Passive Treatment of Mining-Influenced Water: From Bench Scale to O&M

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Abandoned Coal Mine Drainage

Abandoned

- Site mined prior to 1977 Surface Mining Control & Reclamation Act (SMCRA)
- Before SMCRA, little to no requirement for coal miners to reclaim land or treat polluted water

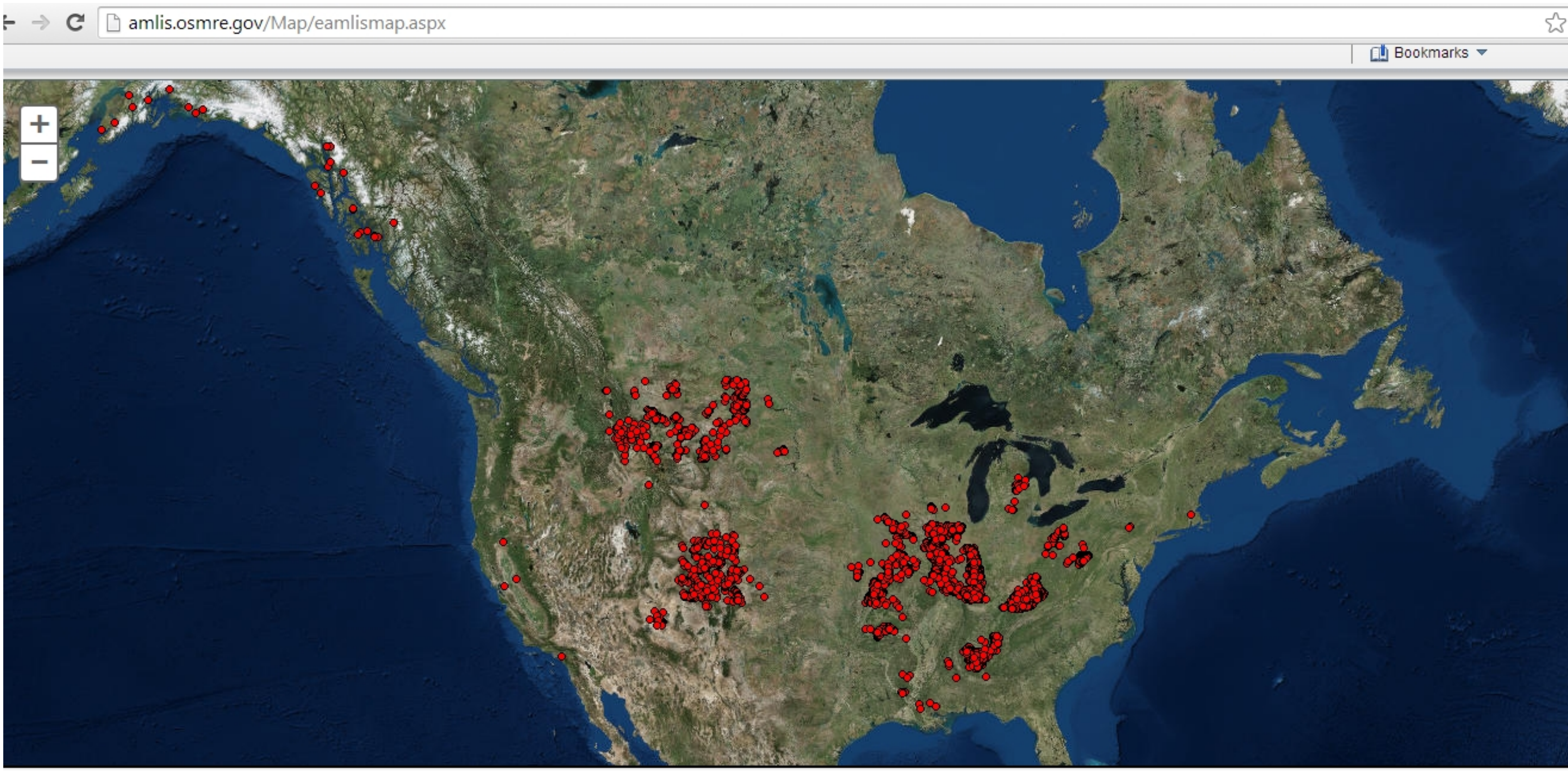
Coal mine drainage

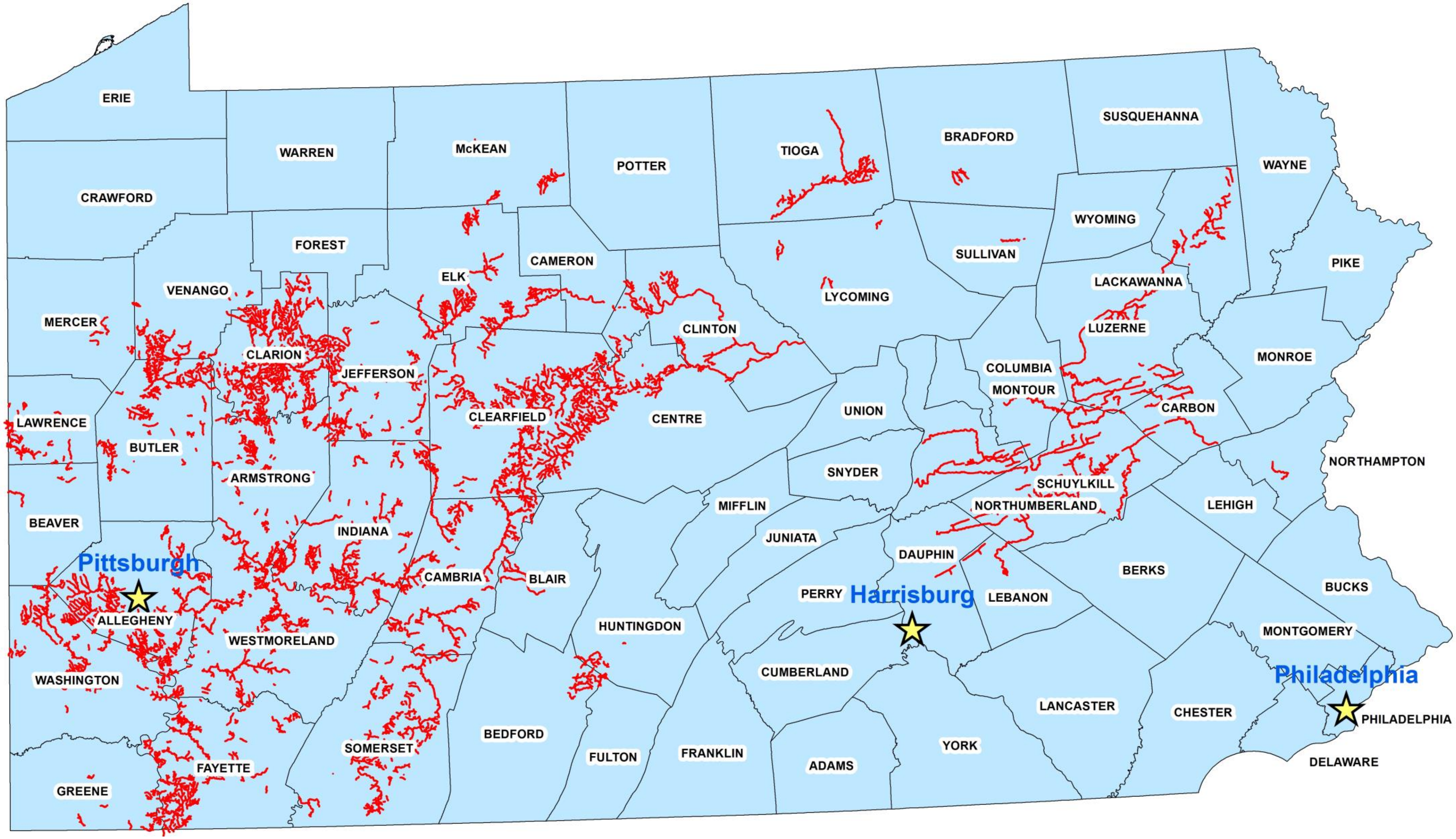
- Water that has become polluted by flowing through unreclaimed coal mines
- Often called abandoned mine drainage (AMD)
- AMD is commonly acidic (pH 2-4) with high metals such as iron and aluminum
- AMD creates habitat unsuitable to support fish and other aquatic life





Abandoned coal mines are a nationwide problem – more than 10,500 mi polluted streams just in PA and WV




ERIE
WARREN
McKEAN
POTTER
TIOGA
BRADFORD
SUSQUEHANNA
WAYNE
CRAWFORD
FOREST
ELK
CAMERON
SULLIVAN
WYOMING
LACKAWANNA
PIKE
VENANGO
MERCER
CLARION
JEFFERSON
CLINTON
LYCOMING
LUZERNE
MONROE
COLUMBIA
MONTOUR
CARBON
LAWRENCE
CLEARFIELD
CENTRE
UNION
BUTLER
ARMSTRONG
SNYDER
NORTHAMPTON
SCHUYLKILL
NORTHUMBERLAND
MIFFLIN
LEHIGH
BEAVER
INDIANA
JUNIATA
Pittsburgh
CAMBRIA
BLAIR
DAUPHIN
BERKS
BUCKS
ALLEGHENY
PERRY
Harrisburg
LEBANON
WESTMORELAND
HUNTINGDON
MONTGOMERY
WASHINGTON
CUMBERLAND
Philadelphia
LANCASTER
CHESTER
PHILADELPHIA
BEDFORD
SOMERSET
FAYETTE
FULTON
FRANKLIN
ADAMS
YORK
DELAWARE
GREENE

Cleaning up abandoned mines generates jobs – Important to local, regional, and state economies

- For every $1 spent on remediation, an additional $1.36 circulates through the local economy (multiplying factor)
- Area property values increase ($2600 lost per acre for property adjacent to polluted stream)

- Sport fishing opportunities and recreational spending increase ($20 million annually)
- Drinking water supply options become cheaper and more plentiful

Long-term operation, maintenance, and rehab provides economic benefits

- Develop schedule of OM&R activities over 20-yr period

System	2017				2018				2019				2020				2021				2022				2023				2024				2025				2026			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
1									X																				X		X									
2									X																				X		X									
3									X																				X											
4									X																				X		X									
5			X		X														X																X					
6			X		X														X																X					
7														X							X																			
8																					X																			
9		X																			X	X		X																

System	2027				2028				2029				2030				2031				2032				2033				2034				2035				2036			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
1									X																				X		X									
2									X																				X		X									
3									X																				X											
4									X																				X		X									
5					X						X														X		X													
6					X						X														X		X													
7	X							X													X																	X		
8	X			X																	X																			
9	X	X																			X	X		X																

System Key
1 Robbins Hollow East Branch 10/15
2 Robbins Hollow East Branch 11/12
3 Robbins Hollow East Branch 13
4 Robbins Hollow East Branch 9
5 Robbins Hollow 10a/10b
6 Robbins Hollow Pipes 1-4
7 Robbins Hollow North Branch
8 Middle Branch
9 Swamp

Task Key
A Vegetation Control
B Organic Substrate Mixing
C Limestone Cleaning
D Organic Substrate Replacement

Limestone Cleaning - Cleaning of Limestone with equipment

System	Tons	Unit Cost	Construction Cost	PM and CO	Total Cost	Interval
RH EB 10/15	850	$7	$5,950	$1,190	$7,140	10
RH EB 11/12	973	$7	$6,811	$1,362	$8,173	10
RH EB 13	450	$15	$6,750	$1,350	$8,100	20
RH EB 9	690	$7	$4,830	$966	$5,796	10
RH 10a/10b	721	$7	$5,047	$1,009	$6,056	4
RH Pipes 1-4	552	$7	$3,864	$773	$4,637	4
Swamp	900	$7	$6,300	$1,260	$7,560	10

- Break down individual activity costs and intervals

	Cost per site per visit	Annual cost
Routine O&M and sampling		
Technical staff	$410	$307,500
Lab analysis	$190	$190,000
Field supplies	N/A	$5,000
Travel	$150	$150,000
Total, routine O&M and sampling	**$750**	**$652,500**
Professional check-ups		
Consultant/Engineer	$1,600	$80,000
Lab analysis	$730	$36,500
Field supplies	N/A	$1,000
Travel	$150	$7,500
Total, professional check-ups	**$2,480**	**$125,000**
Major system maintenance		
Consultant/Engineer	$16,000	$400,000
Unskilled labor (2)	$6,000	$150,000
Skilled labor (3)	$12,000	$300,000
Consultant/Project manager (1)	$7,000	$175,000
Equipment	$10,350	$11,250
Travel	$150	$3,750
Materials	$28,500	$960,000
Total, major system maintenance	**$80,000**	**$2,000,000**
TOTAL		**$2,777,500**

