Design and Early Field Performance of AMD Treatment Systems Developed Under the Appalachian Clean Streams Initiative

Paul Ziemkiewicz and Jennifer Simmons
National Mine Land Reclamation Center
West Virginia University
Morgantown, WV 26506-6064

The Appalachian Clean Streams Initiative (ACSI) was introduced in the fall of 1994 to address the problem of stream pollution from acid mine drainage. The mission of ACSI is to facilitate and coordinate citizens groups, university researchers, the coal industry, corporations, the environmental community, and local, state, and federal agencies involved in cleaning up streams polluted by acid mine drainage (OSM pamphlet). Through the combined efforts of AMD researchers and government agencies the Appalachian Clean Streams Initiative has launched several innovative AMD treatment technologies. Two of the most promising treatment technologies are limestone leach beds and steel slag leach beds. The projects described herein include several states and a variety of settings. The objective of this paper is to provide an overview of some innovative techniques being used within ACSI, particularly those which can provide reliable, efficient and low maintenance AMD treatment. At most these systems have been in place for 4 years. Others were only constructed 6 months ago. So, the results should be considered preliminary as performance monitoring continues.

Limestone Leach Beds

Limestone is commonly used to neutralize acid mine drainage. The benefits include low cost and availability (Skousen, et al 1998). It has a neutralization potential (NP) of between 75 and 100% and is safe and easy to handle. Limestone, when placed in a leach bed, open channel (OLC) or anoxic limestone drain (ALD), will dissolve slowly over time and continually add alkalinity to water passing through it.

In neutral water limestone dissolves very slowly and it dissolves much more quickly in strongly acid water. However, when treating acid drainage with high concentrations of dissolved metals, the dissolution rate is slowed by about 80% due to the precipitation of iron and aluminum hydroxide flocs on the limestone surface (Ziemkiewicz, et al. 1997). This process is called armoring . Clogging of void spaces within the limestone bed is called internal sedimentation. The former phenomenon reduces dissolution rate while the later will tend to reduce the dissolution rate, effectively, to zero. Oxidized, (ferric) hydroxide flocs form at a pH above 3.0, reduced (ferrous) hydroxide flocs form above pH 8.5 while aluminum hydroxide flocs form above a pH of 4.2. Aluminum flocs are not prone to armoring and are easily flushed from a limestone bed. They are not as problematic as ferric hydroxide flocs.

Therefore, limestone treatment works best when used in reducing environments, at very low pH's (below 3.0) or where there is little iron. Limestone may also be used to increase alkalinity of fresh water streams before they reach acid sources. This type of indirect treatment works best when the limestone receives a constant supply of fresh water.

When designing limestone treatment systems, the amount of time the limestone is in contact with water, the residence time, is crucial. In neutral water, open to the air, a limestone bed will generate the maximum alkalinity in about 11 hours. In AMD the required contact time is a function of acidity and flow. Residence time is determined by the following formula:

$$\text{Residence Time}_{\text{(hours)}} = \text{Length}_{\text{(ft.)}} \times \text{Width}_{\text{(ft.)}} \times \text{Depth}_{\text{(ft.)}} \times \text{Void Ratio (\%)}/\text{Flow}_{\text{(cfs)}} \times 3600$$

For sized limestone assume a void ratio of somewhere between 40 and 50%.

Many times the length of an OLC is prohibitive. Limestone leach beds can provide the same residence times as long channels, but in more compact units. In addition, leach beds can be used in anoxic environments where metal precipitation is of concern.

Wilder/ Laurel Creek Project

Laurel Creek is a tributary of the East Fork of the Obey River, which is a tributary to the Cumberland River. This is a wadeable, fast-flowing, warm water stream that flows through the gorges and beautiful scenery of the Cumberland Plateau. Pre-law mining of the Wilder coal seam in this area has resulted in severe acid drainage to Laurel Creek. In fact, the most severely damaged watershed in the East Fork Obey River drainage area is Big Laurel Creek, near the town of Jamestown, TN in Fentress County. Here, acid drainage from deep mine portals and eroding spoil piles has virtually destroyed fish and aquatic life in Laurel Creek and downstream in the East Fork of the Obey River.

To date nine AMD treatment facilities have been installed in the Big Laurel Creek watershed. (Table 1). All of the facilities are characterized as limestone leach beds with varying degrees of success. Excluding the Wilder I site, all leach beds were constructed as a limestone-lined ponds, some of which are overgrown with Typha. Water exits the ponds through the limestone bed and into a PVC pipe which runs from the bottom of the pond through the dam(Figure 1).

Seven systems were flowing and were sampled. Wilder VII at Sandy appears to be performing the best. Table 1 shows that since construction in Fall 1998 it has been reducing acid load by 72%. Wilder V Left has seen a 58% drop in acid load. Wilder I, Wilder III Left, Wilder IIIC, and Wilder IVB are treating similar amounts of acid, reducing their acid load by 23-30%. At the Wilder V Right pond system a piping hole had developed through the limestone bed to one of the drain pipes. It appeared that nearly all of the water leaving the system flowed through the hole resulting in 0% acid treatment. Repair of the piping hole would be simple.

