Selection of ARD treatment alternatives to meet water quality criteria

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We need to address different regulatory mandates for point and non-point sources

- Important goals of the US Federal Clean Water Act:
  A. protect waters from impairment (§402 CWA)
     active, point sources-increasingly stringent end of pipe limits
  B. restore impaired waters (§303 CWA) to their designated use
     legacy or non-point sources-abandoned mines, agriculture, forestry
- This places focus on restoring the maximum miles of stream to their designated use
- Most stream impairment results from multiple discharges
- Need to rationalize treatment to recover the maximum stream values/$

Strategy for watershed restoration:

1. Funded by mitigation or public programs
   - Mitigation=compensation for disturbance
2. Develop watershed based mitigation plans
3. Identify environmental benefits of mitigation projects
4. Identify technologies and costs of projects
5. Prioritize projects
6. Identify project partners/sponsors
7. Install projects
8. Document environmental benefits

Watershed Improvement Planning:

- Develop an inventory of watershed based remediation plans, those plans would include:
  - Description of Problem Areas
  - Remediation strategy
  - Anticipated level of improvement of aquatic resources
  - cost

Quantifying costs and benefits

STEP 1 – Select a Targeted Watershed (10 Digit HUC scale).

STEP 2 – Describe the current condition landscape (CEUs and LEUs).

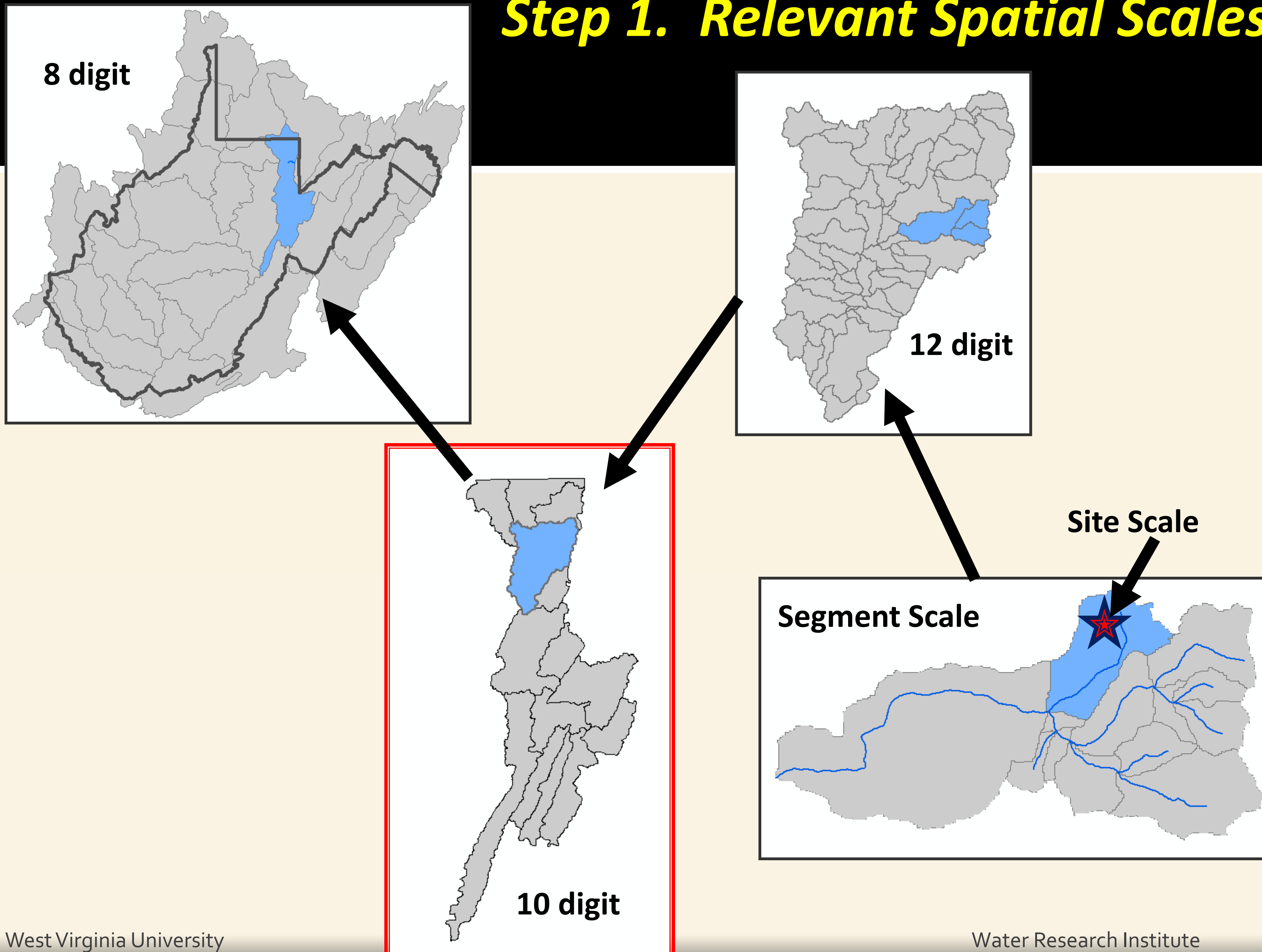
STEP 3 – Design alternative placement of treatment technologies (idealized at-source vs. strategic alternatives with mix of in-stream and at-source).

STEP 4 – Calculate REUs associated with each alternative.

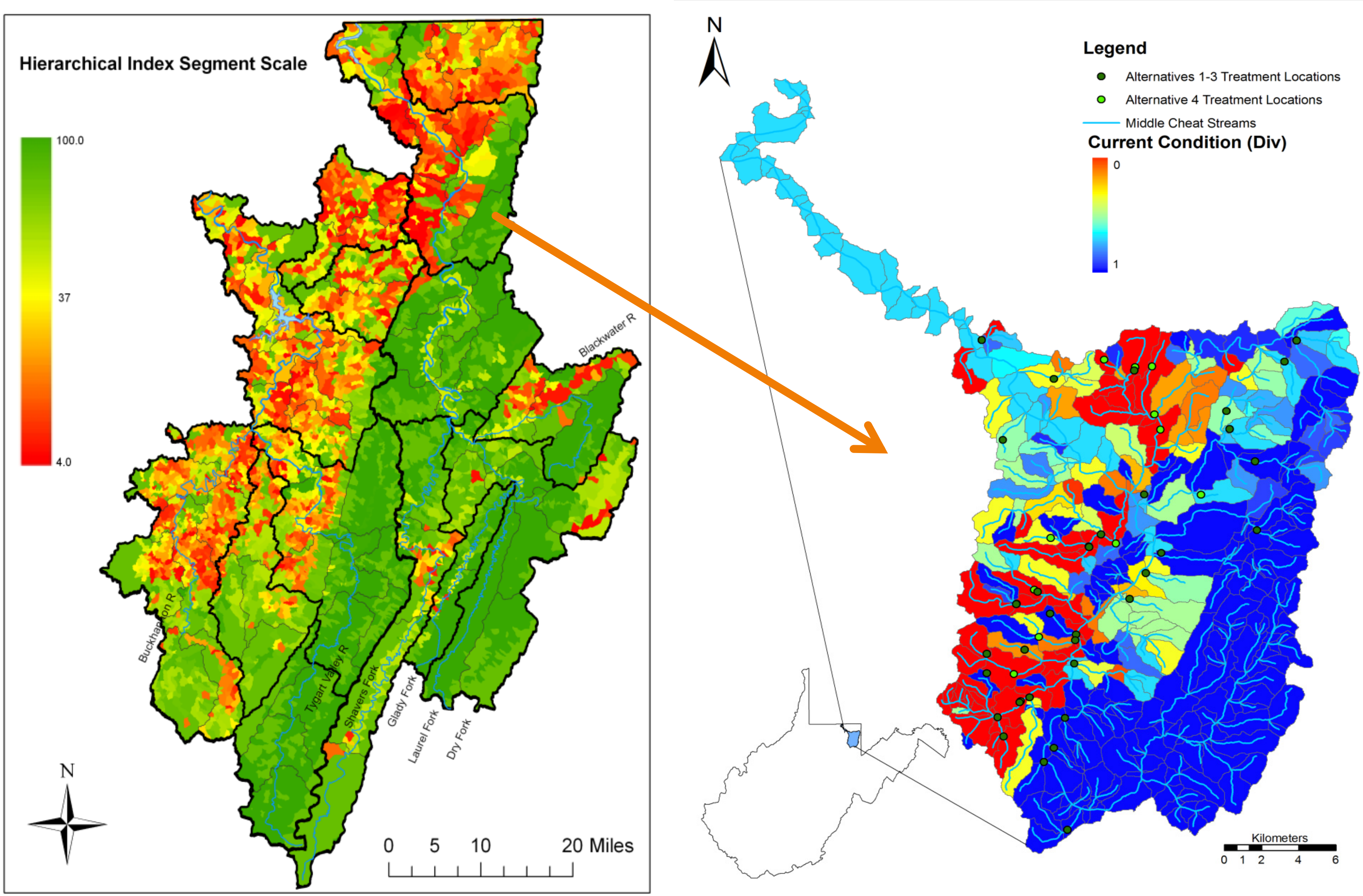
STEP 5 – Calculate $ benefits and Net Present Values associated with each Alternative.

