AN EVALUATION OF PASSIVE TREATMENT SYSTEMS RECEIVING OXIC NET ACIDIC MINE DRAINAGE

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AN EVALUATION OF PASSIVE TREATMENT SYSTEMS RECEIVING OXIC NET ACIDIC MINE DRAINAGE

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Executive Summary

1. In a survey by the Bureau of Abandoned Mine Reclamation (BAMR) of DEP in 2009-10, a disturbing number of publically funded passive AMD treatments systems discharged acid effluent. This DEP survey defined “Failure” as discharging effluent with positive hot peroxide acidity. Effluent was acid not only at systems classified as High Risk using the earlier BAMR Risk Matrix, but also at Medium and Low Risk sites. The present followup investigation is intended to determine reasons for these failures and to compare characteristics of successful systems with the systems discharging acid water.

2. The current investigation consists of a more detailed study of 10 “failed” High Risk systems, 4 “failed” Medium Risk systems, 4 “failed” Low Risk systems and 5 successful Medium and High Risk systems, with most selected at random from sites designed since development of improved sizing guidelines in 2002. Available information on the design, construction and performance of the systems was collected, most were visited and sampled, and the systems were discussed with the local group and designers.

3. At 2 High Risk “failures” (AMD&Art, Webster), the design was poor and did not meet design standards known at the time they were designed. At 3 other sites (Metro, SX0-D6, Clinton Road), the design appears inadequate for the influent AMD, though at SX0-D6 the problem was insufficient space. At 2 sites (Avery, Klondike), problems during construction appear to have degraded system performance. Three sites (AMD & Art, Metro, Webster) have lacked maintenance that would have greatly improved their performance, and at 2 others (Avery, Yellow Creek 2A) the maintenance has been inadequate. At 6 systems (DeSale 1, Kalp, Yellow Cr. 2A, Bear Rock Run, Robbins, McKinley), the sample sites in the DEP survey did not represent the system performance or the use of a net acid failure criterion gave misleading results. At 2 sites (AMD &Art, Harbison-Walker 2), sampling is either lacking or inadequate.

4. At 11 of the 18 “failed” sites, the treatment systems removed 89 to 100% of the influent acidity in the 2008-13 period, and at most, the remaining acidity was Mn acidity which is not a serious problem. Two systems (Metro, Webster), both poorly designed for their influent AMD, accomplished very little treatment. Three systems (Klondike, Cessna, Robbins) removed moderate (69-73%) proportions of the influent acidity and at one (Avery) data is ambiguous on performance. Thus, although the systems were designated as “failures”, more than half performed reasonably at removing acidity.

5. At 5 “failing” sites (DeSale 1, Finleyville, LR0-D2, SX0-D6, Robbins), the receiving streams

have essentially recovered and have fish because of the effectiveness of the investigated systems plus one or more other systems in the watershed. These streams are being considered for removal from the 303d list. At 2 other sites (MR Frog, Bear Rock Run), the stream appears to be largely recovered. Although an individual system may release slightly acidic water, the combined effects of several treatment systems in a watershed can lead to stream recovery.

6. The cost of acidity removal by passive systems, based on several studies and models, is generally less than the cost of removal by active systems. Most of the passive systems remove acidity for less than \$1000/ton (as $CaCO_3$). The median cost for the systems of this study is \$702/metric ton of acidity removed. Four systems with small flow have higher costs, but would be high for active systems also. In contrast, costs using lime or caustic are \$1200/ton and higher. Thus, treatment by passive systems that are well designed and constructed, and are well maintained is considerably less than the alternative. Also, active systems are not perfect and sometimes release water exceeding discharge standards. Another problem is funding of active systems – several State active treatment plants have been abandoned for lack of funds.

7. It is recommended that the State continue to provide funding for construction and maintenance of passive systems but oversight should be considerably improved to ensure good designs and preserve the value of the systems. Watershed Managers should be supported full time to monitor and coordinate treatment systems, and DEP staff should greatly increase their expertise in evaluation of passive systems so that proposals for passive treatment systems have adequate designs. Funding for repairs and renovations of passive systems, as by TAG grants and Quick Response programs, should continue and be improved. In this way, the state will spend funds for AMD treatment in the most effective manner.

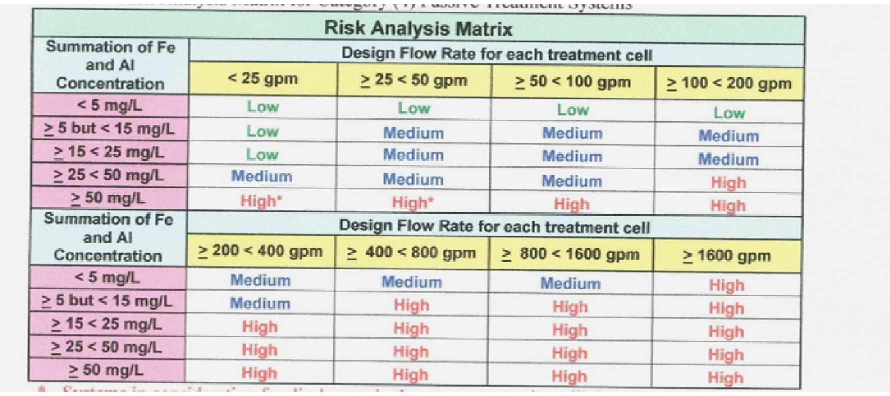
8. The negative points in the DEP evaluation scheme for ranking passive treatment proposals should be eliminated or greatly reduced. This evaluation plan makes it almost impossible to fund treatment for discharges in the High Risk category. Instead, the DEP should carefully evaluate proposals and should conduct continuous oversight to ensure that successful systems are built and are maintained. The successful systems discussed here show that passive systems can be successful on even very acidic and metal-rich water.

Introduction

In 2009-10, the BAMR of PA Department of Environmental Protection (DEP) conducted an evaluation of passive treatment systems for acid mine drainage (AMD). The goal was to obtain data on which to base future plans and funding for remediation of mine drainage discharges treating acid AMD containing appreciable ferric Fe or Al. An incentive for the study was the failure of many passive systems to completely treat their influent AMD. Previous work had developed a “Risk Matrix” for evaluating passive systems of this type, and it was desired to further evaluate this matrix. Systems were classified as High, Medium or Low Risk depending on a combination of flow rate and sum of Fe and Al concentrations in the influent (Figure 1). High Risk systems were assigned large negative points in the evaluation system (BAMR, 2009). This evaluation system made funding for High Risk discharges nearly impossible to obtain from AML sources.

The study covered about 150 passive treatment sites in Pennsylvania that had been built by public funds, such as Growing Greener or EPA 319. Sites were sampled on 2 dates, once in a low flow period in fall 2009 and once in a higher flow period in spring 2010. As a simple criterion, the sites were considered “failures” if the hot peroxide acidity of the effluent at either sampling date was positive.