Cane Creek Project

Cane Creek, in Walker County near Oakman, Alabama was polluted by acid mine drainage from Black Branch. In the lower reaches of Black Branch underground coal mine portals discharged AMD and a coal cleaning operation left large volumes of acid producing refuse in the stream channel. Prior to construction water entering Cane Creek from Black Branch was pH 3.0, had 117 mg/L of acidity, 9.9 mg/L of Al, 5.03 mg/L of Fe and 0.95 mg/L of Mn.

The headwaters of Black Branch are virtually unaffected by mining. The stream and its upstream tributaries are net alkaline and contained less than 1 mg/L of iron. By constructing the leach beds in freshwater systems, the alkalinity of the streams could be increased without precipitating metal hydroxides and coating the limestone. This extra alkalinity can then be used to neutralize and restore slightly acid lakes downstream and indirectly treat acid water entering Black Branch from the gob area.

Leach beds 2, 2a and 4 were constructed between August 1997 and January 1998. These beds were constructed upstream of lakes 2 and 3 which were slightly acidic. Water from these lakes then flow into lake 1, which was also slightly acidic (pH ~ 4.2) but much larger than lakes 2 and 3. To increase alkalinity to the stream before it encountered acid water from the gob areas, leach bed 1 was constructed downstream of lake 1 in March 1998. See Figure 2 for the location and dimensions of leach beds. Water discharging from leach bed 1 then mixes with acid water from the gob pile and enters a settling pond.

There has been concern over the amount of water moving through the leach beds. The summer and fall of 2000 were very dry in this region and, therefore, there were extended periods when little to no alkaline water was leaving the beds. In these instances there was little to no treatment occurring in Black Branch. However, there was visible flow into and out of all leach beds during the latest sampling trip in January 2001.

From an increase of 46.4 mg/L of alkalinity from leach bed 2 (an 89% increase) to 18.43 mg/L of alkalinity added in leach bed 4 (a 42% increase), effluent from all the leach beds had much higher alkalinity than the inflows (Table 2). In addition, sampling in January 2001 showed that mixing of the leach bed effluent water with acid water from the gob pile has decreased acid concentration entering the downstream settling pond by 82%.

Steel Slag Leach Beds

From the use of limestone-treatment systems it has become obvious that limestone, while still a highly effective treatment for some forms of acid water, has many limitations in the field. The most obvious is the fact that it is susceptible to metal precipitation and therefore becomes less effective as the limestone becomes coated. Although most limestone systems are capable of reducing acidity levels to some degree, most have demonstrated less than 100% neutralization of acid mine drainage. Therefore, recent research in passive treatment design has focused on discovering new, more effective forms of alkaline materials.

One of the most promising new sources of alkalinity is steel slags. Steel slags are byproducts formed during the production of steel. They are composed primarily of hydrated amorphous silica and calcium compounds, especially calcium oxide, with smaller amounts of aluminum, magnesium, iron, titanium and manganese compounds and crystalline silica. Steel slags have high neutralization potentials (from about 50-70%)and can generate exceptionally high levels of alkalinity over extended periods. Additionally, unlike limestone, slag particles do not armor (Ziemkiewicz and Skousen, 1998).

Due to the fact that steel slag fines can leach extremely high levels of alkalinity over long periods of time, they are excellent materials for leach beds. Effluent from slag leach beds have pHs above 10 and have alkalinity concentrations in the thousands of mg/L. Slag leach beds may receive AMD directly or effluent from "fresh water" beds may be combined with an AMD source downstream to treat acid indirectly. Both applications have been used in AMD treatment and both have been very successful.

McCarty Highwall Project

The McCarty Highwall is an abandoned surface, and possible underground, mine site located about 10 miles southeast of Bruceton Mills in Preston County, West Virginia. Prior to construction at McCarty, water seeping out along an old spoil pile was flowing into a channel and mixing with a second spoil seep approximately 500 ft downstream. These two seeps form a small stream that flows south into Beaver Creek and eventually into the Cheat River. Along the way the stream picks up several other small AMD seeps. A 1997 reconnaissance study by the Corps of Engineers showed the first seep was moderately acidic with a pH of 4.1 and a net acidity of 27.5 mg/L. The second seep was similar with a pH of 3.9 and 24.5 mg/l acidity.

Due to the acidity of the on-site AMD sources and the presence of additional acid sources downstream, limestone treatment was insufficient. A stronger alkalinity source was needed: one that would raise the alkalinity of the on-site water to levels that would neutralize additional AMD downstream of the site and one that would last for at least 10 years without maintenance. Earlier studies with steel slag indicated its suitability for such situations.

