Long-Term Performance of Passive AMD Treatment Systems

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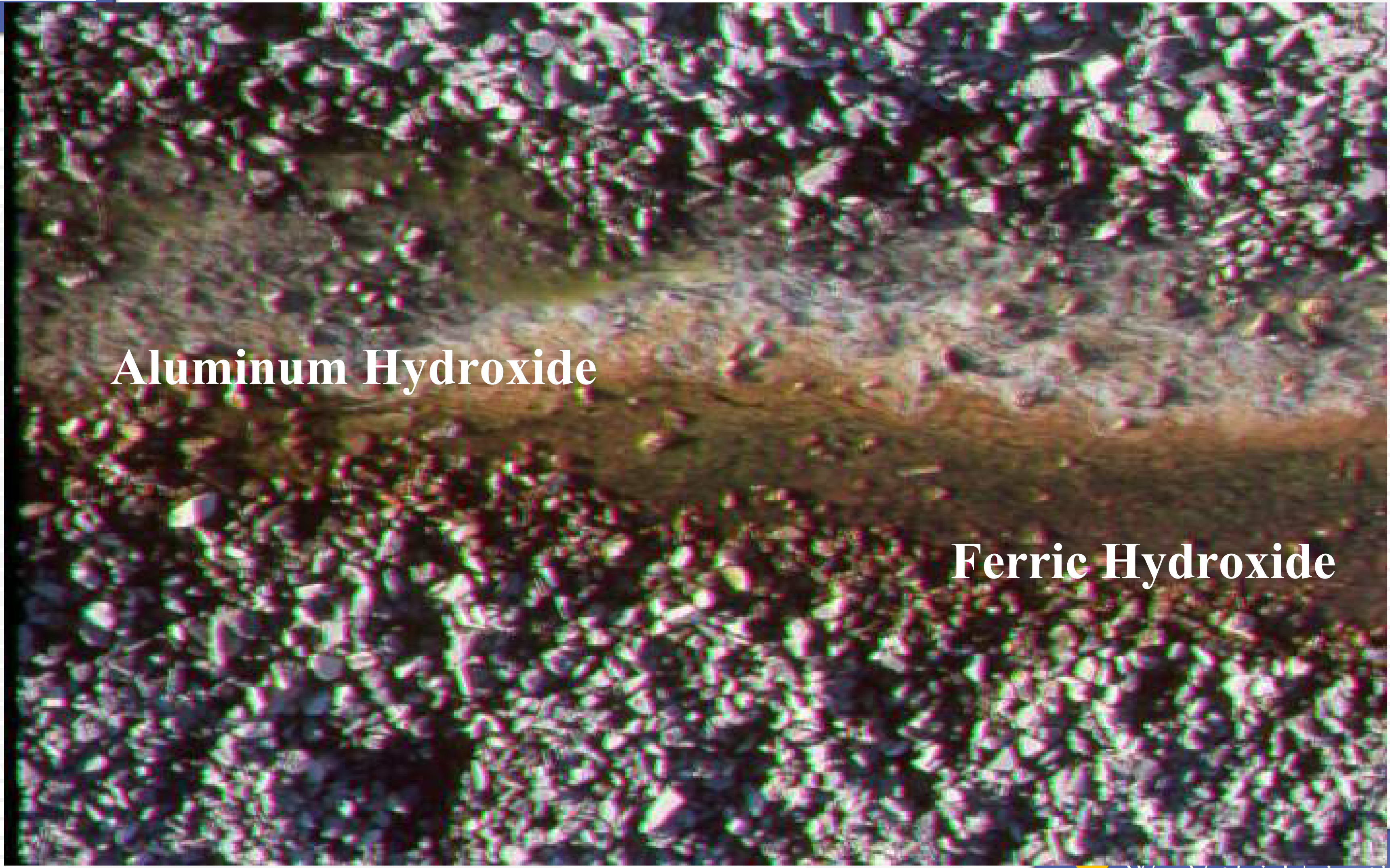
Typical AMD affected Stream:

pH 2.5, 2000 mg/L acidity

Metal Hydroxide Precipitation in OLC



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Types of Passive Systems Evaluated

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

Project Coverage

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

System Design Parameters

- Amounts of materials used
  - Limestone
  - Steel Slag
  - Ca(OH)2
  - Soda Ash Briquettes
  - Compost