- Categorize and annualize all costs

Jobs analysis - Long-term OM&R

- What would it would cost to fund a 20-year trust that would cover the necessary OM&R activities for 250 passive treatment systems across PA not eligible for funding from Title IV AML Set-Aside Fund?
- Result: Fully funded 20-year trust would range from $39 million up to $47 million
- Type I and Type II Regional Input-Output Modeling Systems utilized
- Estimated annual cost of ongoing maintenance at all modeled sites throughout Pennsylvania totals $2.8 million (average of $11,200 per site per year).
- OM&R expenditures would support 34 jobs per year

Passive Treatment of Coal Mine Drainage

Common Passive Technologies Used in the Eastern US for Coal Mine Drainage

- Ponds
  - oxidize Fe, settle solids, mixing
- Constructed Wetlands
  - polishing ,Mn and solids removal
- Anoxic limestone beds
  - alkalinity generation
- Oxic limestone beds
  - alkalinity generation, metal removal, polishing
- Vertical flow ponds
  - alkalinity generation and metal removal

Ponds

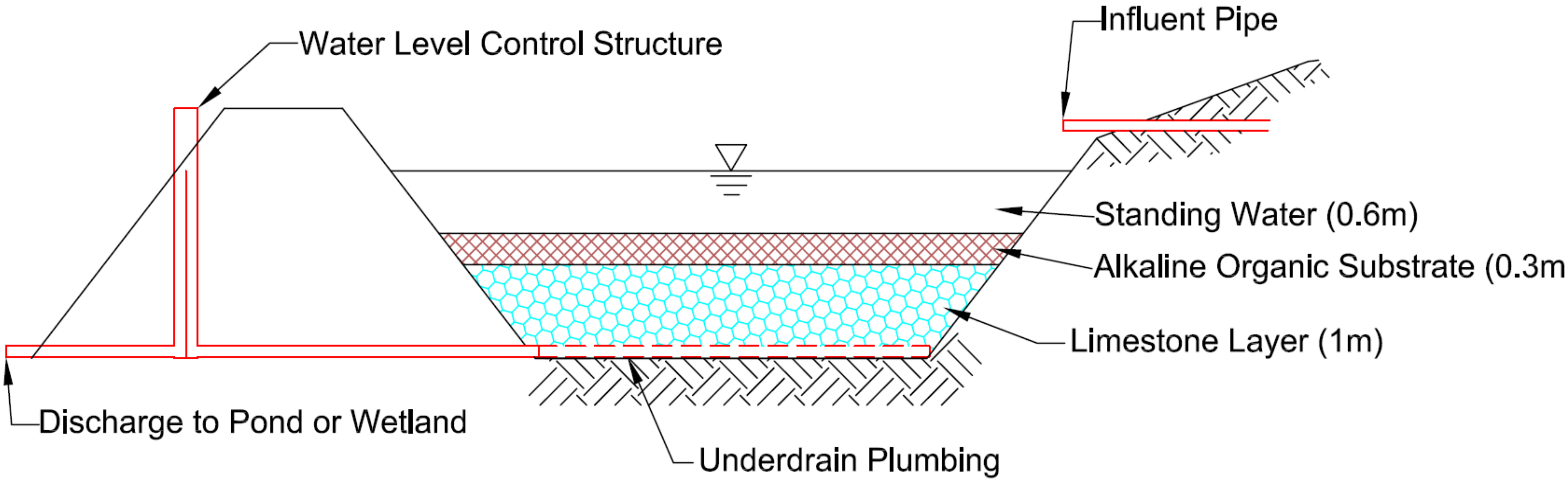
Constructed Wetlands

Limestone Beds