In October 2000, a series of open limestone channels (OLCs) and steel slag leach beds were installed downstream of seeps 1 and 2 (Figure 3). All four OLCs were constructed of a limestone sand liner and 6-8" limestone rocks. The leach beds consisted of a settling basin and steel slag check dam. Both check dams were formed from 150 tons of steel slag and rip rapped along the back with 6-8 " limestone rocks. A 200 ft open limestone channel (OLC #1) was constructed from the upper spoil seep to the edge of the first settling basin. A secondary OLC (OLC #1b) was constructed to the left of OLC #1 to carry AMD from an intermittent spoil seep to the first basin. Water leaches from the basin through the center of a steel slag check dam and enters a 300 ft open limestone channel (OLC #2). OLC #2 exits into a limestone gravel area along the edge of the second settlement basin. AMD from the downstream seep flows from the left of basin #2 through a 100 ft open limestone channel (OLC #3) and exits into the gravel area at the edge of the second settling basin. Water enters into settling basin #2 from OLCs #2 and #3 and exits the system through a second steel slag check dam and forms the headwaters of an unnamed tributary of Beaver Creek.

Since installation the site has been sampled four times and the results are promising. Water leaving OLC #1 and #3 have pHs at or slightly below 6.0 and have from 21.4 to 23.3 mg/L alkalinity. After exiting the system at the outflow of leach bed #2 the water is at pH 10.9 and has 129 mg/L of alkalinity. Measurements in January 2001 show that water leaving the system has a net alkaline load of 8.5 tpy. When compared to the pre-construction water leaving the site at similar flows we see a reduced acid load of 19.0 tpy. The excess alkalinity leaving the site can then be used to treat additional AMD that enters the channel downstream of the project area. As a result of the additional acid inputs, much of this alkalinity is consumed. A sample taken approximately ½ mile downstream from leach bed #2 shows that the water here is at pH 8.0 and still has 22.6 mg/L alkalinity (Table 3).

The potential for leaching dangerous levels of heavy metals from steel slags had previously been tested with negative results in the laboratory. Discharges from the slag leach beds is being monitored to verify these conclusions under field conditions. The results indicate that there has been no increase in toxic elements in the effluent water. In fact, the original acid mine drainage was higher in Nickel and Zinc than water leaving the slag leach beds (Table 4).

Buckeye Furnace Project

The Buckeye Furnace Reclamation Project is located in the Buffer Run watershed of Little Raccoon Creek along Buckeye Furnace Road in Milton Township, Jackson County, Ohio. The site is a 65-acre complex of abandoned coal refuse piles, mine seeps and underground mine discharges. The #4 Brookville coal seam was deep mined here in the early 1900s. Subsequent strip mining in the early 1970s and the operation of a modern underground mine and associated wash facility have created most of the acid mine drainage on this site. Seeps in the acid refuse and numerous deep mines discharged over 675 tons of acid, 143 tons of iron and 50 tons of aluminum per year into Buffer Run and its receiving stream, Little Raccoon Creek This site was among the four worst known sources of AMD in the Little Raccoon Creek watershed.

A multi-unit treatment system was constructed at Buckeye Furnace between July 1998 and October 1999. The system consisted of two steel slag leach beds, a settling pond, a SAPS and an ALD. The slag leach beds were constructed upstream of the site on two freshwater tributaries of Buffer Run (Figure 4). Water from the leach beds flowed into Buffer Run and mixed with acid water from a seep in the spoil material. This "mixture" water then flowed into a settling pond. A SAPS and an ALD were also constructed on the site to treat other seeps and mine discharges, however, we are primarily concerned with the performance of the slag leach beds.

The sources of acid being treated by these slag leach beds are the slightly acidic Buffer Run upstream of the site, and the seep that comes in below the slag beds. Their average combined acidity concentration is 681 mg/L. Water leaving the leach beds from an upstream fresh water source has an average alkalinity of 1944 mg/L, which should adequately treat the 1840.3 mg/L acidity in the system (Table 5). However, the pond discharge water is still slightly net acid, but compared to the water entering the system it is 98% less acidic (Table 5). Again monitoring of heavy metals in the water showed no increase. In fact, the untreated water was often higher in some metals than the discharge of the settling pond.

Additionally, we have seen a steady decrease in alkalinity from the McCarty slag beds that we have not seen in the Buckeye Furnace beds. Figures 5 and 6 show these declines in both systems. Figures 7 and 8 show the difference in design of these two systems that may explain this difference.

Table 1 : Summary of treatment sites and water quality in the Big Laurel Creek watershed, Wilder , TN.

Site Name	Construction Date	incoming pH	inflow acid load	outflow acid load	% Change in acid load
Wilder I	Sep-93	3.0	5.3	4.1	23%
Wilder III Left	Jun-96	3.2	3.8	2.7	29%
Wilder IIIC	Jun-96	2.2	1.0	0.7	30%
Wilder IVB	Aug-96	2.5	55.6	39.2	29%
Wilder V Right	Jun-97	2.3	33.7	33.7	0%
Wilder V Left	Jun-97	2.2	55.4	23.1	58%
Wilder VIII at Sandy	Fall 98	2.6	10.6	3.0	72%

Table 2: Water quality of leach bed influent and effluent, gob pile seep and settling pond on Black Branch at Cane Creek site

