MONITORING OF PASSIVE TREATMENT SYSTEMS: AN UPDATE

Ben B. Faulkner

and

Jeff G. Skousen

INTRODUCTION

Wetlands and anoxic limestone drains (ALDs) are passive treatment systems in contrast to active chemical treatment systems. Wetlands have been used for decades in the treatment of municipal wastewater (WPCF 1990) but only within the last 10 years have they received serious attention in the treatment of AMD. Researchers at Wright State University and West Virginia University independently noted that AMD from abandoned mined lands (AML) was improved after passing through natural Sphagnum wetlands in Ohio and West Virginia (Huntsman et al. 1978, Wieder and Lang 1982). Since then, investigators have documented many other sites where the same phenomenon was observed (Brooks et al. 1985, Burris 1984, Samuel et al. 1988). Artificial wetlands were constructed by operators and researchers, and results have generally been positive.

The criteria for construction and sizing wetlands has developed over the years largely due to trial and error and by contributions from researchers (Hedin and Nairn, 1992). Considerable variability exists in construction specifications and sizing since the mechanisms of alkalinity generation and metals removal are not entirely understood. Generally, sizing is dependent on consideration for iron, manganese, net acidity or alkalinity, with additional and aluminum removal. Oxidation, hydrolysis, and precipitation reactions consume (any) alkalinity in the influent water, and this acidity generation must be accounted for if there is to be net improvement in water quality at the effluent. Additional alkalinity generation to buffer the water in the wetland is accomplished by installing an anoxic limestone drain (ALD) upgrade of the wetland and/or encouraging sulfate reduction processes within the wetland by adding organic matter to the substrate, and by encouraging subsurface flow in the sulfate reducing zone. Sulfate reduction can generate up to 200 mg/1 of sulfides which are available for metal complexation (Rabenhorst et al. 1992). A low redox potential is required for this process. Factors such as climate, season, and organic matter inputs can dramatically affect the amount of sulfide generation and subsequent metal reduction.

ALDs have received much attention recently because they have the potential to add alkalinity to mine water without biological or seasonal limitations (Brodie et al. 1990, Nairn et al. 1990, Skousen 1991, and Turner and McCoy 1990). An ALD consists of crushed limestone buried in a trench, underdrain, or cell which is protected from the influence of atmospheric or dissolved oxygen. Acid water is intercepted underground and the limestone dissolves (generating alkalinity) without becoming armored. The conditioned water is then brought to the surface, and once exposed to oxygen, the metals dissolved in the water precipitate more rapidly than if untreated by the ALD. A sump or pond to collect metals prior to introduction to an aerobic or compost wetland reduces stress to the wetland vegetation and extends the longevity of the wetland.

ALDs require AMD which is free of dissolved oxygen (DO), and are more likely to produce desirable long-term effectiveness when iron is largely in the ferrous state and aluminum concentrations are fairly low (less than 50 mg/1).

Utilization of an ALD is complicated by mixed ferric/ferrous iron concentrations in AND and/or when intermediate DO concentrations are found in the water (i.e., 2 to 4 mg/1). Current research involves pretreatment of AND with an organic, anaerobic wetland to strip DO concentrations, and to either aerobically precipitate ferric iron in the surface of the wetland or anaerobically convert ferric iron to ferrous iron through iron reduction.

At the 1992 Task Force Symposium, we reported that ALDs and wetlands exhibited at least limited success at all project sites in our study (Skousen and Faulkner 1992). Since that time, continued monitoring of these and new sites has generated more data on the effectiveness of passive systems on treatment of AMD.

RESULTS OF AMD TREATMENT WITH PASSIVE SYSTEMS IN WEST VIRGINIA

The oldest passive systems reported in this paper were constructed by the West Virginia Division of Environmental Protection (WVDEP) under its AMD-Bond Forfeiture (AMD-BF) Program. Table 1 lists the sites where passive treatment technologies have been installed, and inflow and outflow measurements for pH, acidity, alkalinity, iron, manganese, aluminum, and sulfate on each site. The efficiency of these wetland systems is seen in the removal of iron (Table 2) and the neutralization of acidity (Table 3).

Averages over approximately 3 years show dramatic but variable improvements in pH, and reductions in acidity, iron, manganese, and aluminum. Cumulative graphs for each site demonstrate this variability, and seasonal trends are obvious (Figure 1).

WETLANDS

Keister

The Keister wetland has a relatively high area to load ratio (5495 ft^2:lb.Fe). It reduced the acidity of an average 4 gpm flow from 250 to 60 mg/1 (77% reduction), and increased pH from 3.1 to 5.4. Iron was generally reduced from 23 to 9 mg/l (62%), while manganese was reduced from 23 to 20 (11%). Aluminum was decreased on the average from 11 to 6 mg/l (45%).

This site exhibits a very low acid load, compared to other bond forfeiture sites. The large capital cost of installing these three systems at Keister ($225,000) suggest that chemical treatment may have been cheaper, but the difficulty of maintaining adequate chemical treatment facilities at this remote site with poor access and low flows is hard to calculate. Further, the receiving stream has not had to bear wide fluctuations in pH which are common with most chemical systems, especially those requiring only periodic maintenance such as this.