oxic

anoxic

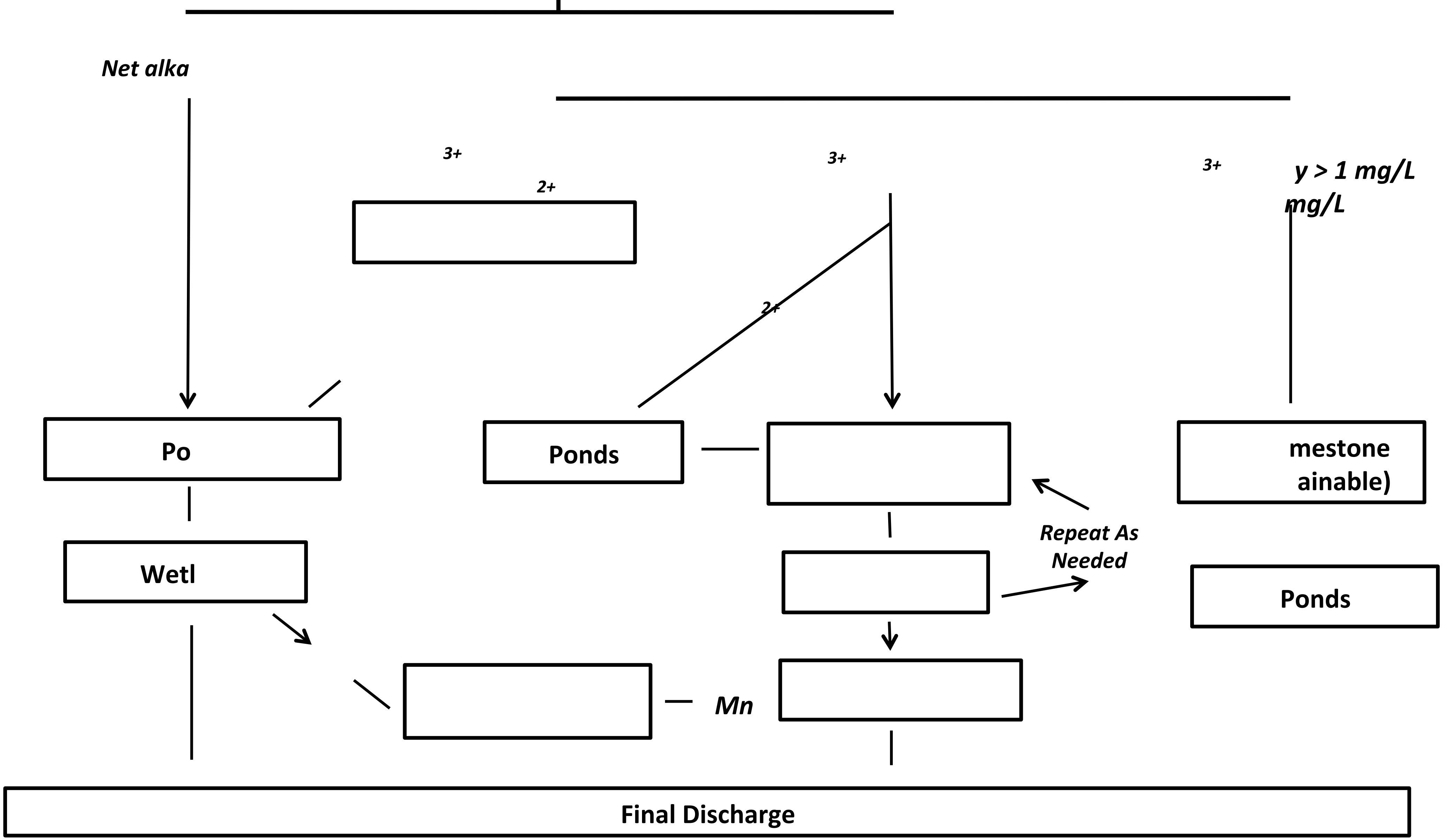
Vertical Flow Pond



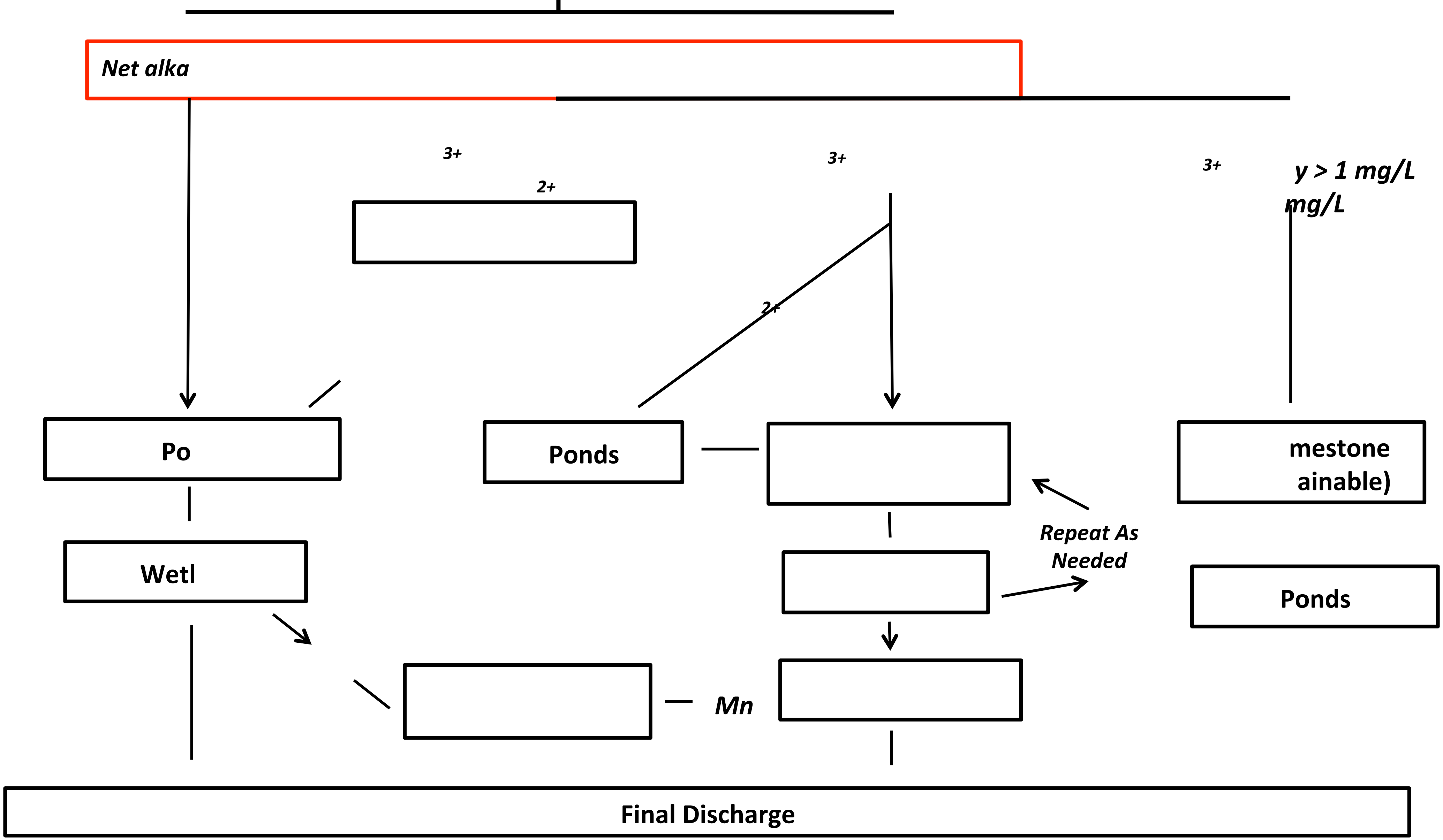
Technology is based on chemistry

Sizing is based on loadings

Characterize Mine Water

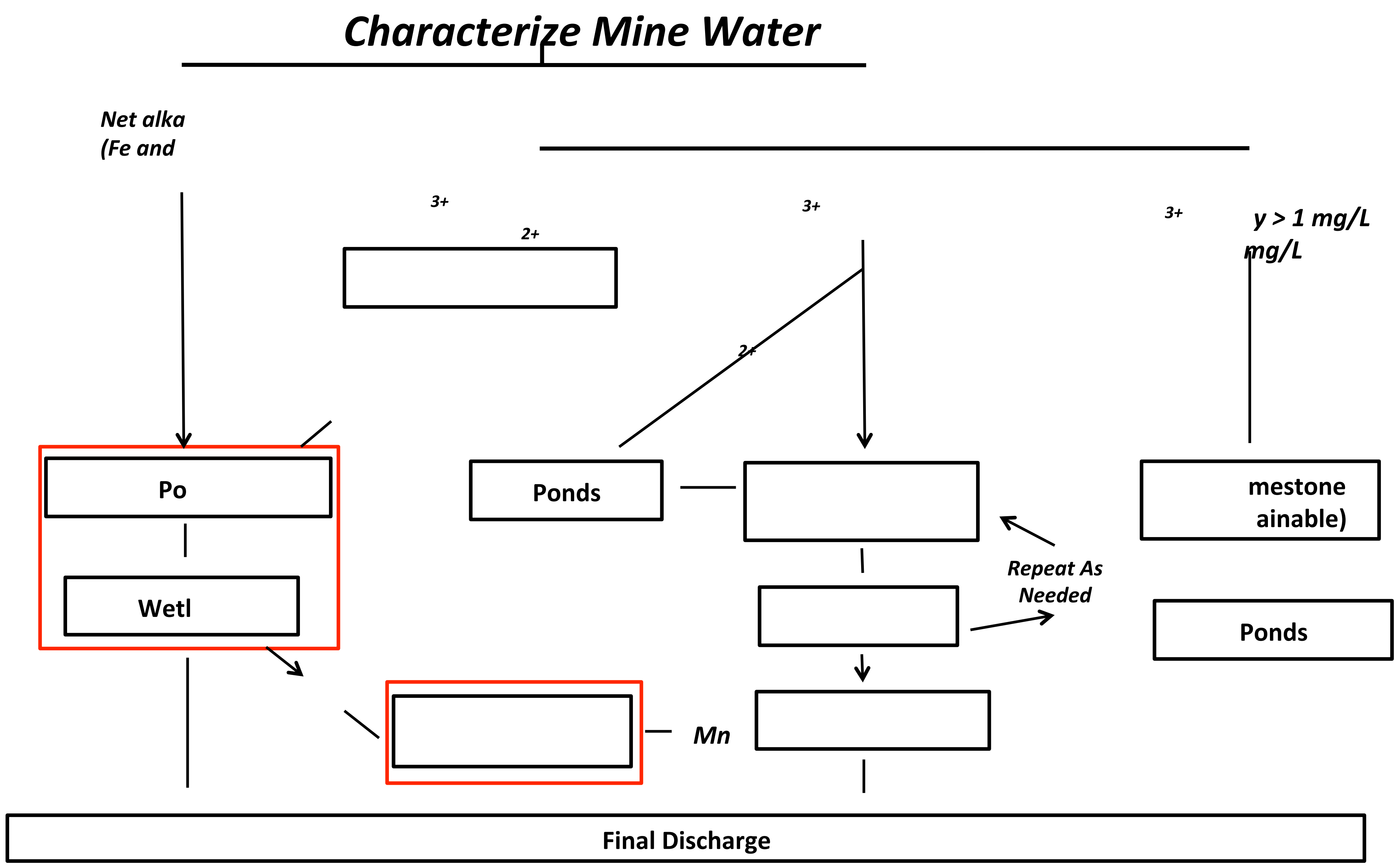


Characterize Mine Water



Treatment of Net Alkaline Mine Water

- Generation of alkalinity not required
- Al is always < 1 mg/L
- Fe and Mn removal by oxidizing processes

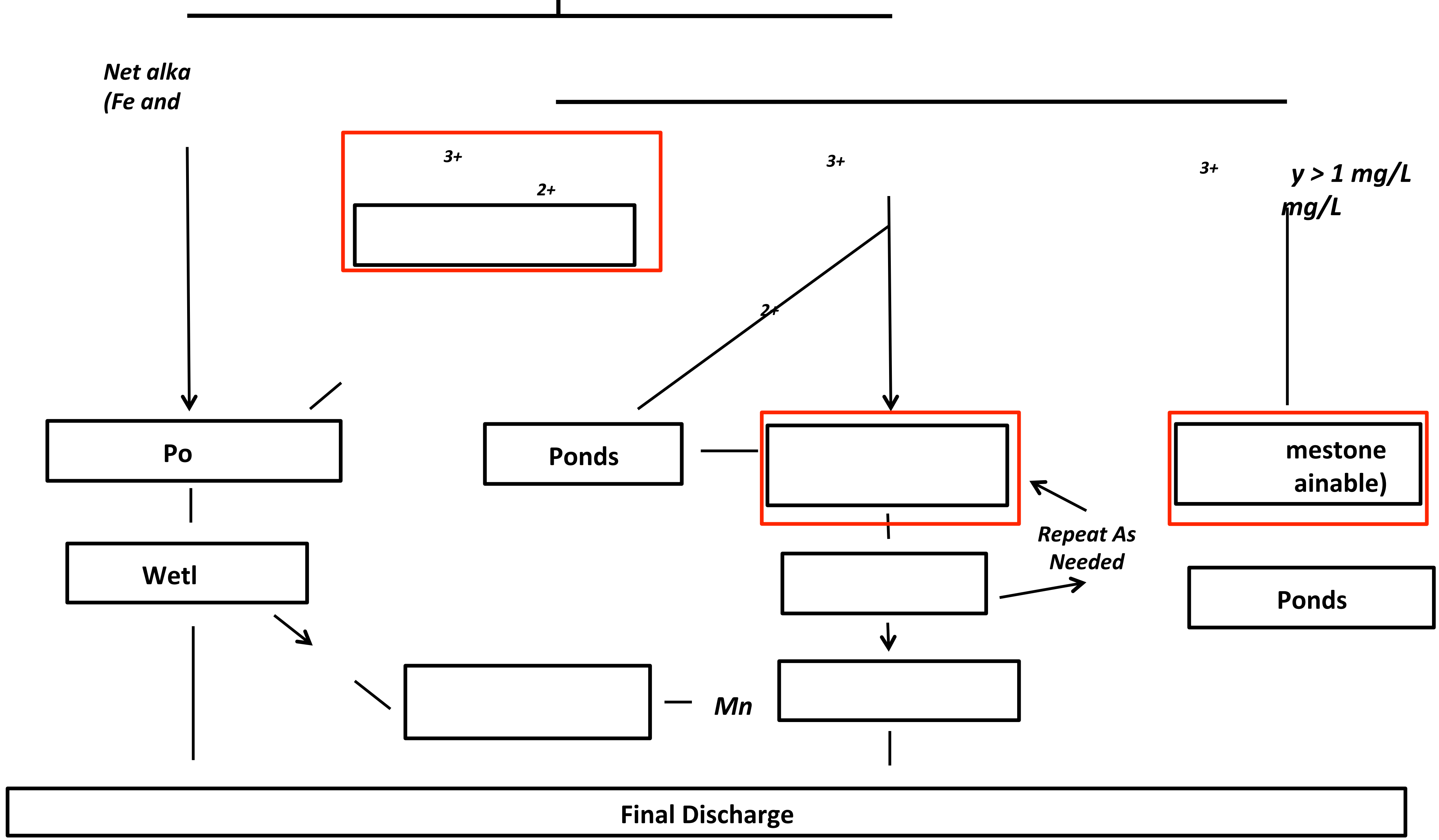


Characterize Mine Water
Net alka
(Fe and
3+
2+
3+
2+
3+
y > 1 mg/L
mg/L
Po
Wetl
Ponds
mestone
ainable)
Repeat As
Needed
Ponds
Mn
Final Discharge

Treatment of Net Acidic Mine Water

- Neutralize acidity
  1. Calcite dissolution
  2. Bacterial processes in organic substrate
- Remove metal contaminants
  1. Al, Fe, Mn, others
  2. Primary removal as oxide and hydroxide solids
  3. Secondary removal as sulfides and carbonates

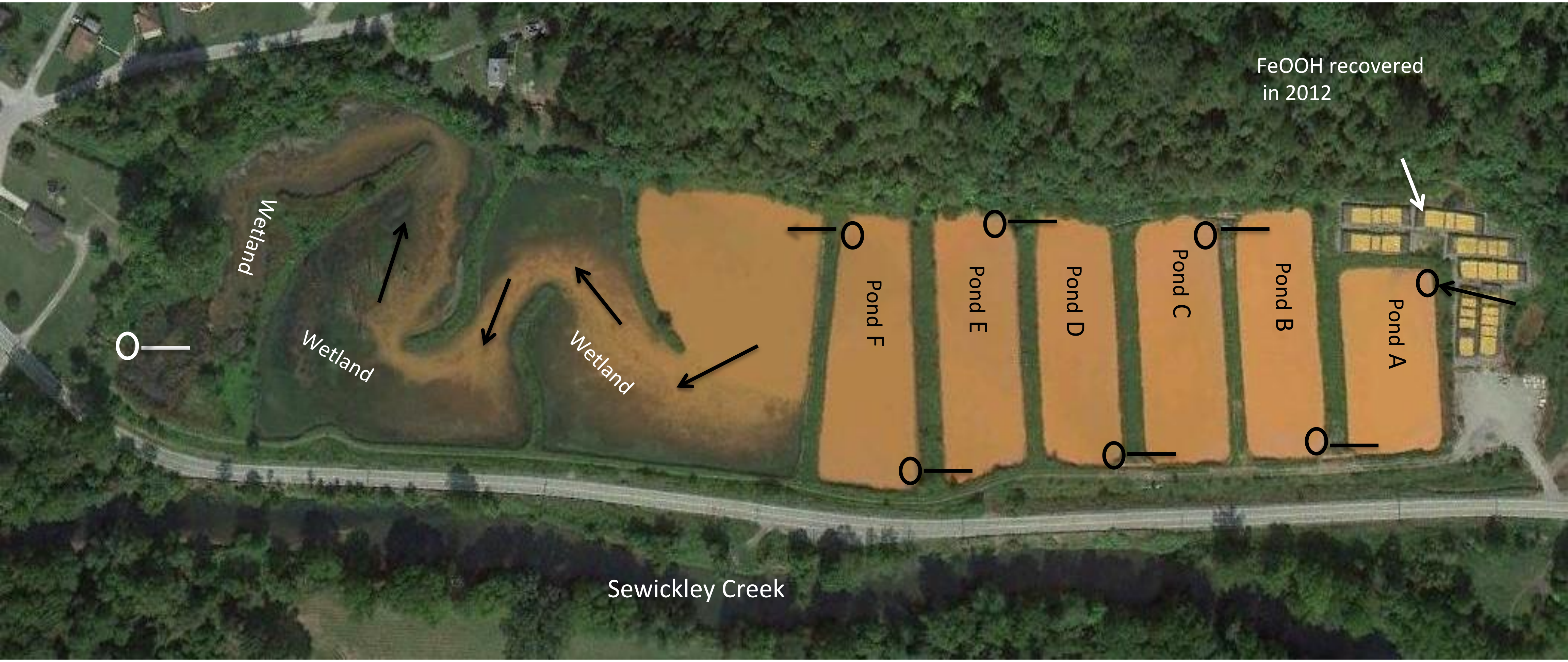
Characterize Mine Water

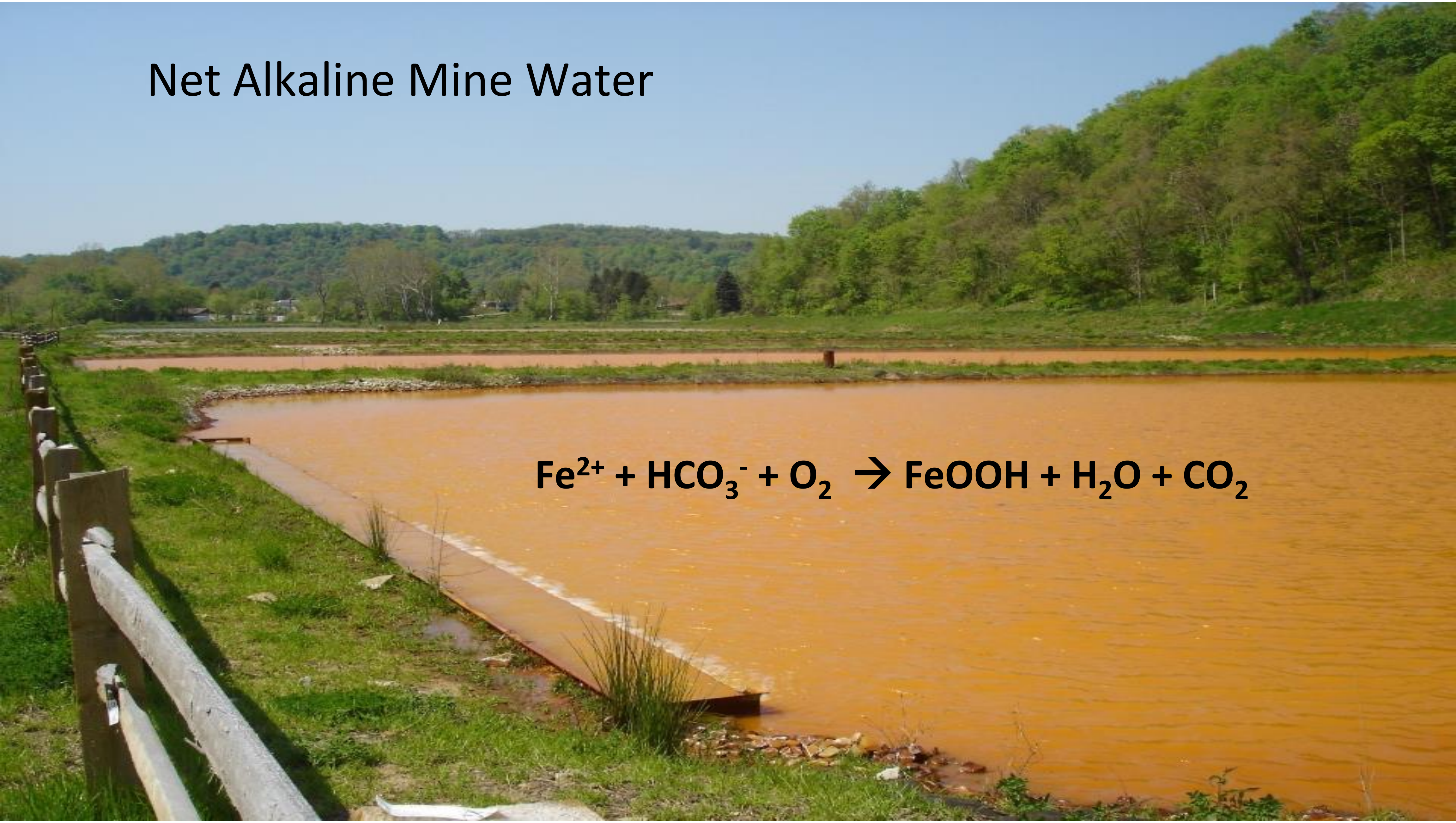


Long-term Performance and Costs: Marchand System

Case Studies

Marchand Passive System (Westmoreland County)