Description	pH	acid (mg/L)	alk (mg/L)	acd-alk (mg/L)	T Fe (mg/L)	Al (mg/L)	Mn (mg/L)	% Change in Alkalinity	% Change in Acidity
LB4 in	6.9	0.0	20.7	-20.7	0.5	0.4	0.2		
LB4 out	8.1	0.0	35.4	-35.4	0.4	0.4	0.2	42%	-
LB2 in	6.7	1.4	7.1	-5.8	0.0	0.0	0.0		
LB2 out	8.1	0.0	50.9	-50.9	0.0	0.0	0.0	89%	-
LB2a in	6.9	0.0	10.1	-10.1	0.9	0.6	0.2		
LB2a out	7.4	0.0	26.9	-26.9	0.5	0.6	0.2	62%	-
LB1 In	5.1	11.7	1.8	9.9	0.0	24.3	9.5		
LB1 Out	7.4	0.0	26.4	-26.4	0.0	0.0	0.0	137%	-
AMD from Gob Pile	3.3	187.5	0.5	187.0	41.1	9.4	2.9		
Settling Pond	5.1	33.4	0.0	33.4	3.9	3.3	1.4	-	82%

Table 3: Water quality at discharge of McCarty Highwall site, before and after construction. Constructed in Oct 2000. Data represents 4 sample dates taken between 10/00 and 01/01.

Description	Flow (gpm)	pH	acid (mg/L)	alk (mg/L)	acd-alk (mg/L)	TFe (mg/L)	Al (mg/L)	Mn (mg/L)	acid load
Pre-construction									
Site discharge	104.0	3.7	45.9	0	45.9	0.6	2.9	3.4	10.5
Post-construction									
Top OLC#1		4.8	13.0	2.8	10.2	0.0	1.1	0.0	-
Bottom OLC#1		6.5	1.5	15.0	-13.5	0.0	0.5	2.5	-
Leachbed #1 Out		11.0	0.0	14.7	-14.7	0.0	0.0	0.0	-
Bottom OLC#2		10.8	0.0	17.7	-17.7	0.0	0.0	0.0	-
Top OLC#3		3.8	28.2	0.0	28.2	0.0	0.0	1.5	-
Bottom OLC#3		6.8	0.0	16.6	-16.6	0.0	0.0	0.8	-
Leachbed #2 Out	104.0	11.4	0.0	37.0	-37.0	0.0	0.0	0.0	-8.5

Table 4: Metal concentrations of water at various sample stations at McCarty Highwall. Constructed in Oct 2000. Data represents average of 4 sample dats conducted between 10/00 and 01/01.

sampling station	Sb (mg/L)	As (mg/L)	Ba (mg/L)	Be (mg/L)	Cd (mg/L)	Cr (mg/L)	Pb (mg/L)	Hg (mg/L)
Pre-construction								
Outflow	0	0	0	0	0	0	0	0
Post-construction								
Top OLC#1	0	0	0.012	0	0	0	0	0
Bottom OLC#1	0	0	0.015	0	0	0.001	0	0
Leachbed #1 Out	0	0	0.022	0	0	0.004	0	0
Bottom OLC#2	0	0	0.032	0	0	0.004	0	0
Top OLC#3	0	0	0.015	0	0	0	0	0
Bottom OLC#3	0	0	0.032	0	0.001	0	0	0
Leachbed #2 Out	0	0	0.045	0	0	0.005	0	0
Beaver pond outflow	0	0	0.020	0	0	0	0	0

sampling station	Se (mg/L)	Ag (mg/L)	Cu (mg/L)	Ni (mg/L)	Tl (mg/L)	V (mg/L)	Zn (mg/L)
Pre-construction							
Outflow	0	0	0	0.402	0	0	0.696
Post-construction							
Top OLC#1	0	0	0	0.130	0	0	0.253
Bottom OLC#1	0	0	0	0.127	0	0	0.242
Leachbed #1 Out	0	0	0	0.054	0	0	0.076
Bottom OLC#2	0	0	0	0	0	0	0.080
Top OLC#3	0	0	0	0.257	0	0	0.157
Bottom OLC#3	0	0	0	0.070	0	0	0.148
Leachbed #2 Out	0	0	0	0	0	0	0
Beaver pond outflow	0	0	0	0	0	0	0

Table 5: Average water quality at various samples stations in Buckeye Furnace. Slag leach beds constructed between July 1998 and October 1999. Data represents average of two sample dates conducted on 12/15/99 and 3/13/00.