The low, sporadic flows at Keister System #2 and System #3 do not allow a meaningful calculation of acid neutralized or subsequent cost analysis.

S.Kelly

The S.Kelly wetland site varies from the earlier design in an effort to encourage subsurface flow under and through the humic strata by the use of a geotextile fabric which was placed under and on the upstream side of the hay bale barriers. This wetland system provided limited surface area for the amount of iron load (326 ft^2:lb.Fe) because the construction area was quite limited, and the flows and iron concentrations were high.

Early observations suggested that the attempt to encourage subsurface flow has been largely unsuccessful. Most of the flow appears to pass through and over the haybale dikes, rather than under them.

This system has demonstrated a significant reduction in iron concentrations on all sampling occasions, with a 31 month average of 68% reduction (from 105 to 33 mg/1). Acidity generally increased through the system for the first fall and winter, but continues to improve in reduction. An apparent influx of acid drainage subsurface to the system makes a mass-balance impossible. Flows increase an average of 43% from influent to effluent. It is more meaningful to compare pre-construction loadings to post-construction loadings. In the 24 month period prior to construction of the system, an average of 14.8 gpm with acidity of 2432 mg/l left the site (432 lbs./day). Since the system has been constructed, the average effluent flow has been gauged at 25.1 gpm with acidity of 1366 mg/l acidity (376 lbs./day). It is remarkable that the total acid load of this site has been reduced by only 13% (432 to 376 lbs./day) since the construction of the system, and the iron load has been reduced by over 75% (from 47 lbs./day to 11 lbs./day). These reductions were accomplished without any vegetation in the wetland.

Pierce

This wetland employs the "classic" approach to wetland construction. utilizes surface flow over a limestone-enriched, organic substrate. It also provides a relatively high surface area to iron load ratio (2483 ft^2:lb.Fe).

The system has averaged about 73% removal of the iron and about 50% of the acidity with substantial seasonal variation. It has consistently removed a small percentage of aluminum (25%) and manganese (11%) except during large flows.

Z&F

Construction of this wetland employed organic substrates similar to the previous designs, but encouraged subsurface flow by means of 6-inch plastic pipes under earthen barriers. This wetland provided the least surface area per pound of iron (230 ft^2:lb.Fe), but has reduced metals substantially and consistently since its construction over 36 months ago. Only a mild pH enhancement has been seen despite removal of 66% of the acidity. Much of the acidity is associated with the removal of iron (77% removal from influent to effluent) and perhaps aluminum (also reduced approximately 63%) while manganese has sometimes been removed and sometimes increased through the system.

Removal of an average of 33% of the acid load prior to construction (277 to 184 lbs./day) could be viewed as removing a total of over 50 tons of acid in 3 years. To have accomplished this chemically, over $100,000 in caustic soda would have had to have been dispensed. Attendant labor and sludge removal costs associated with this type of treatment would have likely doubled this figure. The $110,000 construction cost appears to have been well worth the investment.

All the wetland systems exhibit seasonal variability with respect to acidity and metal removal efficiency. These trends can best be seen by the graphs (Figure 1) of the percent reduction of acidity and metals in each system. Further scrutiny of the sizing of each site indicates the best iron removal and acidity reduction performance per unit area of wetland has been exhibited at the site with the smallest area to load ratio (Tables 2 and 3).

ANOXIC LIMESTONE DRAINS

ALD treatment results are also found in Table 1. ALD and wetland construction criteria are summarized in Table 4.

Greendale

Most ALDs under WVDEP's AMD-BF Program were constructed at the Greendale site in Clay County in 1991 (Figure 2). All drains generated substantial alkalinity for a few months but some were overcome as acidity resurfaced and alkalinity diminished. Generally, aluminum has been retained in the drains, and iron and manganese left the drain in approximate pre-drain concentrations.

"Autopsies" of failed or poorly functioning drains at Greendale in 1992 have been accomplished as additional trenches and wetlands were installed. It can now be said with certainty that hay should not be buried in proximity to the drain as it encourages the growth of organisms on the limestone, reducing pore space and effectiveness of the limestone. Where hay had not been placed in the drain, the limestone was clean.

New drains have omitted the hay (originally thought to serve as an oxygen sink and to promote C02 production and thereby increase limestone dissolution) and included larger stone (6-8 inch) placed at the bottom of the drain and also at the collection zones (Figure 3). Substantial "grit" and metal precipitates are generated upon excavation, so measures must be taken to allow these to settle before contact with the finer limestone (#57).

Benham

WVDEP has installed modified septic tanks at four locations at this site in Boone County in an attempt to study anoxic drain conditions without the difficulty of re-excavating earthen drains. Problems have arisen with differential settling and plugging from iron and grit.

Lobo Capital

Two ALDs and small wetlands were installed at Lobo Capital but the landowner's activities have disrupted the function of the anoxic alkaline drains from this Preston County deep mine, and monitoring has been hampered.

The ALDs/Wetlands on the site caused remarkable improvement in the quality of Glade Run, the receiving stream, for a few months. However, the drain was likely undersized hydraulically for the large flows. This problem was compounded by the presence of bacterial growth on the limestone in the proximity of the hay.

