

PASSIVE TREATMENT OF ACID MINE DRAINAGE IN THE MID-CONTINENTAL U. S. – CONSTRUCTION PROBLEMS AND POSSIBLE SOLUTIONS¹.

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Abstract: Passive treatment technology has been primarily developed in Appalachia for treatment of discharges that lie above drainage. Because of differences in geochemistry, hydrogeology and mining methods in the Illinois and Interior Coal Basins, the application of passive treatment technology for the treatment of Acid Mine drainage (AMD) requires additional design considerations. In the Illinois Basin, most of the surface and underground mines lie below drainage. At a typical discharge, the acidic and metal-laden ground water seeps directly into streams and agricultural ditches as diffuse base flow. In this hydrologic setting AMD impacts are reduced (the “deep and dark” prevention method applies). Many AMD problems in the Midwest are associated with coal refuse disposal areas. These facilities are usually placed above the surface and, as such, above drainage. Common practice for prevention of AMD, where the coarse refuse is net acidic, is to use compaction followed by the construction a soil cap to restrict infiltration.

This paper presents several problems that have restricted application of passive treatment at a number of mid-continent sites and suggest measures needed to remedy these limitations. The problems discussed include: 1) the collection of AMD from diffuse sources and the generation of sufficient hydraulic head for application of a vertical flow pond (VFP), 2) treatment of AMD with high acidity and metal loading, and 3) high aluminum content. Several sites will be discussed, including the Old Bevier, Cedar Creek, and Otter Creek AML projects in Missouri and the artesian Rock Island No.7 mine pool discharge in Oklahoma.

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Introduction

In the mid-continent U.S., implementation of passive AMD treatment technology is progressing at a slower pace than in the Appalachia coalfields. This is due, in part, to comparative number of sites producing long-term AMD. Institutional limitations also restrict passive treatment applications; a number of mid-continent states receive minimum program funding and as such have only a small number of AML program staff. Funding and personnel limitations, therefore, restrict the ability of these agencies to provide the necessary treatment facility maintenance. However, the greatest restrictions for passive treatment application in the mid-western U.S. are technical. These technical problems discussed include:

- 1) collection of AMD from diffuse sources and the generation of sufficient hydraulic head for application of a vertical flow pond (VFP),
- 2) treatment of AMD with high acidity and metal loading, and
- 3) treatment of AMD with high aluminum content.

Several case examples will be presented that discuss sites in the region where passive treatment application is difficult due to these technical problems. It is hoped that, if the proposed technologies can economically overcome the technical limitations, more treatment applications will be constructed in the mid-continent.

Collection of AMD from a Diffuse Sources and the Generation of the Hydraulic Head Needed to Facilitate Passive Treatment.

In a typical Illinois and Interior Coal Basin AMD discharge, the acidic and metal-laden ground water does not seep into streams from point large, discrete point sources. Instead, AMD occurs there as numerous small seeps discharging directly into streams and agricultural ditches as diffuse base flow. The collection of the accumulating AMD is, therefore, difficult. If treatment is not possible within the water course, measures must be taken to intercept the AMD as ground water and convey this drainage to a treatment facility. Conveying the intercepted

water in a pipeline provides the possibility of generating sufficient elevation head to overcome pressure losses within passive treatment structures such as a vertical flow pond (VFP)

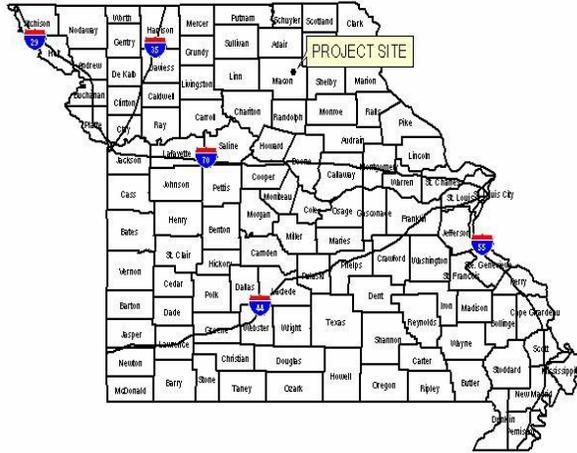
Case Example: Construction of a Two-Stage VFP - the Old Bevier Project, Missouri

Located 11.2 km (7 mi) southwest of the city of Macon in Macon County, Missouri, the AMD at the Old Bevier Project site is primarily from underground workings that lie just above drainage (Figure 1). Pre-SMCRA surface mining operations partially “daylighted” the down-dip portions of these underground workings. The surface mining intercepted AMD in a mine pool perched above stream level. This AMD infiltrates through the spoil to form seeps along the drainage channels. Initial AML reclamation in 1990-1991 consisted of covering final surface mine pits and any acid-forming materials with a 1.5- to 1.8-meter (5- to 6-foot) thick layer of clay-rich soil and reconstructing the stream channel. This channel was raised to isolate surface drainage from an AMD seepage zone in the old streambed. The final pit (the North Trench, Figure 1) apparently intercepted underground workings and is the principle source of AMD. A French drain in the North Trench collects seepage and directs the AMD, along with water from another drain in the west-trending drainage, into the original Old Bevier Passive Treatment Wetland, an aerobic wetland that received alkalinity from dilution water. The dilution water source was difficult to maintain so a replacement method was needed to remediate the highly acidic and metal-laden AMD seepage at this remote site.

Solution: Extend and Rehabilitate the AMD Collection Pipeline and Reconstruct Wetlands with Addition of Two-Stage VFP-based System.

A passive treatment facility was constructed in 1990-1991, and then reconstructed in 2001. The Old Bevier II Project rehabilitated the initial Old Bevier Wetland by extension and reconstruction of the AMD collection pipeline (Fig. 1) and construction of a more efficient passive treatment system (Behum and others, 2002; Codner, 2003). The passive treatment facility includes a two-stage VFP plus an anaerobic wetland to provide alkalinity along with oxidation ponds and aerobic wetlands to precipitate metal hydroxides (Fig. 2). The AMD conveyed into the wetland by the French drain was “pretreated” with alkalinity (120 to 180 mg/L as equivalent CaCO_3 , Table 1) derived from the limestone bedding. The pipeline also provided

sufficient head (1.8 to 2.4 m or 6 to 8 ft) to allow for pressure losses within the two VFP's. The average discharge being treated is about 2.5 L/sec (40 GPM).



Old Bevier II Project Site Location

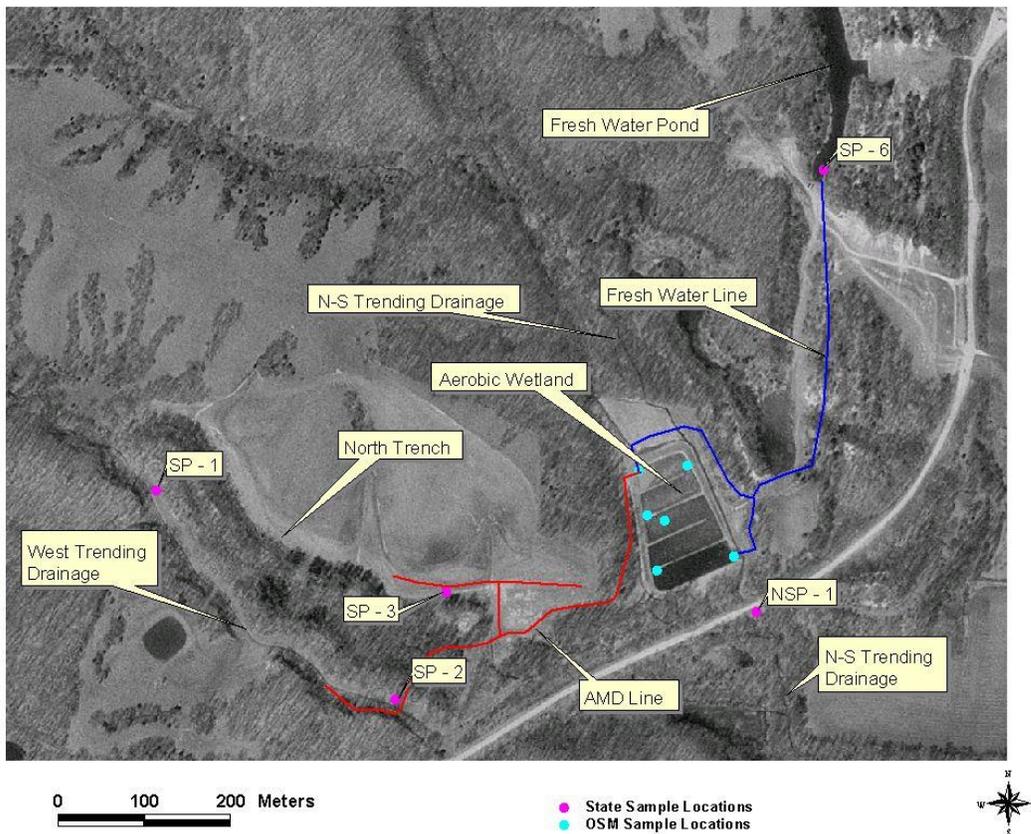


Figure 1. The 1990-1991 Old Bevier Wetland, Missouri.