STEP 6 – Implement monitoring program designed to quantify benefits of restoration plan.

Step 1. Relevant Spatial Scales



Step 2 – Current Conditions Middle Cheat R.



EcoUnit Concept

= a measure of the functional significance of a measurable unit of stream (length or surface area).

EU = Functional Weights x Stream Segment Length (km)

- **calculated for all stream segments within a defined area**
- ***scalable from stream segment to whole watershed***
- **decision making "currency"**

Example Restoration Goals:

Brook Trout Reproductive Habitat EcoUnit = stream length (m) weighted by its potential value as habitat for brook trout spawning and juvenile recruitment (Petty and Thorne 2005; Jeffers et al. 2008).

Warmwater Fishery EcoUnit = stream length (km) weighted by its potential value as habitat for smallmouth bass (Merovich and Petty 2007).

Invertebrate Diversity EcoUnit = stream length (km^2) weighted by its potential to support diverse macroinvertebrate assemblages (Merovich and Petty 2007).

Organic Matter Processing EcoUnit = stream length (m) weighted by its potential value in converting coarse particulate organic matter to biomass.

EcoUnit Calculation

HEU = SL x EP = Historic EUs

CEU = SL x EP x EC = Current EUs

LEU = HEU – CEU = Lost EUs

REU = LEU x ER = Restorable EUs

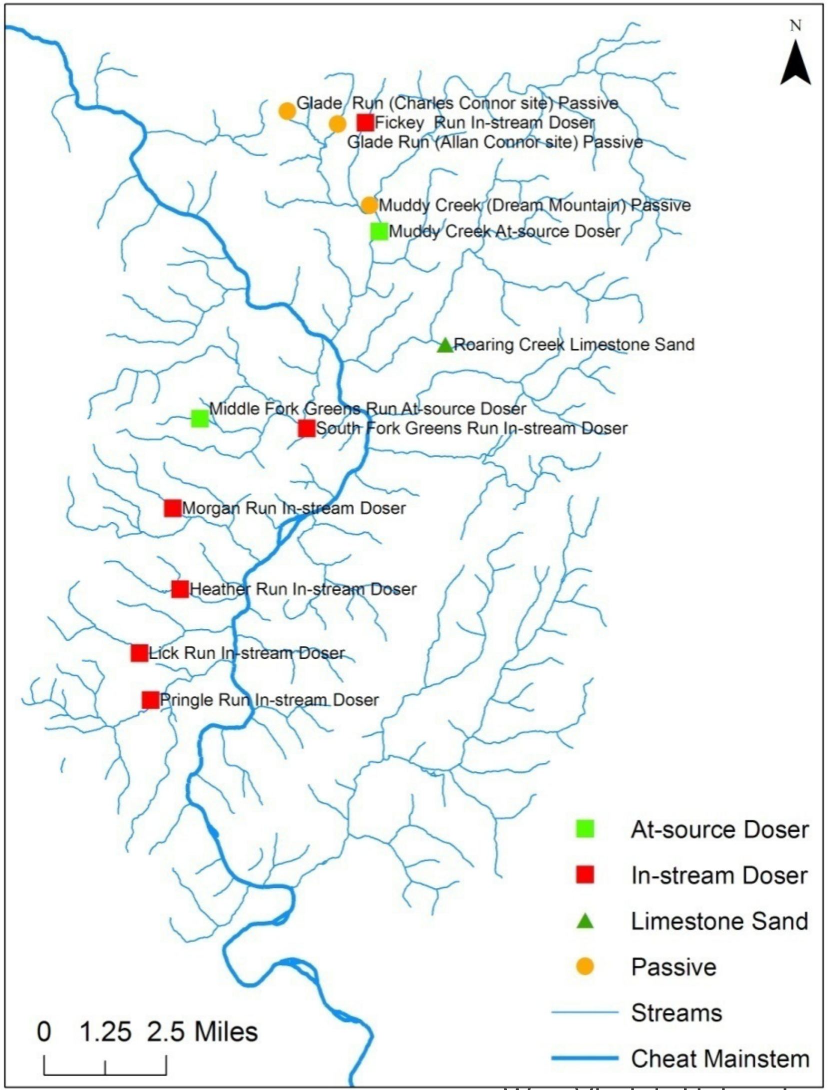
FEU = CEU + REU = Future EUs

- SL = segment length
- EP = ecological potential weight
- EC = ecological condition weight
- ER = ecological restorability weight

Current Conditions in Middle Cheat

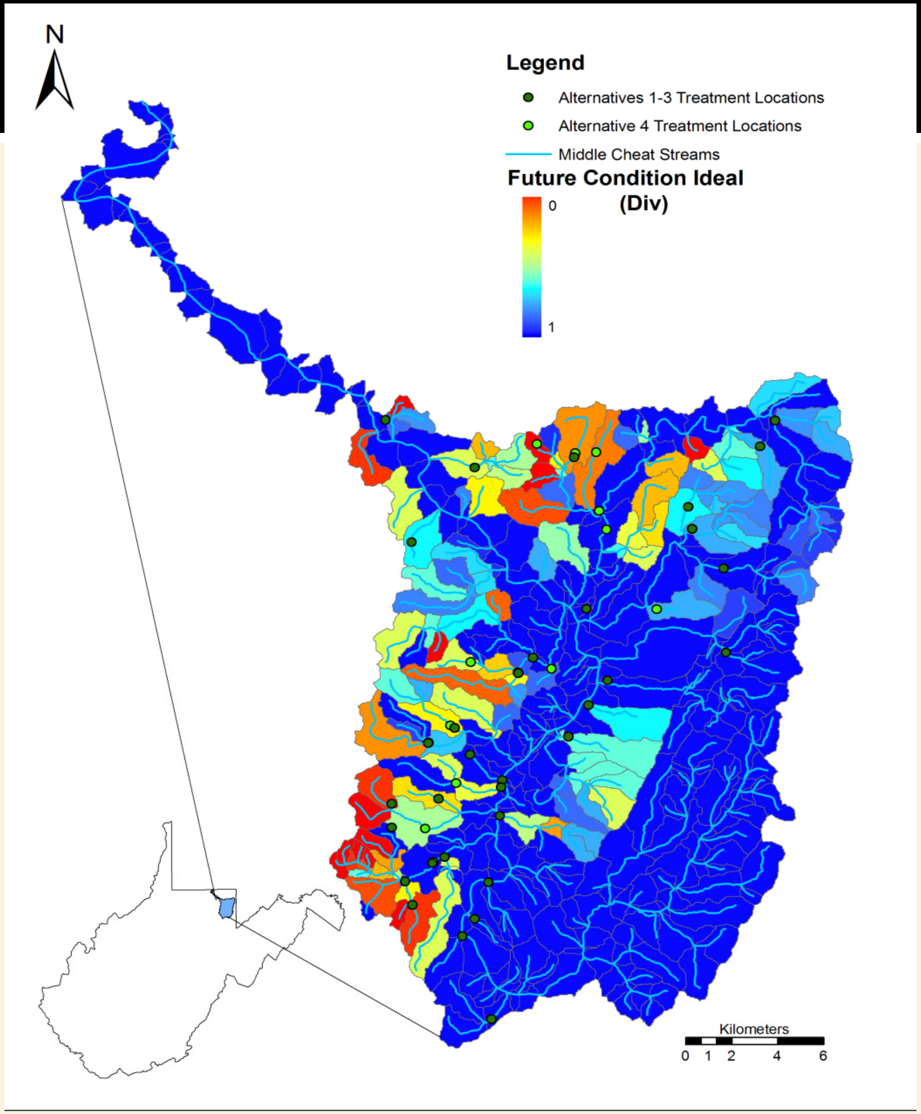
	EcoUnits (miles)			
	Diversity	Coldwater Fishery	Warmwater Fishery	Overall Fishery
HEUs	332	258	50	326
CEUs	235	132	28	171
LEUs	96	126	21	155

STEP 3 – Alternative Treatment Strategies (technology and placement)