Figure 1. DEP Risk Analysis Matrix (2009)



Risk Analysis Matrix

Summation of Fe and Al Concentration	Design Flow Rate for each treatment cell			
	< 25 gpm	≥ 25 < 50 gpm	≥ 50 < 100 gpm	≥ 100 < 200 gpm
< 5 mg/L	Low	Low	Low	Low
≥ 5 but < 15 mg/L	Low	Medium	Medium	Medium
≥ 15 < 25 mg/L	Low	Medium	Medium	Medium
≥ 25 < 50 mg/L	Medium	Medium	Medium	High
≥ 50 mg/L	High*	High*	High	High
Summation of Fe and Al Concentration	**Design Flow Rate for each treatment cell**			
	≥ 200 < 400 gpm	≥ 400 < 800 gpm	≥ 800 < 1600 gpm	≥ 1600 gpm
< 5 mg/L	Medium	Medium	Medium	High
≥ 5 but < 15 mg/L	Medium	High	High	High
≥ 15 < 25 mg/L	High	High	High	High
≥ 25 < 50 mg/L	High	High	High	High
≥ 50 mg/L	High	High	High	High

Table 1. Numbers of Alkaline and Acid Sites in DEP 2009-10 Study									
				All years	**Post-2004**				**Pre-2004**
Risk Level	**Total**	**Pre-2004**	**Post-2004**	**% "Failure'**	**Acid**	**Alkaline**	**Uncertain**	**% "Failure'**	**%"Failure"**
High	53	30	23	52	9	12	2	39	67
Medium	45	28	17	40	7	10	0	41	39
Low	39	15	24	26	6	16	2	25	27
"Failure" = positive effluent acidity									

A tabular summary of the results as evaluated by the committee is listed in Appendix A. Table 1 summarizes the results of the DEP study. According to the criterion of net alkalinity, about 52% of the High Risk systems were said to have “failed”, and about 40% of the Medium and 26% of the Low Risk systems “failed”. This level of “failure” was surprising and shocking, considering that numerous successful systems were known, and was the incentive for this further study. The high proportion of failures is particularly surprising in the Medium and Low Risk categories, and suggests serious problems in applying the concepts underlying passive treatment technology.

Examination of the data for different time periods shows that the High Risk systems built before 2004 have a much higher failure rate of 67%. Part of this difference is perhaps due to deterioration with increasing age, but some is certainly due to use of incorrect sizing criteria prior to about 2003. Rose and Dietz (2002) showed that the 12-20 hr. retention time guideline used for most systems up to that date was inadequate for many systems, and that an areal acidity loading of 25-40 $g/m^2/d$ gave much better results. Rose (2006) showed that many of the older failed systems were too small based on acidity loading. If only systems built in 2004 and later are considered, only 39% of High Risk systems "failed", as did lower percentages of Medium and Low Risk systems.

Nevertheless, the very significant level of poor performance is discouraging, and leads to the question as to why so many systems are unsuccessful, and what can be done to improve the passive treatment technology.

In this study, a group of about 25 sites was chosen for more detailed investigation. The goal was to gain a better understanding of the causes for "failure" vs. success. The approach is to investigate "failed" systems to identify the cause of "failure" and to identify key factors in successful systems.

Selection of Systems for Study

The systems for study were chosen mainly from the list of 150 studied systems, based on the following guidelines:

1. Ten High Risk Failures, 5 Medium Risk Failures and 5 Low Risk Failures were sought.

2. Five High and Medium Risk Successes were selected to compare design and construction features with the failures.

3. Most of the chosen "failing" systems were from those constructed after 2003, on the basis that Rose and Dietz (2002) showed that the previous sizing guideline for vertical flow ponds (12-20 hrs. retention time in limestone) was not relevant, and that an areal acidity loading of 35-40 $g/m^2/d$ gave much better results. Systems less than about 5 years old were also avoided because of a short history.

4. Some attempt was made to include systems with Limestone Ponds and Bioreactors as well as Vertical Flow Ponds.

5. Systems were all from the bituminous districts, because the characteristics of very high high flow and much lower metal concentrations in the anthracite region seemed to complicate understanding.

The systems were chosen largely randomly from the group fitting the above characteristics, though with some attempt to select sites with a wide distribution in geography and designer. Some systems were rejected because there did not seem to be enough information available. The DeSale 1, Harbison-Walker 2 and McKinley systems, constructed before 2003, were included because they were thought to have been performing generally well, yet turned up on the “failure” list.

Table 2 lists the chosen systems. Only 4 Medium Risk and 4 Low Risk systems seemed to have good information and characteristics for study. The location of the sites is shown on a map of the state (Figure 2).

Some Definitions and Concepts

The following discusses some terms and concepts used in this report.

Acidity and Alkalinity The Acidity data used here are all hot peroxide acidity values as specified by the PA DEP for mine drainage studies (APHA 1998; USEPA, 1979). Negative acidity values are used rather than reporting zero if the contribution from the initial titration down to pH 4 exceeds the acidity titration to pH 8.2. All acidity concentrations are in mg/L of $CaCO_3$, though for brevity $CaCO_3$ is not stated in the tables. A positive acidity is “net acid”, and a negative acidity is “net alkaline”. This relation

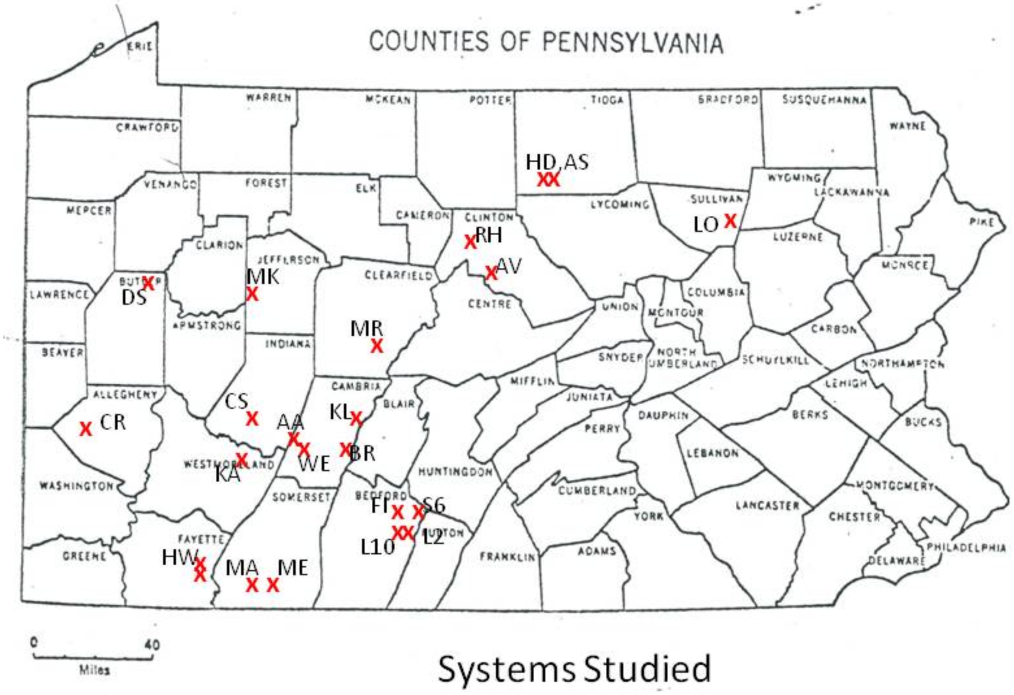


Figure 2. Location of passive systems studied. AA=AMD&Art, AS= Anna S, AV=Avery, BR=Bear Rock Run, CR=Clinton Road, CS=Cessna Run, DS=DeSale 1, FI=Finleyville, HD=Hunters Drift, HW=Harbison-Walker 1 & 2, KA=Kalp, KL=Klondike-1, LO=Loyalsock, L2=LR0-D2, L10=LR0D10, MA=Maust, ME=Metro, MK=McKinley, MR=MR Frog, RH=Robbins Hollow, WE=Webster.