Kodiak

An ALD and wetland (precipitation and polishing pond) were installed at this surface mine in Braxton County. Additional work to ensure positive flow and reduce future maintenance are necessary but preliminary results show substantial reductions in acidity, iron and aluminum.

Lillybrook

A relatively high pH (net alkaline), high iron seep in Raleigh/Mercer Counties is being treated. The water from the site joins other seepage and enters the existing sediment pond which is completely full of sediment and supports a lush volunteer cattail population. A concrete box modified from a septic tank was filled with limestone and installed at the site in November 1992. Alkalinity has been increased substantially (23 to 260 mg/1) which should improve the efficiency of the existing wetland.

Preston

An ALD/Wetland treats a small flow of 3.5 gpm with acidity at 775 mg/1 and iron of 570 mg/l. Effluent water from the limestone cell has a pH of 6.0, acidity of 413 mg/1 (28% reduction) and iron of 550 mg/l (4% reduction). The ALD-treated water then enters an aerobic wetland. At the exit of the wetland, the pH drops to 3.3, and acidity is reduced to 190 mg/1 (76% reduction) and iron is reduced to 20 mg/l (96% reduction).

Kittle Flats

One of the most serious and controversial AND sites in West Virginia will be the site for the construction of ALDs in the spring of 1993.

DISCUSSION

Monitoring of passive systems has led to the following general observations on ALD construction.

ORGANIC MATTER - Addition of hay (even separated from limestone by geotextile fabric) leads to compromise of limestone dissolution by growth of organisms. Some builders have enjoyed undocumented success using chicken litter.

SIZING - High limestone to acid load ratios are not the primary factor in ALD success. While many of the AMD-BF drains have been inhibited by the coating of limestone by organic matter, large drains (> 20 tons of lime per ton of acid load) have not had demonstrably improved success over small ones (< 20). The reduction in acid load per ton of limestone is quite variable and does not correlate with this ratio. The grade of limestone does not appear to be critical. More acidic water seems to increase limestone dissolution.

STONE SIZE AND CONFIGURATION - Larger limestone (6 to 12 inch) increases hydraulic conductivity but has limited surface area for alkalinity generation. Larger stone also provides settling area for grit and other settleable matter generated during construction. Wide, deep drains of a graded configuration (Figure 3) should capitalize on the advantages of both stone sizes. There is some speculation that providing limited slope (1 to 2%) to the drain may aid in maintaining desired flow patterns.

PROTECTION FROM OXYGEN - Where inadequate measures were taken to prevent oxygen intrusion, iron oxidation and limestone armoring is inevitable. Using plastic on the upgrade side of the drain across slopes can be disadvantageous as seepage fails to enter the drain and comes to the surface. Clay-lined geotextile fabric is a promising method to prevent leakage from the drain in spoil, but providing adequate excavation and large stone placement for collection is imperative.

PIPES - Observations of precipitate deposition on pipe walls and at perforations suggest that larger pipes (6 to 10 inch) with larger perforations (1 inch or greater) promote longevity. Avoid elevation changes or place perforations on top of transfer pipes bedded in large stone.

ACKNOWLEDGMENT

Funding for wetland research at West Virginia University has been primarily provided by the USDI, Bureau of Mines through the National Mine Land Reclamation Center at WVU. Thanks go to Dr. Paul Ziemkiewicz, NMLRC Director.

Special thanks go to Mr. Rich Casdorph, Mr. Roger Green, and Mr. Jimmie Seckman of the WVDEP, and to Sturm Environmental Services.

LITERATURE CITED

Brodie, G.A., C.R. Britt, H. Taylor, T. Tomaszewski, and D. Turner. 1990. Passive anoxic limestone drains to increase effectiveness of wetlands acid drainage treatment systems. In: Proceedings, 12th National Association of Abandoned Mined Land Conference, Breckinridge, CO.

Brooks, R., D.E. Samuel, and J.B. Hill. 1985. Wetlands and water management on mined lands. Proceedings of a Conference. The Pennsylvania State University, University Park, PA

Burris, J.E. 1984. Treatment of mine drainage by wetlands. Contribution No. 264, Department of Biology, The Pennsylvania State University, University Park, PA.

Hedin, R.S., and R.W. Nairn. 1992. Designing and sizing passive mine drainage treatment systems. In: Proceedings of the 13th West Virginia Surface Mine Drainage Task Force Symposium, Morgantown, WV.

Huntsman, B.E., J.B. Solch, and M.D. Porter. 1978. Utilization of a Sphagnum species dominated bog for coal acid mine drainage abatement. Abstracts, 91st Annual Meeting

Geologic Society America, Ottawa, Ontario, Canada.

Nairn, R.W., R.S. Hedin, and G.R. Watzlaf. 1990. A preliminary review of the use of anoxic limestone drains in the passive treatment of acid mine drainage. In: Proceedings, 12th West Virginia Surface Mine Drainage Task Force Symposium, Morgantown, WV.

Rabenhorst, M.C., B.R. James, and J.N. Shaw. 1992. Evaluation of potential wetland substrates for optimizing sulfate reduction. p. 90-97. In: Proceedings, 1992 American Society for Surface Mining and Reclamation, Duluth, MN.

