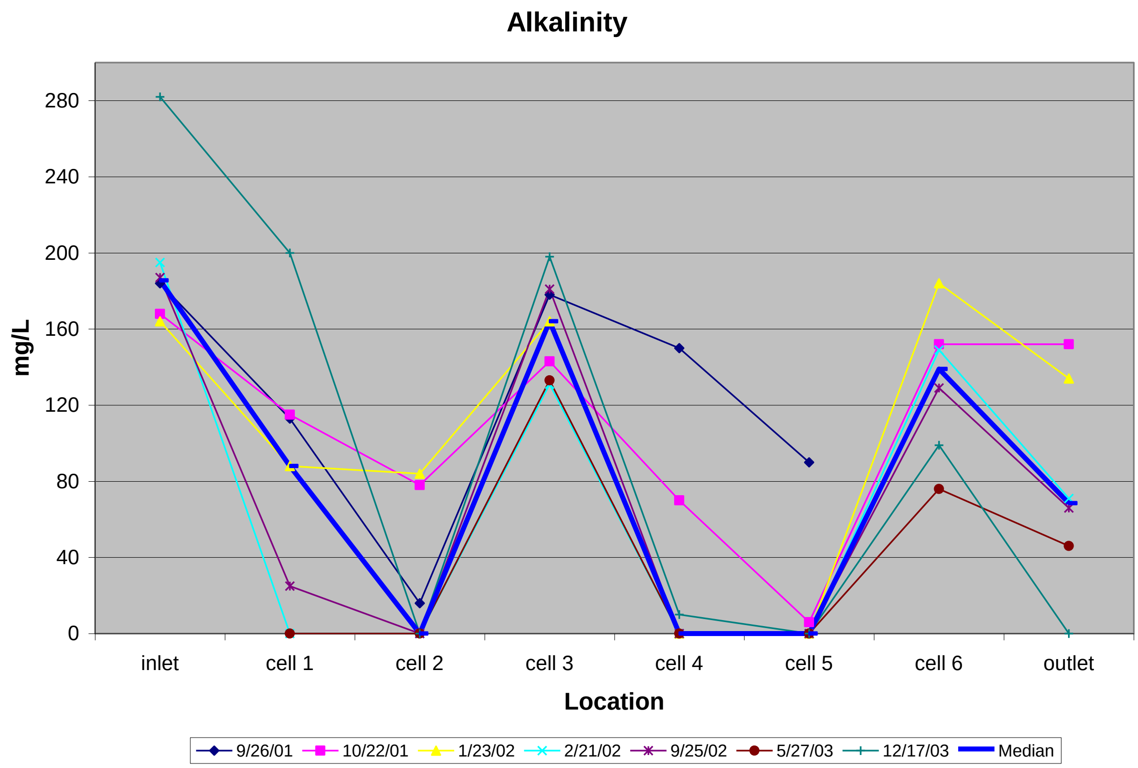

Figure 8. Changes in Total Alkalinity within the Old Bevier II Passive Treatment System.

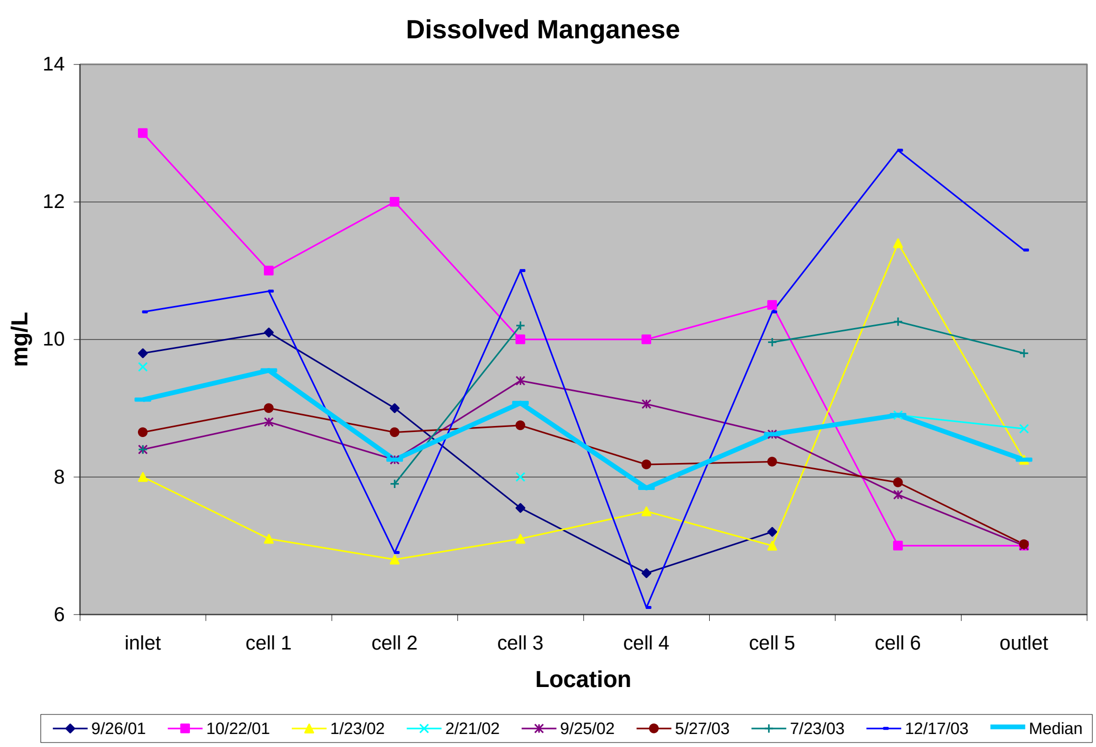

Figure 9. Changes in Manganese within the Old Bevier II Passive Treatment System.