Table 2. Sites Selected for Evaluation

High Risk-Failure				
Site	County	Built	Effluent	Types
YELLOW CREEK 2A BIO RE	Indiana	2002	Acid	Bioreactor
WEBSTER	Cambria	2004	Acid	2 VFP's
Finleyville	Bedford	2005	Acid	4 Ls beds, flushers
Kalp Discharge	Fayette	2007	Acid	Ls bed, 2 VFP's
Klondike KL-1	Cambria	2007	Acid	VFP
Avery Big Run	Centre	2005	Acid?	Ls bed, VFP
AMD & Art	Cambria	2004	Acid	Anoxic wetlands, VFP
Harbison Walker II	Fayette	2000	Acid	VFP's, LS beds, Wetlands
DeSale I	Butler	2000	Acid	2 VFP's, HFLB
Metro	Somerset	2003	Acid	2 VFP's
High Risk-Success				
Hunters Drift	Tioga	2004	Alk	4 VFP's
Maust	Somerset	1998	Alk	2 VFP's
Anna S	Tioga	2004	Alk	4 VFP's
Loyalsock C Vein #3	Sullivan	2005	Alk	1 VFP
Harbison Walker I	Fayette	1999	Alk	ALD, VFP
Medium Risk-Failure				
Longs Run LRO-D2	Bedford	2005	Acid	Upflow Ls bed, siphon
MR FrOG B	Clearfield	2008	Acid	Ls bed
Six Mile Run SXO-D6	Bedford	2008	Acid	VFP with siphon
Clinton Road	Allegheny	2004	Acid	2 VFP's
Low Risk -Failure				
Cessna Run	Indiana	2005	Acid?	2 upflow Ls beds
Robbins	Clinton	2005	Acid	2 Limestone beds
Bear Rock Run	Cambria	2009	Acid?	HFLB and wetland
McKinley	Jefferson	1996	Acid	VFP

reflects the fact the hot peroxide acidity procedure includes an initial step of titration down to pH 4 that amounts to an alkalinity titration; this initial "alkalinity" is then subtracted from the following acidity results to obtain the reported acidity value. Alkalinity is usually a lab measurement but may be a field measurement, and involves titration down to pH 4.5 or 4. Net acidity and alkalinity are <u>not</u> determined as the difference of acidity and alkalinity, in contrast to some state regulations.

<u>Metal concentrations</u> The reported metal concentrations are nearly all total concentrations, and may include some suspended Fe, Mn or Al precipitate.

<u>Vertical Flow Pond</u> A Vertical Flow Pond is a pond with a layer of limestone fragments in the

bottom, overlain by an organic layer of compost and other materials, and then by water (Figure 3). An underdrain of perforated pipes lies in the limestone layer and allows AMD to flow down through the compost and limestone layers, and then out through the underdrain and a standpipe or water level control unit at a level slightly below the water level in the pond. The organic matter reduces the oxidation state of the AMD, removing O_2 and converting ferric iron to ferrous iron and possibly some SO_4 to H_2S, generating some alkalinity in the process. The limestone then acts to neutralize the remaining acidity and provide net alkalinity. This type is also called a SAPS (Successive Alkalinity Producing System) or a Vertical Flow Wetland. The Vertical Flow Pond may be flushable (see below).

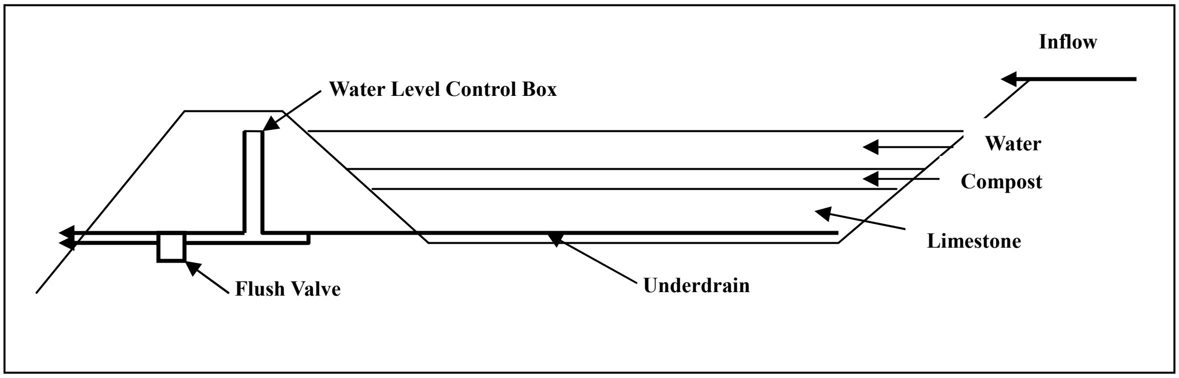


Figure 3. Diagram of Vertical Flow Pond.

<u>Bioreactor</u> A bioreactor is similar to a Vertical Flow Pond except that the limestone and compost are mixed into a single thick layer, possibly underlain by a thinner layer of limestone or sandstone containing the underdrain. This design appears to function better with high-Al AMD.

<u>Limestone Pond or Limestone Bed</u> This type of system is composed completely of limestone fragments. The AMD may flow in at the surface of the bed and out the bottom (downflow type) or flow in at the bottom of the bed (upflow type) and overflow from the top. Most limestone beds are flushable. An additional type of limestone bed is a Horizontal Flow Limestone Bed (HFLB), usually used to remove Mn after Fe and Al have been removed.

<u>Flushable system</u> Several types of flushing are possible. The purpose of flushing is to remove the accumulated Al and perhaps Fe precipitate that has accumulated in the limestone and possibly in the compost layers. The flushing may be manual, in which a large valve is manually opened on the underdrain every month or so. Tests indicate that manual flushing removes only 5% or less of the accumulating Al precipitate and is not very effective. A second technology is a siphon, which flushes when the water level in the limestone bed or pond reaches a maximum level, and flushes the system down several feet until the siphon breaks, flushing out precipitate from the limestone bed in the process. A

third method is an automatic flushing system (Agridrain), which uses a small computer and a solar cell to time the opening of a large valve on the underdrain. Initial manual flushing systems were typically flushed only an hour or less, until obvious suspended material diminished. Some recent systems flush a limestone bed all the way to the bottom, to clean the entire limestone layer (Weaver et al., 2004).

Methods of Investigation and Data Sources

In general, the intent has been to acquire all the information that can be easily obtained on the sites. A primary source of information has been the Datashed website www.datashed.org. This database has provided information on location, date of construction, designer, responsible local group, current contacts, maps and diagrams of the system, sample points, water sampling data, reports on the system and other information. The website includes much data from sampling by the state, as well as by local groups. At most sites it includes the 2009 and 2010 sampling for the DEP survey. When the current project was first considered, there appeared to be major gaps in the data in Datashed, but that was almost completely remedied by the time work started seriously. This website is the source of much of the information listed on the SUMMARY SHEET for each project, as found in Appendix B.

Nearly all sites were visited during the project, between May and September 2013. DeSale 1 and McKinley were not visited during the study, but had been visited previously. Avery was not visited but is the subject of a recent report by Hedin Environmental.

At each site, the various ponds and other treatment units were inspected, field measurements of flow, pH, alkalinity, temperature, specific conductance and other water measurements were made at numerous points, and samples were collected for lab analysis from several points in the system. The samples were submitted and analyzed in the DEP labs for a suite of mine drainage parameters: pH, hot acidity, alkalinity, total Fe, Mn Al, SO_4, ferrous iron, total dissolved solids, and total suspended sediment. Flow was measured at previously installed weirs or with a bucket and stop watch method. At some sites it was difficult to obtain a good flow value, and more emphasis should be placed in designing systems so that flow can be easily measured at several locations.

For most sites, the local group was contacted and the site discussed with them, and with the engineer designing the site. Aspects of the design, problems, maintenance and operation were discussed with these people.

