Long-Term Performance of Passive AMD Treatment Systems

Paul F. Ziemkiewicz, Director

National Mine Land Reclamation Center

Extent of Project Area

- Evaluated 49 passive AMD treatment sites throughout the US
  - Al, IN, KY, MD, OH, TN, and WV
- Total of 137 treatment units

Materials and Methods

- Collection of pre- and post-treatment water quality data
- Collection of system design information
- Calculation of acid load reductions
- Calculation of treatment unit cost
- Calculation of service life
- Calculation of cost per ton of acid reduced per year

Collection of water quality data

- Where possible, influent and effluent data
- If not possible, pre-treatment and post-treatment data
- Required parameters
  - Acidity
  - Alkalinity
  - Flow

System Design Parameters

- Amounts of materials used
  - Limestone
  - Steel Slag
  - Ca(OH)2
  - Soda Ash Briquettes
  - Compost
- System dimensions (to calculate yd3 of material excavated)

Acid Load Reductions

- Mass of base needed to neutralize
  - Flow (gpm) x acidity (mg/L) x 0.0022 = acid load (tons/year)
  - Influent acid load – Effluent acid load = acid load reduction (tons/year)

Calculation of Passive Treatment Unit Cost

- Excavation Cost = $3/yd3 of earth moved
- Materials Cost
  - Limestone = $25/ ton
  - Steel Slag = $25/ ton
  - Calcium Hydroxide = $70/ ton
  - Soda Ash Briquettes = $263 ton
  - Compost = $25/ yd3

Estimated Service Life

- Service life is the expected period of performance for a given treatment unit

- SL (yrs) = $\frac{\text{(Tons of Alk. Material) x (\% NP)}}{\text{Acid load removal rate (tpy)}}$

- Assigned a maximum value of 20 years

Cost to Treat a Ton of Acid

- System Efficiency = $/ton acid load removed
- Efficiency over the Service Life = $/ton acid load removed/yr

Cost of Active Treatment

- Estimated annual cost of treating 1 ton of acid with caustic soda (NaOH)
- Estimated to be $500/ton of acid/year
- Cost does not include equipment, labor, sludge pond construction, cleaning, piping or other maintenance costs

Determination of Treatment Success

- Successful treatment units must meet the following criteria
  - Must have a net positive acid load reduction
  - Lower cost of treatment than caustic

Confounding Factors in Performance Evaluations

- Poor fit between system type and water quality
  - Example: using a ALD to treat high Al water
- Undocumented inflow of acid or alkaline water into the system
- Pre-construction estimates of influent quality and quantity may not reflect current conditions

Types of Passive Systems Evaluated

- Aerobic Wetlands
- AMD Treatment Ponds
- Anaerobic Wetlands
- ALDs
- ALD/ Wetland combos
- Vertical Flow Wetlands
- OLCs
- Limestone leach Beds
- Steel Slag Leach Beds

Table 1. Design requirements and factors for passive treatment systems.

System Type	Requirements	Construction	Design Factors	References
Aerobic Wetland	Net alkaline water	Shallow ponds with emergent plants	10-20 g Fe/sq. m /day 0.5-1.0 g Mn/sq. m /day	Hedin et al. 1994
Anaerobic Wetland	Net acidic water Low flow	Flow over and within substrate	3.5 g acidity/m /day	Hedin et al. 1994 Wildeman et al. 1993 Eger 1994
Anoxic Limestone Drain	Net acidic water Low DO, Fe, Al	Flow through limestone	15 hrs residence time	Hedin and Watzlaf 1994
Vertical Flow Wetland	Net acidic water	Vertical flow through organics/limestone	15-30 cm of organic matter 15 hrs residence time in LS	Kepler and McCleary 1997
Open Limestone Channel	Slope > 12%	Rock lined channel	Treatment is a function of acid load and residence time	Ziemkiewicz et al.
Limestone Leach Bed (AMD)	Inflow pH < 3.0	Flow through limestone bed	1.5 hours residence time maintain pH < 3.0	
Slag Leach Bed	Metal free water	Flow through steel slag fines	1 to 3 hrs residence time	Ziemkiewicz et al.

