A REVIEW OF PASSIVE TREATMENT TECHNOLOGY

JEFF SKOUSEN, CARL ZIPPER, ARTHUR ROSE, PAUL ZIEMKIEWICZ, ROBERT NAIRN, LOUIS MCDONALD AND ROBERT KLEINMANN

Background of presentation

This presentation grew from talks given by Jeff Skousen in Canada in 2015 and earlier papers by Skousen and Zipper

It has been updated and extended by the current list of authors.

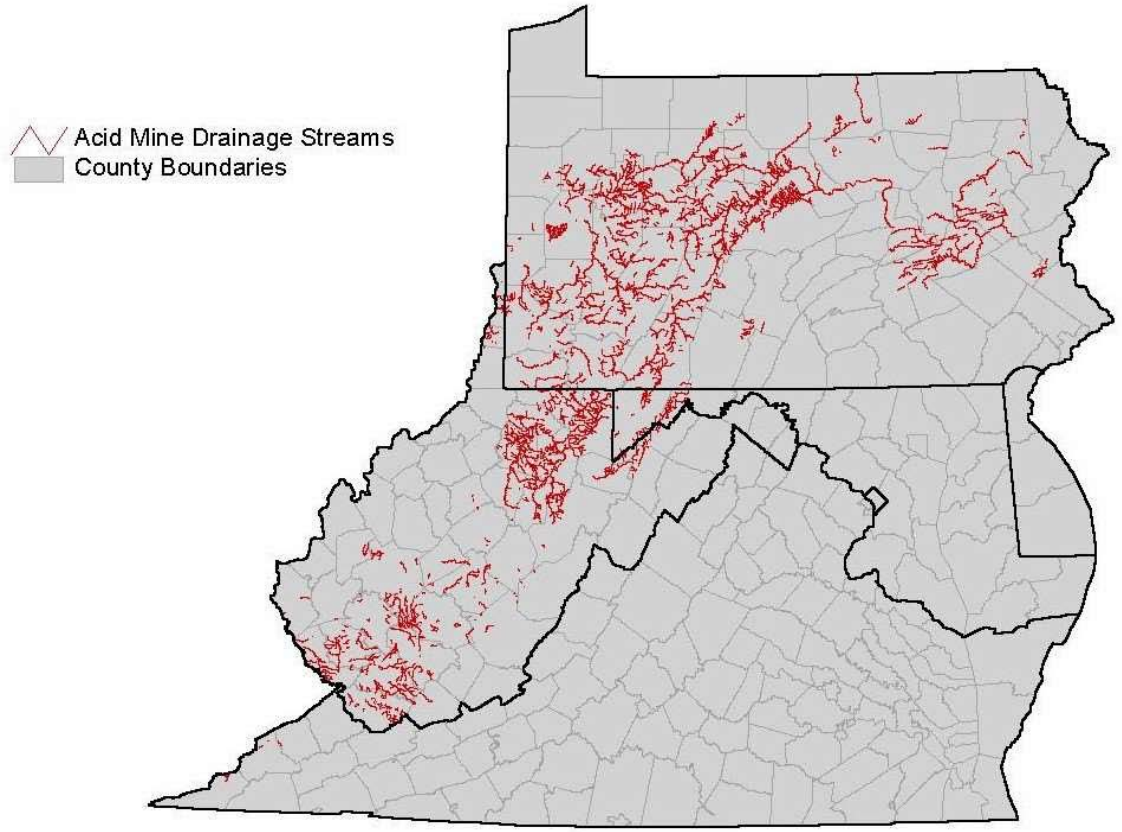
A print version is in press at Mine Water and the Environment, and is on-line at http://link.springer.com/article/10.1007/s10230-016-0417-1

The paper includes sizing and design parameters, success/failure information and about 200 references.

The perspective is mainly eastern US where about 500 passive systems have been constructed.

In today's version I'll summarize the publication but emphasize certain topics and features, including a method not covered in the review.

Acid Mine Drainage Streams



Types of Passive Systems

Treatment is accomplished by **biological and organic** effects, largely on redox state of Fe, S and Mn, and **chemically** by limestone to neutralize acidity.