For each system, a SUMMARY SHEET was prepared with basic data on the 23 systems, including average influent and effluent water chemistry for the period 2008-2013 (Appendix B). Also in this Appendix are a short DESCRIPTION and discussion of the system and of its problems and crucial features, as well as a map of the system and its sample points, and the water quality data for the period 2008-2013. The 2008-13 period was considered to represent the medium-term functioning of the system.

In a few cases, the system can be classified as a success from the 2008-13 data, but one of the 2009-10 effluents was acid, so the classifications differ.

Discussion of Systems

Tables 3, 4 and 5 summarize evaluation of the "failed" systems. Table 3 highlights sources of problems at sites and rates overall performance and maintenance.

Table 3	Summary of Characteristics and Problems						
System	**Design**	**Constr.**	**Maint.**	**Sampling**	**Perform. (%*)**	**Stream**	**Type**
AMD & Art	**Poor**		**Lacking**	**Lacking**	**Unclear (??)**		AW,VFP
Avery		**Problems**	**Inadeq.**		**Unclear (100?)**		LS,VFP
DeSale 1			Good	**Misleading**	**Good (99)**	**Recov.**	VFP,HFLB
Finleyville			Good		**Good (91)**	**Recov.**	LS,VFP
Harb-Walk. 2			Fair	**Lacking?**	**Poor (??)**		VFP, LS
Kalp			Good	**Misleading**	**Good (100?)**	?	LS,VFP
Klondike 1		**Problems**	Good		**Fair (73)**		VFP
Metro	**Inadeq.**		**Lacking**		**Poor (18)**		VFP
Webster	**Poor**		**Lacking**		**Poor (37)**		VFP
Yellow Cr.			**Inadeq.**	**Misleading**	**Fair (100)**		Bio
Long Run LR0D2	Unclear		Good		**Unclear (92?)**	**Recov.?**	LS
Six Mile SX0D6			Good		**Fair (92)**	**Recov.?**	VFP
MR Frog	Unclear	Unclear	**Unclear**		**Fair (100?)**	**Recov.?**	LS. AW?
Clinton Road	**Inadeq.**		Fair		**Fair (100?)**		LS
Cessna Run			Fair		**Good (69)**	?	LS
Robbins			Good	**Misleading**	**Good (70)**	**Recov**	LS
Bear Rock Run			Fair	**Misleading**	**Good (100)**	**Recov**	LS
McKinley			Good	**Misleading**	**Good (89)**	**?**	VFP
*% acidity removal 2008-13							
BIO, bioreactor; VFP, vertical flow pond; AW, anoxic wetland; LS, limestone bed;							
	HFLB, horizontal flow limestone bed						

Table 4 summarizes available data on influent and effluent water chemistry. Note that for some systems, very little data exists for the period 2008-13. Also, some systems include two or more units, which are shown as weighted averages in this compilation. The data is derived from the more detailed compilations in Appendix B.

Table 5 briefly describes problems and accomplishments at the systems.

The writer had previously evaluated about 30 other passive treatment systems, and it was intended that some of these would be re-studied and discussed in this report, but time has not allowed this. The previous studies are discussed in Rose and Dietz (2002), Rose (2004), Rose (2006), and other papers.

Based on this information and that in Appendix B, the various types of problems degrading the performance of the systems are discussed.

Table 4.	Average chemistry of inflow and outflow of systems														
		Inflow						Outflow							
Site	Flow	pH	Acidity	Alkal.	Fe	Mn	Al	pH	Acidity	Alkal.	Fe	Mn	Al	N	Built
	gal/min		mg/L	mg/L	mg/L	mg/L	mg/L		mg/L	mg/L	mg/L	mg/L	mg/L		
High Risk "Failures"															
AMD & Art	210	3.3	352	0	17	2.2	31	6.6	-38	111	46	5.6	2.5	1	2004
Avery	190	2.9	355	0	40	66	19	7.2	-76	102	22	18	0.2	3	2004
DeSale 1	31	4	250	0	80	48	11	6.5	3	32	0.8	26	0.5	9	2000
Finleyville	303	3.1	149	0	2.5	1.6	14.5	5.2	14	10	0.5	0.8	4.6	7	2005
Klondike KL-1	24	3	357	0	120	37	2	3.8	98	0	13	28	1.3	60	2007
Harbison Walker 2	35	3.4	373	0	1.9	28	70	6.2	-96	30	2	23	2	1	2000
Kalp	460	3.1	164	0	22	1.8	10	6.3	-8.1	24	0.9	1.8	1.5	25	2007
Metro	53	3	629	0	120	18	49	2.8	516	0	60	38	38	3	2003
Webster	480	2.8	326	0	23	4.8	34	3.4	206	1	13	5	25	35	2004
Yellow Creek 2A	12	2.8	451	0	40	3.8	43	6.9	-192	228	7	2.7	1.1	21	2004/09
Low (L) and Med.(M) Risk "Failure"															
Bear Rock Run(L)	33	4.9	8		2.2	0.5	0.4	6.2	-14	11	0.2	0.4	0.2	3	1998
Cessna Run (L)	111	3.8	70	0	1	17	4	5.2	29	8	3	10	2.1	8	2005
Clinton Road (M)	27	2.9	423	0	8	8	47	5.3	-87	144	41	13	4	1	2006
Long Run LR0-D2 (M)	30	3.8	142	0	13	1.7	11	4.6	12	2	0.9	0.9	1.3	1	2005
McKinley 1 (L)	15	3.9	81	0	0.5	34	3.4	6.3	9	29	1.2	16	1.9	3	1996
MR Frog (M)	86	3.7	44	0	0.5	3.1	3.7	7.2	-68	94	0.9	0.4	0.4	3	2008
Robbins Hollow (L)	11	3.5	126	0	0.3	1.7	20	5.3	39	12	12	5	6	7	2005
Six Mile Run SX0-D6 (M)	23	3.1	366	0	51	2.5	32	5.3	29	8	3.4	1.8	3.2	5	2008
Successes															
Anna S (H)	203	3.3	113	0	5.1	7.7	10.4	7.3	-99	120	1.2	2.9	0.3	13	2004
Hunters Drift (H)	208	2.8	349	0	37	7	37	7.2	-95	116	0.4	2.7	0.2	15	2004
Harbison Walker 1 (H)	14	4.5	177	1	89	20	0	7.2	-12	27	0.2	8	0	3	1999
Longs Run LR0-D10	20	3.2	442	0	145	5.4	10.1	6.7	-61	104	6.6	3.3	0.3	3	2005
Loyalsock (M)	350	3.8	31		0.6	1	2.3	7.8	-46	55	0.3	0.8	0.3	6	1999
Maust	15	3.2	124	0	42	13	1.9	7.1	-54	69	0.2	2.8	0.1	11	1998

Systems with Design Problems

For 3 systems, the design of the system appears to be a major source of poor performance. The Webster system receives a very large flow (480 gal/min) of high-Al AMD (34 mg/L). The system was designed as two simple VFP's with no obvious provision for handling the very high Al. No real provision for flushing appears to have been incorporated, and no arrangements for routine flushing were made. Within 2 years the effluent was net acid, and after about 5 years the system ceased to treat significantly. Most water is now overflowing the two VFP's, rather than flowing thru them for treatment.

There is no indication that the compost contained limestone, which might have improved the performance. The system is inferred to be largely plugged with Al precipitate.

The sizing parameters for the AMD and Art system are unknown, but the single VFP is woefully undersized for the loading, which may be as high as 400 $g/m^2/d$. Probably the action of 3 anaerobic wetlands was assumed to handle much of the loading. The system has also suffered from almost complete lack of maintenance, leading to a blockage and breakage of the inflow system for several years.