Preliminary post-remediation water samples were collected October 2001 through January 2003 (Table 1). Water analyses indicate the system is operating as expected with a high iron removal rate initially, followed by reduced performance during the winter. Initially, the system was removing about 99% of the iron and achieving a near neutral (6.95) pH.

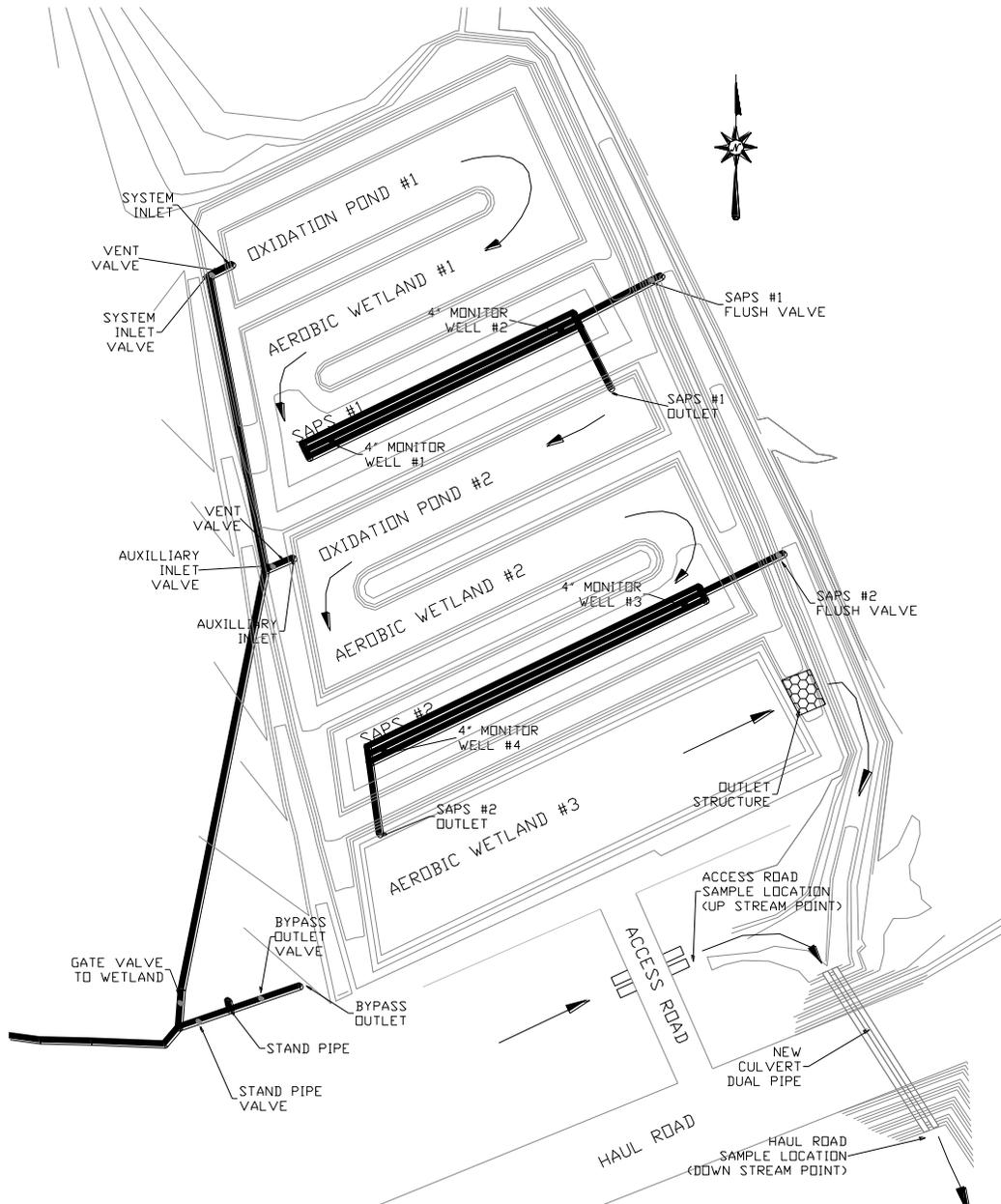


Figure 2. The 2000-2001 Reconstructed Old Bevier II Passive Treatment Facility.

Table 1. 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 Median**	753	599	447	454	191	95	132	26	mg/L
Acidity 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:

$$\text{Metal Acidity (calc.)} = 50[2 \text{Fe}_2^{+}/56 + 3\text{Fe}_3^{+}/56 + 3\text{Al}/27 + 2\text{Mn}/55 + 1000(10-\text{pH})].$$

*** Lab values are not included.

Contaminant Load Calculations

Acid loading = 2.52 L/sec x 60 sec/min x 60 min/hr x 24 hr/d x 683 mg/L x 1 g/1000 mg = 148,490 g/d. Fe loading = 2.52 L/sec x 60 sec/min x 60 min/hr x 24 hr/day x 408 mg/L x 1 g/1000 mg = 88,833 g/d.

Mn loading = 2.52 L/sec x 60 sec/min x 60 min/hr x 24 hr/day x 9.1 mg/L x 1 g/1000 mg = 1,981 g/d.

SO₄ loading = 2.52 L/sec x 60 sec/min x 60 min/hr x 24 hr/day x 1,800 mg/L x 1 g/1000 mg = 391,910 g/d.

Current iron removal rate is about 95% (Table 1). During the initial operation of this system the discharge was net alkaline at 152 mg/L; current net alkalinity is about 44 mg/L. Initial alkalinity generation was high due to the system's fresh limestone and compost. While this system was not specifically designed to remove manganese, about 50 % of the manganese was initially being removed; currently, the manganese removal rate has fallen to about 15 %. Given a total acidity of about 50 mg/L at the outlet, a slight net alkalinity is expected in winter months with improvements anticipated during the summer when biotic activity increases.

Limitations.

Collection of diffuse AMD with a limestone-bedded pipeline would not be practical with a site that has relatively high aluminum (>1 mg/L). Aluminum precipitates may form if limestone bedding is used in the french drain, creating plugging problems. Using non-calcareous bedding stone, such as, river gravel, sand, or crushed sandstone would avoid this problem, but would not add alkalinity.

Treatment of AMD with High Acidity and Metal Loading

The application of passive treatment is difficult where there is total metal acidity. Carbonate chemistry limits the ability of limestone (calcium carbonate) to react with the AMD at atmospheric or near atmospheric pressure present in passive treatment systems. Therefore, limestone-based treatment systems, such as an ALD or VFP, are inherently limited in the amount of alkalinity that a can be added by each step (a treatment cell). Increases in alkalinity addition can be achieved cascading of treatment through the use of multiple VFP's (i.e. a successive alkaline producing system or SAPS; Kepler and McCleary, 1994; Skovan and Clouser, 1998) and/or adding a VFP to an ALD (Hedin and others, 1994). Dilution is also effective, especially if the "fresh" water has natural or artificially-enhanced alkalinity (Black and others, 1999).

Case Example: Rock Island No.7 Mine Pool Discharge, Oklahoma

The former Rock Island Coal Mining Co. Mine 7 is located immediately east of Hartshorne, OK (Fig. 3) and was one of a series of mines operated by the company during the early part of the 20th century (Fig. 4). The No. 7 mine was abandoned in the 1930's. Three shaft entries and

two parallel slope entries access the abandoned underground workings (Fig. 3 and 4). An AMD discharge, ranging from the 19 to 76 L/min (5 to 20 GPM) of highly mineral-laden water discharges from a 55-m (80-ft) deep airshaft. Between 1999 and 2003, the Oklahoma Conservation Commission (OCC) and the mid-continent regional coordinating center (MCRCC) of the Office of Surface Mining have collected water samples and measured discharge (Table 2).