Largely **biological** treatment:

- **Aerobic wetlands (AeW)**
- **Anaerobic wetlands (AnW)**
- **Vertical flow wetlands (VFP, VFW)**
- **Sulfate-reducing bioreactors (SRB)**
- **Fibrous metal removal units**
  - (Continued)

Types of Passive Systems (cont.)

Mainly Chemical:

- **Anoxic limestone drains (ALD)**
- **Flushed limestone beds (FLB)**
- **Limestone Leach beds (LLB)**
- **Low-pH Fe removal systems**
- **Open limestone channels (OLC)**
- **Limestone sand**
- **Manganese removal beds (MRB)**
- **Steel slag beds**
- **Diversion wells**

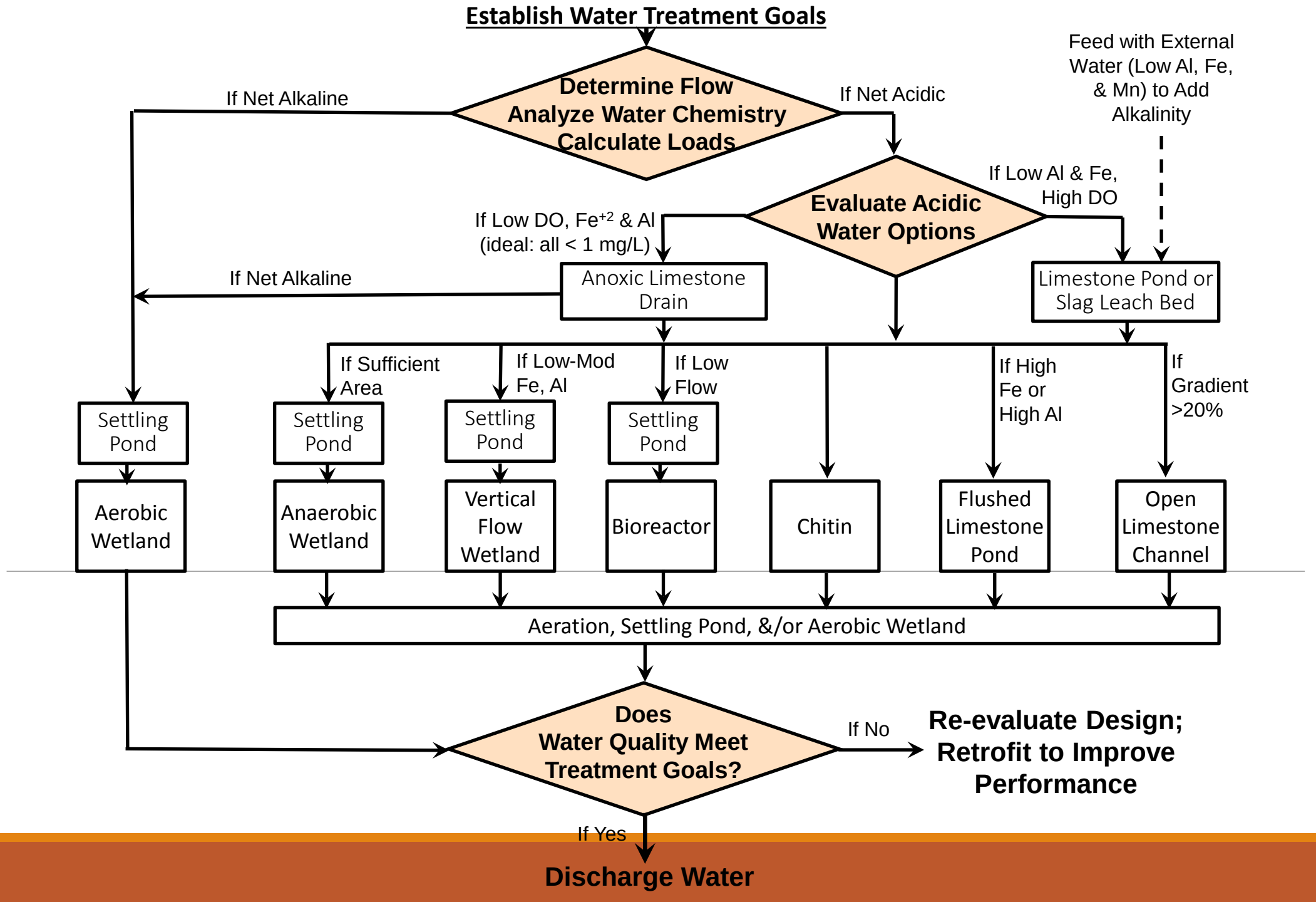
AMD Chemistry

Mine Drainage can be acid (AMD) or alkaline; both are treatable passively

If limestone is present in overburden or spoil, drainage may be alkaline but Fe-rich.

To select a treatment method, data on **chemistry** (pH, acidity, Fe, Al, Mn, redox state) and **flow** are needed.

Systems are usually sized to treat the 75^{th} to 90^{th} percentile of the flow and load


Establish Water Treatment Goals
Determine Flow
Analyze Water Chemistry
Calculate Loads
If Net Alkaline