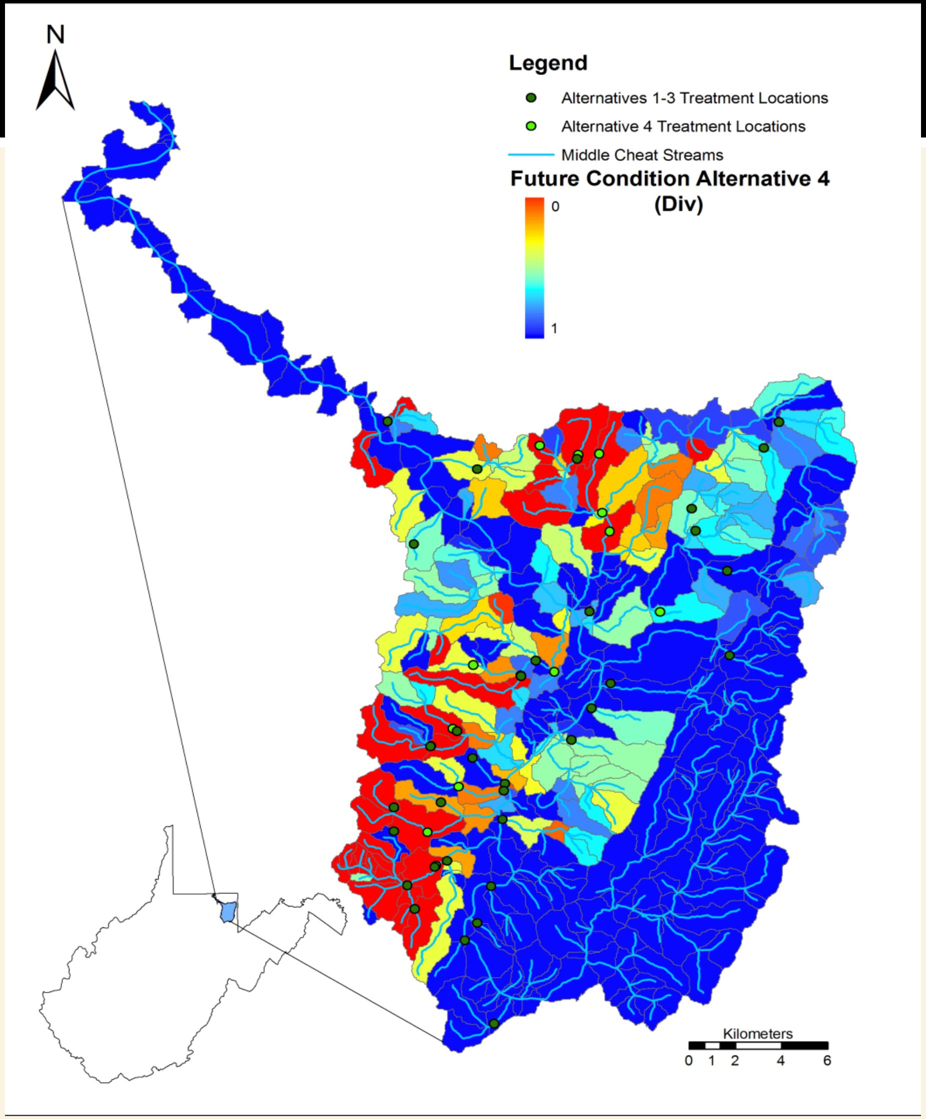


1. In-stream, headwater dosing
2. Full at-source dosing
3. Full at source passive with in-stream finishing dosers
4. Strategic mixture of the above technologies

Step 4 – Calculate REUs and FEUs for various alternatives



Future Condition – Ideal



Future Condition – Alt 4

REUs in Middle Cheat

	Restorable EcoUnits (miles)			
Alternative	Diversity	Coldwater Fishery	Warmwater Fishery	Overall Fishery
Ideal	41	27	21	56
1	13	0.5	14	19
2 / 3	31	10	21	38
4	19	4	19	25

Step 5 – Calculate NPVs for each Alternative

- NPV = (total benefit – total cost) x annual discounting factor.
- Fishery benefits = $28,000 / fishery mile (from USFWS 2006).
- Benefits (from restored fishery miles) begin accruing in year 3.
- Parentheses indicate a net cost to restoration.

Annual Costs, Present Value*

(2007 dollars, discounted at 3%)

Alternative	1 Year Project	5 Year Project	10 Year Project	20 Year Project
1	1,628,356	7,681,117	14,306,916	24,952,605
2	1,768,628	8,342,793	15,539,360	27,102,103
3	1,528,350	7,209,380	13,428,254	23,420,136
4	286,340	1,350,693	2,515,813	4,387,814

Total Cost over Project Lifetime, Present Value*

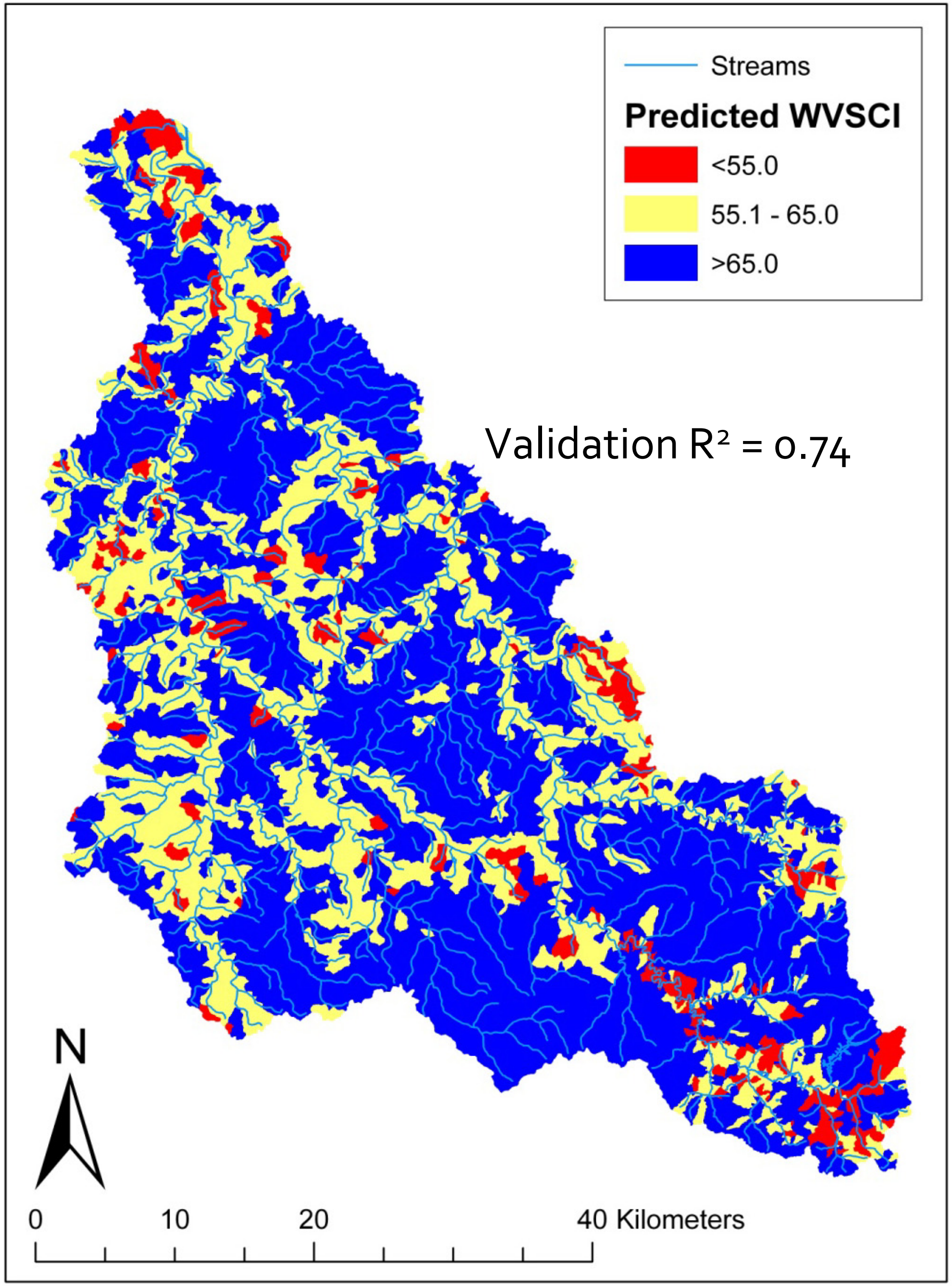
(2007 dollars, discounted at 3%)

Alternative	1 Year Project	5 Year Project	10 Year Project	20 Year Project
1	6,878,356	12,931,117	19,556,916	30,202,605
2	13,468,628	20,042,793	27,239,360	38,802,103
3	20,604,987	26,286,017	32,504,891	42,496,773
4	3,876,622	4,940,975	6,106,095	7,978,096

Net Present Value of Alternatives, Overall Fishery

(2007 dollars, discounted at 3%)

Alternative	Total 1 Year	Total 5 Year	Total 10 Year	Total 20 Year
1	(6,878,356)	(11,453,887)	(15,888,246)	(23,004,288)
2	(13,468,628)	(17,111,414)	(19,959,343)	(24,517,941)
3	(20,604,987)	(23,354,638)	(25,224,875)	(28,212,612)
4	(3,876,622)	(2,985,953)	(1,250,840)	1,548,428



Current Conditions: WVSCI

Mining: $R^2 = 0.69$; $p < 0.003$

	Estimate	R^2
Intercept	75.692	
asin√%SM	-14.131	0.21
logNPDES (DM)	-5.930	0.48

Developed: $R^2 = 0.80$, $p = 0.0003$

	Estimate	R^2
Intercept	76.15	
200M Structures	-0.51	0.64
Log NPDES (Sewage)	-4.25	0.16