- System dimensions (to calculate volume of material excavated)

Acid Load Reductions

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

Estimated Service Life

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

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

- Assigned a maximum value of 20 years

Cost to Treat a Ton of Acid

- System Efficiency = $/ton acid load removed

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

Cost of Active Treatment

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

Determination of Treatment Success

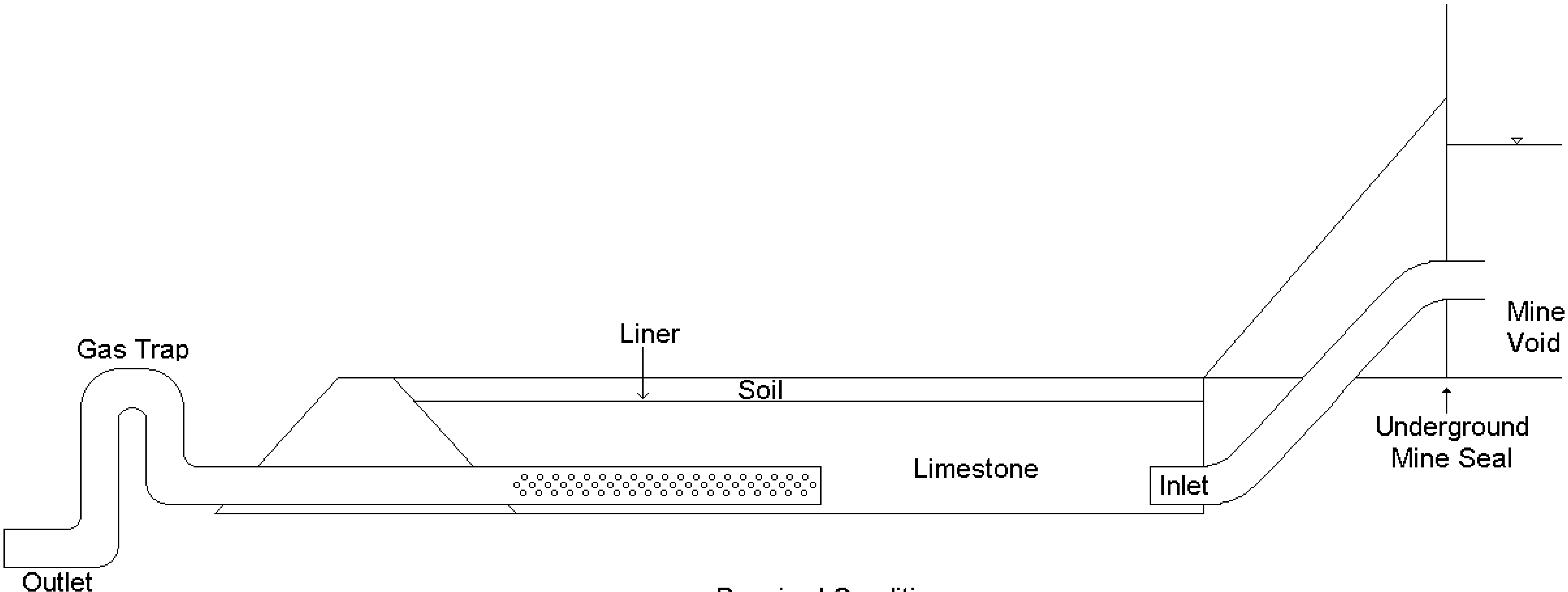
- Successful treatment units must meet the following criteria
  - Must have a net positive acid load reduction
  - Lower cost of treatment than caustic