If Net Acidic
Feed with External Water (Low Al, Fe, & Mn) to Add Alkalinity
Evaluate Acidic Water Options
If Low Al & Fe, High DO
If Low DO, Fe+2 & Al (ideal: all < 1 mg/L)
If Net Alkaline
Anoxic Limestone Drain
Limestone Pond or Slag Leach Bed
If Sufficient Area
If Low-Mod Fe, Al
If Low Flow
If High Fe or High Al
If Gradient >20%
Settling Pond
Settling Pond
Settling Pond
Settling Pond
Aerobic Wetland
Anaerobic Wetland
Vertical Flow Wetland
Bioreactor
Chitin
Flushed Limestone Pond
Open Limestone Channel
Aeration, Settling Pond, &/or Aerobic Wetland
Does Water Quality Meet Treatment Goals?
If No
Re-evaluate Design; Retrofit to Improve Performance
If Yes
Discharge Water

Acidity

Acidity is the amount of alkaline material to neutralize the water, usually to pH 8.3

In mine drainage, Fe, Al, Mn and other cations can furnish acidity.

$$Fe^{2+} + .25\ O_2 + 2.5H_2O = Fe(OH)_3 + 2H^+$$

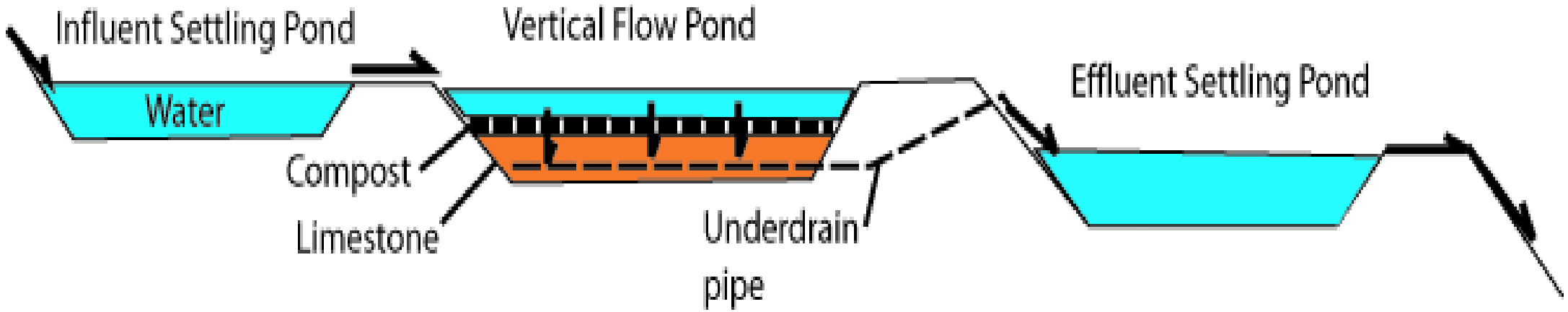
Acidity by Standard Methods or the EPA method is a NET Acidity, in contrast to some state regulations that specify Acidity minus Alkalinity (WRONG!).