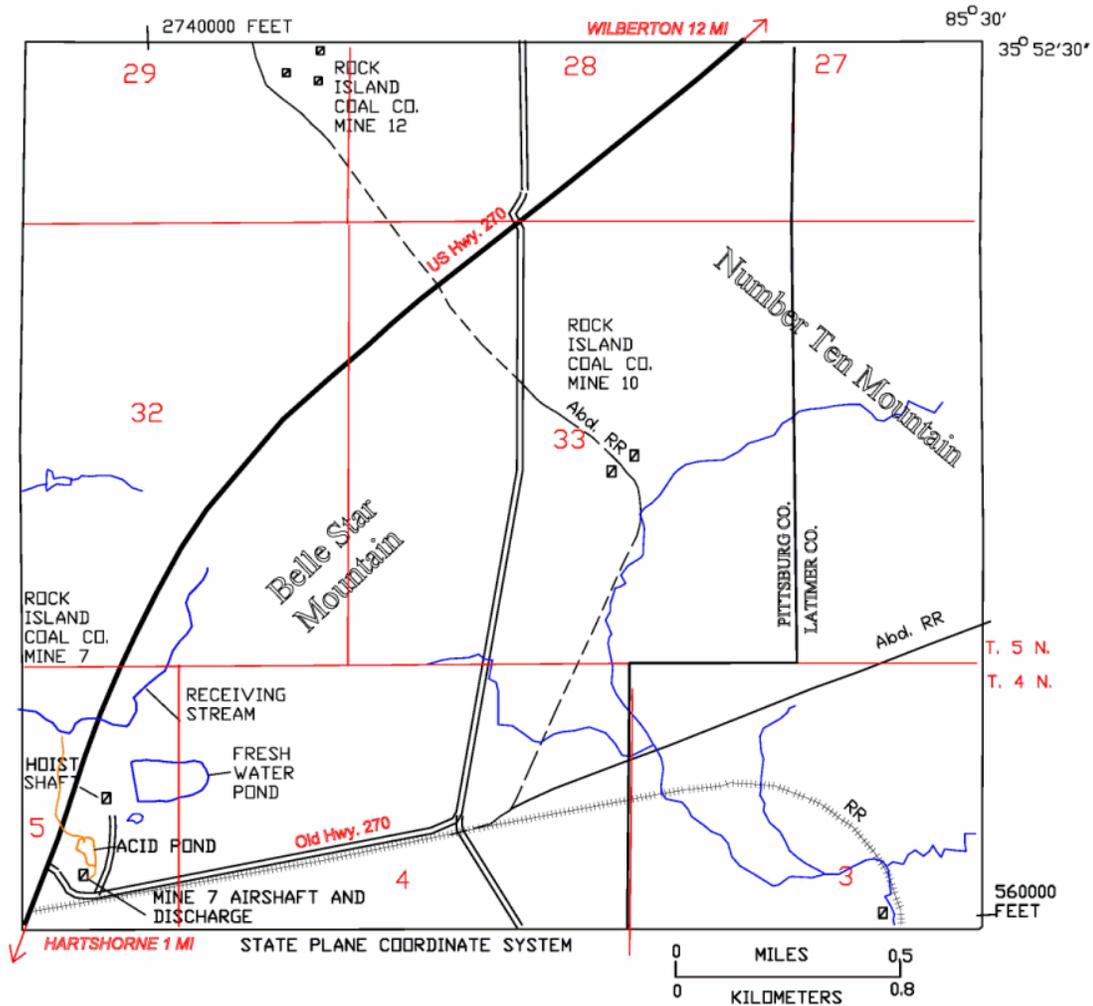


Figure 3. Location of the Mine No. 7 Discharge, Hartshorne, Oklahoma

Table 2. Design Parameters: Untreated AMD Quality and Contaminant Load for the Rock Island Mine 7 Discharge, Oklahoma.*

Parameter	Range	Median	Units	Comments
pH	5.29 to 5.54	5.42	S.U.	24 measurements
Eh (est.)		90	mv	5 measurements
Conductivity		11,445	uS	22 measurements
DO		0.3	mg/L	22 measurements, mean = 0.4 mg/L
Fe		770	mg/L	23 analyses, mean = 858 mg/L
Al		0.18	mg/L	22 analyses, mean = 0.48 mg/L
Mn		17.4	mg/L	22 analyses, mean = 20.8 mg/L
T. Acidity		1,454	mg/L	15 analyses, mean = 1,500 mg/L
T. Alkalinity		112	mg/L	21 analyses, mean = 121 mg/L
Calcium		318	mg/L	11 analyses, mean = 313 mg/L
Magnesium		230	mg/L	9 analyses, mean = 241 mg/L
Sulfate		7,146	mg/L	18 analyses, mean = 8,029 mg/L
Sodium		1,813	mg/L	6 analyses, mean = 1,995 mg/L
Flow @ Inlet		0.32	L/sec	5 GPM is a typical value

*These tests are a combination of OCC and OSM-MCRCC field measurements, OCC/Oklahoma University lab, OSM field and in-house lab analysis and EPA-certified lab analysis.

Contaminant Load Calculations

Acid loading = 0.32 L/sec x 60 sec/min x 60 min/hr x 24 hr/d x 1,454 mg/L x 1 g/1000 mg = 40,200 g/d. Fe loading = 0.32 L/sec x 60 sec/min x 60 min/hr x 24 hr/day x 770 mg/L x 1 g/1000 mg = 21,290 g/d. Mn loading = 0.32 L/sec x 60 sec/min x 60 min/hr x 24 hr/day x 17.4 mg/L x 1 g/1000 mg = 481 g/d. SO₄ loading = 0.32 L/sec x 60 sec/min x 60 min/hr x 24 hr/day x 7,146 mg/L x 1 g/1000 mg = 197,570 g/d.

Seeps around the periphery of a deteriorating concrete cap discharge AMD except during periods of low precipitation. The pH of the discharge is only moderately low, ranging from 5.29 to 5.54 S.U. However, this seep is a significant water quality problem, because of high levels of dissolved constituents, especially sulfate (4,200 to 12,760 mg/L, median = 9,981 mg/L, Table 2), iron (670 to 1,357 mg/L, median = 914 mg/L) and manganese (15.6 to 50 mg/L, median = 20.9 mg/L). The total acidity of the AMD is high at between 1,233 and 2,037 mg/L (median = 1,679

mg/L, Table2). Because of the low pH and high iron and sulfate levels, these water resources are unusable by both wildlife and livestock.

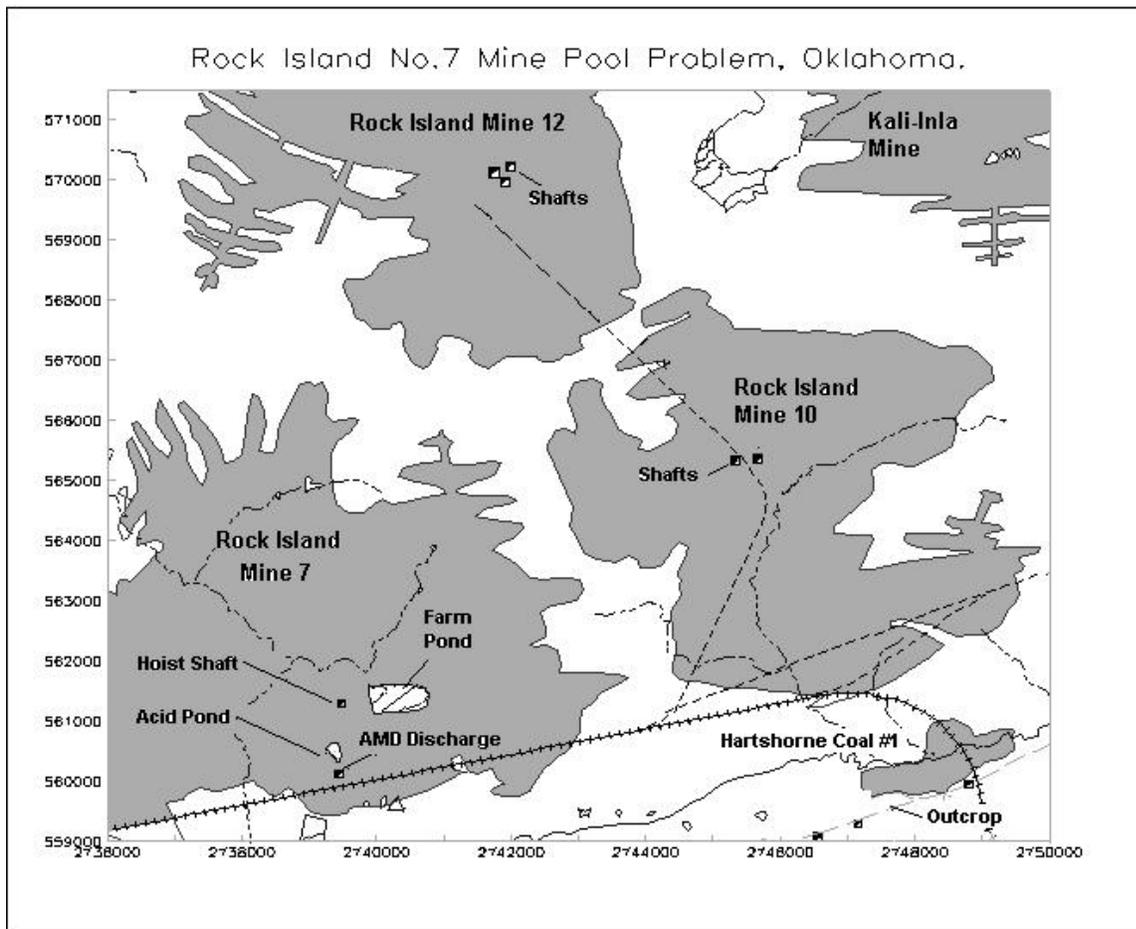


Figure 4. Location of Underground Mines in the Central Part of the Hartshorne Basin.

Solution: Construction of an ALD within the Abandoned Mine Shaft Followed by Dilution and a Three-Stage Vertical Flow Pond-based Passive Treatment System.

The concrete cap of the airshaft is deteriorating and represents a potential hazard to the local population. The OCC with the assistance of OSM-MCRCC plan to repair/replace the cap and construct a shaft backfill that will act as a vertically-oriented ALD (Hedin and Watzlaf, 1994). This structure will serve the dual purpose of a shaft backfill and AMD water treatment, eliminating a safety hazard and a portion of the environmental impact associated with the Rock Island Mine 7 airshaft. Fig. 5 illustrates the suggested design for this type of structural shaft fill. By using both dolomitic limestone (high structural strength) and high-calcium limestone (high

neutralization potential) in the shaft, both geotechnical and acid abatement concerns can be addressed (Fig. 5). It is suggested that dolomitic stone be placed in the lower part of the shaft, since it is less prone to acid dissolution. Coarse-grained, non-calcareous rock, such as silica-cemented sandstone rip-rap, could be substituted for the dolomitic foundation rock. The high-calcium (high-Ca) limestone is to be placed in the upper part of the fill. Based on jar tests (Watzlaf and Hedin, 1993) high-Ca stone should provide about 150 mg/L alkalinity to aid in metal precipitation. The vertical ALD should be capped with a removable, two-piece concrete structure (Fig. 4).