Confounding Factors in Performance Evaluations

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

Anaerobic Wetland

Anoxic Limestone Drain



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

Anoxic Limestone Drain, under construction

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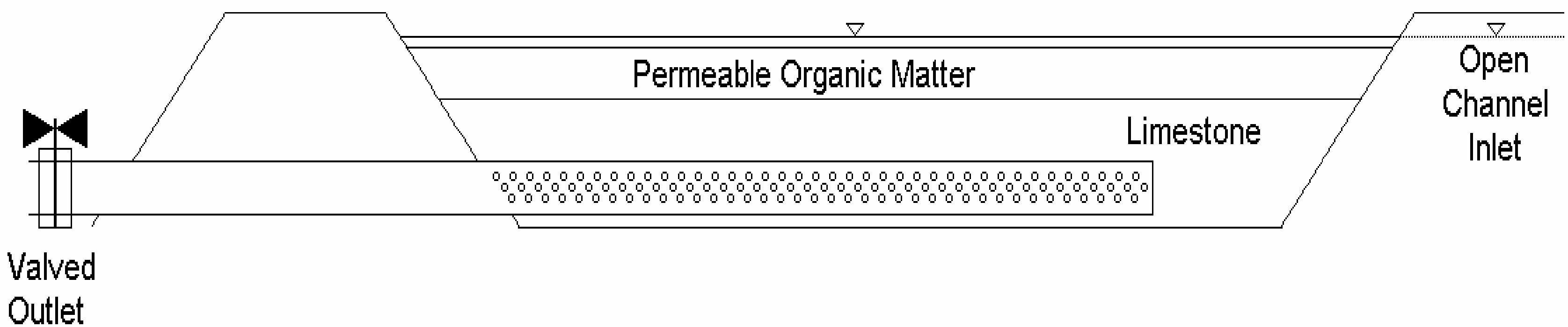
Vertical Flow Wetland (SAPS)