Calculated Acidity:

$$\text{Acidity (mg/L } CaCO_3) = 50(2C_{Fe}/56 + 2C_{Mn}/55 + 3C_{Al}/27 + 10^{3-pH}) - \text{Alkalinity}$$

- Concentrations (C) should be dissolved amounts for this equation.

Vertical Flow Wetlands/Ponds



SCHEMATIC DIAGRAM OF VERTICAL FLOW SYSTEM

Processes in a VFW

Water layer

Possible Fe oxidation and precipitation, settling on compost (bad)

Compost layer

Consumption of dissolved O2

Reduction of Fe^{3+} to Fe^{2+}, SO_4^{2-} to S^{2-}, some FeS formation

Generation of some alkalinity

Limestone layer

Neutralization of acidity, increased pH

Possible precipitation of Al

Oxidation-Settling pond

Oxidation of Fe, precipitation as Fe(OH)3

Settling of Fe and Al precipitates.

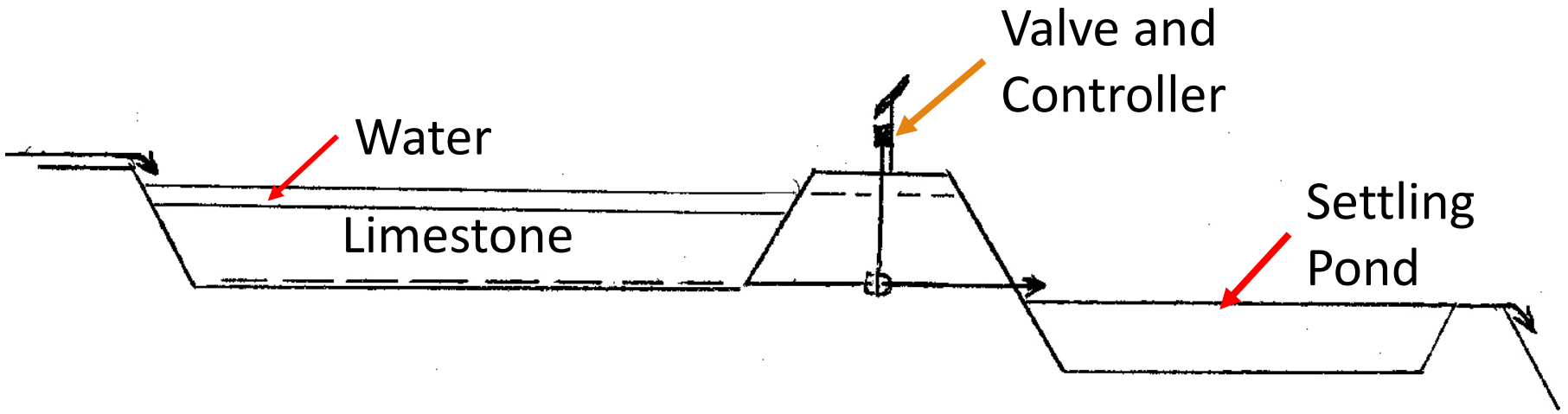
Al problems

- Al(OH)3 will precipitate in the limestone layer at pH>5;
- Coating and plugging limestone.
- Problem does not seem to be serious up to about 10-20 mg/L?
- Solutions:
  - Periodic Flushing (covered later)
  - Add 10-25% fine limestone to compost – Al hangs up in the compost; limestone bed operates OK. Systems with limestone-amended compost seem to be more effective in treatment.