The Harbison-Walker 2 system has at least 4 inflows, and does not seem to be designed for long-term treatment of these high-Al AMD discharges. Part of the time the system has successfully treated some of the discharges, but handling of the high Al in the AC discharges and treatment of the remaining discharges has been incomplete. Maintenance has also been inadequate.

Two other systems appear to have significant inadequacies in design. At Metro, the extremely high Al (49 mg/L) apparently was planned to be handled by flushing and recovery of the Al precipitate, but the mechanism for accomplishing this is unclear, and it was never implemented by the local group, the Southern Alleghenies Conservancy. At Clinton Road, two simple VFP's were built for Al-rich AMD (47 mg/L), but the systems do not capture a lot of the AMD in the small valley, and they were not flushed so are now partly plugged with Al and Fe precipitate. The plan was apparently to renovate the systems after about 7 years, but this has been only partially successful.

Systems with Construction Problems

The high-Fe Klondike KL1 system appears to suffer from compaction of the compost layer by equipment during construction and during rehab events. At flow rates more than about 20 gal/min, the system overflows. The compaction was caused by running tracked and wheeled vehicles over the compost. The result is short circuiting thru the non-compacted portion of the system. Plans are underway to remove the existing compost, rip the underlying limestone, and replace with new compost.

At Avery, considerable water flowed into the excavations during construction, resulting in placing lining in some ponds, but apparently the modifications were inadequate, and there is extensive subsurface flow of AMD beneath and around the system. Also, neither of the siphons at the site is operating properly. One is thought to have lost the air in the siphon owing to infrequent operation, and at the other, the underdrain leading to it is apparently too small to allow the siphon the operate long enough to draw down the water level before breaking the siphon.

Few details are available for MR Frog, but flushing and treatment at one of the two systems are inadequate, possibly because of leakage. The other system at the site is working well.

Maintenance Problems

Maintenance includes routine inspections and water sampling, flushing if required, and small to moderate rehab work if needed. At some sites, the maintenance has been excellent and has contributed to good performance of the systems. In Broad Top Township in Bedford County (Finleyville, SX0-D6, LR0-D2, LR0-D10), the township has consistently inspected and maintained their systems, and conducted repairs and modifications where needed. For example, it was found that in upflow limestone beds at several systems, if the perforated pipes of the inflow system were connected directly to the flushing pipes, the flush removed mainly water that was little treated. The underdrains were exposed and disconnected. Limestone in several beds was cleaned after a few years of service.

At Robbins Hollow, performance was monitored and one system was rebuilt because of poor performance. At Kalp, declining performance has led the local group to initiate repairs and rehab. At Klondike, several modifications to the system have been made or are underway. Most of the other systems studied have had some inspection and minor repairs. The Technical Assistance Grants (TAG) and Quick Response Programs have been crucial contributors to needed activities.

At several systems, lack of maintenance has been a source of significant problems. As noted, at Metro, no flushing or other work was done on a very high Al system. The Southern Alleghenies Conservancy is apparently the nominal local group, but has never been active in the required maintenance. At AMD & Art, the inflow grate was plugged with leaves, and the exposed inflow pipe was broken (by shooting?) for several years, so that no water reached the treatment system. The village of Vintondale was supposed to do maintenance. When visited in 2013, we encountered by accident two high school students who had repaired the blockage and pipe problems on their own, and re-started treatment. At Yellow Creek, a broken valve is apparently preventing flow to the 2B system. At Avery, the state, who designed and constructed the system, apparently has not recognized the need for renovations, and the local watershed group is no longer allowed into the site by the property owner.

Table 5. SUMMARY OF CAUSES FOR "FAILURE"

High Risk Systems

AMD & Art Maintenance and sampling have been lacking for many years. The inflow was blocked and broken for several years. A sample for this study suggests that the system may be capable of generating net alkaline water, though the VFP is considerably undersized.

Avery Much water flows under and around the system rather than through it, and neither siphon works properly, so that much acid and metal-rich water reaches the final HFLB. However, the final outflow (RDOUT) is net alkaline, for reasons that are not clear.

DeSale 1 After 13 years, this system removes essentially all Fe and Al and produces net alkaline water much of the time, or has mainly Mn acidity. The receiving streams have largely recovered and have fish. This system is erroneously classified as "failure".

Finleyville This system removes about 90% of acidity and 75% of Al from a large flow, and along with numerous other systems, greatly improves downstream conditions, to the point that it is close to removal from the 303d list. Modifications to improve performance are proposed.

Klondike KL-1 The system has removed about 75% of 400 mg/L acidity and 90% of 120 mg/L Fe. The problem appears to be short circuiting caused by compaction of compost by driving on it during construction. The compost will be replaced in 2013-14.

Harbison-Walker 2 This complex system with 4 high-Al discharges has apparently released net acid water from 2 of its discharges most of its history. The system does not seem to have been designed or maintained for its high-Al inflow.

Kalp The system has generated net alkaline effluent from 2007 to 2012, but recently has deteriorated, probably because of plugging the upflow limestone bed. Additional seepage into the final wetland appears to have been a cause for net acid final outflow in the DEP study. Rehab is underway.

Metro This High-Al system was not flushed by the local group and is accomplishing almost no treatment.

Webster This High-Al system was not designed to handle the Al, and has largely plugged, so that little treatment is being accomplished.

Yellow Creek 2A The Yellow Creek 2A system is generating net alkaline water, but lack of maintenance on the associated 2B system results in the combined outflow being acid.

Medium and Low Risk Systems

Bear Rock Run The single net acidic result for this system is probably in error, because calculated acidity from Fe, Mn, Al, pH and alkalinity shows negative acidity. The receiving stream appears to have recovered.

Cessna Run The system removes only about half the acidity from slightly acid inflow. However Cessna Run downstream appears OK.

Clinton Run The two VFP's partially treat part of the Al-rich AMD originating in this small watershed. The VFP's should be flushed to remove the accumulated precipitate, and have become partially plugged.

Long Run LR0-D2 The flow is small and intermittent. The system may leak so that the siphon rarely operates. The receiving stream is essentially recovered because of this and 12 other passive systems.

McKinley 1 This Low Risk system has generated net alkaline water most of the time for 17 years. Both samples in 2009-10 were net alkaline. The site was erroneously included in the "failure" list, possibly because of confusion with McKinley 2. It does need some rehab.

MR Frog Of the 2 systems at this site, System A with a flushed limestone pond generates net alkaline water. System B only partially treats a second small discharge, possibly because of leakage. Little information is available.

Robbins Hollow EB 10/15 The site contains 2 small discharges, of which the system treats EB10 to alkalinity, but the mixture with EB15 is slightly acid. However, 3 other nearby systems in the vicinity provide enough alkalinity that the Robbins Hollow stream is net alkaline.

Six Mile Run SX0-D6 This system treats more than 90% of the acidity in this discharge, and is as large as the site can accommodate. The stream has largely recovered and is being tested for removal from the 303d list.

Misleading Sampling

At several systems, misleading samples or erroneous analyses are responsible for the designation of "Failure". At Bear Rock Run, reported acidities of +6 and +8 in the 2009-10 effluent led to inclusion in the failure list. However, acidities calculated from pH, Fe, Mn, Al and alkalinity are both negative (-18 and -8), as is the sample taken for this study. Either the acidities or the metal, alkalinity and pH values are in error. This is a successful system.

At Yellow Creek and Robbins EB10/15, the collected samples are misleading because of multiple flows to the sample point. The effluent of Yellow Creek 2A is strongly net alkaline, but its effluent mixes with flow from 2B and possibly other sources, and the combined flow, currently untreated, is net acid. At the Robbins site, discharge 10 is treated satisfactorily, and mixes with untreated discharge 15, so that the combination is acid. However, the Robbins Hollow stream is net alkaline because of the alkalinity from 2 other nearby systems.