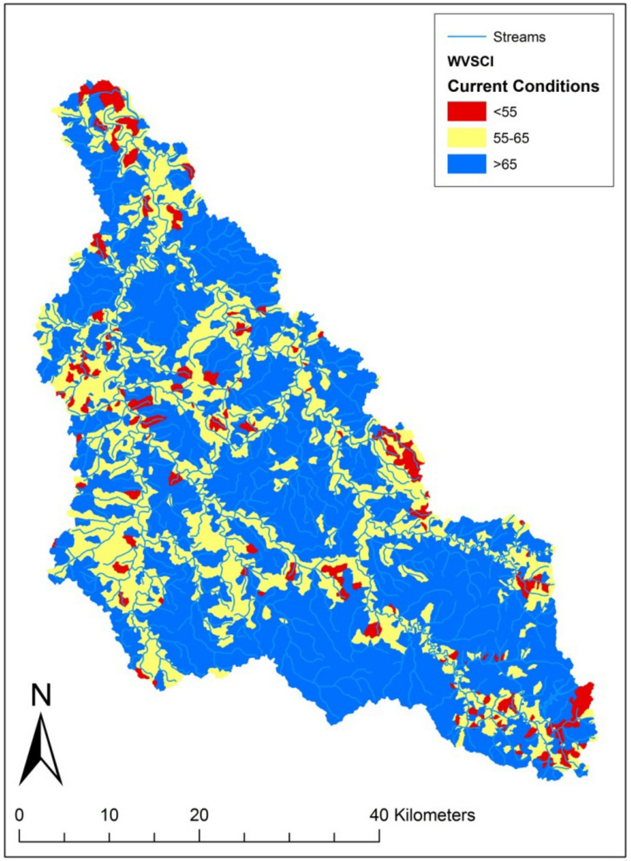
Combined: $R^2 = 0.71$; $p < 0.0001$

	Estimate	R^2
Intercept	74.27	
asin√%SM	-21.36	0.19
200M Structures	-0.54	0.52

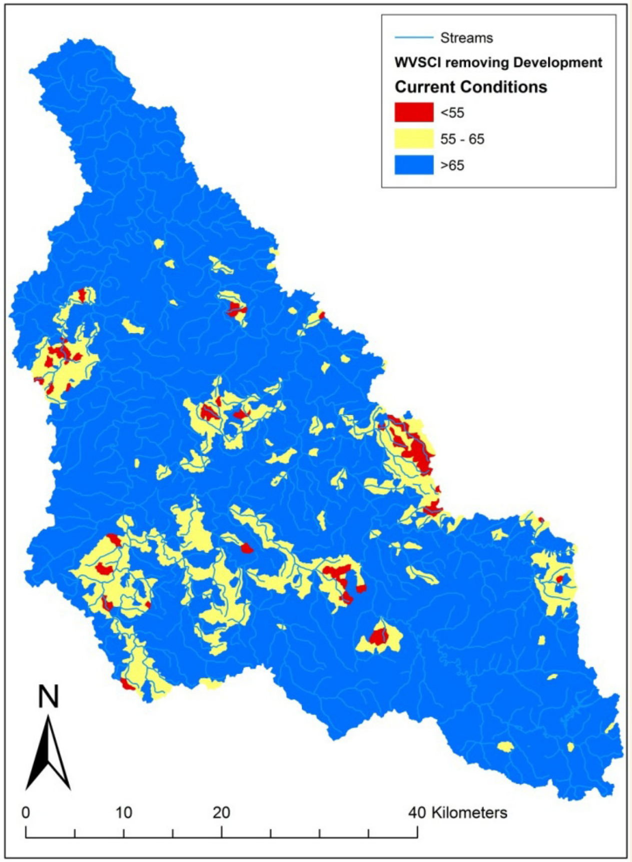
Watershed Futures Planner:

Stream Condition Index: Reduced Residential Effect

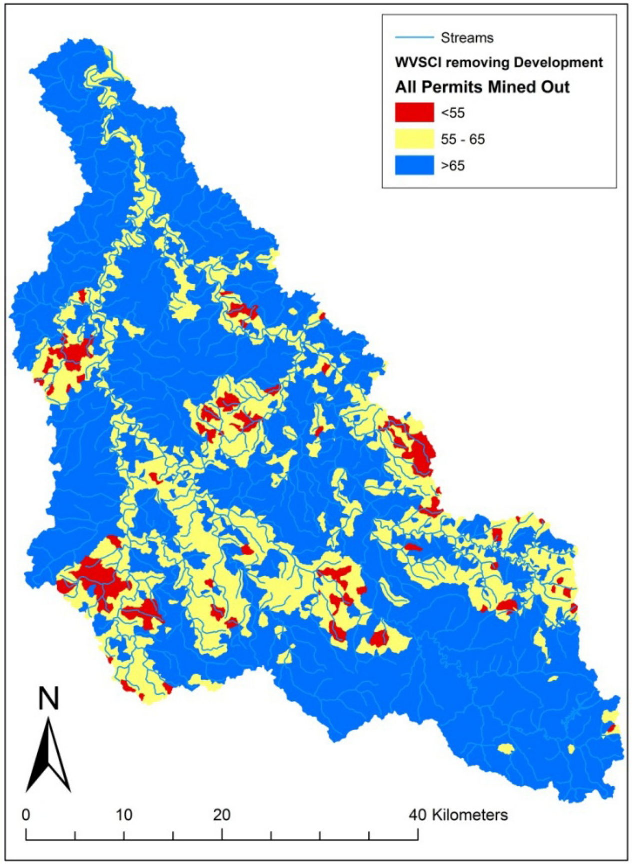
Current



Current w/ RRE



RRE + All permits



# streams impaired	1506	607 ↓60%	1302 ↓14%

Treatment Options

- At source lime dosing with sludge collection and disposal
- In stream dosing:
  - Limestone sand dump stations
  - Lime dosers
- At source passive treatment

At-source lime doser

Sludge Cleanout

In Stream Dosing: Middle Fork Limestone Sand Station

In Stream Dosers: Maryland

Boxholm

Pumpkonsult

Aquafix

In Stream Lime Dosing: West Virginia

On Site Passive Treatment
Open Limestone Channel: West Virginia

Indirect treatment
Slag Leach Bed: Ohio

Treatment technology selection: AMDzine

Compliance with CWA §402 permitting conditions:

- pH 6-9
- Fe_{total} 1.42 mg/L
- Mn_{total} 1.0 mg/L
- Al_{total} 0.43 mg/L

In order to meet compliance requirements all systems are designed to meet **maximum** flow

AMDzine

- AMD is treated in series by separate technologies
- AMDzine evaluates how those technologies are assembled to meet
  - a specific WQ standard
  - at a particular site
- CapX and OpX costs generated separately
- Currently being used to meet compliance with a Federal Court Order

Input: site information and regulatory standards

Site Name	A1
Discharge Standards	
pH	
min	6.00
max	9.00
Iron (mg/L)	1.42
Aluminum (mg/L)	0.43
Manganese (mg/L)	1

Raw Water Data	
Flow (gpm)	
min	1.00
max	300.00
Average	25.00
pH average	2.50
Acidity (hot) (mg/L)	50.00
Alkalinity	3.00
Fe Total (mg/L)	300.00
Fe Dissolved (mg/L)	100.00
Fe Ferrous (mg/L)	100.00
Al (mg/L)	80.00
Mn (mg/L)	5.00
Sulfate (mg/L)	2500.00
Calcium (mg/L)	300.00
Magnesium (mg/L)	65.00
DO (mg/L)	0.50
1 hr. Aeration Test	
Initial pH	2.50
Ending pH	3.00

Calculated Data	
Iron Load (Ferrous)	lbs/day
min	1.202
max	360.479
average	30.040
	mg/L
Al acidity	444.77
Fe ++ acidity	
Fe +++ acidity	268.62
Mn Acidity	9.10
pH Acidity	158.11
Total Acidity	880.61
Sludge injection head	0
Carbon Dioxide Acidity	108.11

Site data	
Height of discharge above stream (ft)	1
Is this a pumped discharge (Y/N)	N
Area of land below discharge elevation with slope less than 10% within 1000 feet of discharge (acres)	2
Single Phase Power	N
Three phase power	N
Distance to 3 phase power	1000
Elevation of Sludge Discharge	1000
elevation of sludge pump	1000
Length of sludge pipe	250
Surface area	2.2
Fresh water available (gpm) up slope	10

The AMDzine decision tree:

	Passive pH adjustment	Unit Appropriate
0	Anoxic Limestone Drain	FALSE
0	Open Limestone Channel	FALSE
0	Vertical flow pond (reducing)	FALSE
0	Vertical flow pond (auto siphon)	FALSE
0	limestone leach bed "D"	FALSE
0	limestone leach bed "M"	FALSE
0	Aerobic wetland	FALSE
0	Anaerobic wetland	FALSE
0	Steel slag bed	TRUE
0	Pre Aeration needed O_2 lbs/hr	
0	Stair step pre-aerator	TRUE
0	Sluce pre-aerator	TRUE
1	Trompe pre-aerator	TRUE
0	Diffusion pre-aeration	TRUE
0	Mechanical pre-aeration	TRUE