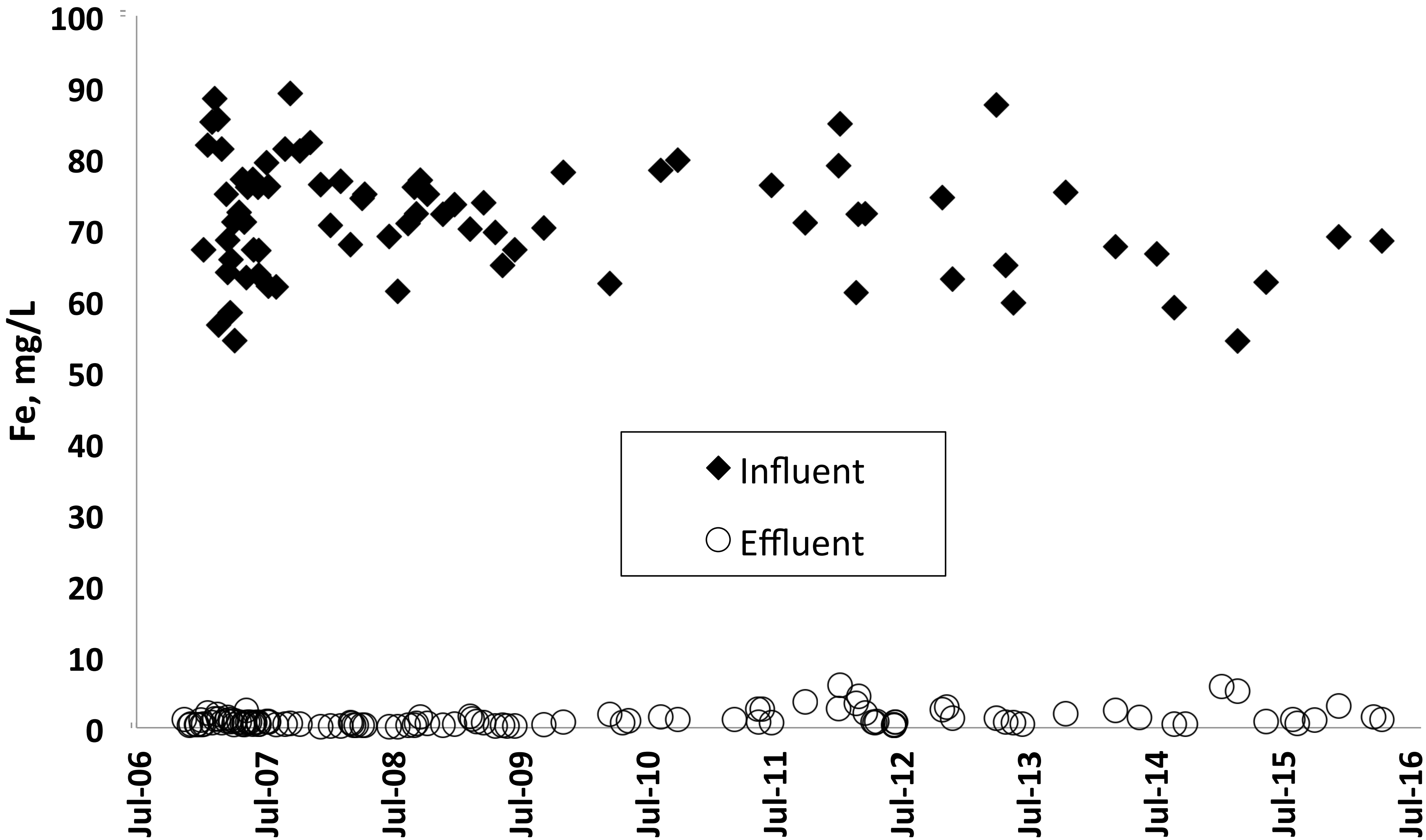

Net Alkaline Mine Water
$Fe^{2+} + HCO_3^- + O_2 \rightarrow FeOOH + H_2O + CO_2$

Marchand Time Line

Year	Activity
2000	Grant to assess feasibility
2004	Grant for design, permitting, construction
2006	System operational
2010	Berm repairs and pipe cleanout
2012	Sludge removal and trough installation (3 ponds)
2016	Trough installation (3 ponds)

Marchand system, Oct 2006 – April 2016

	Flow	pH	Alk	Fe	Al	Mn	SO_4	TSS
	gpm	s.u.		--------------- mg/L		-----------------		
Inflow	1,870	6.3	334	71.6	<0.1	1.2	1,141	26
Effluent	na	7.7	218	1.1	<0.1	0.5	1,163	<6



Fe, mg/L
100
90
80
70
60
50
40
30
20
10
0
Influent
Effluent
Jul-06
Jul-07
Jul-08
Jul-09
Jul-10
Jul-11
Jul-12
Jul-13
Jul-14
Jul-15
Jul-16

Operation and Maintenance

- Routine inspections and sampling
  - Quarterly, ½ day
- System improvements
  - Berm reinforcement; trough installations
- Sludge management
  - 750,000 gallon/year sludge
  - ~5% of pond volume

Sludge Management: 2012

- Cleaned first three ponds
- Installed bypass system to enable pond dewatering and continuous treatment
- Replaced three problem pipes with open troughs




Elemental composition of solids

Al	C	Ca	Fe	K	Mg	Mn	Na	P	S	Si	LOI
%	%	%	%	%	%	%	%	%	%	%	%
0.2	0.7	0.6	52.6	< 0.1	0.1	< 0.1	0.1	< 0.1	0.2	0.9	17

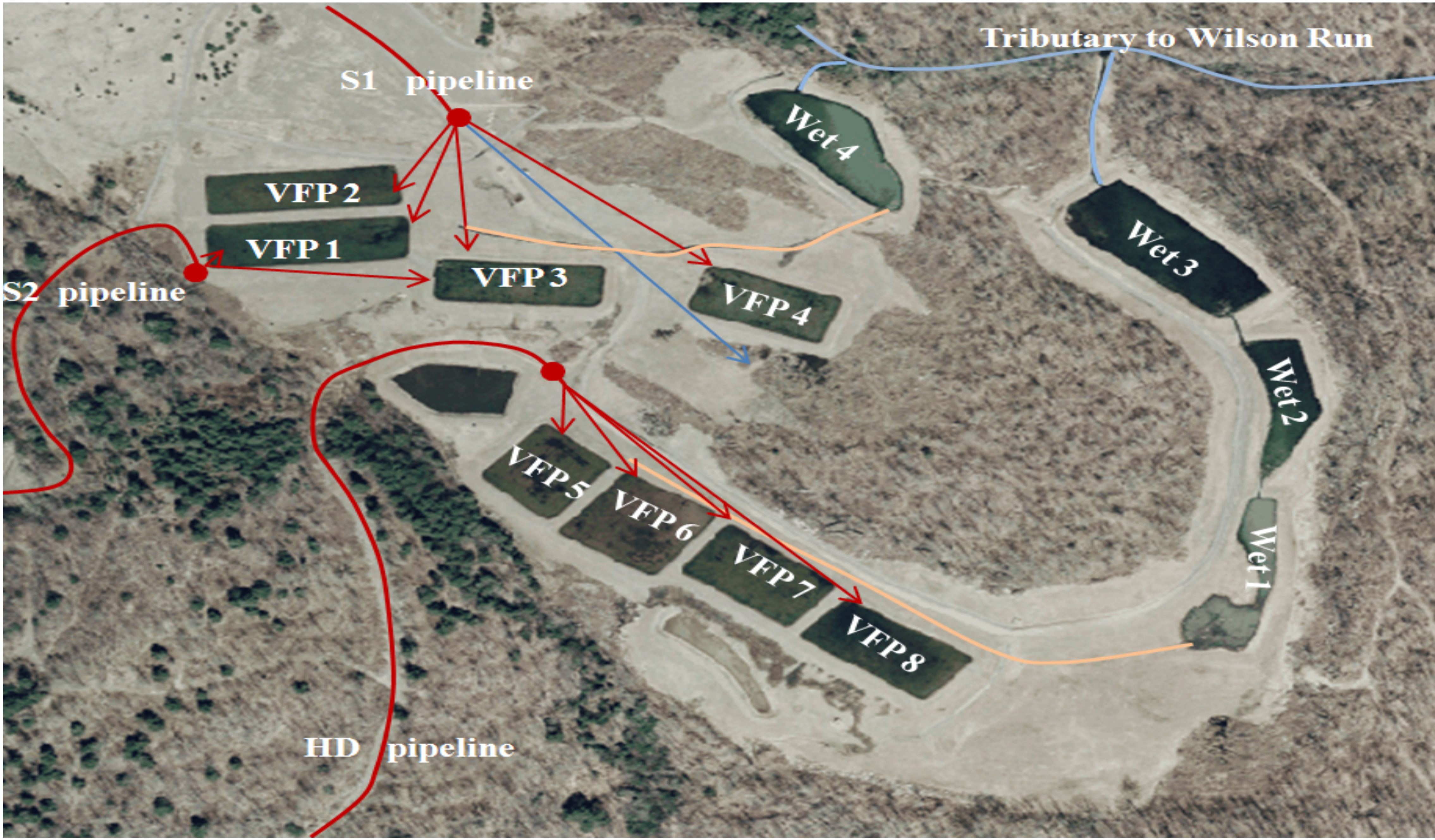
- Solids are ~50% Fe and are mixture of FeOOH and $Fe(OH)_3$
- Concentrations of hazardous metals all below limits in EPA Part 503 Biosolids rule
- Solids have value as pigment and for remediation purposes

Marchand costs, 2000 – 2016
(1,850 gpm, 72 mg/L Fe)

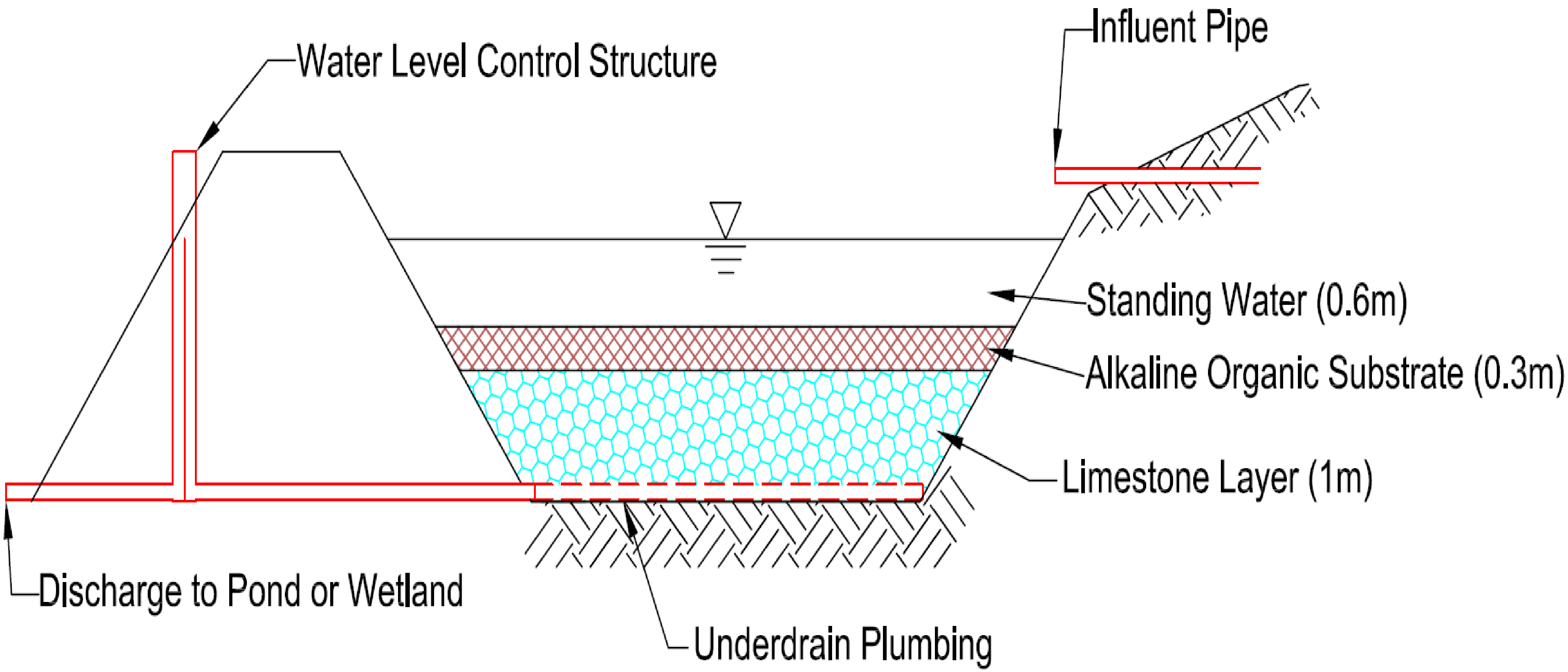
Year	Cost	Activity
2000	$105,000	Treatment feasibility (PA DEP Grant)
2004	$1,282,000	System design, permitting, and construction
2010	$15,000	Berm repairs and pipe cleaning
2012	$87,935	Sludge removal (3 ponds); trough and bypass installation
2016	$18,000	Trough installation and repairs
Annual	$3,000/yr	Hedin Environmental and Sewickley Creek Watershed Association, quarterly inspections and routine maintenance
Periodic		Remove iron sludge every 7-10 years