Samuel, D.E., J.C. Sencindiver, and H.W. Rauch. 1988. Water and soil parameters affecting growth of cattails. p. 367-374. In: Mine Drainage and Surface Mine Reclamation, Vol. I. Info. Circular No. 9183. U.S. Bureau of Mines, Pittsburgh, PA.

Skousen, J.G. 1991. Anoxic limestone drains for acid mine drainage treatment. Green Lands 21(4): 30-35.

Skousen, J.G., and B.B. Faulkner. 1992. Preliminary results of anoxic limestone drains in West Virginia. In: Proceedings, 13th West Virginia Surface Mine Drainage Task Force Symposium, Morgantown, WV.

Turner, D., and D. McCoy. 1990. Anoxic alkaline drain treatment system, a low cost acid mine drainage treatment alternative. In: 1990 National Symposium on Mining. University of Kentucky, Lexington, KY.

Wieder, R.K., and G.E. Lang. 1982. Modification of acid mine drainage in a fresh water wetland. p. 43-53. In: Symposium on Wetlands of the Unglaciated Appalachian Region. West Virginia University, Morgantown, WV.

WPCF. 1990. Natural systems for wastewater treatment. Water Pollution Control Federation, Washington, D.C.

Table 1. Characteristics of AMD before and after passing through passive systems in West Virginia.

Site	gpm	pH		Acid		Alk		Fe		Mn		Al		SO_4		Acid Load		Com-ment
		In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	
WETLANDS																		
Keister1	4.4	3.1	5.4	252	59			23	9	23	20	27	13	673	466	13	3	
Keister2/3	2.5	4.0	4.8	106	56			11	3	11	11	10	8	356	347	3	2	
S.Kelly	25.1	2.9	3.1	1383	1366			105	33	51	50	157	163	2558	2660	413	408	
Pierce	25.5	3.3	4.4	118	57			10	2	8	7	9	7	217	227	36	17	
Z & F	8.1	2.5	3.5	2388	801			376	86	51	40	206	76	2821	1662	2300		
ALD																		
Greendale																		
1 6/61	12	3.1	6.0	195	125	0	30	130	110	24	19	3	0	300	500	40	12	*1
2 5/71	1.5	2.9	5.7	700	0	0	160	190	160	160	80	28	0	1900	1400	30	1	*2
4 422	0.5	3.1	6.4	290	100	0	100	22	70	95	90	24	0	1000	1400	6	0	*3
424	3	2.6	6.1	280	140	0	30	160	140	40	50	4	0	1000	1000	8	3	
428	5	3.1	5.6	280	220	0	25	21	150	95	50	24	0	1100	1100	12	2	*5
413	2	2.9	6.2	600	70	0	75	120	110	90	50	80	0	1800	900	60	2	*4
5 271	1	2.8	3.4	1000	650	0	0	140	130	200	160	100	70	2400	2000	30	7	*6
272	1	2.8	4.7	700	350	0	1	130	100	170	130	55	30	1600	1600	20	3	*6
6 201	5	2.8	4.3	2000	1000	0	0	300	361	140	140	140	100	3000	2000	150	48	

Table 1. Continued

Site	gpm	pH		Acid		Alk		Fe		Mn		Al		SO_4		Acid Load		Comment
10 293	1	2.9	6.0	370	80	0	50	80	80	105	96	9	1	1300	1300	6	0	*7
296	4	2.8	6.1	266	145	0	80	300	210	120	90	94	0	2060	1500	74	5	*8
297	5	2.8	3.7	600	310	0	0	300	100	120	90	94	17	2060	1500	70	25	*9
298	3	2.6	4.8	1200	600	0	6	150	300	140	120	70	10	2300	2000	5	10	*10
12 371	1	3.0	6.8	800	0	0	340	30	30	45	12	50	0	1100	600	1	0	
13 351	1	3.1	6.1	750	30	0	80	41	10	160	140	88	2	2660	2000	30	0	*6
Kodiak	4.0	2.8	4.3	2210	30	0	0	124	1	45	2	287	3	2900	140	105	1	
Lillybrook	16.0	5.7	6.4	17	0	23	259	60	43	21	21	0	0	101	45	3	0	
Preston	12.0	3.5	6.1	775	595	0	308	570	350	12	12	50	1	1326	1330	110	41	

*1 ALD excavation picked up additional AMD flow.
*2 Substantial leaking from drain.
*3 Substantial blockage/leaking in drain; revised in summer '92.
*4 All AMD was not captured in drain; collection was not effective.
*5 #428 was result of cutting #422 and #424 in half, and outletting AMD of the ALD.
*6 Drains appear to have been overcome by blockage, acidity (not autopsied).
*7 Substantial leakage and repaired in summer 1992.
*8 Drain autopsied and repaired, problem due to durface erosion.
*9 Installed 6"-8" stone only (note ▲ pH).
*10 Probably encountered additional AMD at excavation.