0	Post Aeration needed O_2 lbs/hr	
0	Stair step aerator	TRUE
0	Sluce aerator	TRUE
0	Trompe aeration	TRUE
0	Hydrogen peroxide (lbs / month)	FALSE
0	Diffusion aeration	TRUE
0	Mechanical aeration	TRUE
0	Settling pond (detention time hr)	FALSE
0	Clarifier	FALSE
0	Semiactive pH adjustment	
0	Doser (quick lime)	FALSE
0	Doser (hydrated lime)	FALSE
0	Sodium Hydroxide	FALSE
0	Active pH adjustment	
0	Hydrated lime (std)	FALSE
0	Hydrated Lime (high density)	FALSE

Two strategies for treating the same not so bad water -capX only

Red highlight indicates WQ standard is not met

			Area	Raw WQ				
	Q max (gpm)	Installed	Used	pH	Acidity	Fe	Mn	Al
	300	Cost	ft2	6.5	17.2	3.0	5.0	4.0
Unit 1	Stair step pre-aerator	$ 110	135	7.0	17.2	3.0	5.0	4.00
Unit 2	Vertical flow pond (reducing)	$ 276,370	48,036	7.1	14.5	3.0	5.0	0.48
Unit 3	Trompe aeration	$ 1,113	36	7.1	14.5	3.0	5.0	0.48
Unit 4	Settling pond	$ 11,770	1,400	7.1	14.5	0.9	1.0	0.48
Unit 5	limestone leach bed "M"	$ 105,330	23,528	7.1	0	0.1	0.4	0
Unit 6								
Final WQ				7.10		0.90	1.00	0.00
Target WQ				6.00		1.42	1.00	0.43
	TOTAL	$ 394,693	73,136					
	Acres		1.68					

			Area	Raw WQ				
		Installed	Used	pH	Acidity	Fe	Mn	Al
		Cost	ft2	6.0	14.5	3.0	5.0	4.0
Unit 1	Trompe pre-aerator	$ 27,165	889	5.5	13.1	3.0	5.0	4.00
Unit 2	Doser (hydrated lime)	$ 116,722	1,800	7.5	0.0	3.0	5.0	4.00
Unit 3	Settling pond	$ 11,770	1,400	7.5	0.0	0.9	1.0	0.48
Unit 4	Settling pond	$ 11,770	1,400	7.5	0.0	0.9	1.0	0.48
Unit 5	Settling pond	$ 11,770	1,400	7.5	0.0	0.9	1.0	0.48
Unit 6								
Final WQ				7.50		0.90	1.00	0.48
Target WQ				6.00		1.42	1.00	0.43
	TOTAL	$ 179,198	6,889					
	Acres		0.16					

Two strategies for treating the same very bad water-capX only

Red highlight indicates WQ standard is not met

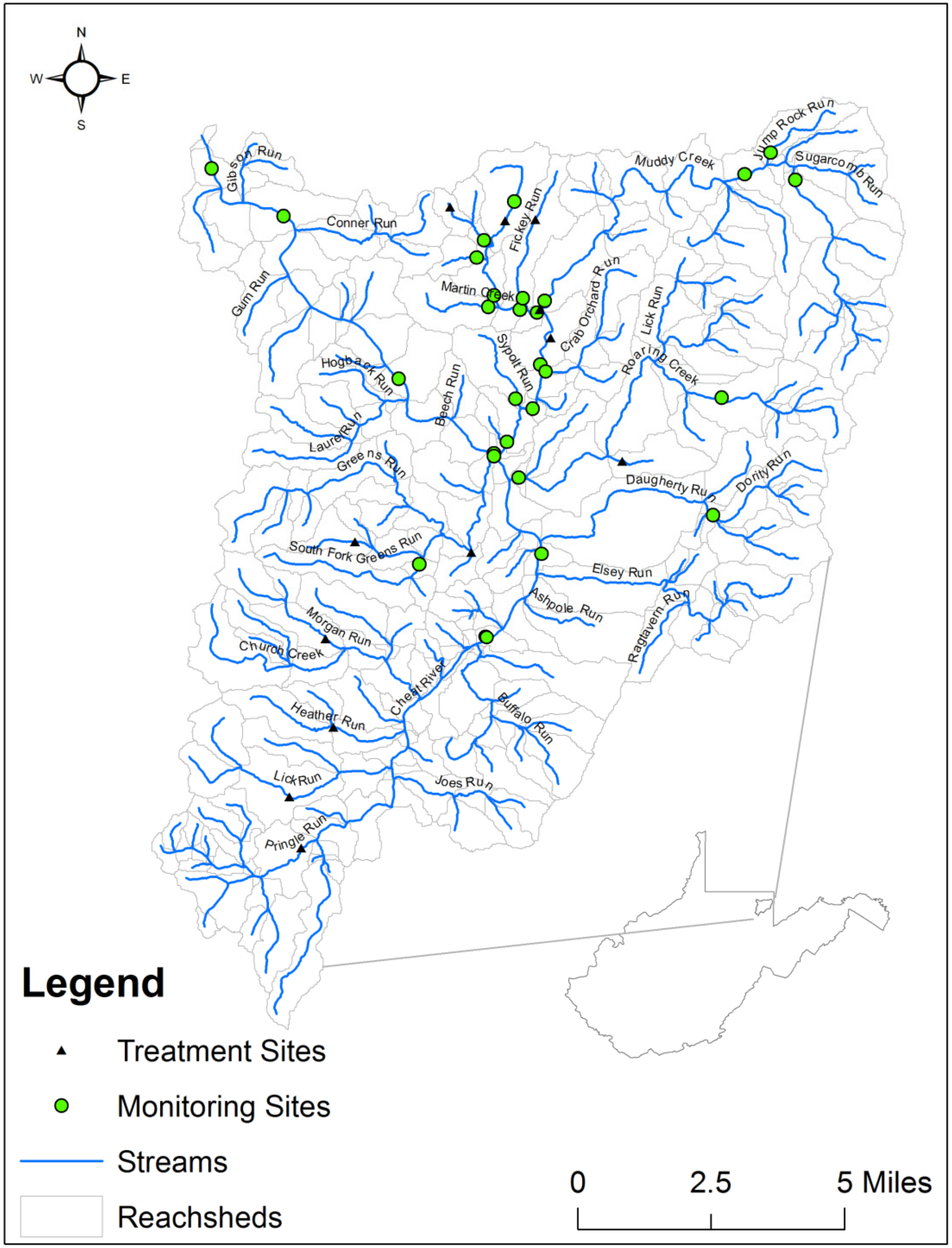
Conventional approach
- stair step aerator
- hydrated lime doser
- settling ponds
- residual aluminum

	Q max (gpm)	Installed	Area Used	Raw WQ pH	Acidity	Fe	Mn	Al
	300	Cost	ft2	2.5	880.6	300.0	5.0	80.0
Unit 1	Stair step aerator	$ 770	45	2.5	772.5	300.0	5.0	80.00
Unit 2	Doser (hydrated lime)	$ 116,722	1,800	7.5	0.0	300.0	5.0	80.00
Unit 3	Settling pond	$ 11,770	1,400	7.5	0.0	0.9	1.0	0.48
Unit 4	Settling pond	$ 11,770	1,400	7.5	0.0	0.9	1.0	0.48
Unit 5								
Unit 6								
Final WQ				7.50		0.90	1.00	0.48
Target WQ				6.00		1.42	1.00	0.43
	TOTAL	$ 141,032	4,645					
	Acres		0.11					

Conventional approach
- stair step aerator
- hydrated lime doser
- settling ponds
- add LLB to scavenge final aluminum

	Q max (gpm)	Installed	Area Used	Raw WQ pH	Acidity	Fe	Mn	Al
	300	Cost	ft2	2.5	880.6	300.0	5.0	80.0
Unit 1	Stair step pre-aerator	$ 110	135	3.0	772.5	300.0	5.0	80.00
Unit 2	Doser (hydrated lime)	$ 116,722	1,800	7.5	0.0	300.0	5.0	80.00
Unit 3	Settling pond	$ 11,770	1,400	7.5	0.0	0.9	1.0	0.48
Unit 4	limestone leach bed "M"	$ 105,330	23,528	7.5	0	0.1	0.4	0
Unit 5								
Unit 6								
Final WQ				7.50		0.09	0.43	0.00
Target WQ				6.00		1.42	1.00	0.43
	TOTAL	$ 233,932	26,863					
	Acres		0.62					