sampling station	laboratory pH	acidity (mg/L)	alkalinity (mg/L)	acid-alk (mg/L)	Fe (mg/L)	Al (mg/L)	Mn (mg/L)	As (mg/L)	Hg (mg/L)
Buffer Run US of site	4.9	19.0	0.0	19.0	2.7	1.2	0.4	0.1	0.0
Effluent Eastern Slag Bed	12.0	0.0	1936.5	-1936.5	0.0	0.0	0.0	0.0	0.0
Effluent Western Slag Bed	12.0	0.0	1951.5	-1951.5	0.1	0.0	0.0	0.0	0.0
Seep D.S. of Slag Beds	3.4	1342.0	0.0	1342.0	572.0	24.8	18.7	0.0	0.0
Discharge settling pond	5.9	14.5	0.0	14.5	12.6	1.8	1.4	0.0	0.0

sampling station	Se (mg/L)	Be (mg/L)	Cd (mg/L)	Cu (mg/L)	Cr (mg/L)	Pb (mg/L)	Ni (mg/L)	Ag (mg/L)
Buffer Run US of site	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Effluent Eastern Slag Bed	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
Effluent Western Slag Bed	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0
Seep D.S. of Slag Beds	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0

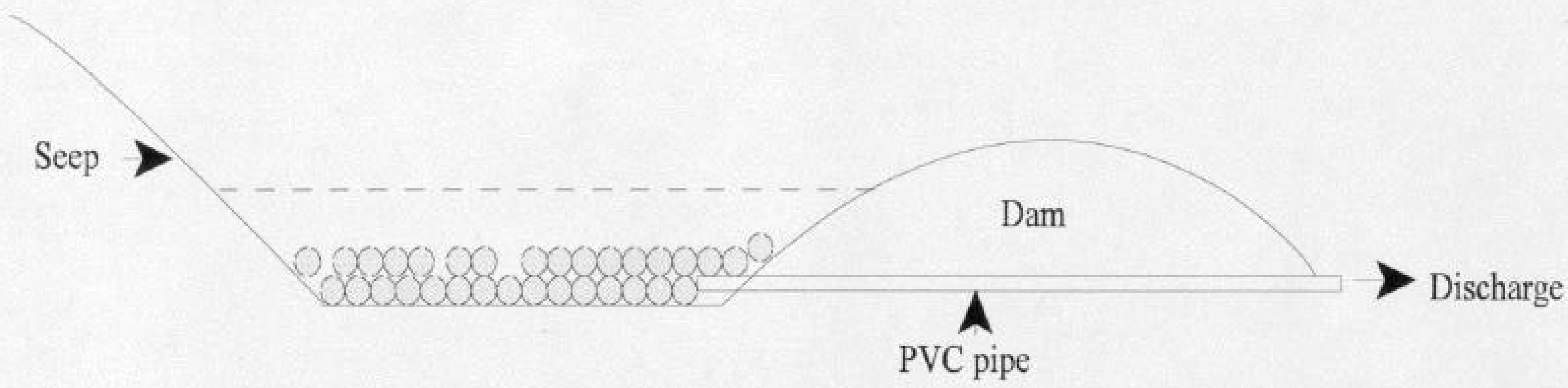


Figure 1: General design of limestone leach bed ponds at Big Laurel Creek

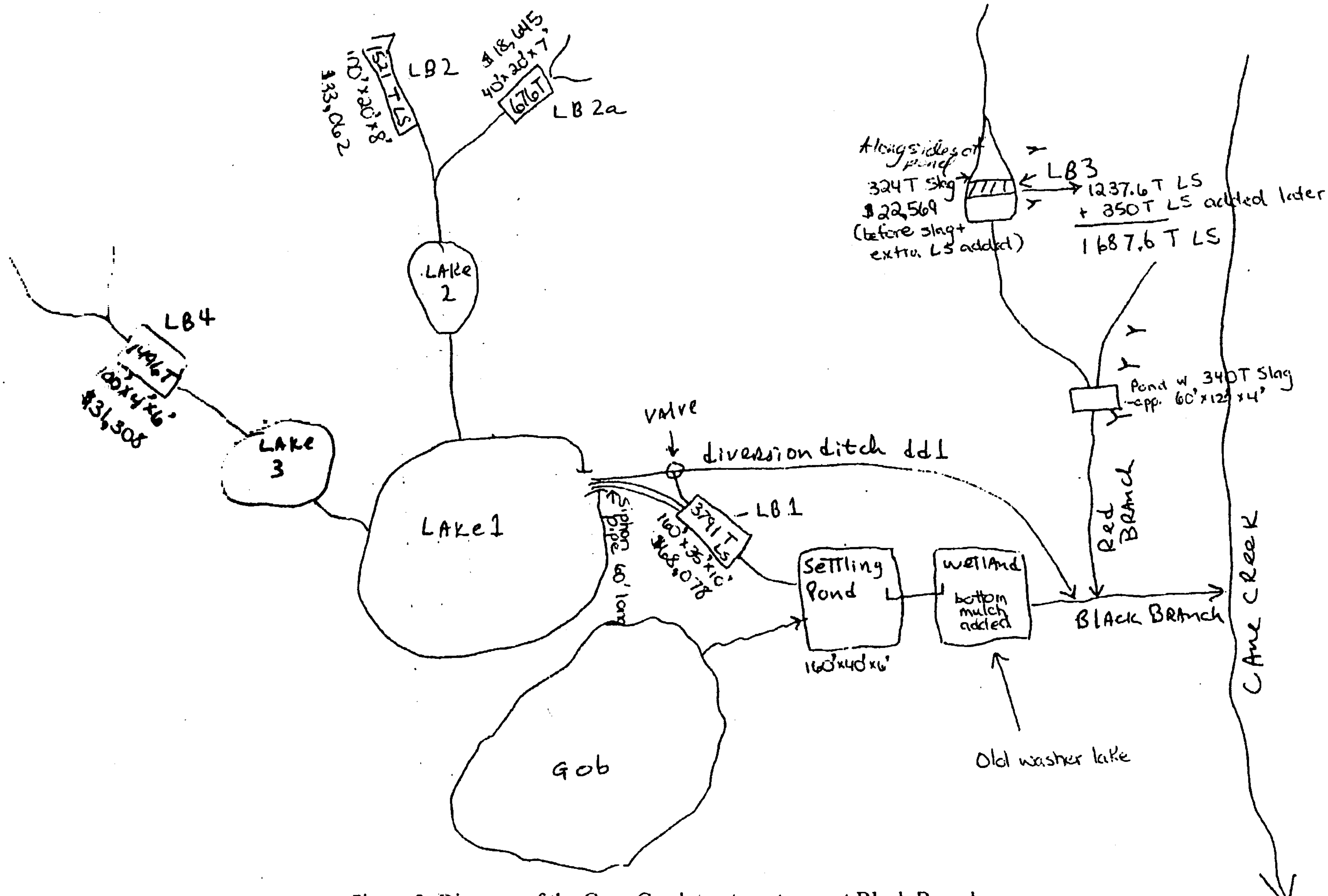


Figure 2: Diagram of the Cane Creek treatment area at Black Branch

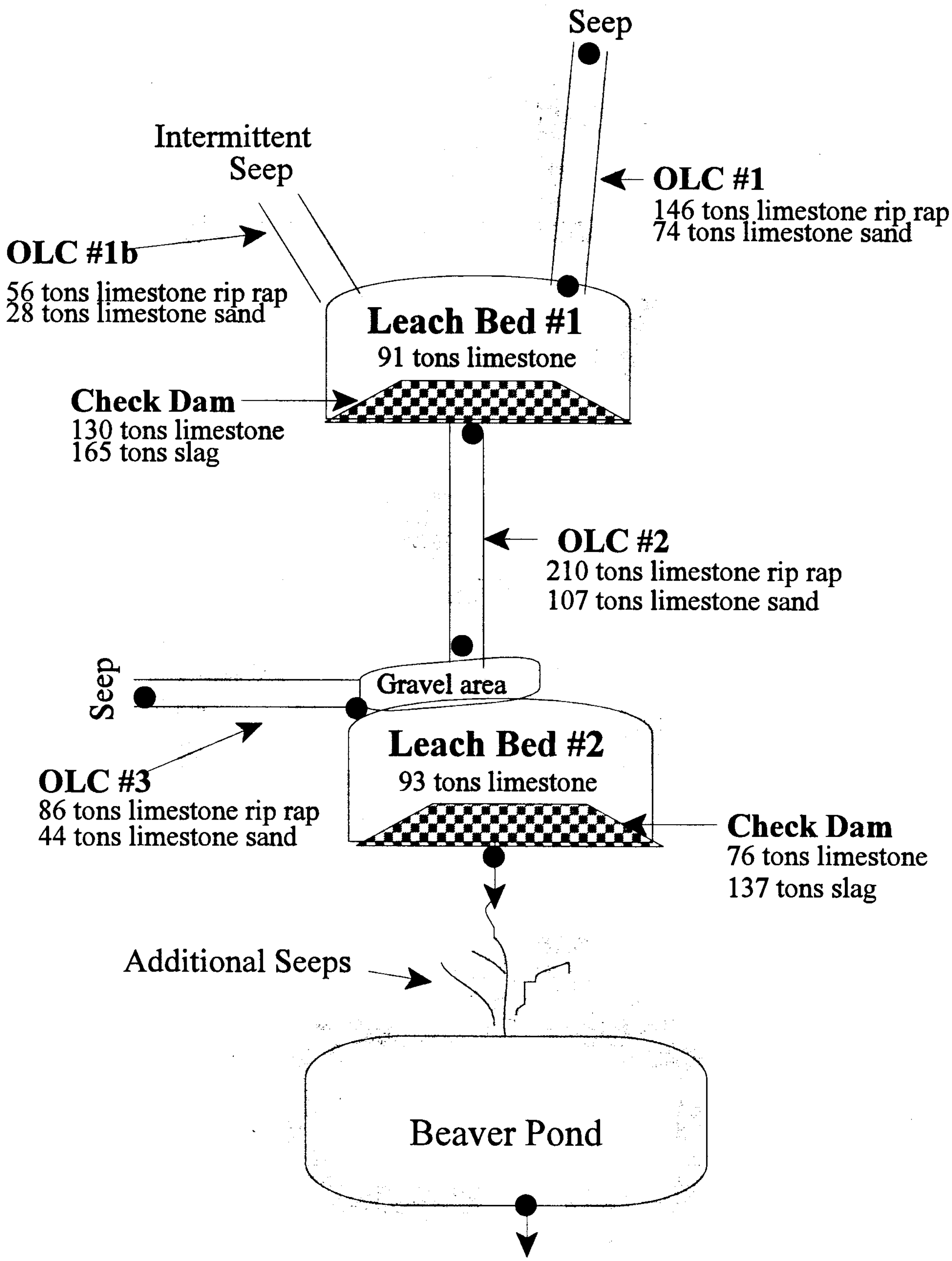


Figure 3: McCarty Highwall Treatment area.
Black dots mark the sample stations.