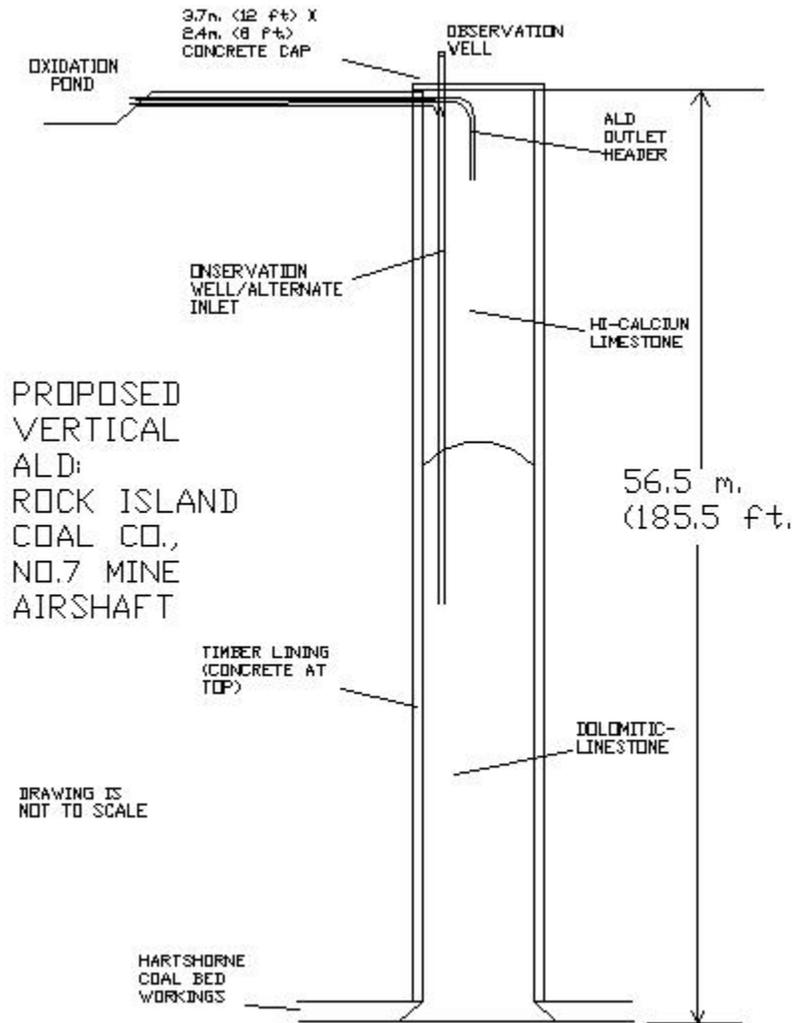


Figure 5. Proposed Backfill Design by Using of a Vertical ALD.

The cap could be designed to be removable to periodically “recharge” the ALD by addition of high-Ca limestone. The outlet of the vertical ALD may then be routed to a series of VFP’s (Figure 6). Metal precipitation would occur in a series of oxidation cells and aerobic wetlands that follow the VFP alkalinity addition structures. Because of the high amount of acidity, it is suggested that the AMD be diluted with an equal amount of alkalinity-enhanced “fresh” water. The alkalinity can possible be boosted to about 70 mg/L (as CaCO₃ equivalent) by a small limestone leach bed (Black and others, 1999).

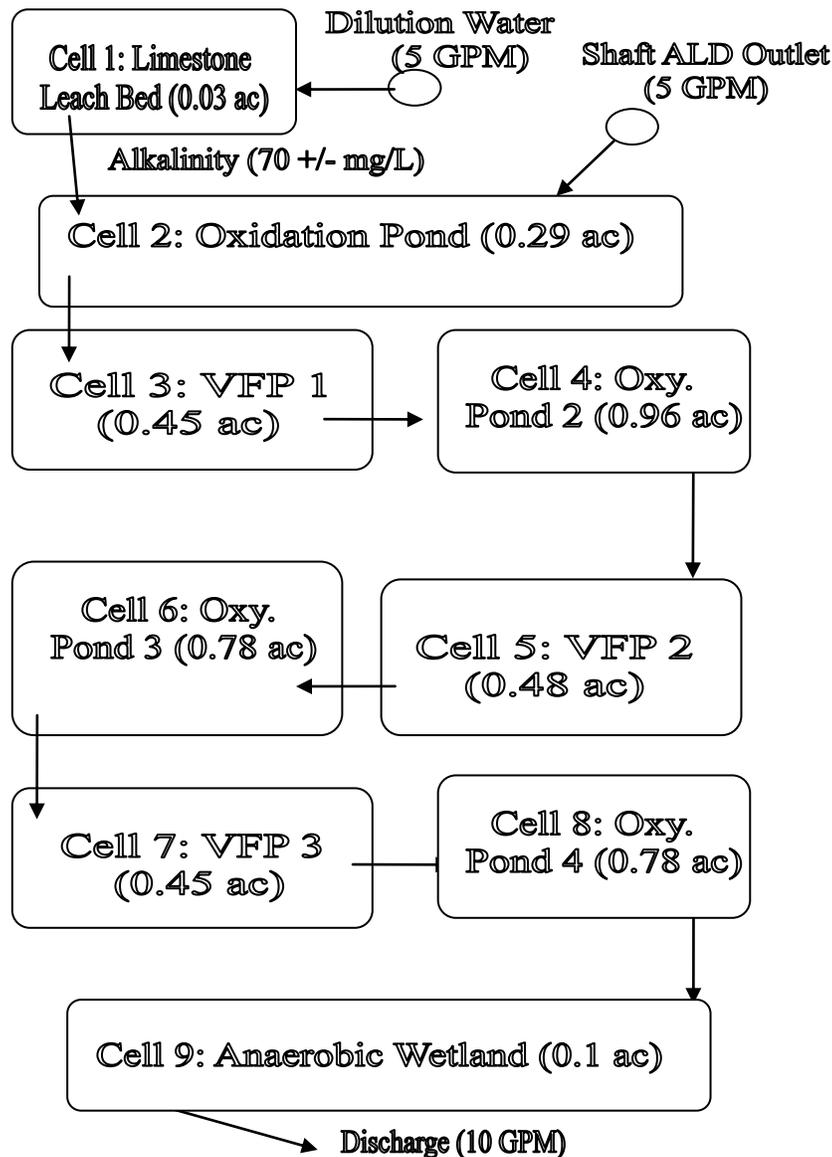


Figure 6. Possible Passive Treatment Flowchart for the Mine 7 Discharge

Limitations.

To maintain control of the AMD discharge location the shaft backfill must not clog. Metal precipitation must be avoided and the treatment stone must be structurally sound. The measures proposed to prevent these problems are the use of more durable, dolomite rock as a foundation and the installation of a deep well that can be used to bypass the upper treatment zone.

Problem Identification: Treatment of AMD with a High Aluminum Content

The presence of aluminum in the AMD presents one of the most difficult problems in design of passive treatment systems. Aluminum is ubiquitous in the Midwest acidic discharges associated with coal refuse facilities because of the preponderance of clay- and shale in the refuse. Two case examples are presented for the discussion of this problem. Technologies to be considered for aluminum removal include dilution with alkalinity-enhanced “fresh” water and treatment by anaerobic wetlands or their vertical flow anaerobic bioreactors.

Case Example 1: the Otter Creek Project, Missouri

The Otter Creek AML site is located approximately 20.9 km (13 mi) south of Clinton, Missouri, in northern St. Clair County (Fig. 7). Surface mining of a shallow coal bed began in 1918 and ended in 1928 (Missouri DNR, 1996). AMD generated by pyrite-bearing shale and fireclay are impacting a tributary to this stream. Otter Creek flows into an important recreational facility, the Harry S. Truman Lake, which is only 4.8 km (3 mi) north of the project site. The Missouri Land Reclamation Program (LRP) reclaimed the Otter Creek site between July, 1997 and April, 1998. Reclamation included the partial grading of the final pits to cover acid-toxic material along with construction was a large dilution water supply impoundment. According to the reclamation plan, any AMD that remained was to be abated by mixing it with this dilution water in a pond that collected the runoff. However, due to the overwhelming acidity of the AMD and lack of neutralization potential present in the dilution water, the current passive system is not capable of effectively treating the AMD (Table 3). Although the metals content in the system discharge water is being lowered considerably compared to the inlet concentrations, the excess acidity results in a discharge pH of 4.0-4.5. The LRP and OSM-MCRCC revisited the

Otter Creek AML reclamation project site to characterize and formulate a number of treatment options in 2001 and 2002 (Kim, 2003).