At McKinley 1, both the 2009-10 samples show net alkaline discharge, as do most previous samples. In the slightly acid samples on other dates, the remaining acidity is mainly from Mn. Possibly the McKinley 1 and 2 sites were confused in classifying the sites.

At Desale 1, the effluent from the HFLB is nearly always net alkaline, and any remaining acidity is mainly from Mn. Seaton Creek, the receiving stream, has recovered except for Mn values, and has fish for the first time in years.

Capture of Influent AMD and Leakage

A significant problem at several sites is incomplete capture of the AMD. These are typically discharges from surface mining in which the AMD seeps out at numerous spots. At Robbins, the EB10/15 system captures and treats the EB10 site but not the EB15 discharge, though the combined treatment of the 4 systems in Robbins Hollow releases net alkaline water to the stream. At AMD and Art, it appears that a second discharge adjacent to the treatment ponds is not treated and is responsible for some acid effluent. At Yellow Creek, part of the discharge is captured and piped to the 2A and 2B treatment systems, but it appears that much additional AMD is not being treated, and flows as a small stream into Yellow Creek. At the Clinton Road site, it appears that much of the AMD in the small valley seeps into the small stream and is not treated. At Kalp, the acidic result at the final wetland outflow appears to result from seeps that are not captured by the inflow system. At Avery, considerable AMD evidently flows under and around the treatment system. Water flowed into the excavations so the ponds were lined, but the liner was punctured to ameliorate up-bulging, so probably the ponds are leaking. At Harbison-Walker 2, the system has treated several of the 4 discharges part of the time, but not all of them. At MR Frog, one discharge is treated well, but the other smaller one does not seem to be flowing properly through the treatment ponds, and may be leaking.

At some of the above sites, such as Kalp, Avery and MR Frog, part of the problem may be leakage from the treatment ponds. Leakage appears to be a significant factor at Long Run LR0-D2. Other sites are known for which leakage turned out to be a problem.

Performance of Limestone Beds

Nine of the systems contain limestone beds as major parts of their treatment system (Avery, Finleyville, Harbison-Walker 2, Kalp, LR0-D2, MR Frog, Cessna, Robbins, Bear Rock Run). Several have multiple limestone beds. It was intended to evaluate the performance of the limestone beds in terms of design, especially sizing. However, the chemistry and flow records of essentially all these systems are incomplete, and it was concluded that useful results could not be obtained with the available data. In particular, flow data is lacking for many of the limestone bed systems, and amounts of limestone are not available for some. The lack of flow data is partly because most of these systems have flushing devices, and the flow is not uniform.

As a crude generalization, the data indicate that flushable limestone beds remove significant amounts of acidity and metals, but most apparently do not completely treat water to discharge standards.

A more detailed study of treatment by limestone beds is needed.

Performance of Treatment Systems

In Table 3, the percentage removal of acidity is listed, calculated from the 2008-13 averages in Table 4. As indicated by these results, 5 of the 23 systems have averaged 100% removal in the samples since 2008 (but only 1 to 3 samples for many), and 5 more systems have removed 89% or more of the acidity. Two sites (Metro and Webster) are very low in removal and can clearly be classed as failures. Three are in the 69 to 80% range and are doing considerable treatment but are disappointing and need modification. For three, good data are lacking.

Thus, of the 18 supposedly “failing” systems, 10 of the failures have removed 89% or more of the influent acidity, and 5 appear to have removed 100% of the influent acidity. Thus, I cannot consider them as failures.

Stream Recovery

The ultimate goal is recovery of the receiving streams to normal biota including fish. A watershed overview is preferable to focus on individual systems.

Seven receiving streams have essentially recovered as a result of the passive treatment systems. Bear Rock Run appears to have been restored for many years. Streams in the Broad Top area are largely recovered and are being studied for removal from the 303d list, after construction of more than a dozen passive systems including Finleyville, LR0D2, and SX0D6. Seaton Run and Slippery Rock Creek are largely recovered and have fish in many places as a result of the DeSale systems and others. Morgan Run is reported to have recovered in some sections as a result of MR Frog and several other systems. Upper Robbins Hollow Run is net alkaline as a result of the EB10/15 and other systems, and Middle Branch and Kettle Creek into which it runs is mostly recovered. Receiving streams at several other sites (Cessna Run, Kalp) appear to be in relatively good condition, or at least are significantly improved. The Klondike KL1 system flows into Little Laurel Run which is the focus of a Restoration Plan involving 4 other systems under design and construction.

Based on the above information, seven of the "failing" systems systems have brought their receiving streams back from degradation by AMD, and others will probably do so when the remaining discharges in the watershed are treated as part of ongoing plans. Also, it does not appear that perfect treatment is necessary for stream recovery. Evidence indicates that low Mn contents are not deleterious to biota, and many normal streams are slightly acid, such as pH near 5. More research is need on the practical limits allowing good recovery of stream biota.

Successful Treatment of High Risk AMD Discharges

Five net alkaline sites were sought from the High Risk category for comparison with the "failures". The sites chosen were Hunters Drift, Anna S, Maust, Harbison Walker 1 and Loyalsock C Vein. As it turns out, Maust and Loyalsock systems were funded by coal operators rather than public funds. Also, these two probably fit the Medium Risk category rather than the High Risk, but when chosen were thought to be High Risk. However, all have been successful in releasing net alkaline water for an extended period.

Another High Risk Success is worth including, namely LR0-D10 in the Broad Top area. I was shown this site while visiting other sites in the area. The preconstruction flow and chemistry clearly fall in the High Risk category (Fe 145 mg/L, Al 10 mg/L). The flow enters the system in two places, and the worst one cannot now be sampled, but very high acidities are recorded in parts of the system, indicating that it is still entering. The system, composed of 2 limestone ponds and a VFP, discharges net alkaline water.

Table 4 lists the average inflow and outflow chemistry for 2008-13 for the successful systems. Four are High Risk influent and 2 are Medium Risk influent. The 2 Medium Risk systems have been in operation for 14 to 15 years with consistent net alkaline effluents. One High Risk system has been furnishing alkaline effluent for a similar time; the others 3 are 8 to 9 years old.

The Anna S and Hunters Drift systems are simple Vertical Flow Ponds receiving very acid and

Al-rich water. The distinctive design feature of these systems is the addition of about 25% fine limestone in the compost, and close inspection and sampling, which has led to replacement of the compost in 2013. On draining the systems, the compost was found to be thin (originally 1 ft, now less than 6 inches) and poor in organic component with a high residual of partly reacted limestone. At several other systems, the incorporation of fine limestone in compost has been found to be beneficial. Maust is another of the Successes which had limestone added and has been a long-term success (15 years). Another site at Glasgow treating very acidic (acidity 600 mg/L), high Al (50 mg/L) AMD was rebuilt in 2009 with limestone-amended compost, and in 2013 is still successfully treating a flow of 50 gal/min. Several experimental studies using limestone amended compost show superior results (Thomas and Romanek, 2002; Gusek and Wildeman, 2002; Rose, 2004). The added limestone apparently creates high-pH microenvironments on the limestone surfaces and precipitates Al as a coating that grows inward to the limestone fragment, rather than filling pore space and plugging flow.

The Harbison-Walker 1 system has an ALD as the initial unit in a low-Al AMD, but the effluent of the ALD is still acidic and Fe-rich (89 mg/L). This High Risk effluent is then treated by a VFP followed by a HFLB, with net alkaline effluent over 14 years.