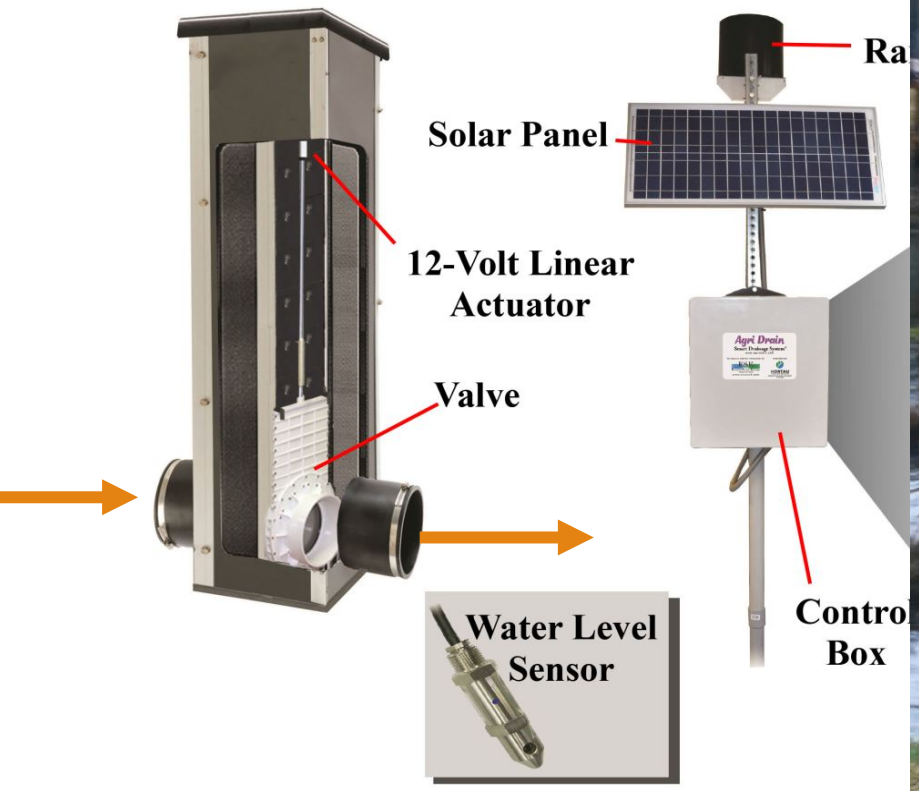
Flushing Systems

- For discharges with moderate to high Al, regular automatic flushing of limestone beds can allow good treatment for many years.
- Flushers consist of a large valve opened weekly or so by a small computer energized by a solar panel.
- On opening the valve, water flows out rapidly, carrying out the interstitial precipitate and some of limestone coatings.
- Automatic weekly flushing is much better than monthly manual flushing.
- Used with limestone beds and some VFW's

Flushable Limestone Pond



Agridrain Flusher



FIBROUS METAL REMOVAL UNITS

Fibrous Metal Removal Units

- A patented method using coconut fiber (coir) to grow and trap Fe, Al and Mn
- The units are boxes up to 8 ft long with upflow thru the fiber mass – very small area.
- The metal compounds grow selectively on the fibers.
- The metal concentration, pH and redox determine the metal removed; metals removed down to tenths of mg/L.
- The boxes are flushed/cleaned periodically to regenerate them.
- Developed and sold by Ecoislands of Altoona, PA.
- www.ecoislandsllc.com