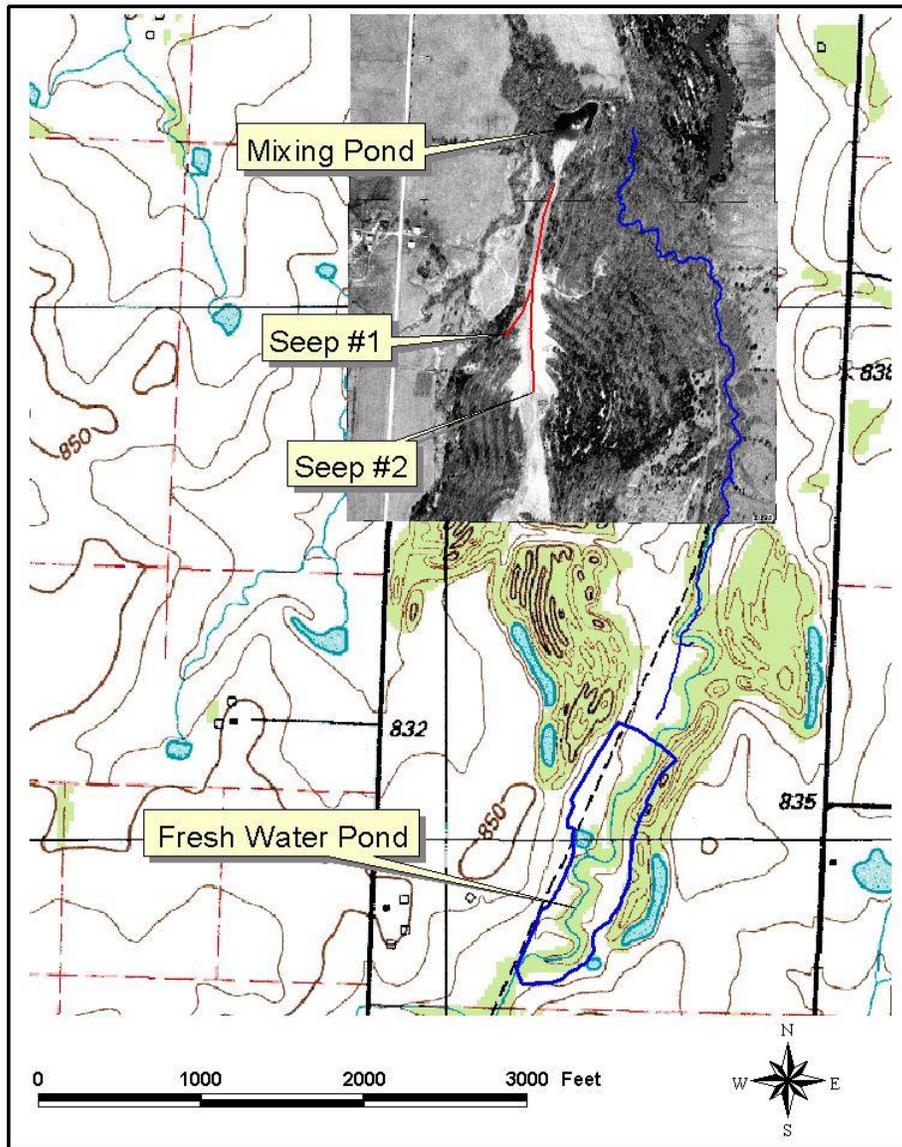


Figure 7. Case Example 1: The Otter Creek Project, Missouri

Table 3. Otter Creek, Missouri Surface Water Data – 2001-2002 Study³

Parameter	Seep 1	Seep 2	Mixing pond Inlet	Mixing Pond Outlet	Fresh Water @ Mixing Pond	Units
pH	2.68	2.53	2.63	4.52	4.94	S.U.
S C	2,008	2,455	2,234	579.3	307.7	µS
DO	1.96	2.31	6.48	5.51	3.04	mg/L
Alkalinity	nm	nm	nm	nm	8	mg/L
Net Acidity	738*	674*	712.3*	116.7*	nm	mg/L
Sulfate	912	1,125	1,340*	288*	115	mg/L
Total Fe	13.8	106.5	45*	2.05*	0.58	mg/L
Total Al	88.5	67.9	76.9*	14.5*	2.82	mg/L
Total Mn	18.1	27.3	31.7*	6.5*	3.83	mg/L
Dissolved Fe	11.9	112.4	41.0	1.51	0.42	mg/L
Dissolved Al	78.1	60.1	42.0	9.5	3.28*	mg/L
Dissolved Mn	16.9	26.9	28.4*	5.0	3.27	mg/L
Flow			57			L/min

nm = not measured

< DL = less than detection limit

SC = Specific Conductance and DO = Dissolved Oxygen.

* EPA-certified lab tests

One new factor discovered during the study was that the AMD at the Otter Creek site contains very high aluminum content (> 60 mg/L, Table 3). Pyritic spoil and the aluminum-rich fireclay in the mine floor are believed to be as the primary sources of AMD at the site. The acidic ground water strips aluminum from fireclay which lies beneath the sandstone-rich, overburden spoil. Flow from the two seeps that form the source of the AMD is variable throughout the year and from year-to-year and range from about 30.28 L/min (8 GPM); an average flow is estimated to be about 56.78 L/min (15 GPM).

³ Source : Kim, 2002; Unless noted sulfate and metal concentrations determined by HACH Colorimeter; Lab : Engineering Surveys and Services Testing Laboratories, Columbia, MO.

Due to very high aluminum concentration in the AMD, it is difficult to treat the AMD directly through conventional passive treatment technologies such as an ALD or a conventional VFP. In these systems, the pH is raised to a level that aluminum hydroxide precipitates will form, coating the crushed limestone surfaces until they eventually clog the system. There are some commercial SAPS designs that are reported to be capable of treating for high aluminum AMD (Kepler and McCleary, 1994; Gusek and Wildeman, 2002). One type employs periodic flushing to loosen and remove build-up aluminum oxide. The success of VFP metal hydroxide removal by flushing is reported to be mixed (Vinci and Schmidt, 2001). The design of the under drain is reported to be critical in allowing for proper retention and flushing action (Peart and Cooper, 1999). Another VFP variant, termed an anaerobic bioreactor system, employs a thick compost layer (> 1 m or > 3 ft) and a thin (15 cm or 0.5 ft) limestone layer. These systems rely more on the sulfate reduction reaction to add alkalinity than on alkalinity added by the limestone. All VFP's requires more maintenance than other passive systems such as aerobic wetlands.

An effective and simpler way to treat the AMD is to add a constant amount of alkaline dilution water stored in a nearby impoundment. To boost alkalinity several methods are suggested. One option is to use a limestone leach bed (Black and others, 1999). Another suggestion in by the authors is to use a VFP to provide a boost in alkalinity, to the "fresh" water prior to mixing the dilution water with the high-aluminum AMD. The amount of alkalinity added to the "fresh" water by a limestone leach bed or "fresh-water" VFP should be improved by using dilution water that is low in dissolved metals, but slightly net acidic (lower pH due primarily to hydrogen ion content). However, studies (Black and others, 1999) show that using net alkaline or slightly acidic water through a limestone treatment structures is considerably less effective than using highly acidic water through a VFP or ALD. Therefore, a lower amount of alkalinity addition is assumed to be generated by limestone leach beds or "fresh-water" VFP's in our conceptual designs. Several solutions were prepared by Kim (2003) in an evaluation of AMD remediation options for this site; one possible solution will be presented in this paper.

Solution: A Single "Fresh-water" VFP, Dilution Water Addition, and of Construction of an Anaerobic Wetland.

By installing a "fresh-water" VFP where the low alkalinity dilution water enters the existing mixing pond the VFP should add sufficient alkalinity to enable metal precipitation and allow for

near neutral discharge from the Otter Creek site. Because the dilution water is low in dissolved metals and is slightly acidic (pH is near 5.0), a “fresh-water” VFP should generate 150 to 200 mg/L of alkalinity. The next phase of the study will use a jar test to evaluate the ability of the “fresh water” VFP to add alkalinity over a minimum of 15-hour retention time in a VFP limestone layer. The limestone reaction or dissolution rate is expected to be much lower with an open air system such as a limestone leach bed. This later technology is expected to produce only about 75 mg/L of alkalinity as CaCO_3 with minimum of 24-hour water retention time in the limestone layer (Black and other, 1999). The AMD at the Otter Creek site requires about 476.9 L/min (126 GPM) of enhanced fresh water to offset the acidity.

Following the “fresh-water” VFP, the existing Otter Creek Project mixing pond would act as an oxidation cell for removal and precipitation of metals. For 24-hour water retention time, about 1,214 m² (0.3 ac) structure would be needed for a flow of 533.7 L/min (141 GPM); 476.9 L/min (126 GPM) of fresh water plus 56.78 L/min (15 GPM) of AMD]. This solution proposes to modify the current mixing pond to include an oxidation pond followed by an anaerobic wetland. This new system allows the AMD water to flow a greater distance before commingling with the dilution water. The oxidation pond should increase metal precipitation. After flowing through this oxidation pond, the discharge enters an anaerobic wetland. The wetland is designed to add alkalinity by use of the sulfate reduction reactions and in the process remove some sulfate as well as iron as a sulfide (pyrite).