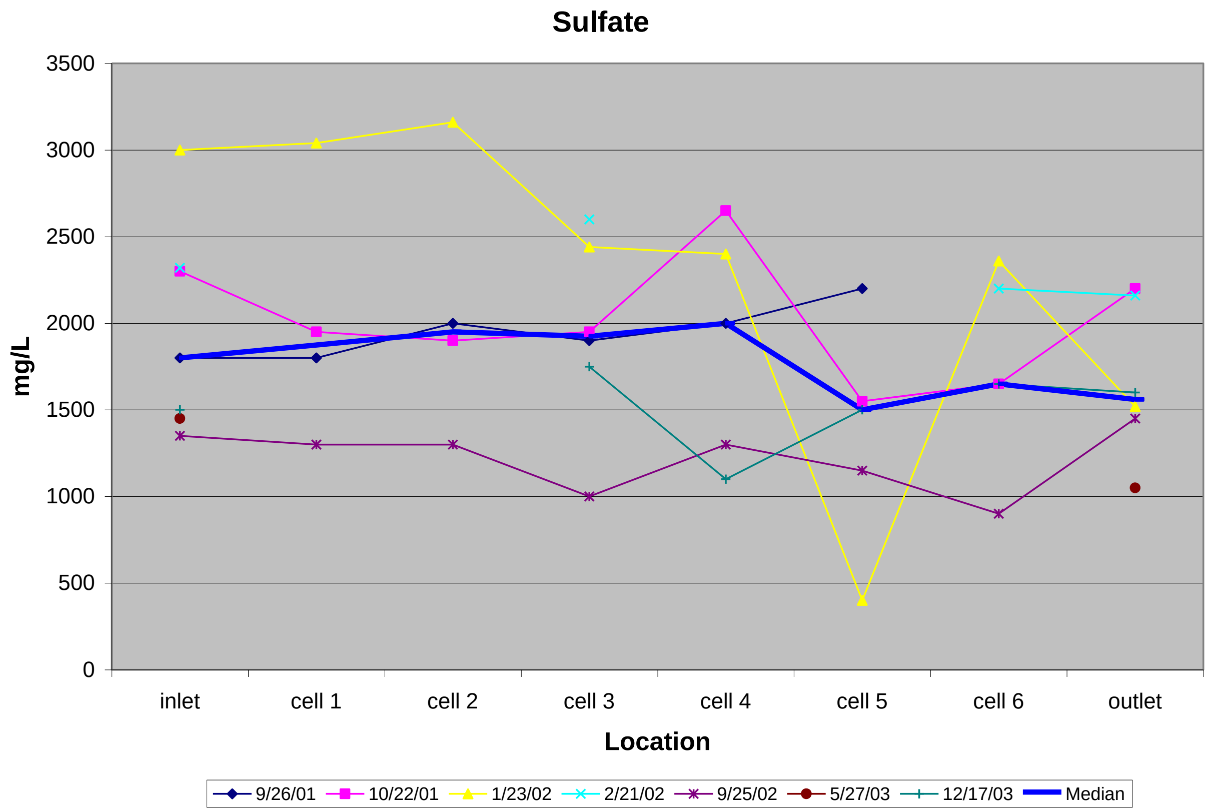

Figure 10. Changes in Sulfate within the Old Bevier II Passive Treatment System.

Conclusions and Lessons Learned

Additional rounds of water sample collection with analysis by an EPA-certified laboratory are planned for 2004 to continue monitor and evaluate the system performance level and to investigate seasonal variations in both treatment and flow. Future AMD treatment projects in Missouri, which require VFP technology, should consider inclusion of: 1) either an upturned outlet pipe, an aerobic wetland, or limestone-lined drop structure before the oxidation pond to allow for more rapid aeration; 2) a schedule for construction that allows completion before winter to allow transplanting of locally-derived emergent plants; and 3) use of improved water level controlling structure for each VFP. In the later improvement it is recommended that in future VFP installations of AgriDrain Corporation's *Inline Water Level Control Structures*[5] the access caps are replaced by caps constructed of non-corrosive materials. The experience gained in the original Old Bevier I project showed that maintenance problems of a long dilution supply pipeline, particularly a pipeline positioned in an area that supports multiple land use, may cause premature failure of an AMD passive treatment system.

Acknowledgements

As mentioned above, Eric Cavazza of PADEP-BAMR provided valuable design assistance. George Watzlaf, DOE, National Energy Technology Laboratory (NETL) provided review comments on draft designs. Additional project or review work was also provided by OSM-MCRCC staff, in particular, Brian Hicks, Ervin Barchenger, Kevin Garnett, and Bill Joseph. Dennis Stinson, formerly of the Missouri Department of Natural Resources' Land Reclamation Program, and current Land Reclamation Program staff member Clint Bishop managed the project activity and conducted design reviews. Thomas Mastaller, OSM, conducted GPS surveys and provided design assistance to the State for Phase I activities. Missouri Land Reclamation Program staff member Michael Mueller and former staff members Angela Glascock and John Mehuys assisted in the Phase 1 and Phase 2 construction activity and data collection efforts. Michael Jenkins of Aquafix Water Treatment Systems, Kingwood, WV, assisted in the sizing and installation of the temporary AMD treatment system. Sherry Baker of Chamness Technologies, Eddyville, IA, provided information on the environmental and growth medium qualities of the manufactured compost material used in the wetland cells.

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[5] Use of this commercial product name is intended to identify the type of technology applied and does not imply endorsement by the Office of Surface Mining nor the Missouri Department of Natural Resources.

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