Long-term Performance and Costs: Anna S Passive System Complex

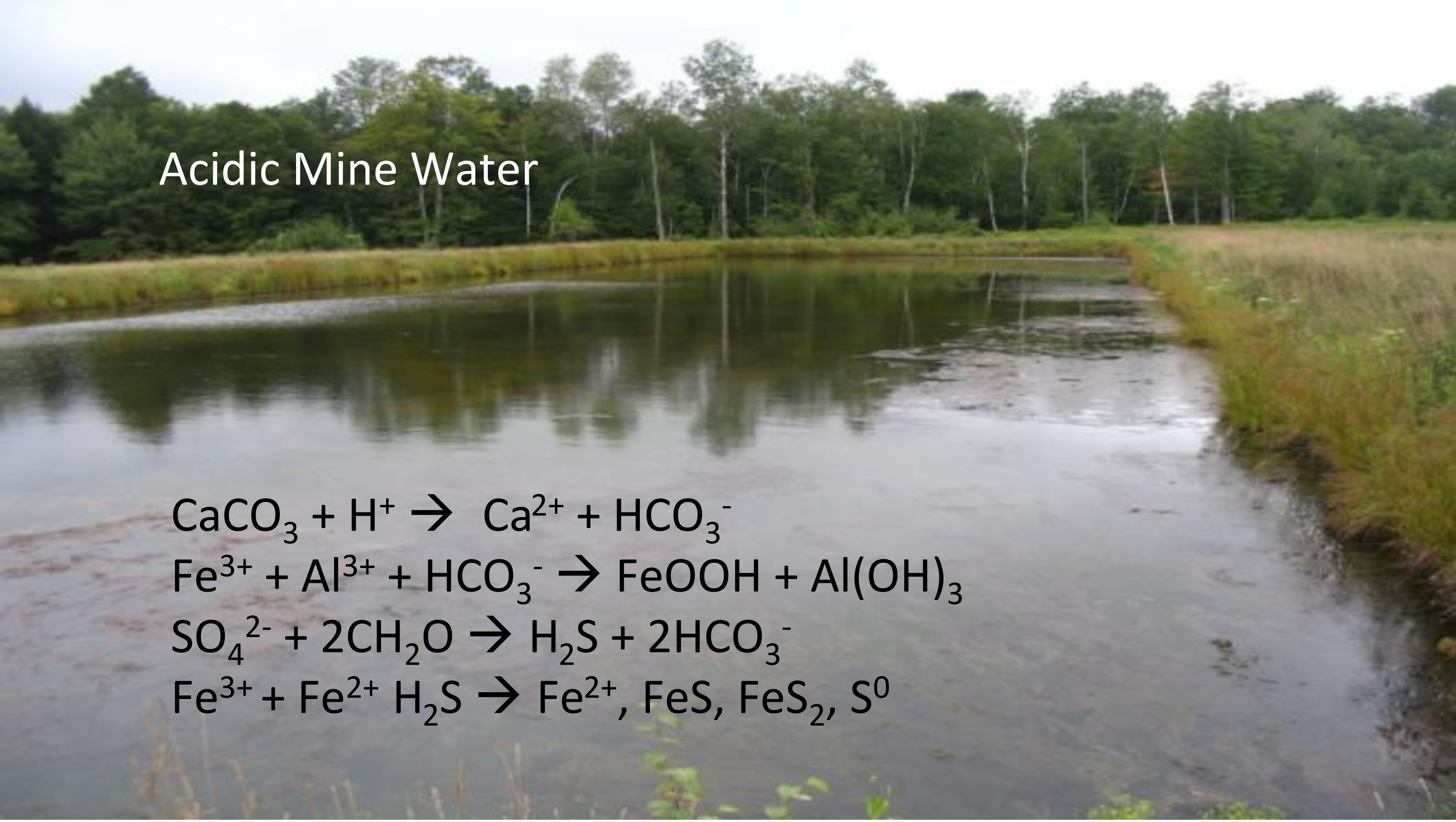
Case Studies



Tributary to Wilson Run
S1 pipeline
Wet 4
VFP 2
VFP 1
VFP 3
S2 pipeline
VFP 4
Wet 3
Wet 2
VFP 5
VFP 6
VFP 7
VFP 8
Wet 1
HD pipeline



Water Level Control Structure
Influent Pipe
Standing Water (0.6m)
Alkaline Organic Substrate (0.3m)
Limestone Layer (1m)
Discharge to Pond or Wetland
Underdrain Plumbing



Acidic Mine Water

$CaCO_3 + H^+ \rightarrow Ca^{2+} + HCO_3^-$

$Fe^{3+} + Al^{3+} + HCO_3^- \rightarrow FeOOH + Al(OH)_3$

$SO_4^{2-} + 2CH_2O \rightarrow H_2S + 2HCO_3^-$

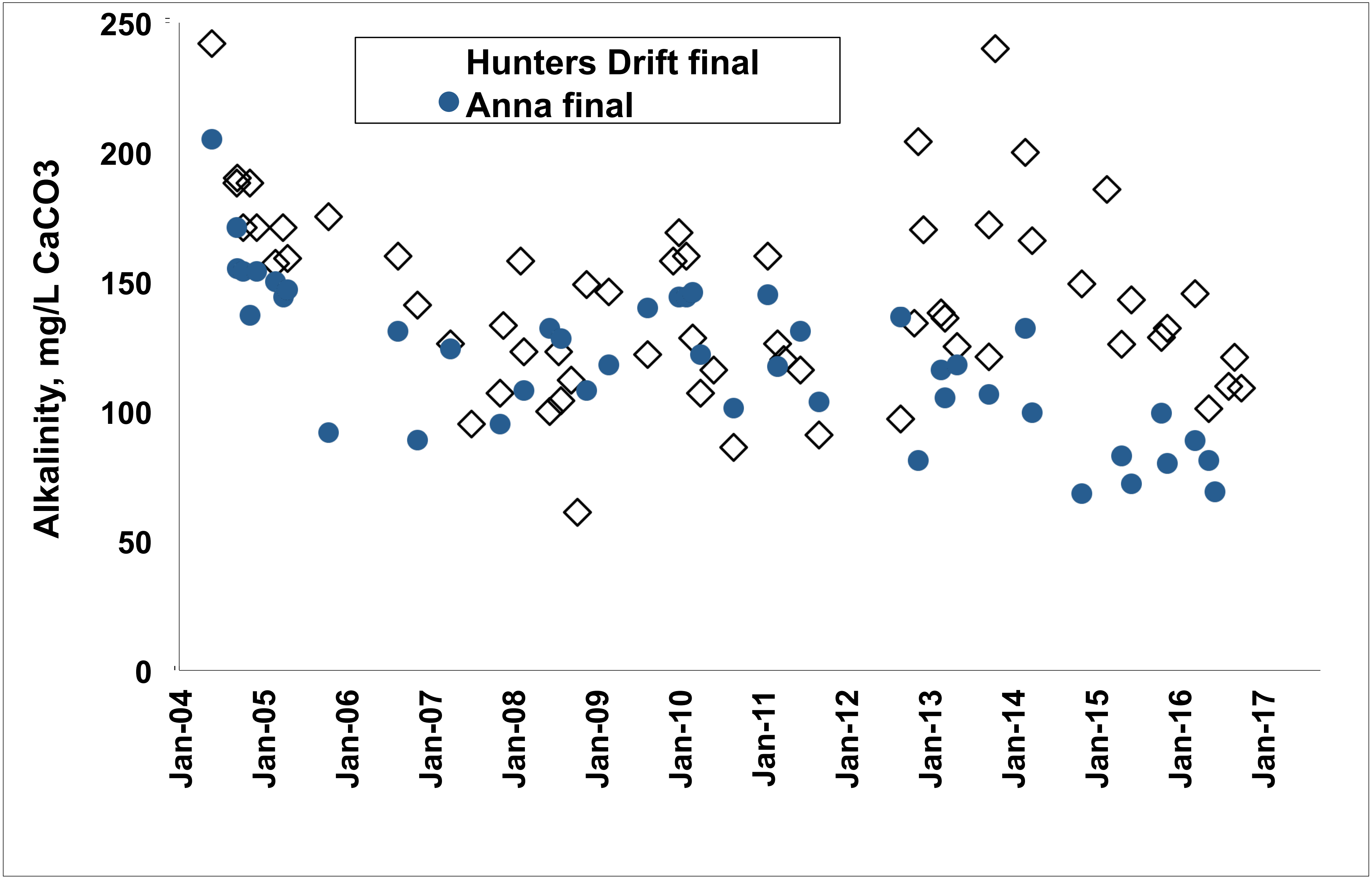
$Fe^{3+} + Fe^{2+}\ H_2S \rightarrow Fe^{2+}, FeS, FeS_2, S^0$

Anna S Passive Treatment Complex timeline

Year	Activity
1999	Feasibility and conceptual design
2001	Grant for final design, permitting, and construction
2004	System operational
2013	Replacement of organic substrate in Hunters Drift VFPs
2016	Replacement of organic substrate in Anna S VFPs

Anna S passive systems, 2004 - 2016

	Flow	pH	Alk	Acid	Fe	Al	Mn	SO_4
	gpm	s.u.	mg/L $CaCO_3$		mg/L	mg/L	mg/L	mg/L
Hunters Drift System								
HD influent	225	2.8	0	347	35.4	32.7	6.4	551
Final	na	7.5	142	-112	0.4	0.3	2.0	493
Anna System								
S1 influent	204	3.1	0	138	6.9	12.3	7.8	342
S2 influent	27	3.8	0	32	1.7	5.7	1.8	130
Final	na	7.5	119	-99	0.8	0.3	3.2	302



Hunters Drift final
Anna final
Alkalinity, mg/L CaCO3
250
200
150
100
50
0
Jan-04
Jan-05
Jan-06
Jan-07
Jan-08
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13
Jan-14
Jan-15
Jan-16
Jan-17

Operation and Maintenance

- Routine inspections and sampling
  - Bi-monthly by Babb Creek Watershed Association
- System improvements and minor maintenance
  - Hunters Drift collection system upgrades; channel cleanouts
- Organic substrate replacement

Organic Substrate Replacement

- Drained individual VFPs and inspected substrate
  - Black substrate (FeS) indicates reducing conditions and viability
  - Brown/grey substrate indicates oxidizing conditions and accumulation of iron and Al hydroxides