Step 6 – Design and initiate monitoring program



NEW TECHNOLOGY SEGMENT:
PRE-TREATMENT AERATION USING A TROMPE

Bruce Leavitt PE PG, Consulting Hydrogeologist
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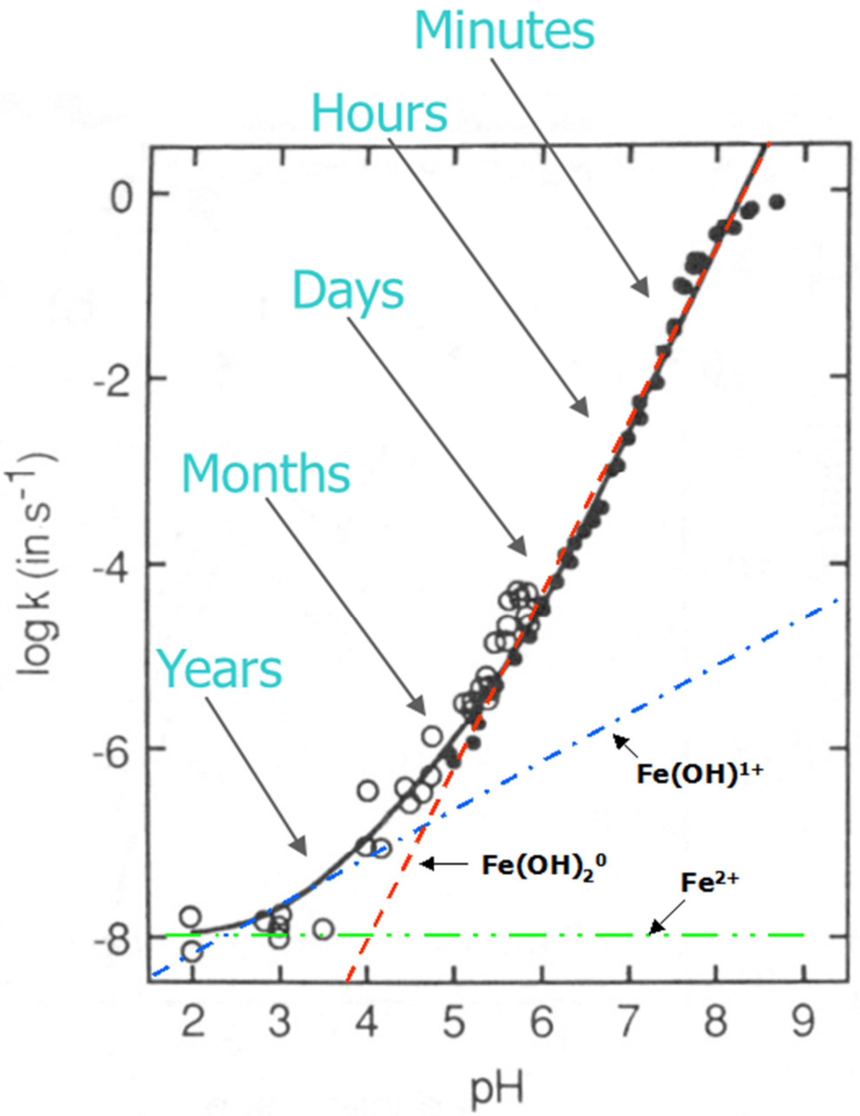
Aeration

- Most mine drainage treatment facilities require aeration for iron oxidation.
- $Fe^{2+} + \frac{1}{4} O_2 + H^+ \longrightarrow Fe^{3+} + \frac{1}{2} H_2O$
- The time required for this reaction to occur is dependent on oxygen transfer to the water and the pH of the water.

Effect of pH



- The higher the pH the faster iron is oxidized.
- As iron is oxidized the pH is lowered lengthening the time required for oxidation.
- This increase in detention time requires a commensurate increase in pond size.

After Dietz 2008

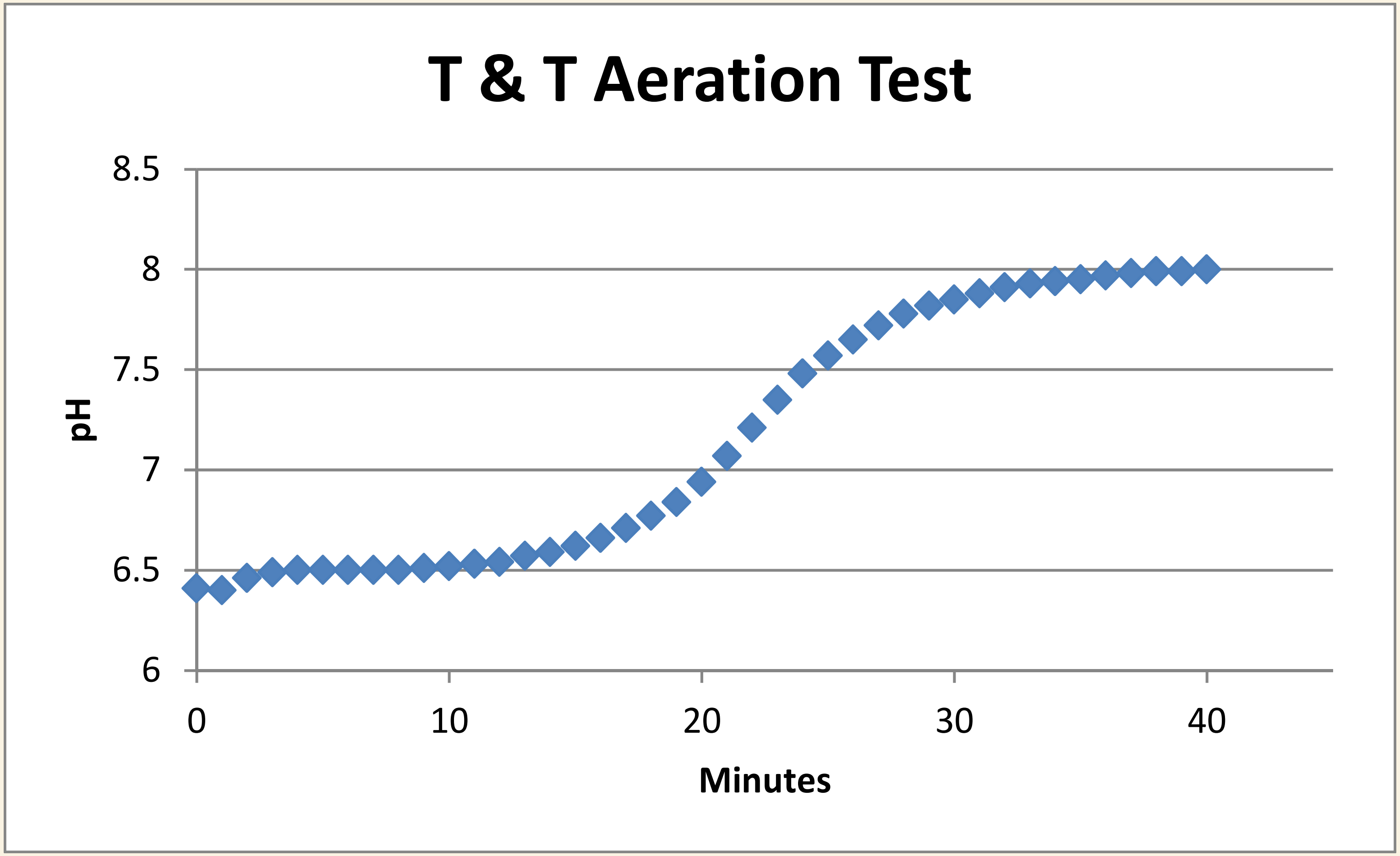
Effect of Carbon Dioxide

- Mine drainage from underground mines frequently contains excess carbon dioxide.
- The effect of this excess carbon dioxide is to lower the pH of the raw water.
- Aeration of mine water will remove the excess carbon dioxide and could increase pH
- Best to lose the CO_2 prior to adding base