Table 2. Construction costs, acid load treated and treatment costs for nine aerobic wetlands (AeW).

Site	Influent pH	Acid Load Treated (ton/yr)	Years in Service (years)	Construction Cost ($)	Estimated Service Life (years)	Efficiency ($/ton/yr)
WV-2a	6.7	11.6	4.0	5,432	20	23.4
WV-7a	6.8	14.3	3.0	13,552	20	47.4
OH-2c	6.0	1.1	1.0	1,334	20	61.0
WV-7b	6.5	7.4	3.0	12,712	20	85.9
WV-2b	7.2	0.4	4.0	4,116	20	514.5
WV-7c	6.6	0.7	3.0	15,484	20	1,106.0
WV-10a	2.5	0.4	1.0	12,093	20	1,512.0
AL-2d	5.0	0.0	4.0	5,500	*	*
MD-3d	5.5	-3.6	2.0	9,680	*	*

* Service life and efficiency cannot be estimated for sites where there is no net reduction of acid load

Table 3. Construction costs, acid load treated and treatment costs for 18 ponds.

Site	Influent pH	Acid Load Treated (ton/yr)	Years in Service (years)	Construction Cost ($)	Estimated Service Life (years)	Efficiency ($/ton/yr)
WV-2g	6.8	0.6	4.0	693	20	57.8
OH-2b	6.0	1.1	1.0	1,333	20	61.0
WV-10d	2.5	3.3	2.5	4,096	20	62.1
WV-30i	4.7	2.0	5.0	20,000	20	500.0
WV-15b	6.3	0.7	3.0	25,719	20	1,837.1
WV-15a	2.7	0.4	3.0	14,934	20	1,866.8
WV-30j	6.3	0.2	5.0	12,000	20	3,000.0
WV-16d	6.4	0.0	4.0	444	*	*
WV-16c	6.2	0.0	4.0	1,068	*	*
WV-2f	6.3	-0.3	4.0	693	*	*
MD-2c	4.5	-0.9	1.0	9,614	*	*
WV-12d	3.7	-0.9	2.0	1,068	*	*
WV-1e	6.3	-1.0	5.0	9,600	*	*
WV-10c	2.5	-1.4	2.5	7,508	*	*
MD-3b	4.5	-2.2	2.0	3,600	*	*
WV-30h	6.3	-2.4	5.0	14,070	*	*
MD-1b	4.0	-2.4	3.0	2,667	*	*
MD-2a	4.0	-2.6	1.0	2,600	*	*

* Service life and efficiency cannot be estimated for sites where there is no net reduction of acid load.