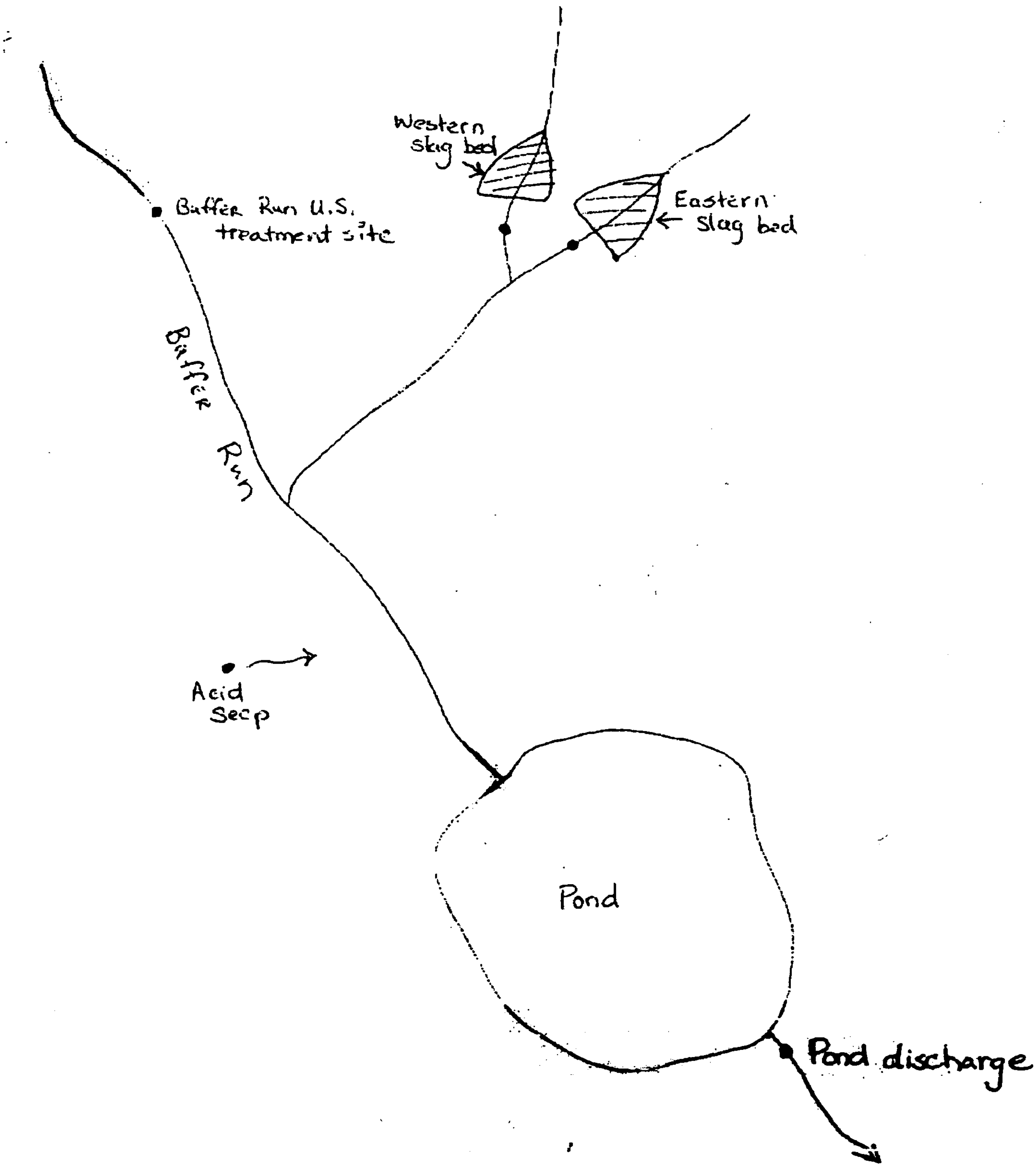


Figure 4: Diagram showing placement of slag leach beds, acid seep and settling pond at Buckeye Furnace