Photos of substrate

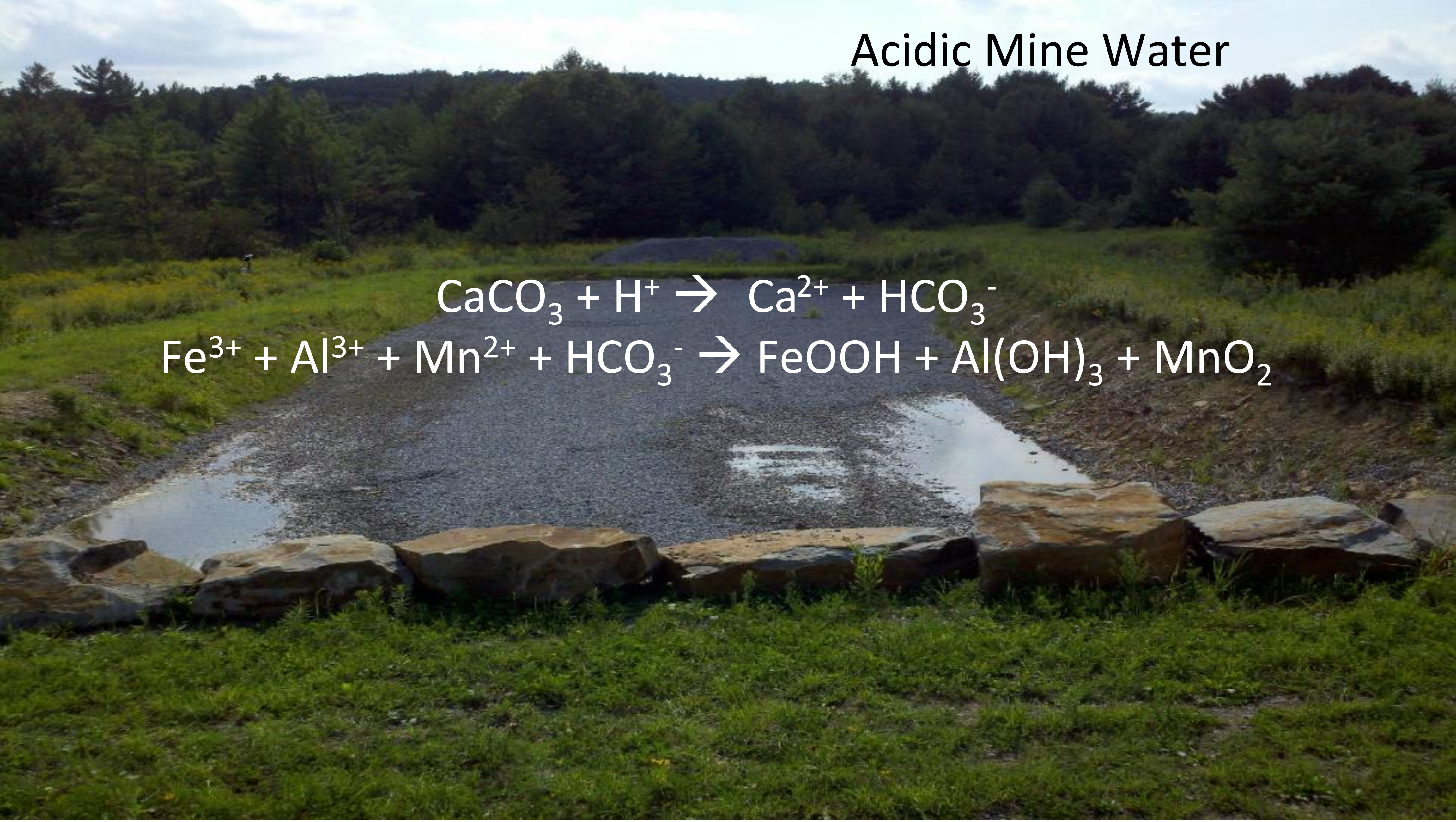
Anna S Passive Complex Costs, 1999 – 2016

(456 gpm, 235 mg/L acidity, 22 mg/L Al, 20 mg/L Fe)

Year	Cost	Activity
1999	25,000	Feasibility and conceptual design
2002	$2,512,00 0	System design, permitting and construction
2012	$210,008	New organic substrate in four VFPs
2015	$201,706	New organic substrate in four VFPs
Annual	$7,670/yr	Babb Creek Watershed Association, bi-monthly inspections and routine maintenance
Periodic		Evaluate organic substrate condition every ten years

Tangascootack #1 Passive System

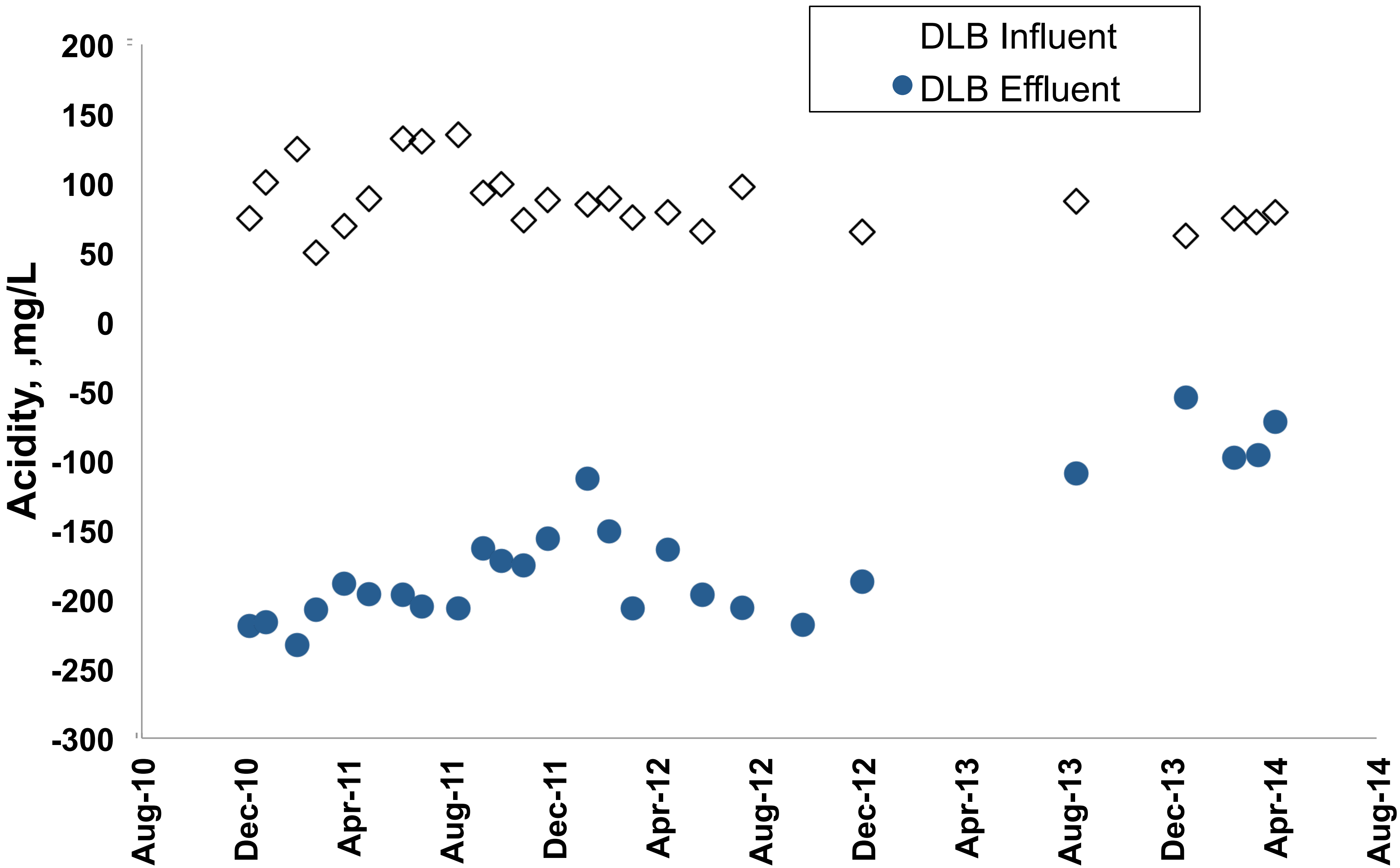
Oxic Limestone Bed (drainable)


Acidic Mine Water
$CaCO_3 + H^+ \rightarrow Ca^{2+} + HCO_3^-$
$Fe^{3+} + Al^{3+} + Mn^{2+} + HCO_3^- \rightarrow FeOOH + Al(OH)_3 + MnO_2$

Agri Drain Smart Drainage System
(solar powered computer controlled gate valve)

Tangascootack #1 system, Nov 2010 – Apr 2014

	Flow	pH	Alk	Acid	Fe	Al	Mn	SO_4
Inflow	na	4.0	0	89	0.2	11.1	25.9	927
DLB out	45	7.3	197	-169	0.1	0.2	1.7	968



DLB Influent
DLB Effluent
Acidity, ,mg/L
200
150
100
50
0
-50
-100
-150
-200
-250
-300
Aug-10
Dec-10
Apr-11
Aug-11
Dec-11
Apr-12
Aug-12
Dec-12
Apr-13
Aug-13
Dec-13
Apr-14
Aug-14

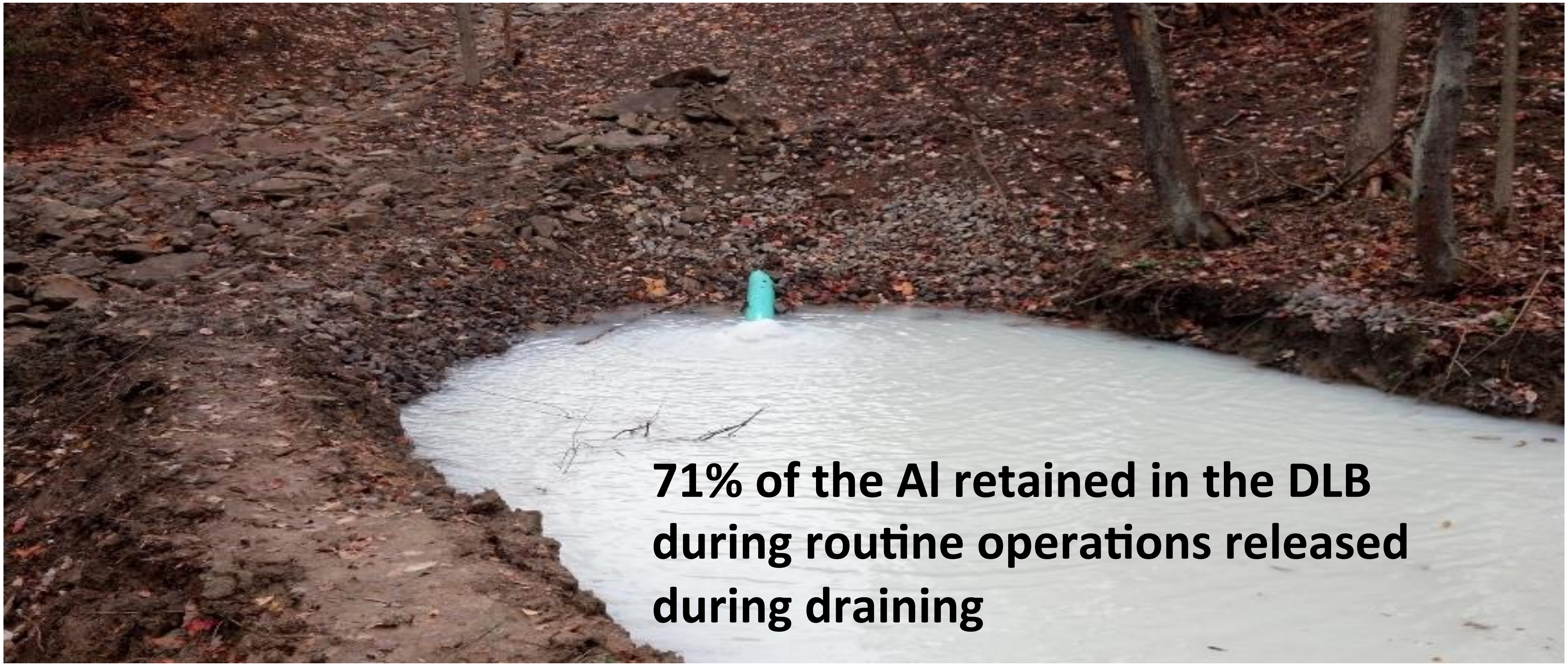
Operation and Maintenance

- Routine inspections and sampling
  - quarterly by Clinton County Conservation District
- Major maintenance: solids management

Solids Management

- Routine draining removes portion of solids
- Infrequent cleaning of stone removes remaining solids