Table 2. Removal of iron and efficiency of four wetlands treating acid mine drainage.

	area m2	Fe in	gpm	g/day	removal %	removal g/d/m2	size m2/g/d
Keister 1	408	23	4	549	62%	0.83	0.74
Keister 3/2	929	11	5	270	72%	0.21	3.44
S. Kelly	1417	105	25	14363	68%	6.89	0.10
Pierce	813	10	26	1334	73%	1.20	0.61
Z & F	863	376	8	16599	77%	14.81	0.05

Table 3. Reduction of acidity and efficiency of four wetlands treating acid mine drainage.

	actual m2	recommended[1] m2	flow gpm	acidity mg/l	acidity g/day	removal %	removal g/d/m2	size m2/g/d
Keister 1	408	859	4	252	6015	62%	9.14	0.07
Keister 3/2	929	371	5	106	2600	72%	2.01	0.36
S. Kelly	1417	27027	25	1383	189187	68%	90.79	0.01
Pierce	813	2343	26	118	16399	73%	14.72	0.05
Z & F	863	15060	8	2388	105418	77%	94.06	0.01

[1] COMPARE AMD-BF WETLANDS TO USBOM RECOMMENDATIONS FOR NET ACID MINE DRAINAGE:
minimum wetland size m2 = acid load (g/d)/7
gpm*mg/l*5.45/7=m2 or, m2*10.7=ft2

Wetlands are generaly much smaller than recommended, but are demonstrating good acid reduction.

Table 4. Passive treatment systems for treating acid mine drainage, through the WVDEP AMD-Bond Forfeiture Program. Construction specifications and dates, and pre and post acidity concentrations are given.

A	B Area #	C Ditch #	D site #	E length	F width	G depth	H Limestone tons	I Flow gpm	J Pre-acidity	K Load t/yr.	L Post-acidity	M J - L Δ ac.	N M/H Δ ac./lime	O H/K lime/load	P CONSTRUCTION	Q DATE
ALD's																
Greendale																
	1	1	61	354	3	1	51	27	195	12	90	105	2.06	4.4	hay/#57	Jul-91
	2	1	71	455	3	1	66	4	700	6	0	700	10.66	10.7	hay/#57	Jul-91
	3	regraded; no additional work to date														
	4	1	424	126	3	1	18	4	350	3	150	200	11.00	6.6	#57	Sep-92
		2	422	147	3	1	21	5	300	3	60	240	11.31	6.4	hay/#57	Jul-91
		3	413	300	3	1	43	18	600	24	70	530	12.24	1.8	hay/#57	Aug-92
		4	428	250	3	1	36	5	350	4	220	130	3.60	10.0	#57	Aug-92
	5	1	271	58	3	1	8	1	1020	2	600	420	50.18	3.7	hay/#57	Jul-91
		2	272	100	3	1	14	2	570	3	350	220	15.25	5.8	hay/#57	Jul-91
	6	1	201	150	3	1	22	5	2000	22	1000	1000	46.20	1.0	6-8"/#57	Aug-92
	7	wetland receiving drainage from Area #6 ALD														
	8	regraded; no additional work to date														
	9	regraded; no additional work to date														
	10	1	298	60	3	1	9	3	1200	8	650	550	63.53	1.1	#57	Sep-92
		2	297	100	3	1	14	4	600	5	310	290	20.10	3.1	6-8"	Sep-92
		3		87	3	1	13								hay/#57	Jul-91
		4		122	3	1	18								hay/#57	Jul-91
		5		72	3	1	10								hay/#57	Jul-91
		6		125	3	1	18								hay/#57	Jul-91
		7		15	3	1	2								hay/#57	Jul-91
		sum3-7	296	421	3	1	61	4	266	2	100	166	2.73	27.3	hay/#57	Jul-91
		8	293	239	3	1	34	6	370	5	60	310	8.99	7.1	hay/#57	Jul-91
	12	1	371	130	3	1	19	2	500	2	180	320	17.06	8.5	6-8"	Sep-92
	13	1	351	103	3	1	15	0	750	0	180	570	38.35	45.0	hay/#57	Jul-91
	total	---------	---------	---------			493			100						
Benham				4 concrete boxes			28	compromised, repaired, compromised again							#57	Oct-92
WETLANDS																
Z & F		1	1					8	2388	42	801	1587			compost	Mar-90
Pierce		1	18					26	118	7	57	61			compost	Sep-90
S.Kelly		1	11					15	1383	46	1366	17		no plants	compost	Aug-90
Keister		3/2	58					5	106	1	56	50		no lime	compost	Aug-90
Keister		1	55					4	252	2	59	193		no lime	compost	Aug-90
ALD & WETLANDS																
Lobo Capital																
	13	1	18	520	10	1	250	23	471	24	23	448	1.79	10.4	hay/#57	Nov-91
	1	1	21	210	10	1	97	51	177	20		177	1.82	4.9	hay/#57	Dec-91
	total	---------	---------	---------			347									
Kodiak			15	130	4	5	128	4	2210	19	30	2180	17.03	6.8	3-4"/#4	Sep-92
Lillybrook			51	concrete box			7	15	17	1	-259	276	39.43	12.5	#57	Dec-92
Kittle Flats				180	16	5	1000								6-9"/#4	PENDING