For a total volume flow of 533.7 L/min [141 GPM; 476.9 L/min (126 GPM) of fresh water plus 56.78 L/min (15 GPM) of AMD] and a 24-hour water retention time, the oxidation pond should be able to hold at least 1,017 m³ (0.825 acre-ft); 1,255 m² (0.31 acres) of water surface with a 0.9 m (3-ft) depth] of water and metals sludge. As for the anaerobic wetland, the limiting factor on sizing criteria is manganese since the manganese removal rate is low for anaerobic wetlands and most of the manganese will flow through the oxidation pond without being precipitated out. Assuming there is a needed to reduce the contaminant load of this pollutant, a 0.5 g/m²/day manganese removal rate can be applied based on Hedin and Nairn (1992). Using this removal rate, about 1.1 Ha (2.8 ac) of water surface would be needed to bring manganese level down to less than 1.0 mg/L. Since the existing mixing pond is only about 0.6 Ha (1.5 ac.) in size, the existing structure would remove most of the iron, aluminum, acidity, and some of the manganese. The anaerobic wetland could be as little as 1,214 m² (0.3 ac.) is sized to have about

3,440 m² (0.85 ac.) of water surface utilizing available space. Anaerobic wetlands are known to generate some alkalinity; the dilution water flow could be reduced, hence requiring a smaller size VFP, anaerobic wetland, and oxidation pond. The estimated discharge water quality would be:

- T. Fe = 0.2 mg/L (95 % removal)
- T. Al = 0.4 mg/L (95 % removal)
- T. Mn = 3.2 mg/L (46 % removal)
- pH = 6.0 +/-
- Sulfate = 184 mg/L (25 % removal)

Additional manganese removal is possible by applying a passive system specifically designed for manganese removal (Rose and others, 2003). Empirical data for sulfate removal was not available for this report; hence, the sulfate concentration was not used in sizing criteria.

Case Example 2: The Upper Cedar Creek Project, Missouri

The Upper Cedar Creek watershed in central Missouri was the one of the worst AML environmental problems in the Midwest (Fig. 8). The Missouri Land Reclamation Program (LRP) completed a cooperative reclamation project to address water quality problems associated with abandoned coal mine lands in the Cedar Creek watershed, which forms the border between Boone and Callaway counties in central Missouri (Fig. 8). Cedar Creek is listed on the Missouri 303(d) list of impaired waters that do not meet the minimum standards required under the Clean Water Act. Periodic discharges of AMD and acidic sediments have severely degraded water quality in Cedar Creek and resulted in numerous fish kills, at times rendering the entire 70.8 km (44 mi) of stream lifeless. In the 1980's, LRP completed three projects reclaiming 285.7 Ha (706 ac) in the Upper Cedar Creek watershed; the total cost was \$4.7 million U.S.

Solution: Vertical Flow and Anaerobic Wetland Systems.

The goal of a more recent project, the Upper Cedar Creek (UCC) Clean Streams/319Project was to improve the receiving stream water quality (MO LRP, 2001). Although the overburden had been regarded, covered and revegetated, some acid-forming materials (mine spoil and coal

waste) remain, generating the continuing water quality problems. The Clean Streams/319 Project has accomplished its goals: mitigating the acid seeps, repairing storm erosion damage, and stabilizing the stream banks to minimized future erosion. Four passive treatment wetlands were constructed and 823 m (2,700 ft) of eroding stream banks were repaired in 2001 to control AMD in Cedar Creek. Preliminary water quality data indicate a significant decrease in acidity, sulfates and dissolved metals in Cedar Creek following wetland construction and stream bank repairs (Allert, 2002; Tables 5 and 6). Two additional anaerobic wetlands were constructed in September 2002 to restore riparian vegetation and remediate minor acid seeps that were obscured by the larger problems addressed in this project. These wetlands are treating several acid seeps downstream of Wetland 1 and should mitigate the most significant seeps on the Boone County side of Cedar Creek. Total cost of the project in 2001 was \$327,768 U.S. of which OSM contributed \$177,768 U.S., under the AML Clean Streams Initiative and the Missouri Department of Natural Resources (DNR) Water Pollution Control Program awarded supplemental funding of \$150,000 U.S. of the Environmental Protection Agency's (EPA) water pollution control funds through a 319 grant.

Upper Cedar Creek Project Passive Treatment Wetlands.

Six AMD treatment wetlands were constructed at the Upper Cedar Creek Clean Streams project site (Codner, 2003). Constructed wetlands add alkalinity, increase pH, and remove dissolved sulfates and metals from the mine drainage (Fig. 9 and 10). Wetlands 1 and 2 each contain a modified form of what is known as a successive alkalinity producing system (SAPS). Like the eastern VFP designs, these systems interlayer of crushed limestone, compost, and standing water (Fig. 10). The discharge drains through these layers into perforated PVC pipes on the bottom of the wetland (Fig. 11) and the impounded water in the wetland creates the hydraulic head necessary to push the water into the drain pipes.

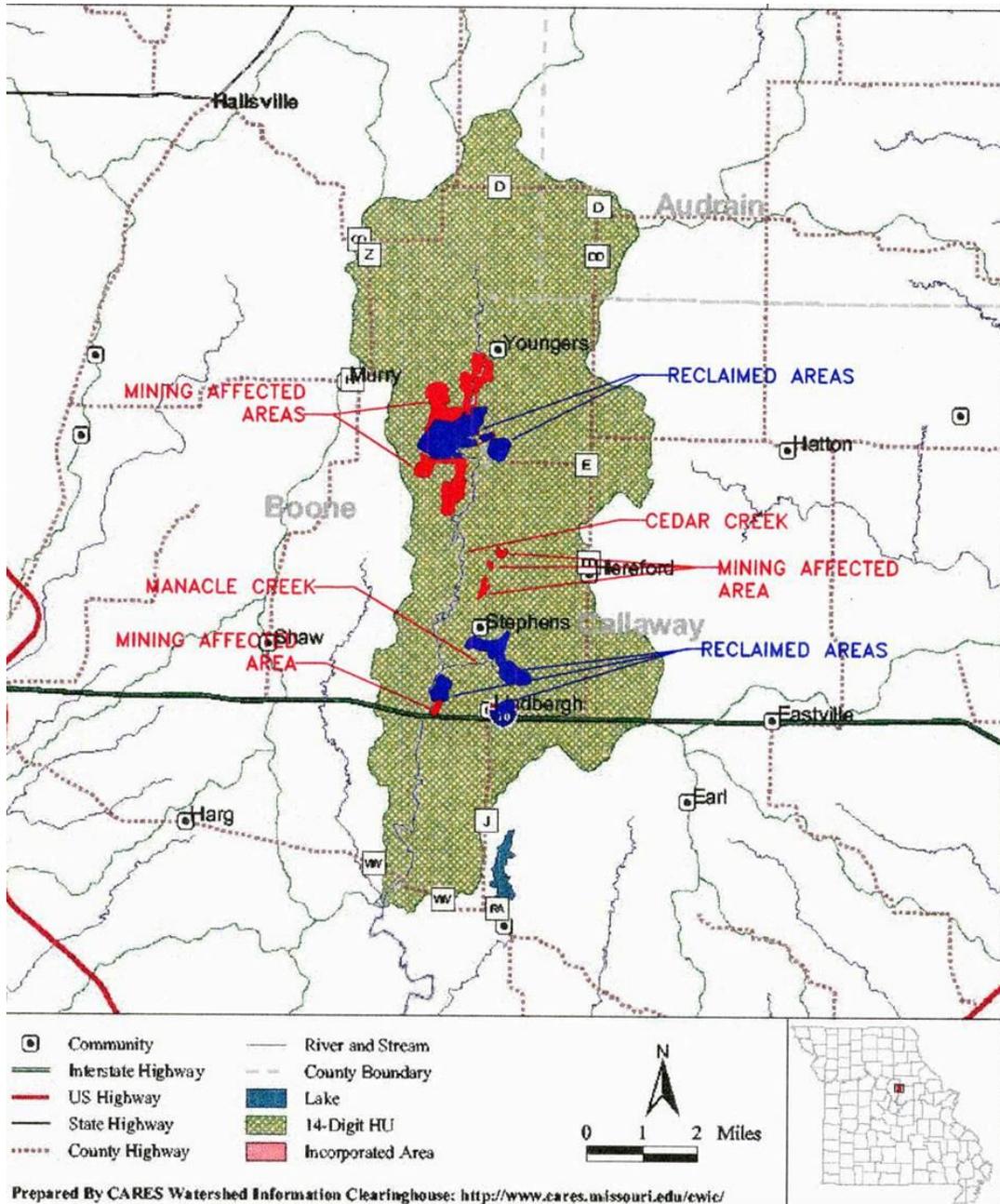


Figure 8. – Location of Upper Cedar Creek Project, Northeast of Columbia, Missouri.