Conditions: Requires Regular Flushing



Vertical Flow Wetland: Construction

Vertical Flow Wetland

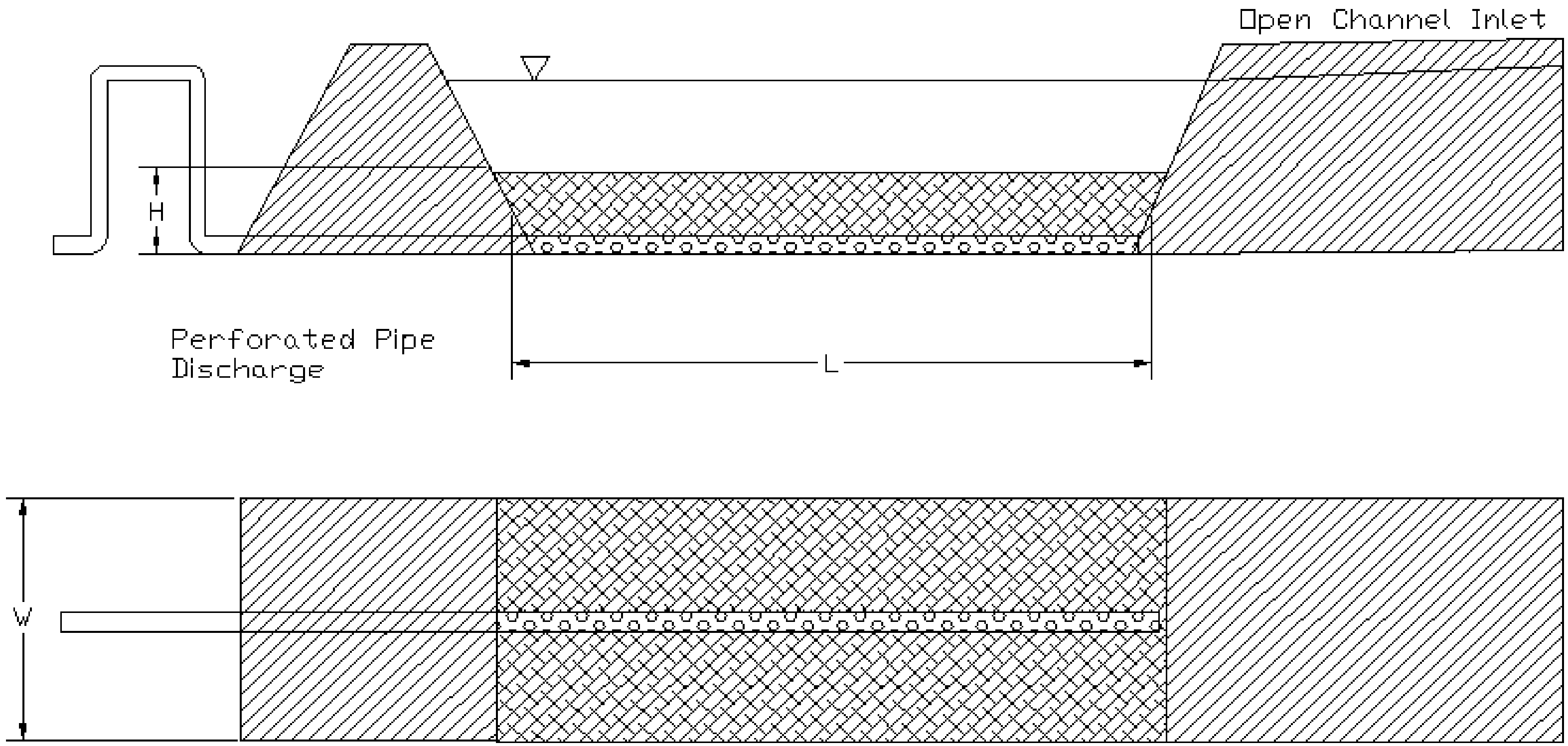
Open Limestone Channel

Open Limestone Channel