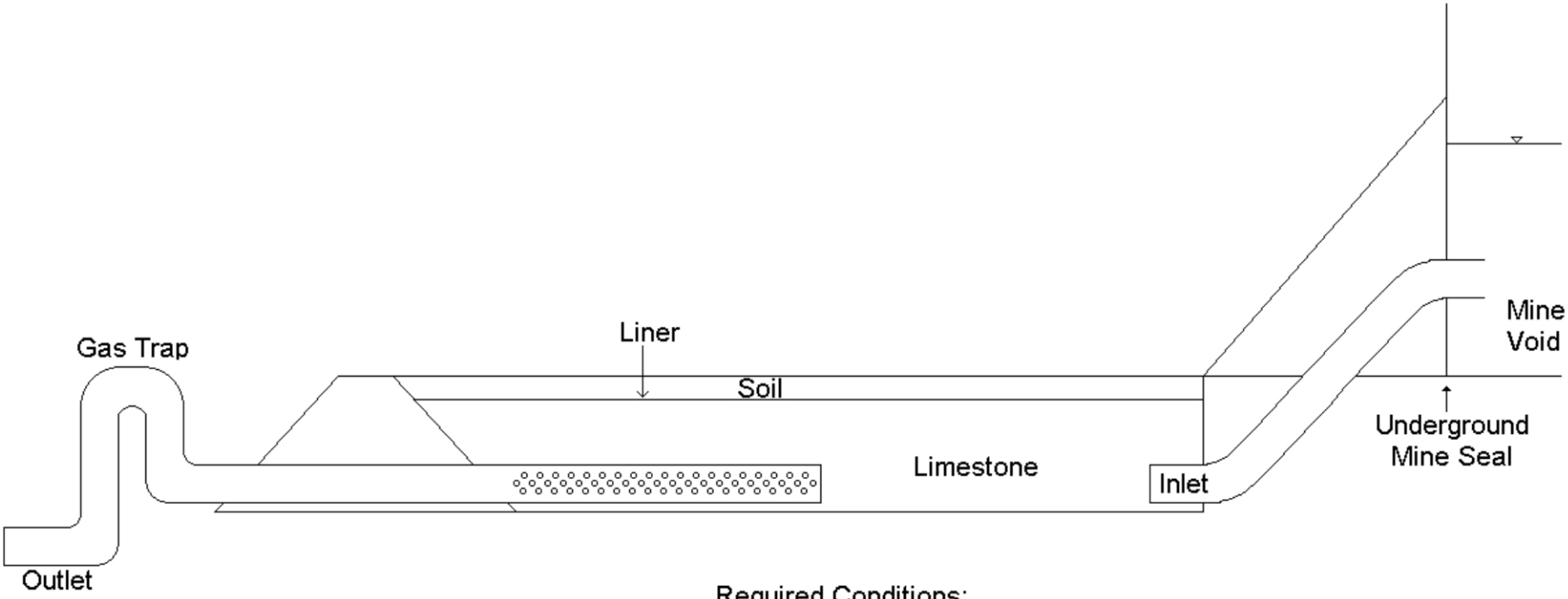
Anaerobic Wetland

Table 4. Construction costs, acid load treated and treatment costs for 18 anaerobic wetlands (AnW).

Site	Influent pH	Acid Load Treated (ton/yr)	Years in Service (years)	Construction Cost ($)	Estimated Service Life (years)	Efficiency ($/ton/yr)
WV-4b	5.9	35.4	4.0	97,925	20	138.3
WV-1g	2.9	10.2	5.0	53,333	20	261.4
WV-34	2.9	24.4	10.0	150,219	20	307.8
WV-35b	2.5	17.4	10.0	116,184	20	333.9
WV-30k	4.6	2.4	5.0	20,000	20	416.7
WV-30l	4.3	1.2	5.0	20,000	20	833.3
WV-6	3.0	31.3	7.0	549,901	20	878.4
WV-29	3.0	3.2	10.0	97,143	20	1,517.9
WV-25b	2.9	3.8	10.0	152,375	20	2,004.9
WV-1h	3.0	1.6	5.0	125,187	20	3,912.1
WV-16b	6.0	0.0	4.0	4,947	*	*
WV-25a	3.0	-0.5	10.0	100,000	*	*
WV-28d	5.8	-1.3	8.5	47,529	*	*
WV-22b	6.5	-1.4	5.0	4,983	*	*
WV-2d	6.7	-3.4	4.0	38,549	*	*
WV-2e	7.2	-5.7	4.0	14,026	*	*
WV-28c	5.7	-7.5	8.5	23,823	*	*
WV-1i	3.7	-160.6	5.0	43,965	*	*

* Service life and efficiency cannot be estimated for sites where there is no net reduction of acid load.

Anoxic Limestone Drain



Required Conditions:
- No Ferric Iron
- No Aluminum
- No D.O.

Anoxic Limestone Drain, under construction

Table 5. Construction costs, acid load treated and treatment costs for 38 anoxic limestone drains (ALD).