Pittsburgh Botanic Garden DLB
solids basin during end of draining



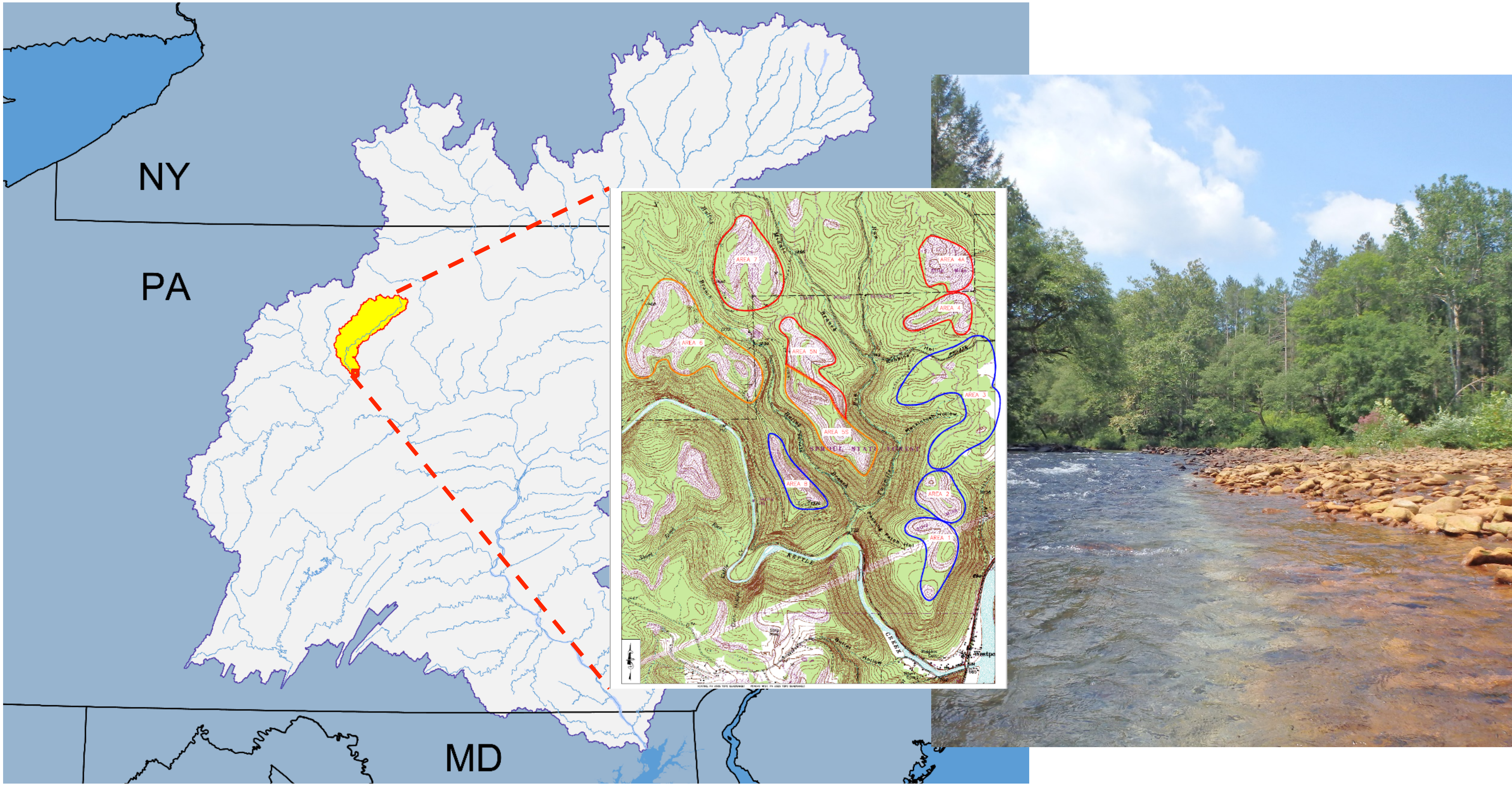
Tangascootac #1 Passive System Costs
(45 gpm, acidity 89 mg/L, Al 11 mg/L, Mn 26 mg/L)

Year	Cost	Activity
2009	$65,572	Design, permit and construction
2012	$5,000	Clean limestone aggregate
Annual	$2,000/yr	Clinton County Conservation District, quarterly inspections, sampling, and routine maintenance
Periodic		Clean and replace limestone aggregate; every four years; $5,000 per event

Projected 20 year treatment costs

			20 year unit costs		
Site	**Water chemistry**	**technology**	**$/1000 gal**	**$/lb-Fe**	**$/ton-$CaCO_3$**
Marchand	Alkaline, Fe	Ponds & wetland	$0.09	$0.15	na
Anna	Acid, Fe, Al, Mn	Vertical flow ponds and wetlands	$0.65	na	$435
Scootac #1	Acid, Al, Mn	Drainable limestone bed and pond	$0.34	na	$324

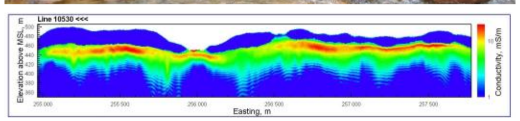
Lower Kettle Creek Watershed Restoration 1999-present

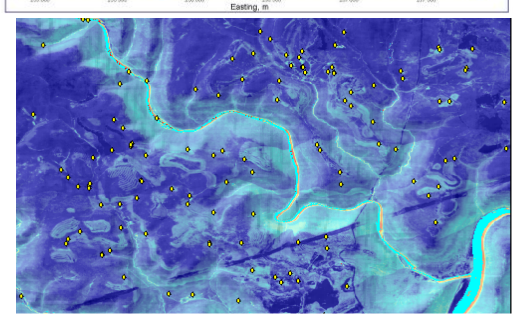


TROUT UNLIMITED

Intensive planning, data collection, and monitoring

Assessment and planning



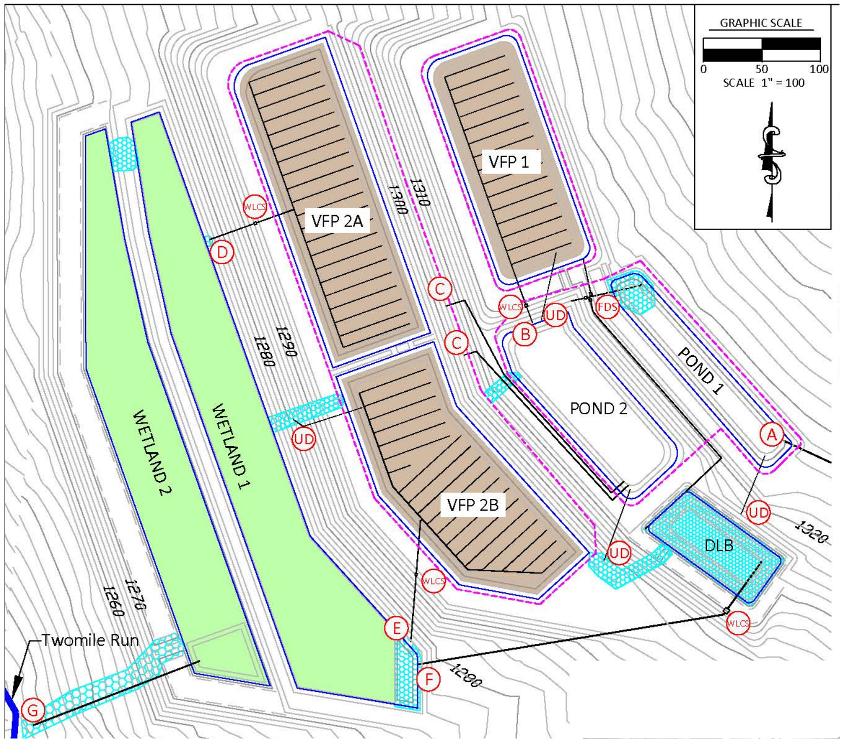


Design, permitting, and construction

Follow-up assessment and planning

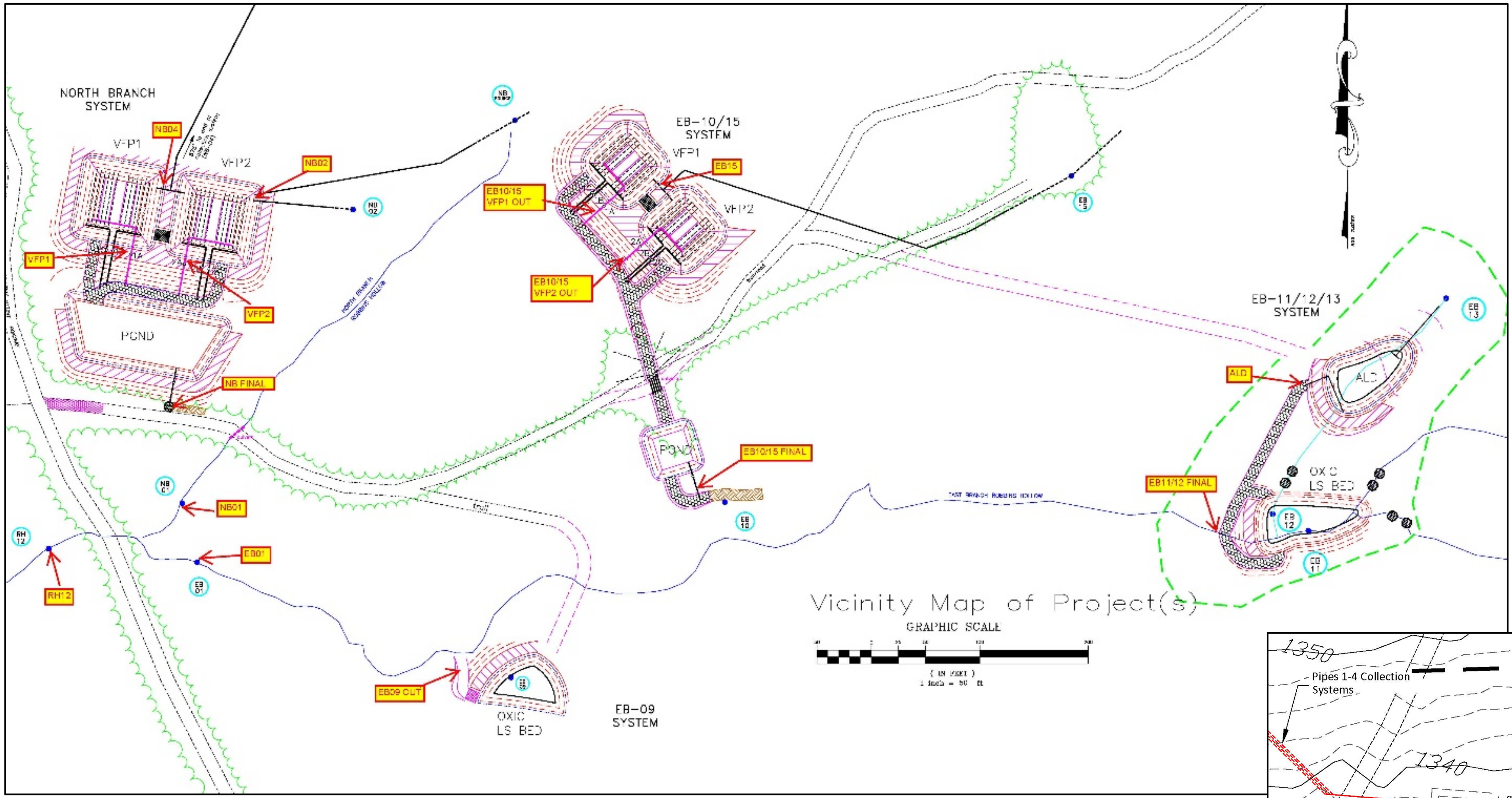
More design, permitting, and construction