Limestone Leach Bed

Steel Slag Leach Bed

Not To Scale



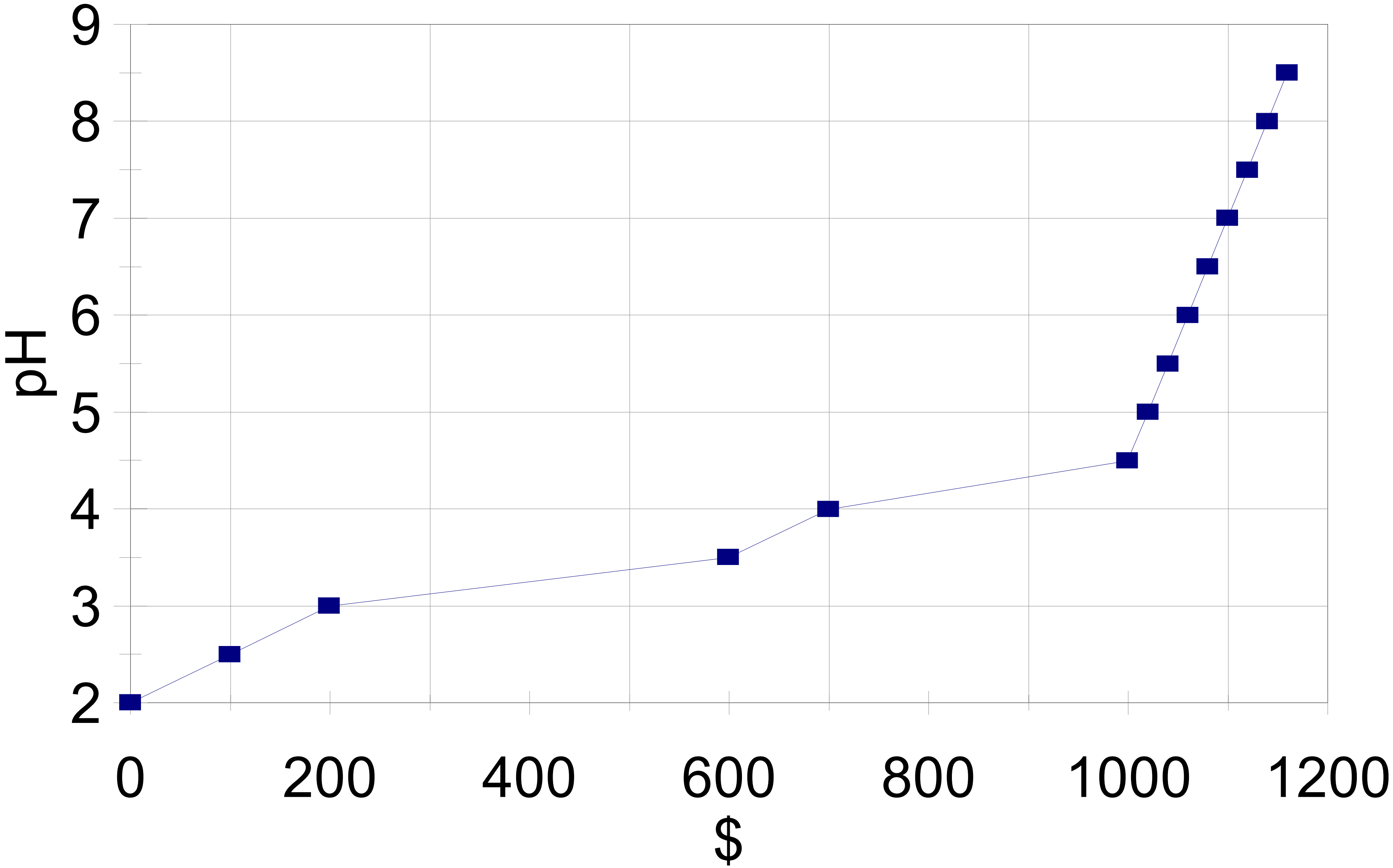
Steel Slag Leach Bed

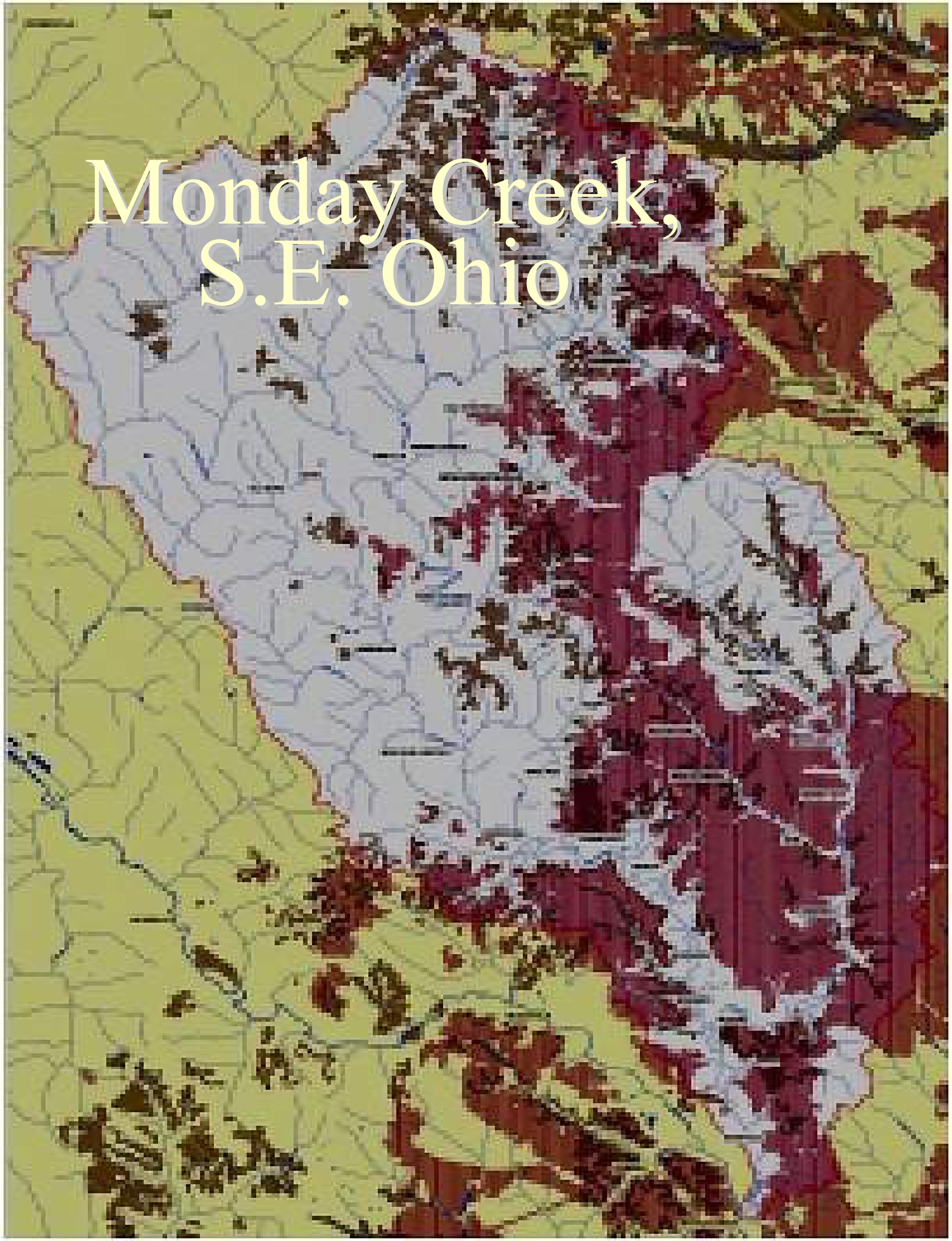
Comparison of Passive Treatment Performance