Table 5. Upper Cedar Creek, Missouri Surface Water Data ⁴

Parameter	VFP 1: Wells 1, 2, 3	VFP 1 Outlet	VFP 2 AMD*	VFP 2 Outlet	OLA 1A/1B AMD**	OLA 1A/1B Outlet**	OLA 3 /4 AMD***	OLA 3 /4 Outlet****
pH	4.89	6.7-7.4	3.5	6.45	3.79	6.65	3.49	7.09
Conductivity	nm	1,595	2,900	1,670	2,955	4,830	2,850	1,490
Alkalinity	210	170	0	239	0	281	0	88
Net Acidity	272	-88	243	-154	197.5	-241	190	-71
Sulfate	4,230	618	1,960	960	1,765	2,940	1,865	655
T. Al	12	nm	nm	nm	nm	nm	31.2	nm
D. Fe	102	1.59	5.34	1.36	23.2	2.4	8.18	0.33
D. Mn	32.8	0.82	nm	7.48	nm	nm	nm	nm
# of Samples	15	5 (Mn=2)	4	4 (Mn=1)	6	3	2 (Al=1)	7

* Measured @ the VPF, Mn = Total Mn, Al = Dissolved Al;

** Measures at the North Swale Road Crossing.

*** Measures at the South Swale Road Crossing.

⁴ Source: Missouri LRP, 2003; Lab : Engineering Surveys and Services Testing Laboratories, Columbia, MO Median values reported in mg/L except pH (S.U.) and Conductivity (microS/cm); nm = not measured; < DL = less than detection limit SC = Specific Conductance and DO = Dissolved Oxygen.

Table 6. Design Details: Organic matter, Limestone rock and Ag lime Cells, Upper Cedar Creek Project Missouri.

<u>Structure</u>	OLA Size	OLA Size	multiplying <u>x 5g/m²/d</u>	Grams of Alkalinity
	<u>sq. meter</u>	<u>Sq. ft.</u>		(CaCO ₃ equiv.) <u>Produced/ Day</u>
OLA Wetland 1	1,044	11,228	X 5	5,220
OLA Wetland 2	964	10,372	X 5	4,820
OLA Wetland 3	948	10,200	X 5	4,740
OLA Wetland 4	697	7,500	X 5	3,485

Note: The two anaerobic wetlands (Wetland 1A and 1B) built in 2002 downstream of Wetland 1 are similar in design and size to OLA 4.

Two design features of the Missouri LRP VFP's are different than a typical Appalachian design (Kepler and McCleary, 1994; Skovan and others, 1998; Fig. 10). First, the 10.7 m (35 ft) wide by 30.5 m (100 ft) long structures are strategically located to allow most of the AMD to enter from seeps in the sides of the structure. Second, because of the low hydraulic head available at the site, the water compost and underlying limestone layers are thinner [water depth 0.3 to 0.76 m (1 to 2.5 ft), 0.46 m (1.5-foot) thick organic compost and limestone thickness 0.61 m (2 ft) of 7.6 – 12.7 cm (3-5 in) diameter limestone plus 15.2 cm (6 in) of hay or straw on the bottom of the VFP]. Otherwise, the structures functions in a similar manner to the classic designs. About 5 tonnes of agricultural limestone was mixed into the compost to increase the amount of alkaline-producing material in each SAP cell. Each cell contains 323 tonnes limestone rock and 197.3 m³ (258 CY) of compost designed to add 200 mg/L of alkalinity as CaCO₃ equivalent). At this rate, the limestone in the SAPS will be consumed at a rate of 22 tonnes per year.

In addition to the VFP's, four anaerobic, compost wetlands called OLA (Organic matter, Limestone rock and Ag lime) cells are constructed at the Upper Cedar Creek project (Fig. 11 and 12). Two are free-standing; two are interconnected to the VFP's. The OLA cells are also located in areas where there are AMD seeps, but where the water quality is better than at the VFP locations. All OLA cells are excavated to a depth 0.61 m (2 ft) below the impoundment water

elevation. In the OLA cells, 0.3 m (1 ft) of standing water is placed over 10.2 cm (4 in) of limestone rock and a 20.3 cm (8 in) mixture of compost and agricultural limestone.

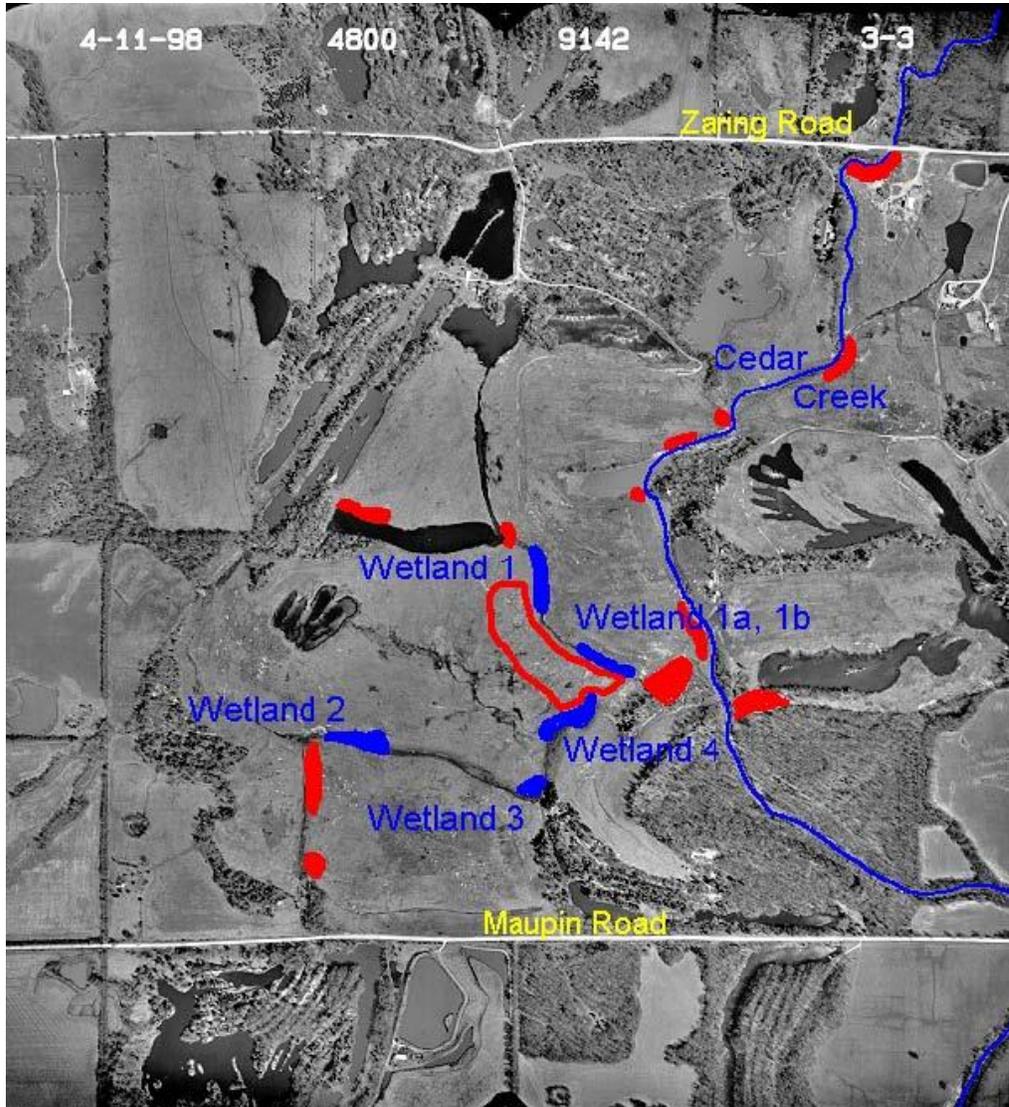


Figure 9. Aerial Photo showing the locations of AMD Seeps and Passive Treatment Wetland, Upper Cedar Creek Project, Missouri.