Reliability of Passive Treatment

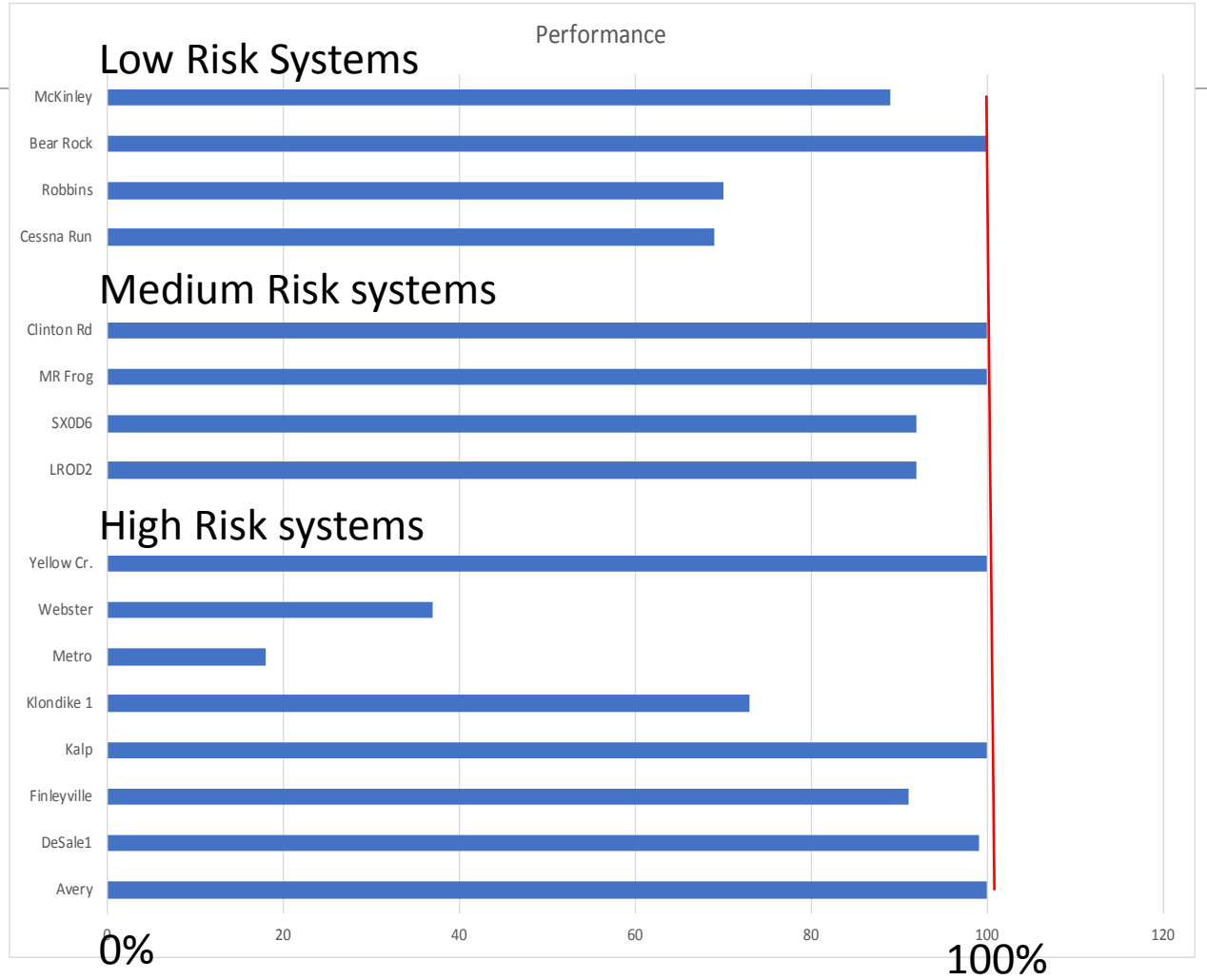
- Many passive systems, especially VFW's, have not completely treated their discharge.
- In a study by PA DEP in 2009-10, about 150 passive systems were sampled twice.
- About 40% of the systems released net acid water, and were termed "failures"
- In 2013 I selected 18 "failures" for further evaluation, plus 6 "successes" with large flow and substantial metals.
- Object – What were the reasons for "failure"?
- Extensive data in www.datashed.org.