Site	Influent pH	Acid Load Treated (tons/yr)	Years in Service (years)	Construction Cost ($)	Estimated Service Life (years)	Efficiency ($/ton/yr)
WV-26	3.0	6.7	8.0	3,488	15	34.1
WV-30b	6.3	4.7	5.0	3,321	20	35.3
WV-32	2.9	8.0	4.0	5,747	20	35.9
WV-1a	3.7	130.9	5.0	115,207	20	44.0
OH-1c	2.9	20.1	2.0	18,154	20	45.0
WV-28b	3.1	15.1	8.5	2,656	3	58.6
WV-19a	3.3	19.5	3.0	26,301	20	67.4
WV-7e	4.1	125.6	3.0	169,695	20	67.6
WV-1b	3.7	121.4	5.0	167,994	20	69.2
WV-2c	4.1	29.4	4.0	42,743	20	72.7
WV-28a	3.0	4.6	8.5	6,829	20	74.2
WV-4a	2.9	7.1	4.0	11,041	20	77.8
WV-22a	2.7	11.0	5.0	17,299	20	78.6
WV-1d	3.7	8.8	5.0	13,957	20	79.3
MD-3a	4.0	13.2	5.0	20,790	20	79.0
WV-30g	2.9	5.1	5.0	8,505	20	83.4
WV-19b	3.3	10.3	3.0	19,050	20	92.5
WV-8a	3.5	17.8	4.5	34,208	20	96.1
WV-5	3.8	9.3	2.0	25,783	20	138.6
WV-30e	4.3	0.8	5.0	2,430	20	151.9
WV-30c	6.5	0.9	5.0	2,916	20	162.0
WV-23h	3.4	15.2	9.0	17,446	6	184.8
WV-30a	5.2	1.3	5.0	7,452	20	286.6
WV-8b	3.4	4.3	4.5	25,099	20	291.8
WV-23f	3.6	2.0	8.0	5,365	8	353.0
WV23a	3.8	2.1	8.0	12,298	16	357.5
WV-23b	3.1	8.9	9.0	18,876	6	357.5
WV-30d	6.3	0.3	5.0	2,969	20	494.8
WV-17	3.1	18.8	12.0	187,110	20	497.6
WV-35a	2.9	20.8	1.4	15,903	1	546.1
WV-7d	5.8	0.2	3.0	2,377	20	594.3
WV-23d	3.9	0.3	9.0	4,004	20	667.3
WV-1c	3.7	2.5	5.0	39,961	20	799.2
WV-16a	3.3	0.0	4.0	32,238	*	*
WV-23c	3.8	-0.1	9.0	2,574	*	*
WV-30f	6.1	-1.9	5.0	3,779	*	*
WV-23e	3.4	-2.7	9.0	4,290	*	*
WV-23a	5.1	-3.2	9.0	14,586	*	*

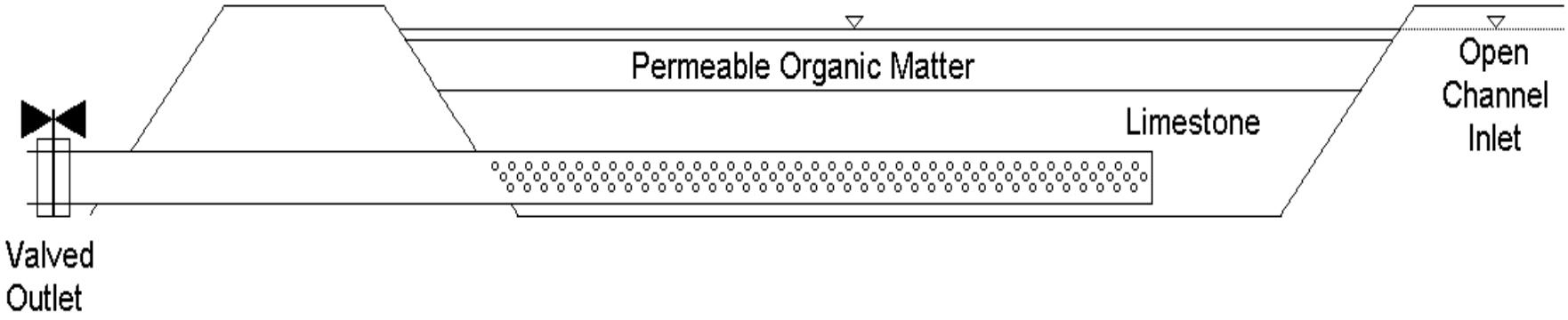
* Service life and efficiency cannot be estimated for sites where there is no net reduction of acid load.