COLUMNS A - C DENOTE THE AREA OF THE PROJECT AND DITCH NUMBER
COLUMN D DENOTES THE WATER SAMPLE SITE NUMBER
COLUMNS E-G DENOTESTHE LINEAR FEET, WIDTH AND DEPTH OF ALKALINE TRENCH
COLUMN H DENOTES THE TONS OF LIMESTONE (ASSUMING 100% $CaCO_3$)
COLUMN I IS AVG. FLOW IN GPM, COLUMN J IS AVG. TOTAL HOT ACIDITY IN MG/L PRE CONSRTUCTION
COLUMN K IS TONS OF ACID PER YEAR
COLUMN L IS THE AVERAGE ACIDITY LESS AVERAGE ALKALINITY GENERATED AT THE TRENCH EFFLUENT
COLUMN M IS THE CHANGE IN PRE AND POST TRENCH ACIDITY
COLUMN N IS COLUMN M DIVIDED BY COLUMN H (change in acidity divided by tons of limestone)
COLUMN O IS TONS OF ACIDITY PER YEAR / TONS OF LIME
COLUMN P INDICATES CONSTRUCTION TYPE
COLUMN Q IS COMPLETION DATE

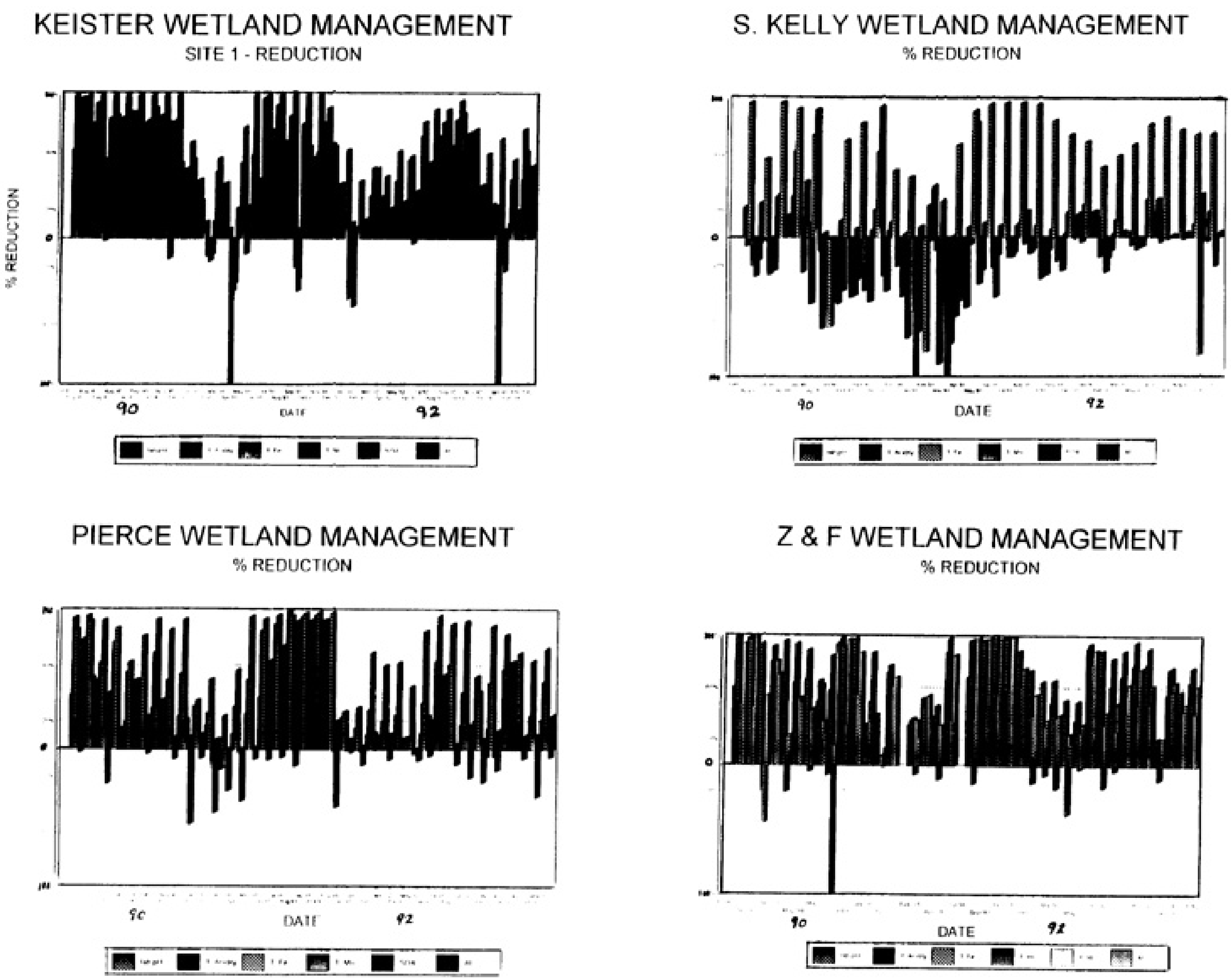


Figure 1. Acidity and metal removal efficiency of four wetland systems in West Virginia.