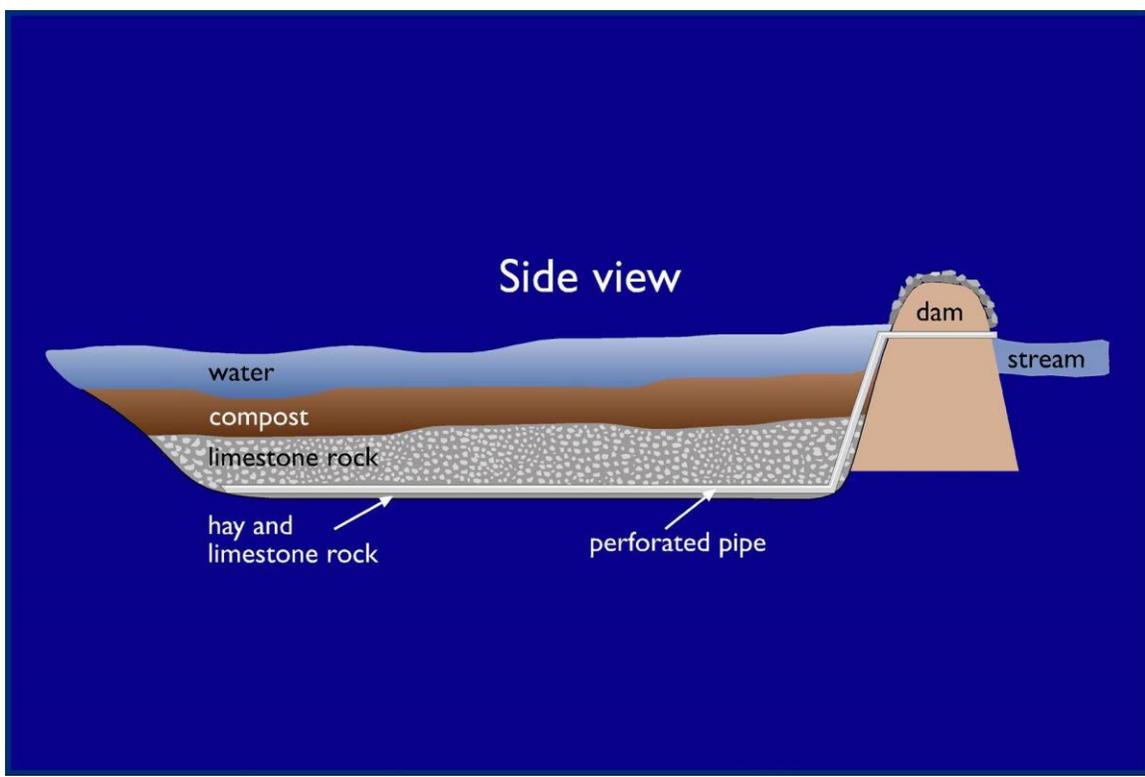
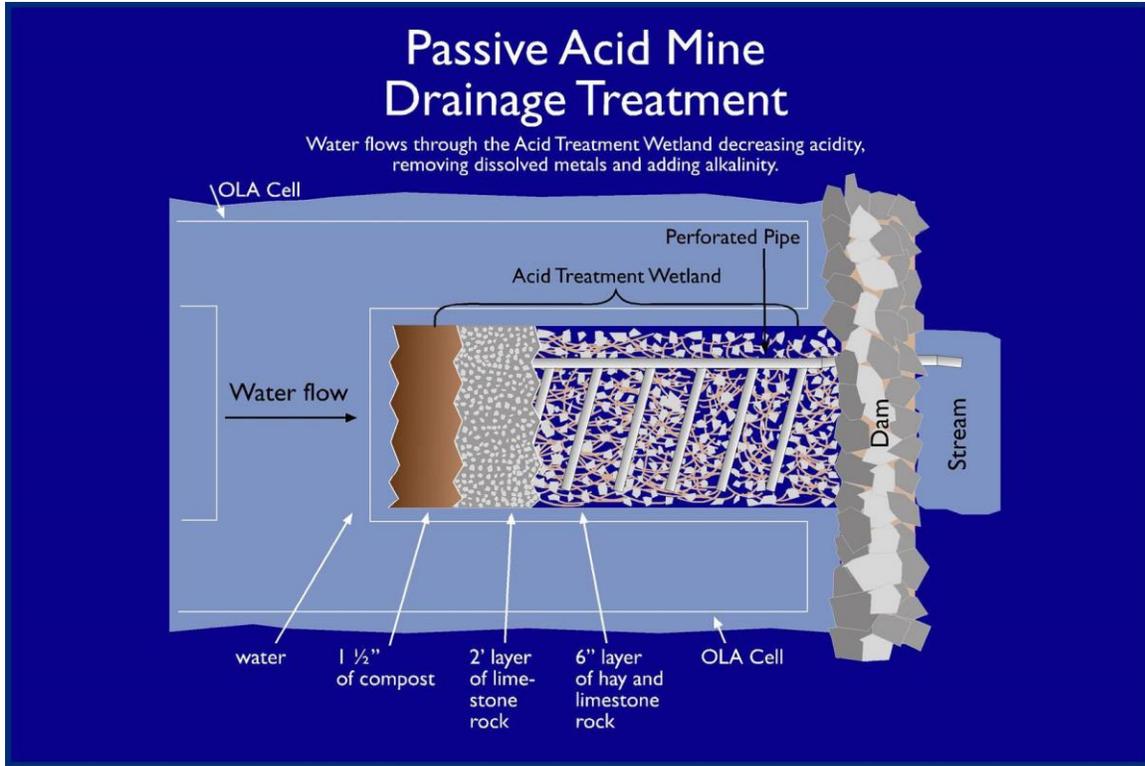


Figure 10. Plan and Side Views of the Vertical Flow Ponds, Upper Cedar Creek Project, Missouri. Note: the VFP is surrounded by OLA Cell Anaerobic Wetlands.

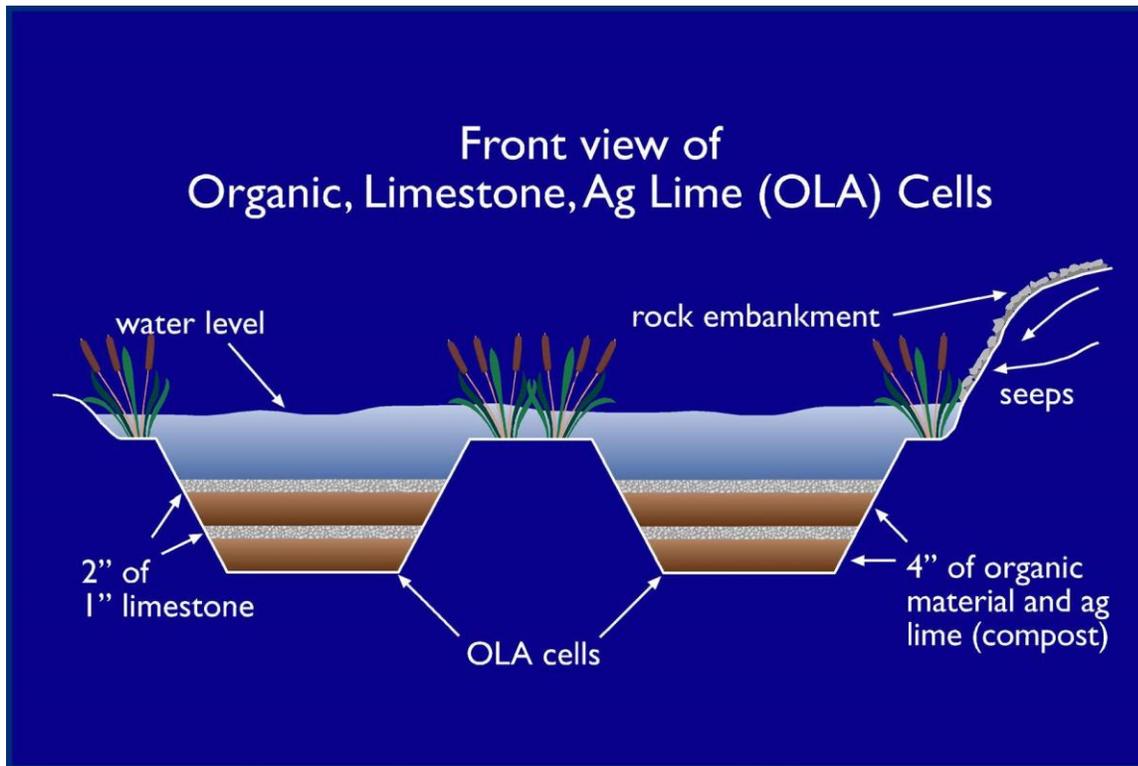


Figure 11. Diagram showing the Organic, Limestone, Ag Lime (OLA) Cells (Anaerobic Wetlands) Constructed at the Upper Cedar Creek Project, Missouri.

According to Bureau of Mines Circular 9389 (Hedin et al, 1994), compost wetlands generate alkalinity at rates between 2-12 g/m²/day (18-107 lb/ac/d). LRP expects to generate a minimum of 5 g/m²/day of alkalinity in the OLA cells. Calculating the life of treatment wetlands can be difficult. Variation in flow and water quality over the course of many years makes it very difficult to model and predict the rates at which alkalinity and organic matter are consumed. LRP estimates that the functional life of the OLA wetlands and VFP's should exceed ten years. Additional native grass seeding and tree planting will continue to promote long-term stream bank and wetland stability. After 4-6 rounds of water tests, the mean iron removal for the modified VFP's range from is a 74.5 to 98.5 % (a higher removal rate occurs where the input iron level is high) and the mean discharge alkalinity is 170 to 239 mg/L (Table 5). Total (net) alkalinity provided by each VFP ranges from 88 to 154 mg/L as CaCO₃ equivalent.

Summary and Conclusions

Technical problems associated with treatment of AMD in the mid-continental U.S. may be overcome with the use of a combination of existing proven and, hopefully, newer emerging technologies. Understanding the site hydrogeology and the AMD chemistry combined with the appropriate application of these technologies is the key. This paper suggests that some sites with perhaps the greatest problem, high aluminum content, may be addressed by mixing the AMD with alkalinity-enhanced “fresh-water.” The use of a down flow alkalinity generating structure, a “fresh-water” VFP, is suggested to boost dilution water alkalinity. A down-flow structure, such as a the modified VFP’s used at Upper Cedar Creek (similar to an anaerobic bioreactor), may also be a good solution for treating many mid-continental U.S. AMD discharges. The other new technology suggested is the construction of an ALD in an abandoned mine shaft in which AMD is discharging as an artesian flow from a large underground mine pool.

In addition, just as maintenance requirements are needed for any passive treatment systems, periodic lime applications on the reclaimed surface may be necessary to rejuvenate acid neutralization potential. Placement of a specialized manganese removal cell at the treatment system (Rose and others, 2003) discharge can raise pH and, in the process, increase manganese removal.

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