Table 6. Construction costs, acid load treated and treatment costs for four anoxic limestone drain - wetland combinations (ALD/W).

Site	Influent pH	Acid Load Treated (tons/yr)	Years in Service (years)	Construction Cost ($)	Estimated Service Life (years)	Efficiency ($/ton/yr)
WV-21	2.7	13.4	5.0	32,725	20	122.1
WV-20	2.3	19.3	6.0	81,325	20	210.7
WV-33b	3.9	0.5	5.0	4,033	20	403.3
WV-33a	5.9	0.0	5.0	3,797	20	9,492.5

Vertical Flow Wetland (SAPS)

Conditions: Requires Regular Flushing



Vertical Flow Wetland

Table 7. Construction costs, acid load treated and treatment costs for 19 vertical flow wetlands (VFW).

Site	Influent pH	Acid Load Treated (ton/yr)	Years in Service (years)	Construction Cost ($)	Estimated Service Life (years)	Efficiency ($/ton/yr)
MD-1c	4.0	21.8	3.0	16,880	20	39.0
KY-1	2.8	68.7	1.0	74,046	20	54.0
WV-3a	3.0	5.9	3.0	14,313	20	121.3
MD-1a	4.0	5.0	3.0	12,771	20	128.0
OH-1b	3.4	21.2	2.0	58,945	20	139.0
IN-1b	5.0	9.5	5.0	27,150	20	143.0
OH-2a	3.6	6.8	1.0	19,898	20	146.0
IN-1a	4.6	6.1	5.0	22,236	20	182.0
WV-3b	2.9	3.9	3.0	15,753	20	202.0
MD-2b	4.0	4.0	3.0	43,878	20	548.0
WV-15c	2.7	4.3	3.0	56,878	20	661.4
WV-7f	5.8	6.1	3.0	89,314	20	732.1
WV-3c	3.0	0.5	3.0	11,461	20	1,146.1
MD-3c	4.0	1.5	3.0	39,907	20	1,330.0
WV-1f	3.4	5.9	5.0	213,267	20	1,807.3
WV-15d	4.9	3.1	3.0	125,406	20	2,022.7
OH-2d	4.8	0.0	1.0	14,486	*	*
WV-16e	6.2	0.0	4.0	11,208	*	*
WV-7g	7.0	-97.2	3.0	101,868	*	*

* Service life and efficiency cannot be estimated for sites where there is no net reduction of acid load.

Open Limestone Channel

Open Limestone Channel

Table 8. Construction costs, acid load treated and treatment costs for 11 open limestone channels (OLC).

Site	Influent pH	Acid Load Treated (tonnes/yr)	Years in Service (years)	Construction Cost ($)	Estimated Service Life (years)	Efficiency ($/tonne/yr)
IN-2b	4.8	13.2	2.0	950	3	24.0
WV-14	3.7	24.1	6.0	24,004	20	49.8
WV-24	4.0	19.4	2.0	46,272	20	119.3
WV-31	2.9	25.0	4.0	73,184	20	146.4
WV-36b	5.6	2.8	1.0	11,250	20	200.9
WV-36a	5.0	1.7	3.0	7,500	20	220.6
WV-11	2.5	6.8	2.5	36,192	20	266.1
WV-12c	4.2	5.0	2.0	28,099	20	281.0
WV-12b	3.5	2.8	2.0	31,590	20	564.1
WV-33c	5.1	0.1	5.0	15,046	20	7,523.0
WV-12a	3.5	-4.7	2.0	34,992	*	*