West Virginia University
Water Research Institute

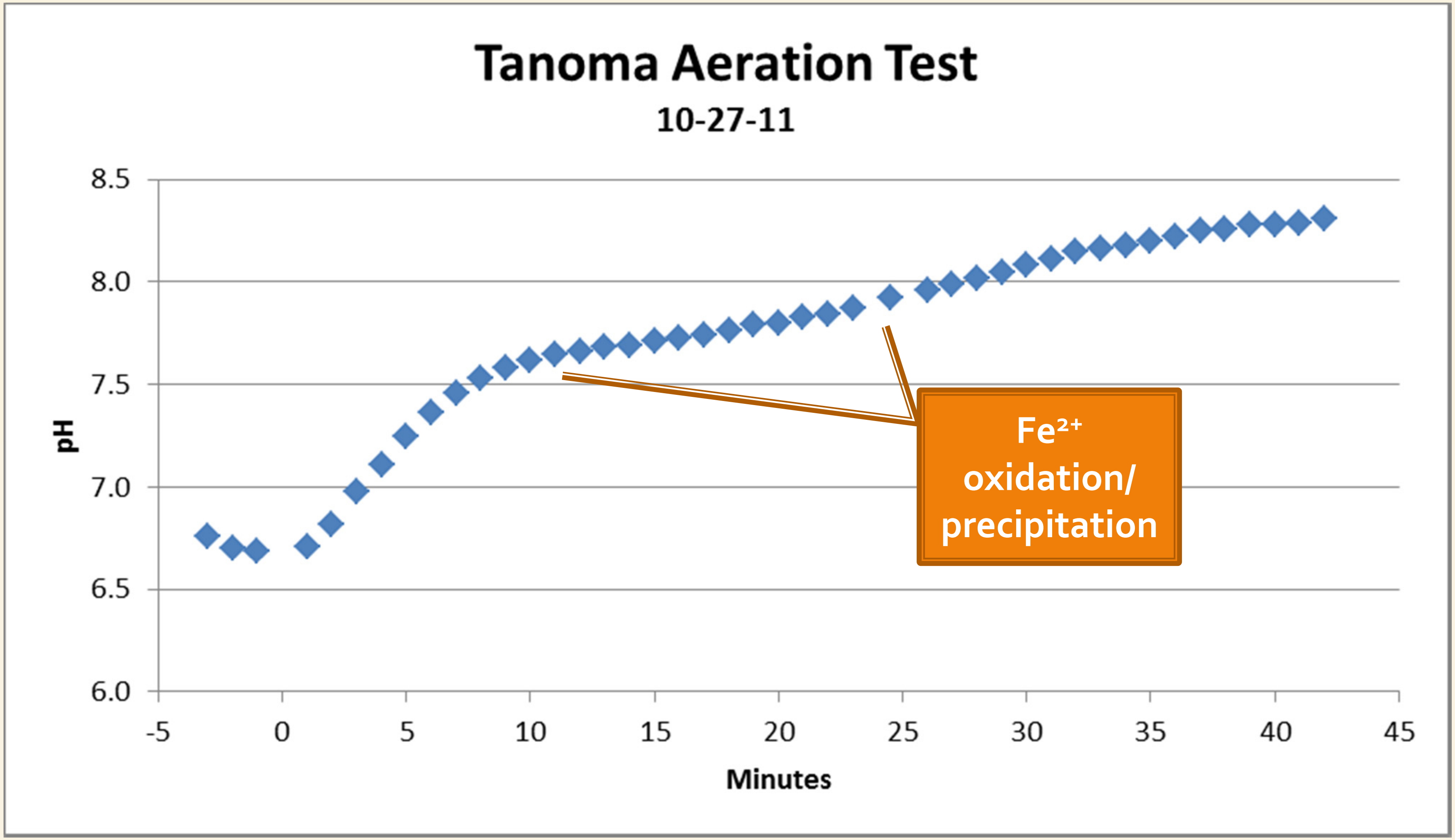
Aeration Removes CO_2 and Increases pH

$H^+ + HCO_3^- \leftrightarrow H_2O + CO_2(g)$



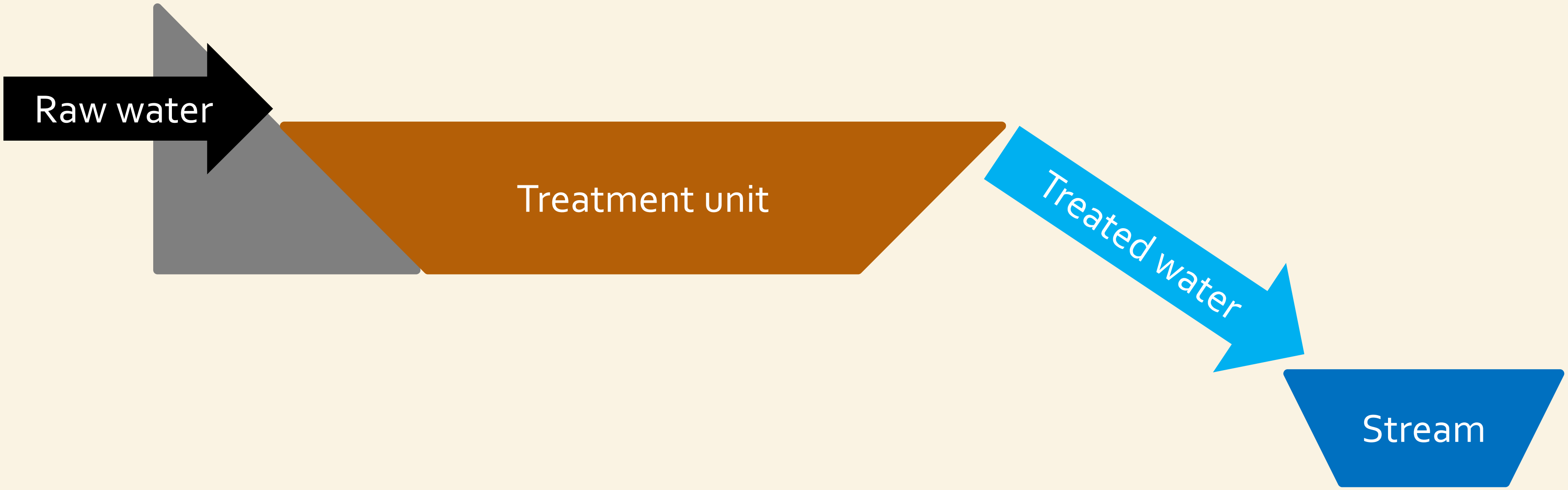
Aeration Removes CO_2 and Increases pH

$$H^+ + HCO_3^- \leftrightarrow H_2O + CO_2\,(g)$$

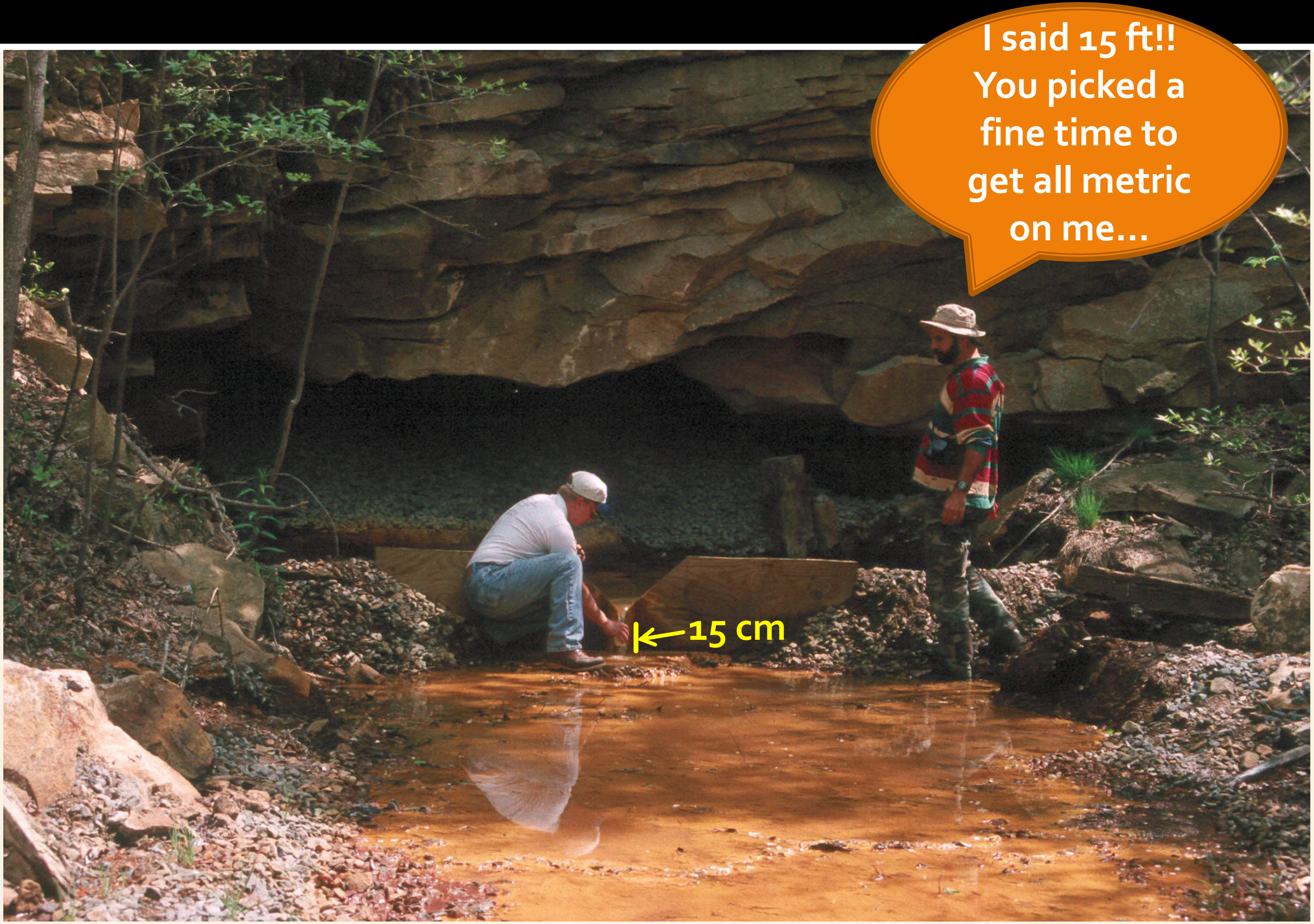


Improving the efficiency of aeration: CO_2 stripping, ferrous oxidation

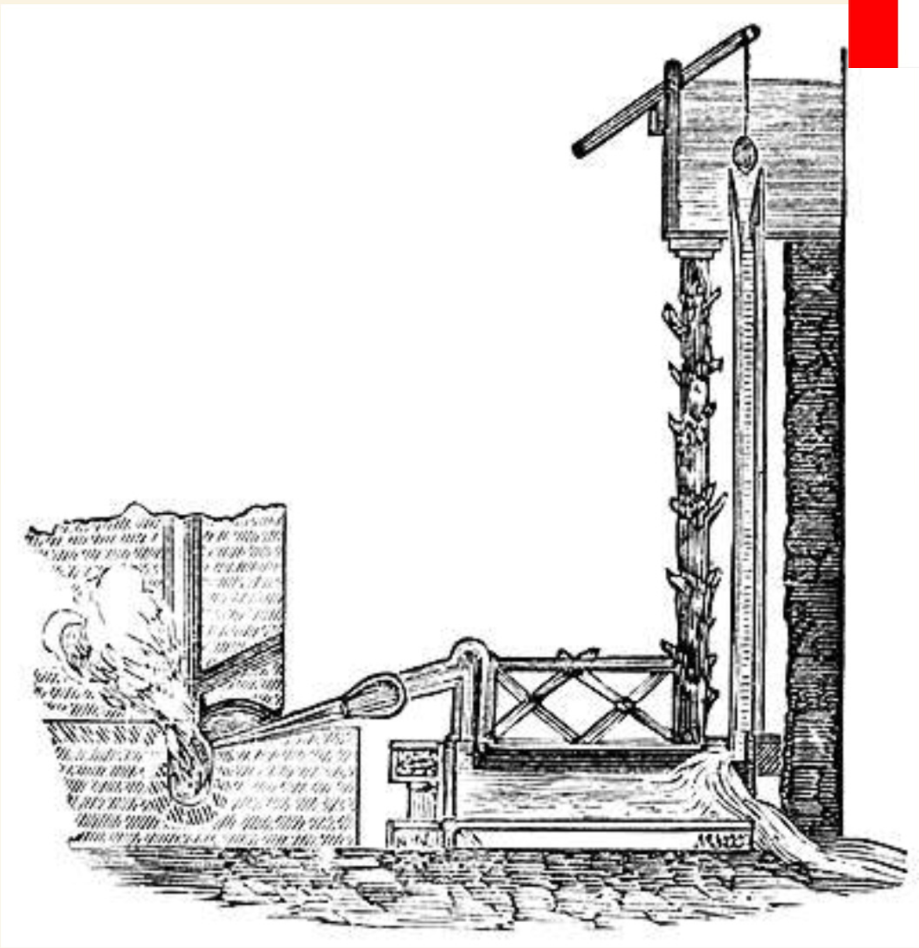
How to get oxygen to the upstream end of the treatment system



Head drop is rarely at the upstream end of the treatment system where you need it

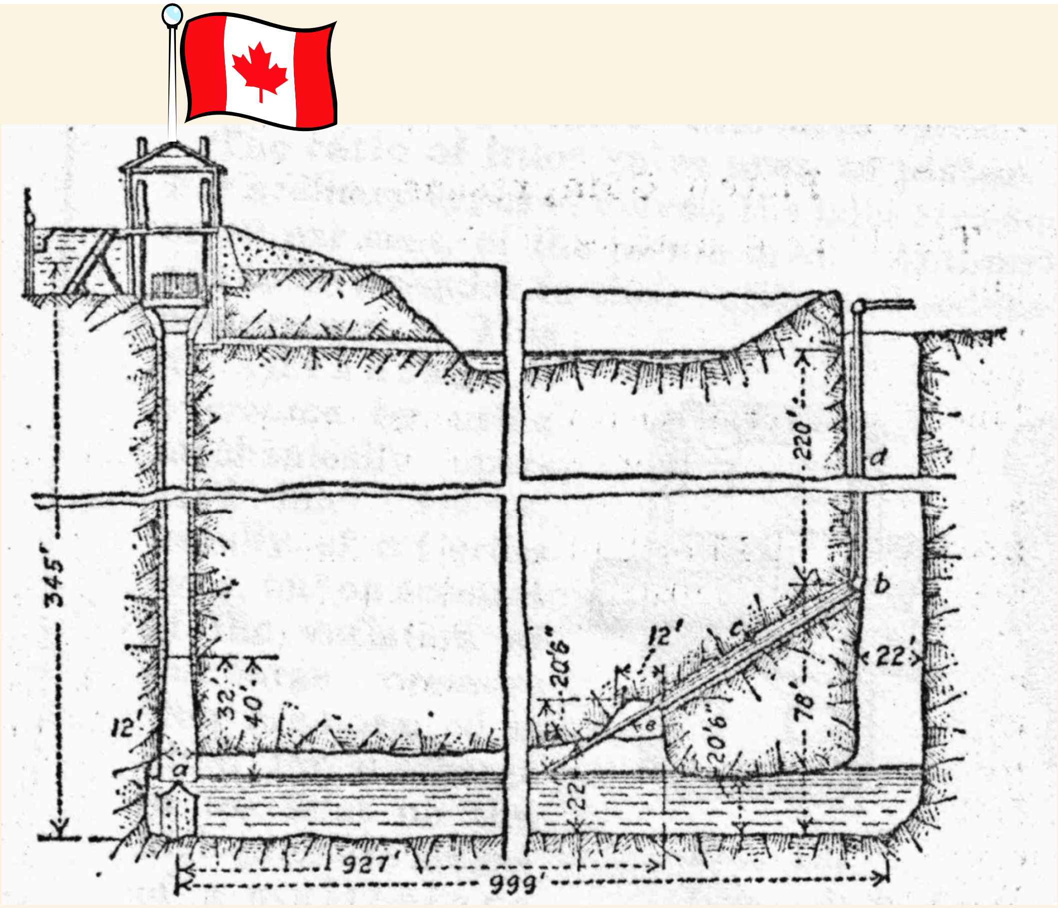