Summary of Problems

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						

Performance of “failed” systems

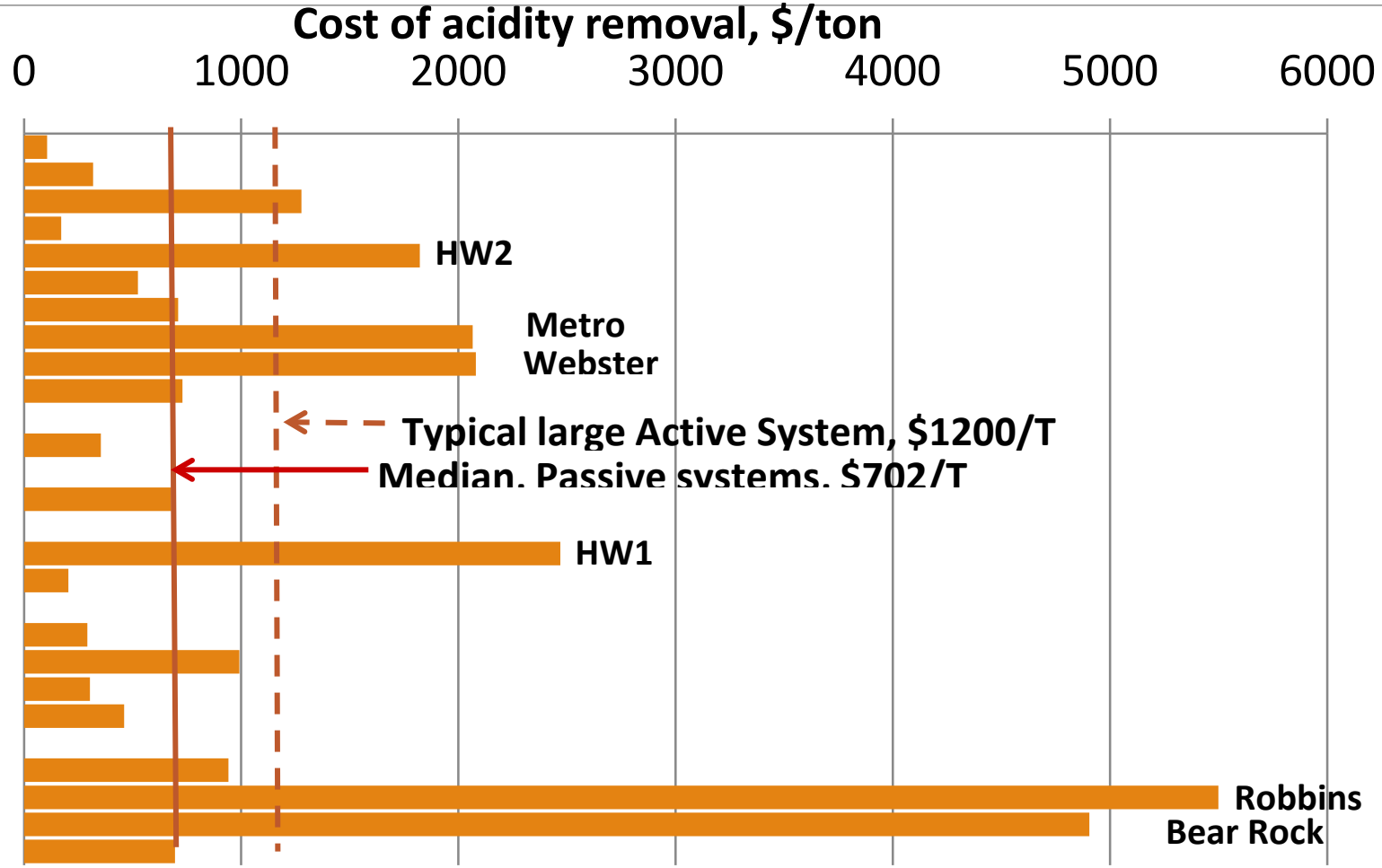
% of influent acidity removed (2005-13)