Figure 5: McCarty Highwall Slag Beds
Alkalinity generated by 2 Slag Beds

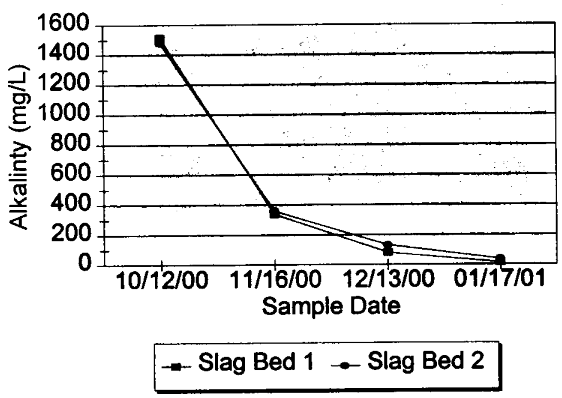


Figure 6: Buckeye Furnace Slag Beds
Alkalinity generation in 2 slag beds

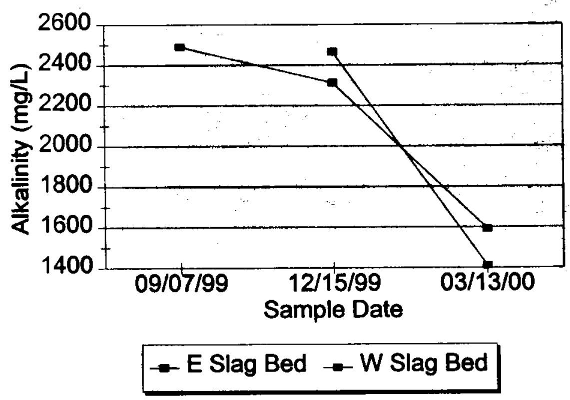


Figure 7: Design of slag leach beds at Buckeye Furnace. Notice the placement of slag in the bottom of the pond and the discharge pipe leading out of the slag.

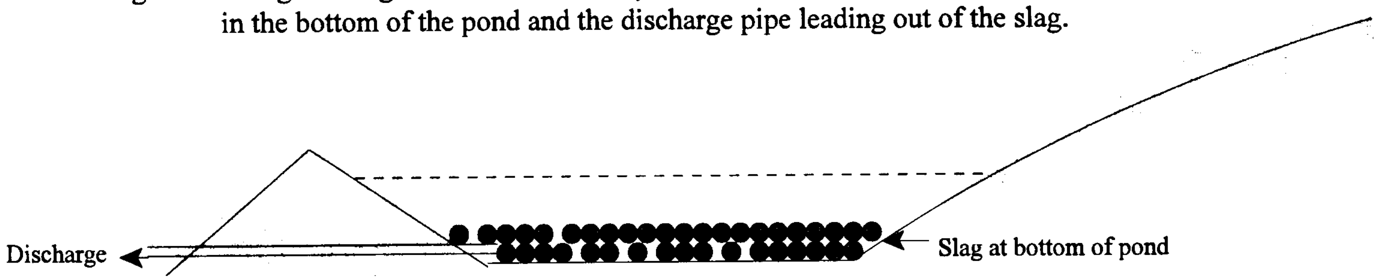
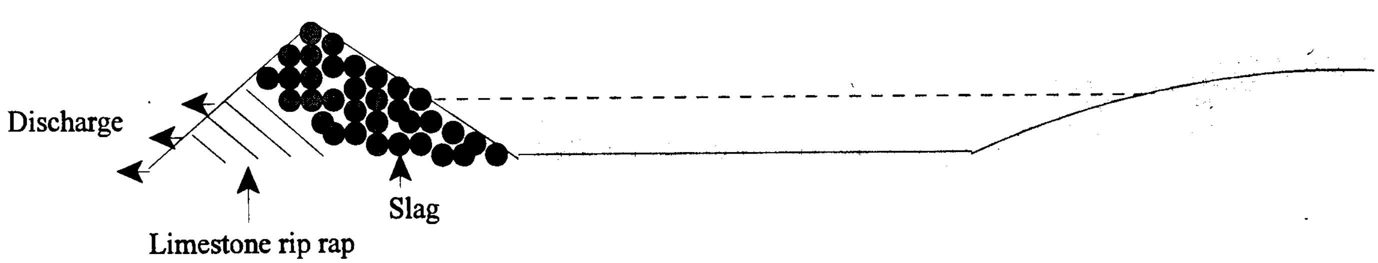


Figure 8: Design of the slag leach beds at McCarty Highwall. Here the leach bed is formed as a slag and limestone check dam. Water discharges all along the downstream face of the dam.



Skousen, J.G., A. Rose, G. Geidel, J. Foreman, R. Evans, and W. Hellier. 1998. Handbook of Technologies for Avoidance and Rernediation of Acid Mine Drainage, ADTI of the USOSM, Published by the National Mine Land Reclamation Center, WVU, Morgantown, WV.

Ziernkiewicz, P.F. and J. G. Skousen. 1998. "The Use of Steel Slag in Acid Mine Drainage Treatment and Control." In Proceeding of the 19th West Virginia Surface Mine Drainage Task Force Symposium, April 7-8, Morgantown, WV.

Ziernkiewicz, P.F. and J. G. Skousen, D. L. Brant, P. C. Stoner and R. J. Lovett. 1997. Acid Mine Drainage Treatment with Armored Limestone in Open Limestone Channels. Journal of Environmental Quality, 26:560-569.