The LR0-D10 system treats highly acidic AMD (acidity 440 mg/L) with very high Fe (145 mg/L) and moderate Al using mainly 2 limestone ponds plus a VFP. The system has been treating since 2005. The limestone was cleaned in 2012.

The Loyalsock system is an example of a high-flow system (350 gal/min) successfully treating AMD with low metals (0.6 mg/L Fe, 2.3 mg/L Al). This system has been operating for 14 years.

The success of these systems treating varied but strongly acid water demonstrates that passive systems that are properly designed, constructed and maintained can be successful. All were carefully designed, and most have been well maintained and renovated if necessary.

Economics of Passive Systems

A key question is the cost of treating by passive systems as compared to active systems. This question has been addressed by Ziemkiewicz et al. (2002), Skousen and Ziemkiewicz (2005) and Rose (2006). Rose (2006) estimated the cost per ton of acidity neutralized for a set of 22 passive systems. The cost of constructing each system was estimated by the AMDTreat computer program, and the amount of acidity removed was based on data for the performance of the systems. The median cost per ton of acid neutralized was about $300/T. For 19 of the 22 passive systems, the cost per ton is less than $1000. Three systems that had failed have higher considerably higher costs, and several lower cost systems on the list have since declined in performance or required renovations, but costs for most would be less than $1000/T. Hedin et al. (2010) cite projected 20-year costs of $403-618/ton of acidity for the High Risk

Anna S and Hunders Drift systems, including periodic replacement of the organic layer and other maintenance.

Table 6 shows the costs for the systems of this study. The cost values are the construction costs compiled by DEP and the flow and acidity for 2008-13 compiled for this study. A 20-year life is assumed. The median cost/ton of acidity removed is $702/metric ton. Seven systems have very high costs exceeding $1000/T. Three are failed or very poorly performing systems: Webster ($2086/T), Metro $2066/T) and Harbixon-Walker 2 ($1823/T). Four are relatively successful systems, based on the discussion above: Robbins ($5499/T), Bear Rock Run ($4905/T), Harbison-Walker 1 ($2469/T) and DeSale 1 ($1277/T). The problem for these is the small flow (11,14, 33 and 35 gal/min). An active system for these would also be expensive for such small flows.

For comparison, costs for active systems were estimated by Ziemkiewicz et al. (2002) as $1200-1500/ton for treatment with NaOH. An AMDTreat calculation for a hydrated lime system treating 200 gal/min with 200 mg/L acidity gives a cost of $1300/ton. This data shows clearly that most passive systems have costs that are lower than most active systems, even if renovations are required at a later date.

Another argument given against passive systems is lack of reliability. If an active system is maintained, it is implied that the effluent always meets discharge standards, and the chemical addition rate can be easily modified, whereas passive systems, lacking active maintenance and easy adjustment, are considered unreliable. In my experience this contrast is misleading. Many active systems fail part of the time. At Brubaker Run, the lime system operated by Bender Coal Co. has released acidic metal-rich water on many occasions, and the simple caustic systems of Cooney Bros. sometimes don't operate. At Glasgow, where both active and passive flow paths are present, the active flow path has released water with elevated Mn and Fe on many occasions, whereas the passive system has very consistently released good quality water meeting all the standards, including Mn. A new plant at Blandburg has occasionally released acid water because of temporary problems. At the new plant near Barnesboro, it is understood that the chemistry of influent AMD has changed so the plant is not as efficient as originally designed. For small to medium sized active systems without full time employees, it appears that active treatment systems commonly fail to operate successfully part of the time. Biota in a receiving stream are subject to erratic episodes of toxic water.

Long-term funding of active systems can also be a problem. For example, State systems at Hawk Run, Bennett Branch and elsewhere were built, operated for a few years, then closed down, apparently because of lack of funds. At a passive system, once built, the expenses are minor, but at an active system the major cost of chemicals, maintenance and sludge disposal continues its entire life and can be difficult to fund. Any active plants should be funded with a trust fund that is completely adequate for a 20-25