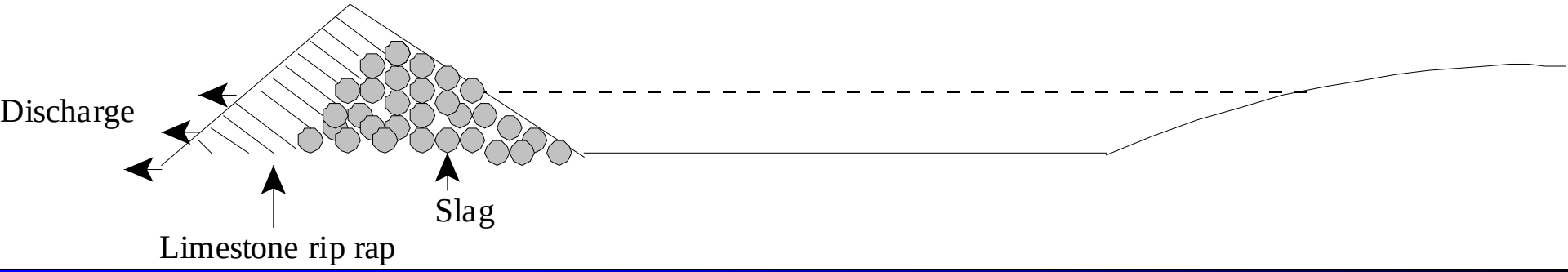
* Service life and efficiency cannot be estimated for sites where there is no net reduction of acid load.

Limestone Leach Bed

Table 9. Construction costs, acid load treated and treatment costs for 18 limestone beds (LSB).

Site	Influent pH	Acid Load Treated (ton/yr)	Years in Service (years)	Construction Cost ($)	Estimated Service Life (years)	Efficiency ($/ton/yr)
WV-36c	5.7	10.9	3.0	3,750	11	31.0
WV-13b	2.8	14.1	5.0	14,122	20	50.1
TN-1c	2.9	58.9	6.0	74,911	20	64.0
WV-13a	3.1	7.2	5.0	14,122	20	98.1
TN-1d	3.0	44.0	1.5	93,436	20	105.0
IN-2a	2.7	47.1	2.0	100,000	20	106.0
TN-2c	2.3	32.3	4.0	120,000	20	186.0
TN-1b	3.1	24.4	2.5	98,989	20	203.0
TN-2d	2.6	7.6	3.0	113,437	20	221.0
WV-9	3.3	2.2	4.0	10,350	20	235.2
TN-2b	2.5	24.1	6.0	113,783	20	236.0
AL-1	4.0	7.4	1.0	35,825	20	242.0
WV-36d	5.6	4.6	1.0	37,500	20	408.0
AL-2c	3.9	10.6	4.0	100,997	20	476.0
AL-2a	6.7	3.6	4.0	37,667	20	523.0
TN-1a	3.2	6.7	4.0	104,991	20	784.0
AL-2b	7.0	0.4	4.0	17,527	20	2,191.0
TN-2a	2.9	1.3	8.0	150,530	20	5,790.0

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.



Steel Slag Leach Bed

Table 10. Construction costs, acid load treated and treatment costs for two slag leach beds (SLB).

Site	Influent pH	Acid Load Treated (ton/yr)	Years in Service (years)	Construction Cost ($)	Estimated Service Life (years)	Efficiency ($/ton/yr)
OH-1a	3.7	313.6	2.0	77,239	20	12.0
WV-37	4.4	19.0	1.0	31,970	20	84.0