Trompe History



- Discovered in 17^{th} century Italy.
- Defining component of the Catalan Forge
- Developed 1 to 16 oz pressure

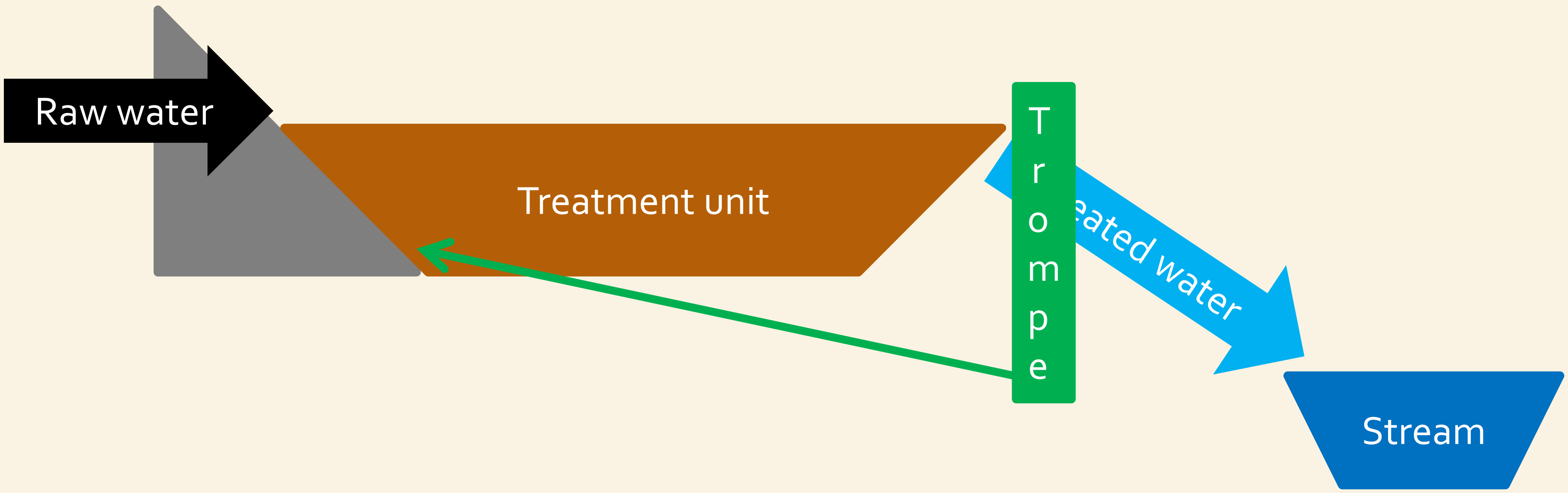
Trompe History Continued



- Rediscovered by Charles Taylor, Canada
- Ragged Chutes Compressor delivered 128 psi to the area mines
- Was in continuous operation for over 70 years with only two maintenance shutdowns.

Re-re discovered by Bruce Leavitt in 2010

A trompe passively generates pressurized air that can be moved uphill.
Also, it only sees treated water



Fine Bubble Aeration Discs

Iron removal: 37% without
62% with trompe

Thank you

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