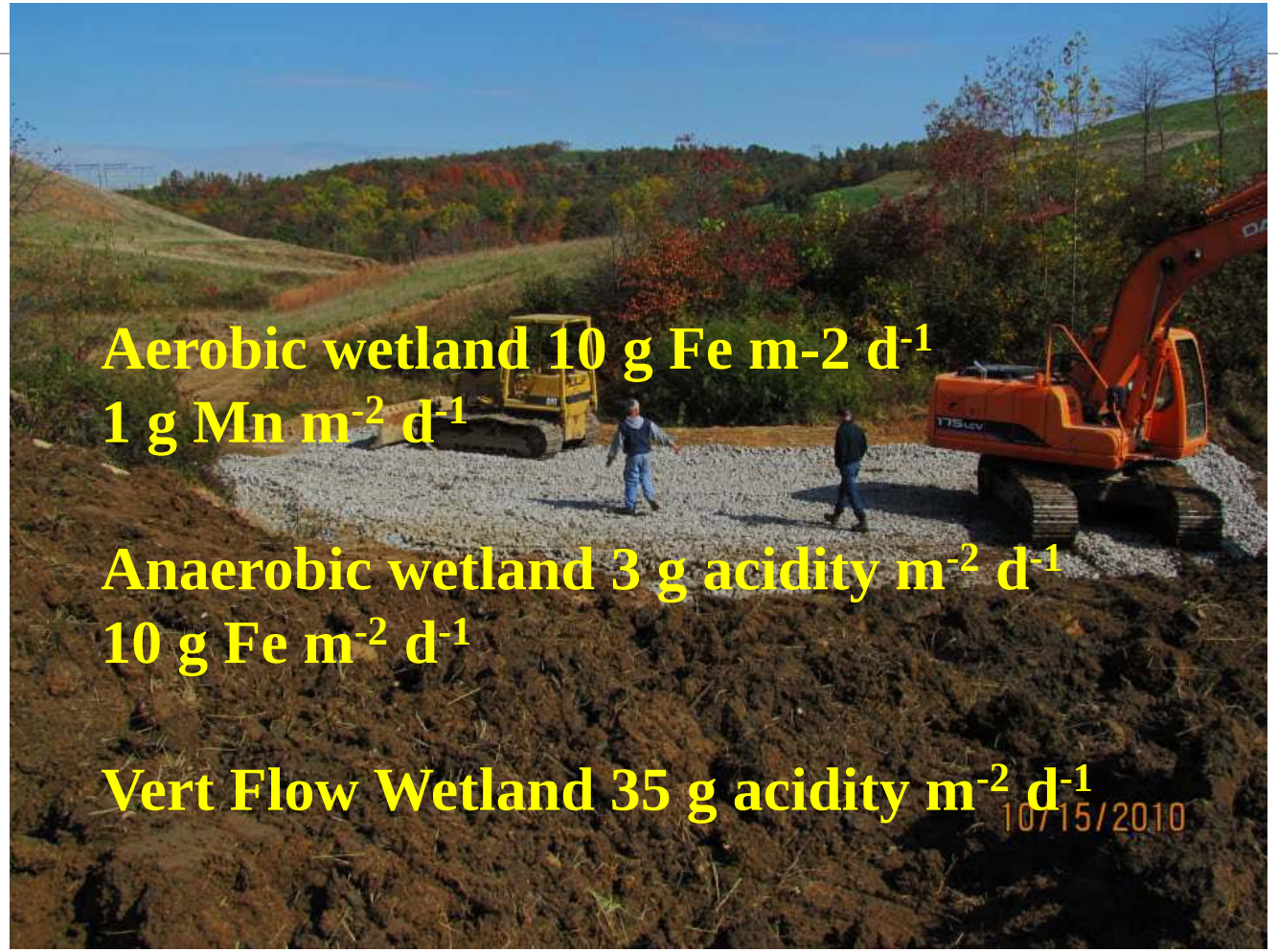
Successful Systems – High Risk

System	Built	Flow	pH in	Acidity in	Fe in	Al in	Acidity out		
Anna S	2004	219	3.2	125	6.2	11	-103		
Hunters Dr	2004	245	2.8	343	35	32	-113		
Glasgow	2009	41	3.2	555	101	55	-112		
Maust	1998	20	3.2	143	33	2	-39		
Longs R D10	2005	20	3.2	442	145	10	-61		

Cost Passive vs. Active



Design and sizing



Maintenance

Passive systems, especially large ones, need monitoring, maintenance and renovation.

Replacement of compost at Klondike-1 (high Fe) after 9 years

VFW's – compost replacement, limestone cleaning after 6-10 yrs.

Conclusions

1. For a review of Passive Treatment Technology, see

Mine Water and the Environment, 2017 , Or

http://link.springer.com/article/10.1007/s10230-016-0417-1

2. Passive treatment is an effective method to restore AMD to acceptable water, but does require correct design and construction, and some maintenance.