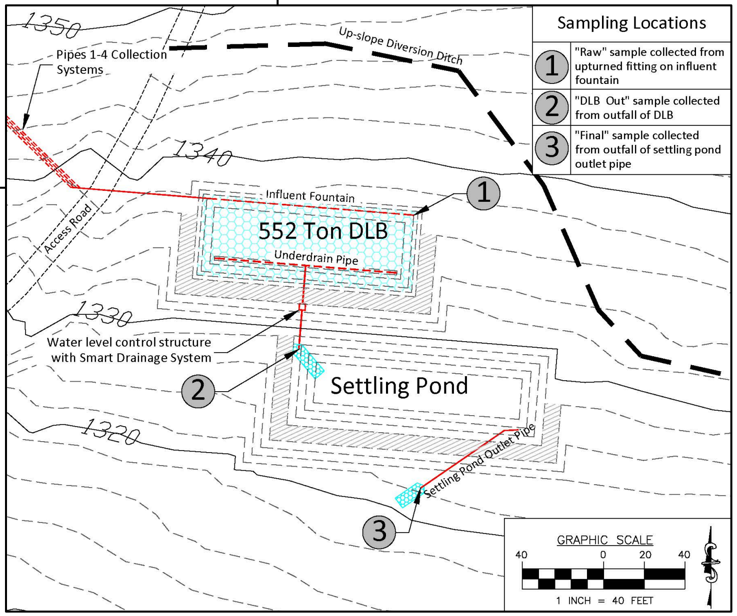
Swamp Area passive treatment system



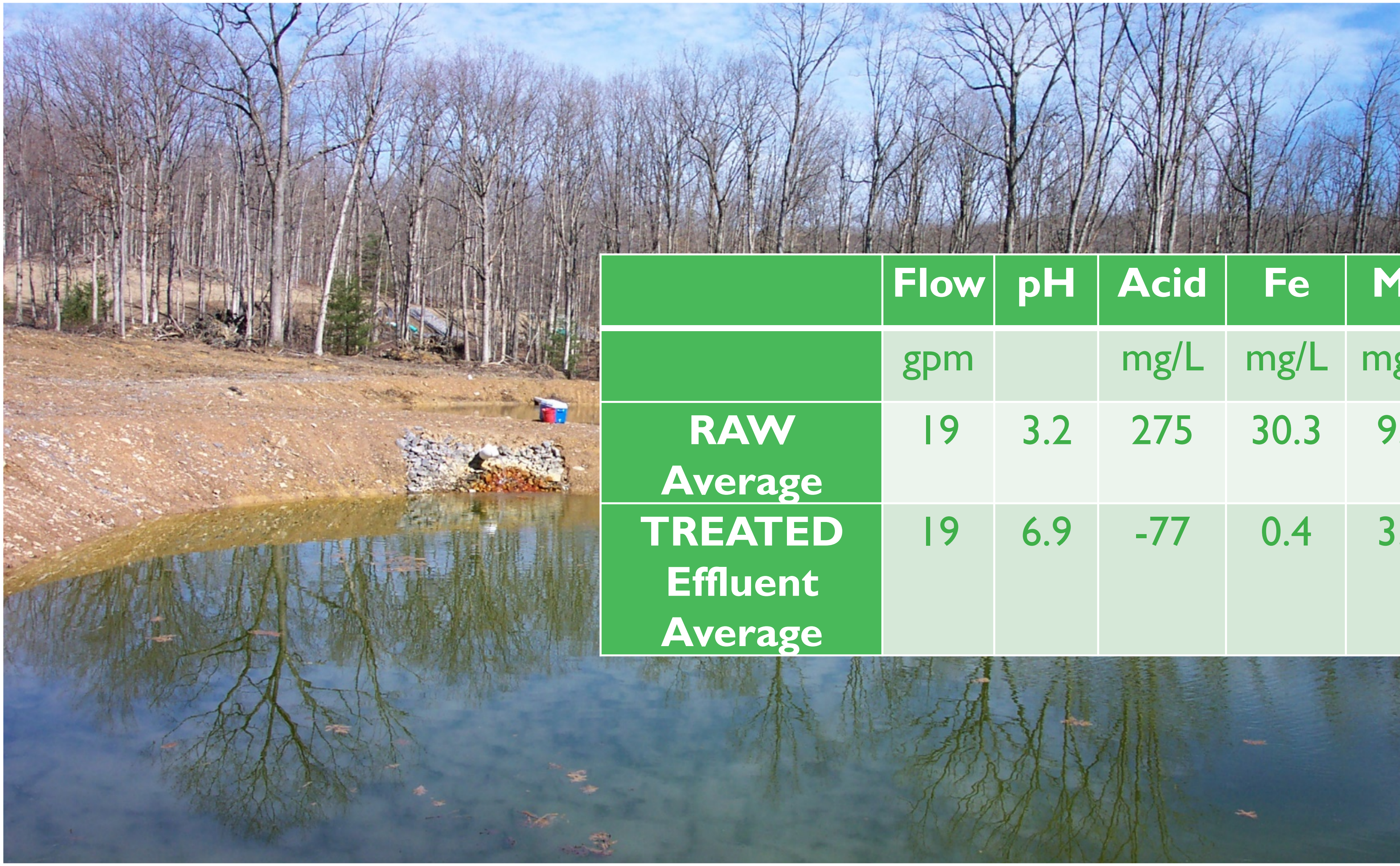
	Flow	pH	Acid	Fe	Mn	Al
	gpm		mg/L	mg/L	mg/L	mg/L
RAW Average	59	3.0	430	63.2	24.9	39.0
TREATED Effluent Average	59	7.6	-149	0.4	9.4	<0.3

Robbins Hollow passive treatment systems (7)



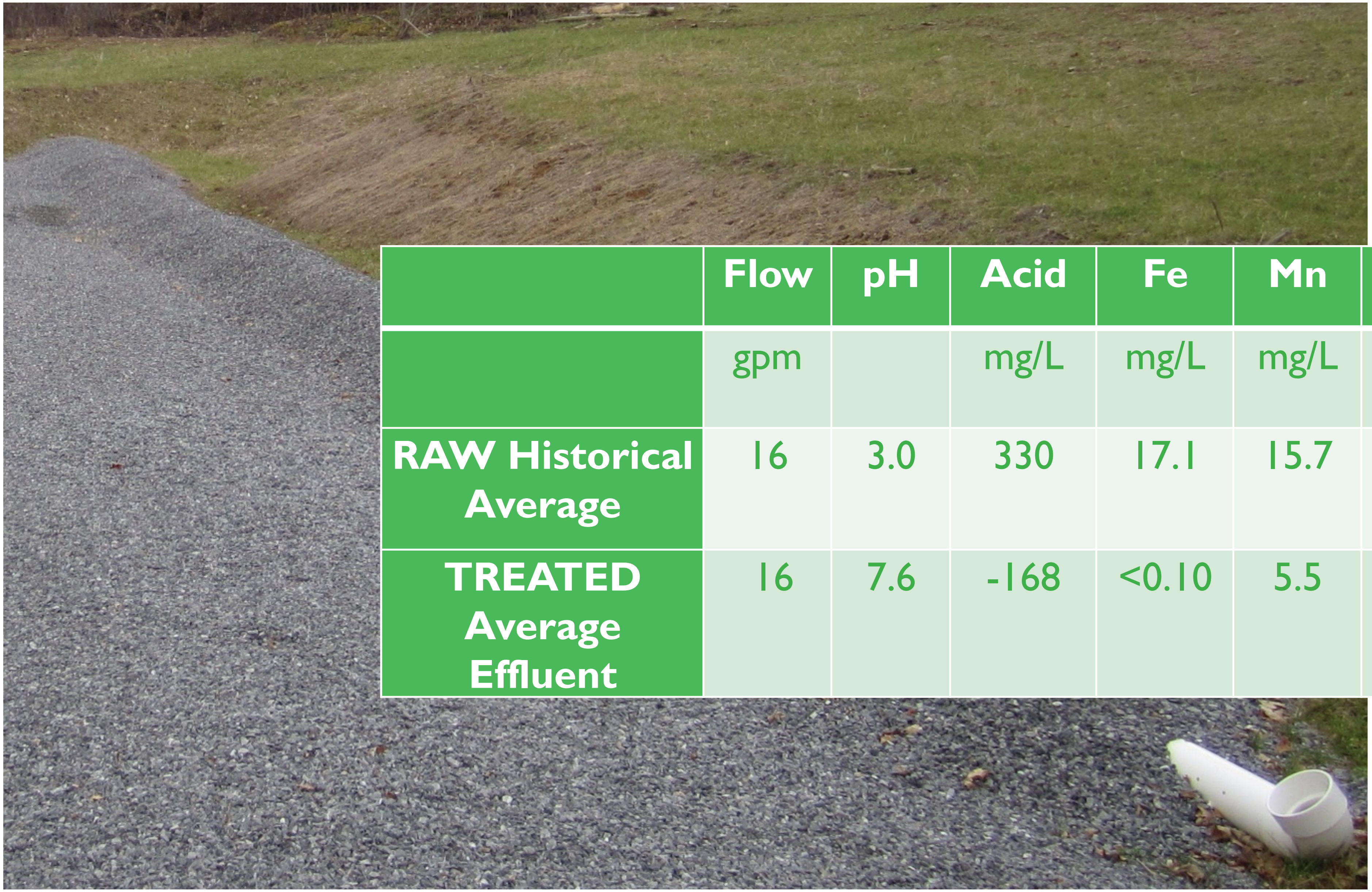


Robbins Hollow passive treatment – Highlighting VFP performance



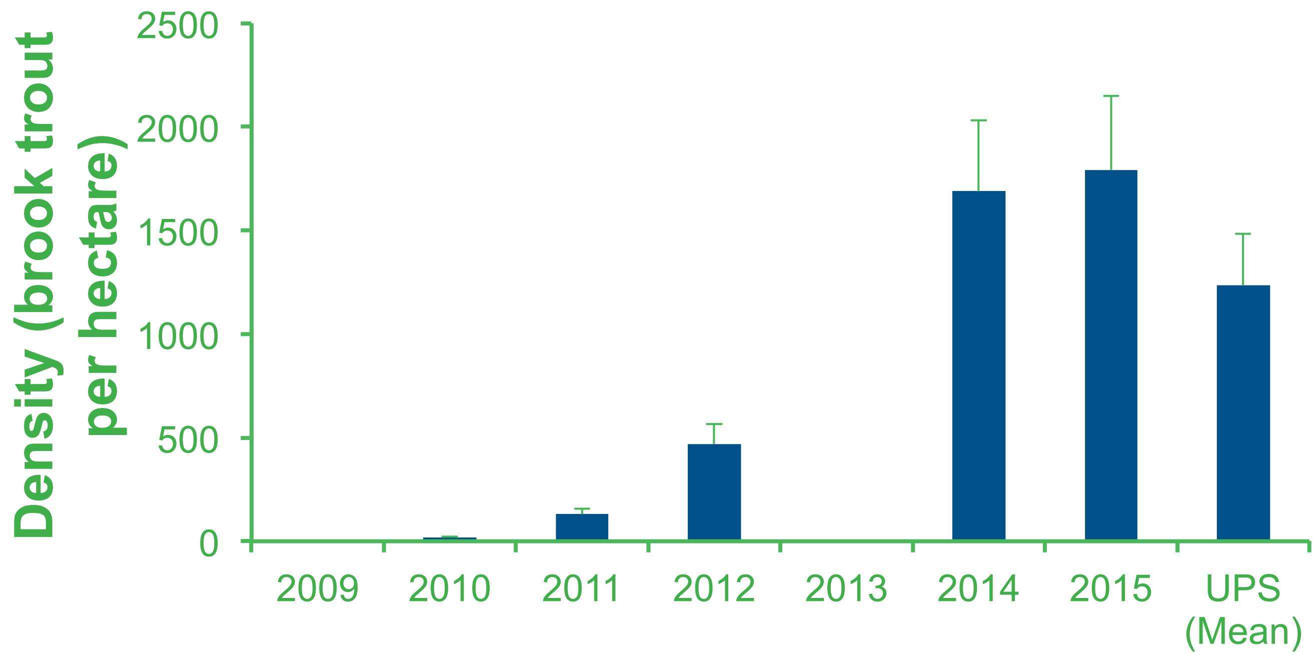
	Flow	pH	Acid	Fe	Mn	Al	SO_4
	gpm		mg/L	mg/L	mg/L	mg/L	mg/L
RAW Average	19	3.2	275	30.3	9.9	27.8	499
TREATED Effluent Average	19	6.9	-77	0.4	3.6	0.5	372

Robbins Hollow Passive Treatment – Highlighting DLB performance



	Flow	pH	Acid	Fe	Mn	Al	SO_4
	gpm		mg/L	mg/L	mg/L	mg/L	mg/L
RAW Historical Average	16	3.0	330	17.1	15.7	39.5	737
TREATED Average Effluent	16	7.6	-168	<0.10	5.5	0.4	429

Passive treatment systems have led to biological recovery



- Nearly 7 miles of native brook trout habitat have been reconnected
- Brook trout are now thriving and reproducing in previously dead stream sections

OM&R activities to date

Keys to ensuring long-term passive treatment success

- Install water collection systems to monitor only AMD flows (minus clean surface water runoff)
- Take time to collect adequate amount of water chemistry and flow data (minimum representation of at least one low flow sampling round and one high flow event)
- Proper design – technology based on chemistry; sizing based on loading
- Proper construction
- Monitor instream and treatment system components quarterly
- Conduct routine inspections, particularly following storm events
- Follow through with routine maintenance
- Decreased performance in one or more of system components is signal to begin planning for additional maintenance or rehab activities

Keys to ensuring long-term passive treatment success

System	2017				2018				2019				2020				2021			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
1									X											
2									X											
3									X											
4									X											
5			X		X														X	
6			X		X														X	
7														X						
8																				
9		X																		

System	2022				2023				2024				2025				2026			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
1									X		X									
2									X		X									
3									X											
4									X		X									
5															X					
6															X					
7	X																			
8	X																			
9	X	X		X																

System	2027				2028				2029				2030				2031			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
1									X											
2									X											
3									X											
4									X											
5					X						X									
6					X						X									
7	X							X												
8	X			X																
9	X	X																		

System	2032				2033				2034				2035				2036			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
1									X		X									
2									X		X									
3									X											
4									X		X									
5					X		X													
6					X		X													
7	X																	X		
8	X																			
9	X	X		X																

System Key
1 Robbins Hollow East Branch 10/15
2 Robbins Hollow East Branch 11/12
3 Robbins Hollow East Branch 13
4 Robbins Hollow East Branch 9
5 Robbins Hollow 10a/10b
6 Robbins Hollow Pipes 1-4
7 Robbins Hollow North Branch
8 Middle Branch
9 Swamp

Task Key
A Vegetation Control
B Organic Substrate Mixing
C Limestone Cleaning
D Organic Substrate Replacement

Limestone Cleaning - Cleaning of Limestone with equipment

System	Tons	Unit Cost	Construction Cost	PM and CO	Total Cost	Interval
RH EB 10/15	850	$7	$5,950	$1,190	$7,140	10
RH EB 11/12	973	$7	$6,811	$1,362	$8,173	10
RH EB 13	450	$15	$6,750	$1,350	$8,100	20
RH EB 9	690	$7	$4,830	$966	$5,796	10
RH 10a/10b	721	$7	$5,047	$1,009	$6,056	4
RH Pipes 1-4	552	$7	$3,864	$773	$4,637	4
Swamp	900	$7	$6,300	$1,260	$7,560	10

Thank You!

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