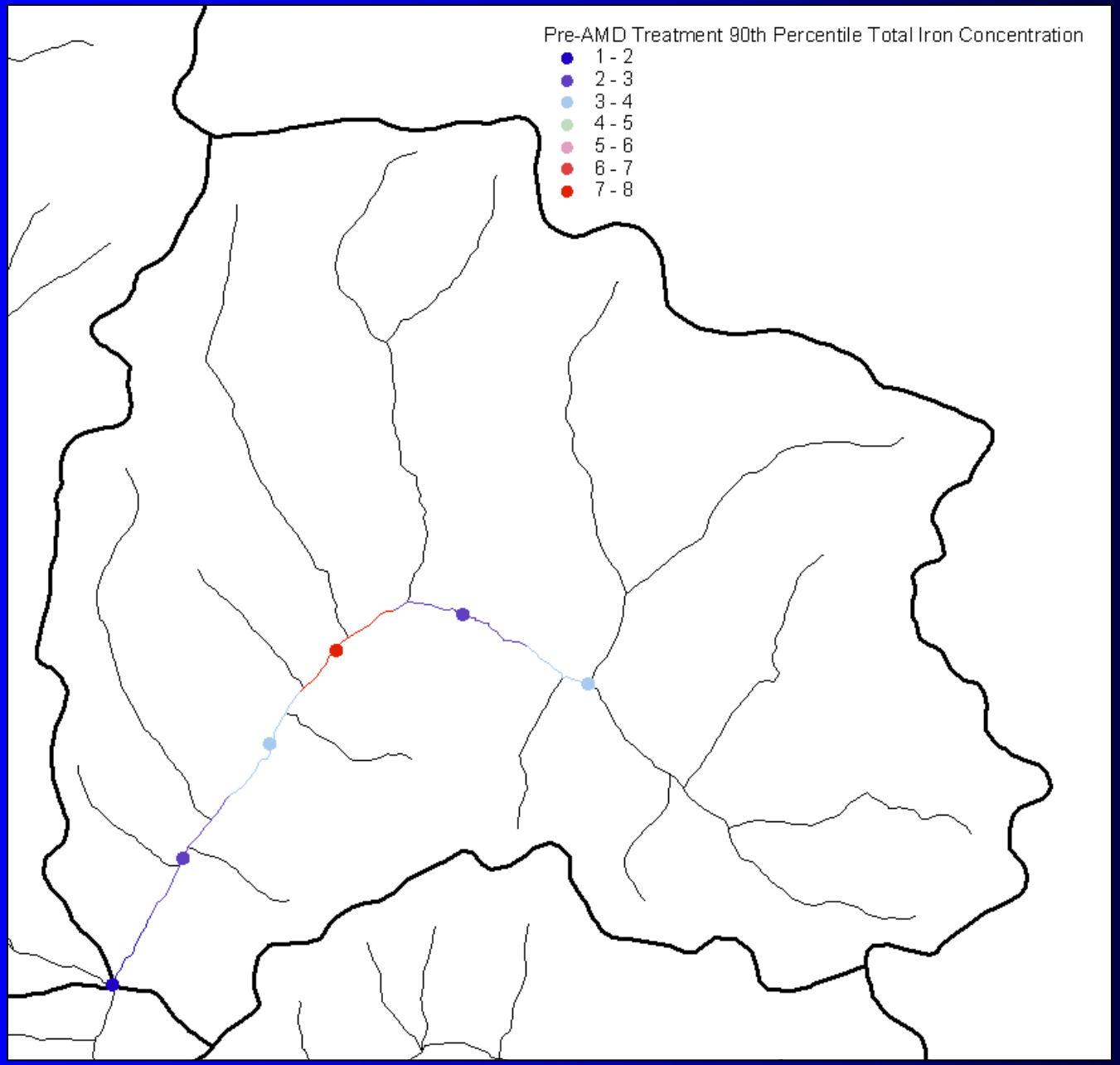
Comparison of Passive Treatment Performance