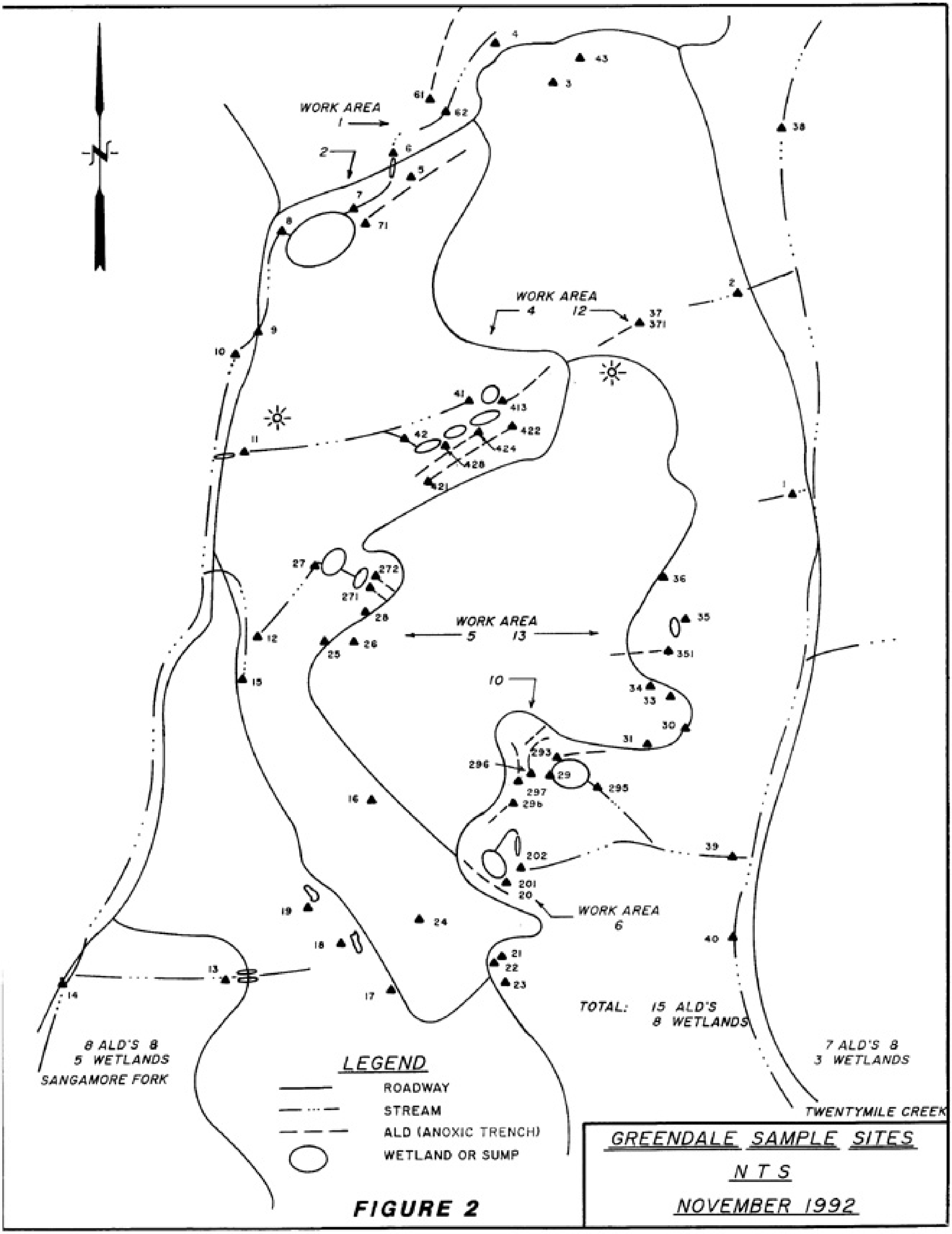
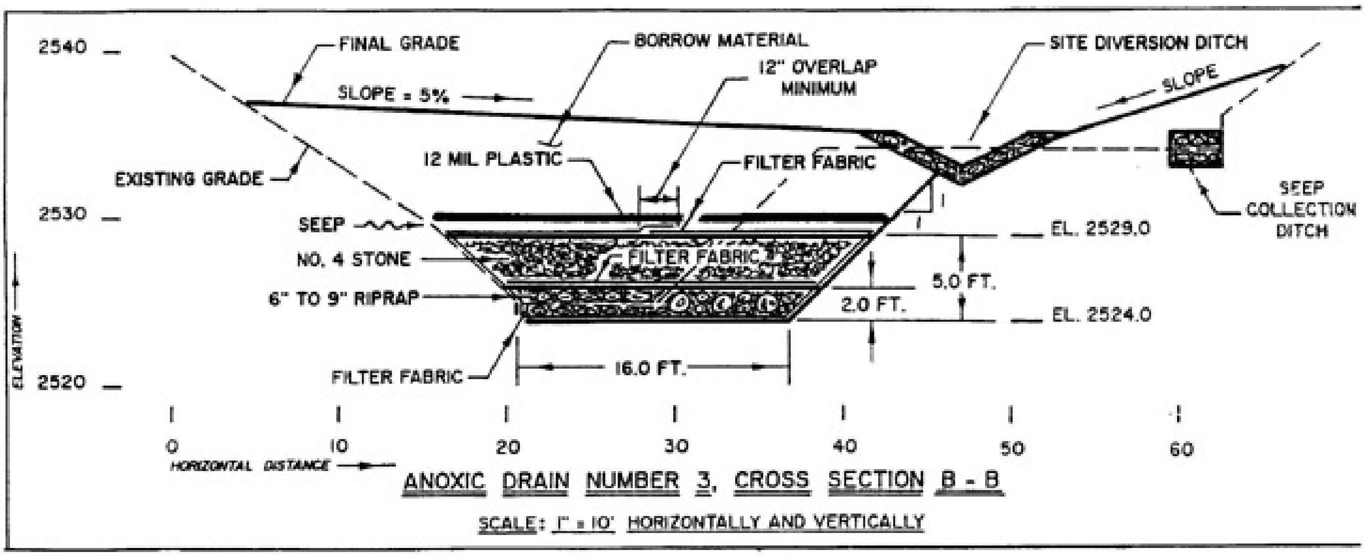