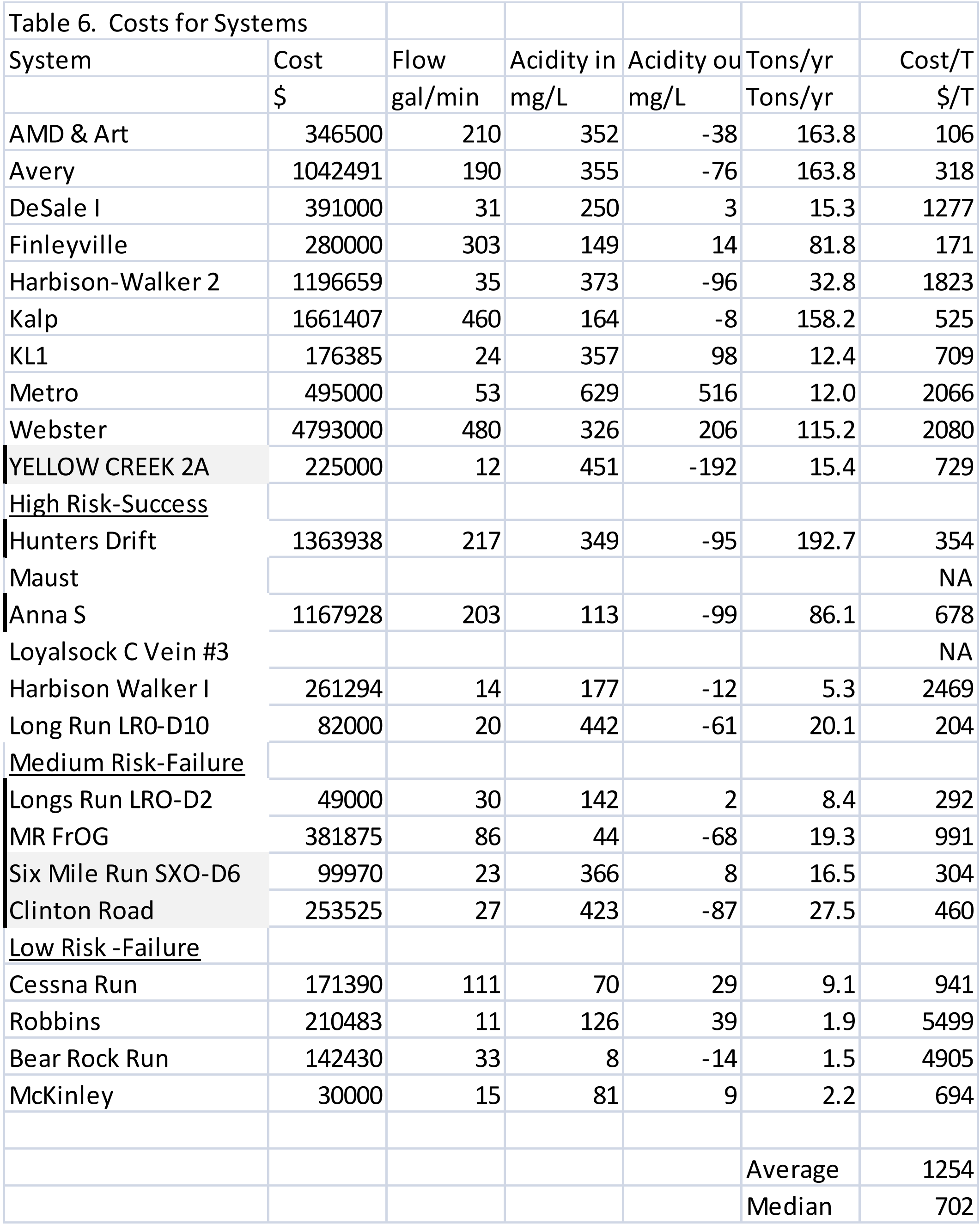


Table 6. Costs for Systems

System	Cost	Flow	Acidity in	Acidity ou	Tons/yr	Cost/T
	$	gal/min	mg/L	mg/L	Tons/yr	$/T
AMD & Art	346500	210	352	-38	163.8	106
Avery	1042491	190	355	-76	163.8	318
DeSale I	391000	31	250	3	15.3	1277
Finleyville	280000	303	149	14	81.8	171
Harbison-Walker 2	1196659	35	373	-96	32.8	1823
Kalp	1661407	460	164	-8	158.2	525
KL1	176385	24	357	98	12.4	709
Metro	495000	53	629	516	12.0	2066
Webster	4793000	480	326	206	115.2	2080
YELLOW CREEK 2A	225000	12	451	-192	15.4	729
High Risk-Success						
Hunters Drift	1363938	217	349	-95	192.7	354
Maust						NA
Anna S	1167928	203	113	-99	86.1	678
Loyalsock C Vein #3						NA
Harbison Walker I	261294	14	177	-12	5.3	2469
Long Run LR0-D10	82000	20	442	-61	20.1	204
Medium Risk-Failure						
Longs Run LRO-D2	49000	30	142	2	8.4	292
MR FrOG	381875	86	44	-68	19.3	991
Six Mile Run SXO-D6	99970	23	366	8	16.5	304
Clinton Road	253525	27	423	-87	27.5	460
Low Risk -Failure						
Cessna Run	171390	111	70	29	9.1	941
Robbins	210483	11	126	39	1.9	5499
Bear Rock Run	142430	33	8	-14	1.5	4905
McKinley	30000	15	81	9	2.2	694
					Average	1254
					Median	702

year life.

The magnitude of the AMD problem in PA is another consideration. There are thousands of AMD discharges in PA. Are we really going to build and maintain thousands of active treatment systems? The number of active treatment systems built by the state in the last 20 years is less than 10, and not all have been maintained. A well-designed and constructed passive system, once built, should operate for its lifetime of 20-25 years with little maintenance.

Recommendations for Successful Passive Treatment

The success of some recent (and older) passive systems in treating High Risk AMD indicates the the technology is capable of good treatment of very nasty AMD. The cost data indicates that successful passive systems are economically low cost compared to active systems. If we are to make significant headway on treating the thousands of AMD discharges that are contaminating thousands of miles of PA waterways, we must use the available funds in the most efficient way. The challenge for the State of Pennsylvania is to develop policies and procedures to build successful passive systems with the available funds. The following paragraphs recommend steps to achieve this goal.

1. Funding of passive systems from State funds such as Growing Greener should be continued, but with better oversight from the state level.

2. The positions of Watershed Manager in the several mining district offices should be restored in priority and strengthened, with the goal of providing assistance and expertise to watershed groups and ensuring much better design, construction and maintenance of passive systems. Currently, the Watershed Managers have become burdened with other tasks and are unable to accomplish the needed oversight.

3. It is clear that maintenance and renovation of passive systems is required for successful long-term performance. Funds should be provided for maintenance of passive systems, as in the current TAG grants and Quick Response funds. These funds should amount to 5 to 10 % of the budget for new passive systems. Such funds will ensure that money spent to build systems is supported to ensure that the systems continue to operate well, just as maintenance and modifications are done at active treatment plants.

4. It is essential that proposals for passive treatment systems be more thoroughly and critically evaluated by State employees. Currently, the State reviewers do not seem to have the knowledge to evaluate proposals, so that dubious designs are funded and constructed if submitted by a registered engineer. More emphasis should be placed on review by State staff who are familiar with the details of passive system technology, and who attend technical meetings where the problems are discussed. The evaluation should include the previous success record of the design engineer. The information acquired in the current study indicates that some experienced designers are able to consistently design and build successful systems, but that the designs of engineers inexperienced in the passive treatment field have frequently failed. The State should task these professionals with conducting continuing evaluations of the treatment systems in their region.

Conclusions

1. In a survey by DEP in 2009-10, a very disturbing number of passive treatments systems for AMD funded by public funds failed to release net alkaline water. Failure in this DEP survey was defined

as effluent with positive acidity. Effluent was acid not only at systems classified as High Risk using the earlier DEP Risk Matrix, but also at Medium and Low Risk sites. The present followup investigation was intended to determine reasons for this failure and to compare characteristics of successful systems with the systems discharging acid water.

2. The current investigation consisted of a more detailed study of 10 "failed" High Risk systems, 4 "failed Medium Risk systems, 4 "failed" Low Risk systems and 5 successful Medium and High Risk systems, with most selected at random from sites designed since development of improved guidelines in 2002. Available information on the design, construction and performance of the systems was collected, most were visited and sampled, and the systems were discussed with the local group and designers.

3. At 2 High Risk "failures" the design was poor and did not meet design standards known at the time they were designed. At 3 other sites, the design appears inadequate for the influent AMD, though at one site the problem was insufficient space. At 2 sites, problems during construction appear to have degraded system performance. Three sites have lacked maintenance that would have greatly improved their performance, and at 2 others the maintenance has been inadequate. At 7 systems, the sample sites in the DEP survey did not represent the system performance or the use of a net acid failure criterion gave misleading results.

4. At 10 of the 18 "failed" sites, the treatment systems removed 89% or more of the influent acidity in the 2008-13 period, and at most, the remaining acidity was Mn acidity which is not a serious problem. Two or 3 systems, all poorly designed for their influent AMD, accomplished very little treatment. Three systems removed moderate proportions of the influent acidity and at one data is lacking on performance. Thus, although the systems were designated as "failures", more than half performed reasonably at removing acidity.

5. At 3 supposedly failing sites, the receiving streams have essentially recovered and have fish because of the effectiveness of the investigated systems plus one or more other systems in the watershed. At 4 other sites, the streams appear to be largely recovered and are being considered for removal from the 303d list. Although an individual system may release slightly acidic water, the combined effects of several treatment systems in a watershed can lead to stream recovery.

6. The cost of acidity removal by passive systems, based on several studies and models, is generally less than the cost of removal by active systems. Most of the passive systems remove acidity for less than \$1000/ton (as $CaCO_3$). The median cost for the systems of this study is \$702/metric ton of acidity removed. Four systems with small flow have higher costs, but would be high for active systems also. In contrast, costs using lime or caustic are \$1200/ton and higher. Thus, treatment by passive systems that are well designed and constructed, and are well maintained is considerably less than the alternative. Also, active systems are not perfect and sometimes release water exceeding discharge

standards. Another problem is the continued funding of active systems – several State active treatment plants have been abandoned for lack of funds.

7. It is recommended that the State continue to provide funding for construction and maintenance of passive systems but oversight should be considerably improved. Watershed Managers should be supported full time to monitor and coordinate treatment systems, and DEP staff should greatly increase their expertise in evaluation of passive systems. Funding for repairs and renovations of passive systems, as by TAG grants and Quick Response programs, should continue and be improved because it is clear that for good performance, passive systems do need maintenance and renovation over their lifetime.

8. The negative points in the DEP evaluation scheme for ranking passive treatment proposals should be eliminated or greatly reduced. This evaluation plan makes it almost impossible to fund treatment for discharges in the High Risk category. Instead, the DEP should carefully evaluate proposals and should conduct continuous oversight to ensure that successful systems are built and are maintained. The successful systems discussed here show that passive systems can be successful on even very acidic and metal-rich water.

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