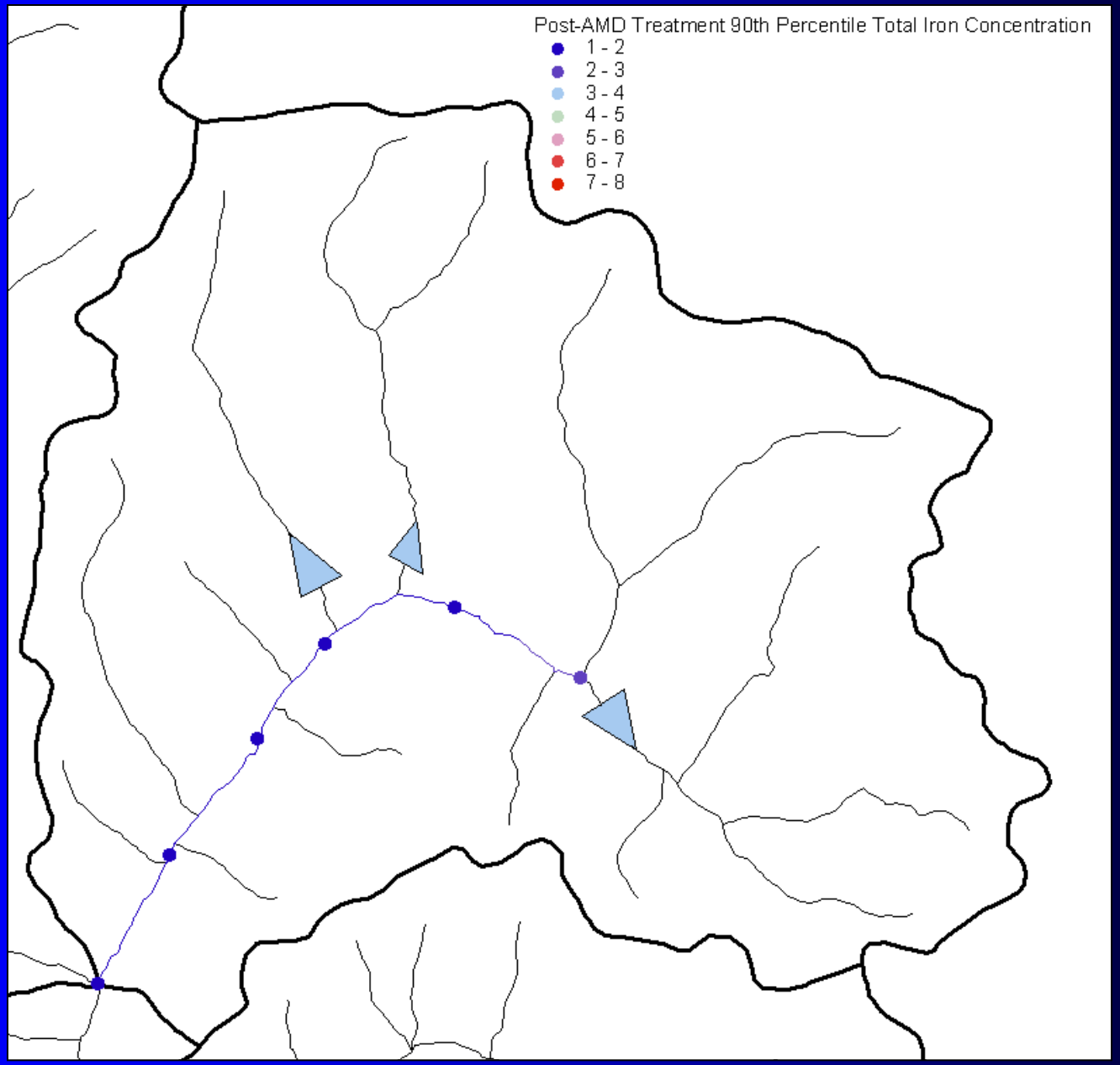
Table 11. Summary of the treatment effectiveness (positive vs negative) and cost (successful vs failure) of 137 passive treatment systems.

System Type	Number of Units	Average Total Cost	Average Acid Treated (tons/yr)	Percent With Positive Treatment	Percent Successful Treatment
SLB	2	$54,604	166.3	100%	100%
LSB	18	$68,997	17.1	100%	78%
ALD	38	$29,327	16.8	87%	76%
ALD/W	4	$30,468	8.3	100%	75%
OLC	11	$28,098	8.7	91%	73%
VFW	19	$51,035	4.1	84%	47%
AeW	9	$8,878	3.6	78%	44%
AnW	18	$92,227	-2.7	56%	28%
Ponds	18	$7,317	-0.3	39%	22%
Total:	137				

Most Cost Efficient Systems

- Provide a high level of reliability and are most cost efficient
  - Limestone Leach Beds
  - Anoxic Limestone Drains
  - Open Limestone Drains


Pre-AMD Treatment 90th Percentile Total Iron Concentration
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
6 - 7
7 - 8


Post-AMD Treatment 90th Percentile Total Iron Concentration
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
6 - 7
7 - 8

AMD Treatment Cost vs. Change in pH