WORK AREA 1
2
WORK AREA 4 12
WORK AREA 5 13
10
WORK AREA 6
TOTAL: 15 ALD'S 8 WETLANDS
8 ALD'S 8 5 WETLANDS
SANGAMORE FORK
7 ALD'S 8 3 WETLANDS
TWENTYMILE CREEK
LEGEND
ROADWAY
STREAM
ALD (ANOXIC TRENCH)
WETLAND OR SUMP
GREENDALE SAMPLE SITES
N T S
NOVEMBER 1992

FIGURE 2



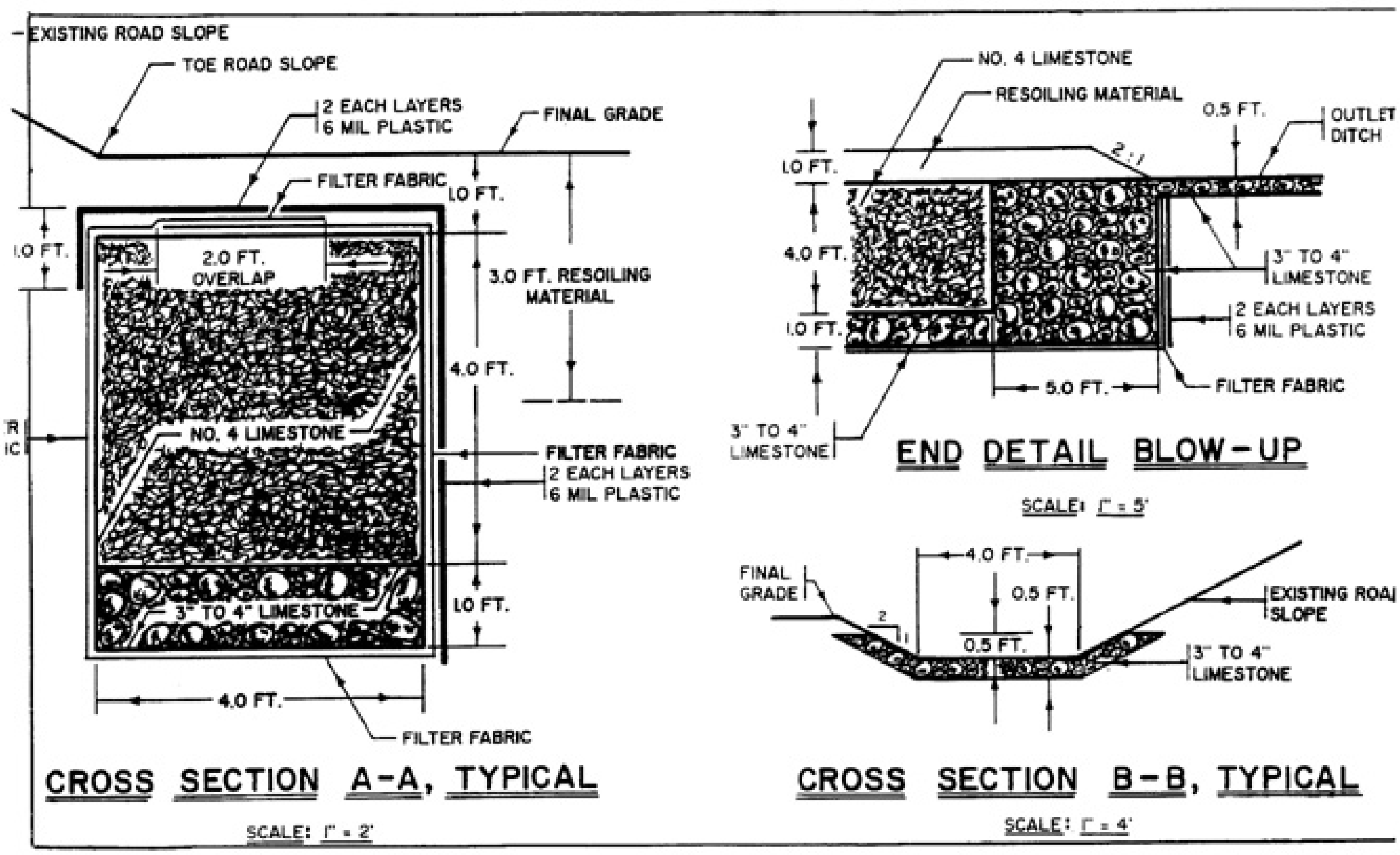


Figure 3. Anoxic limestone drain (ALD) construction specifications.