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

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

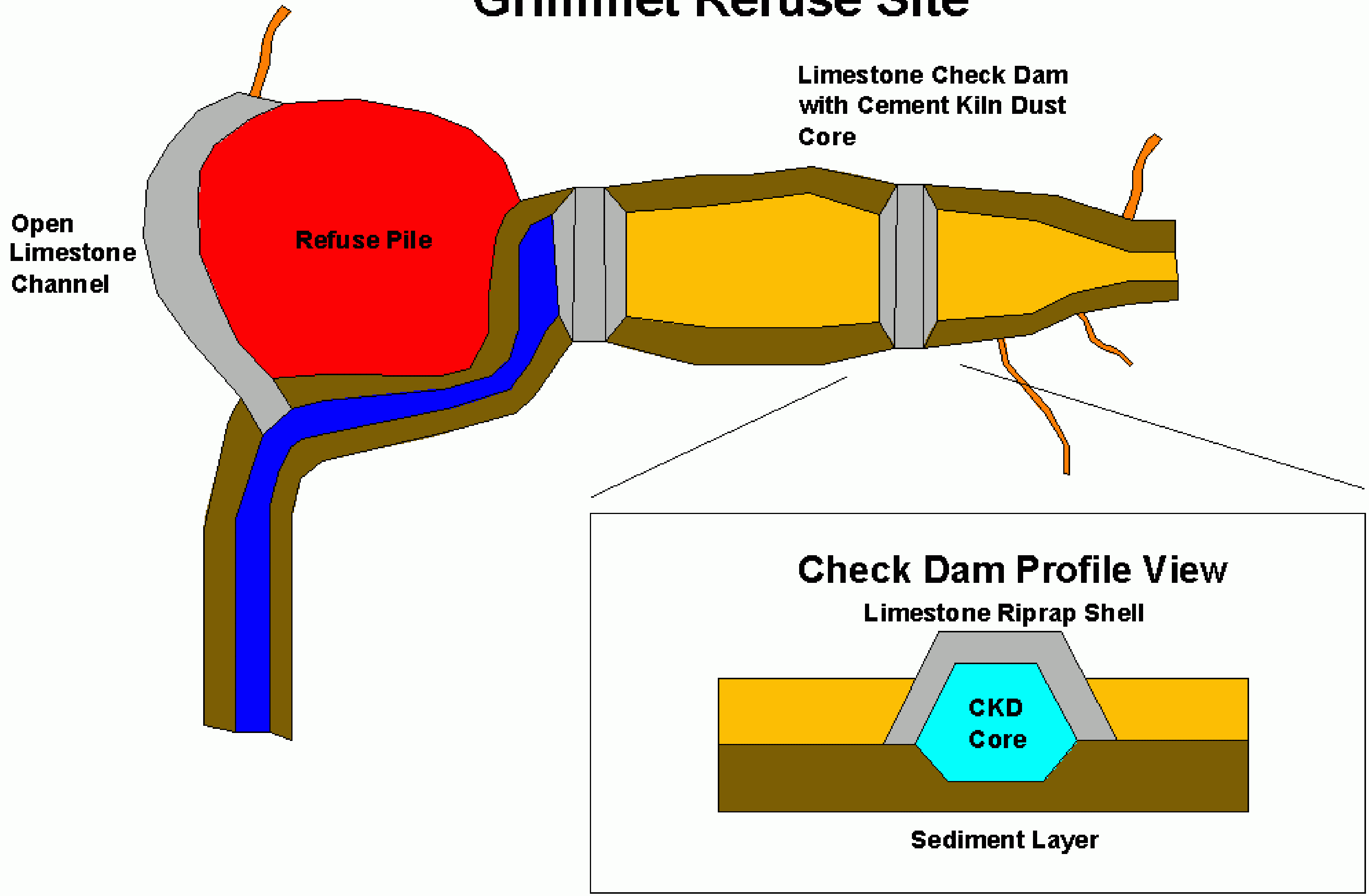
AMD Treatment Cost vs. Change in pH



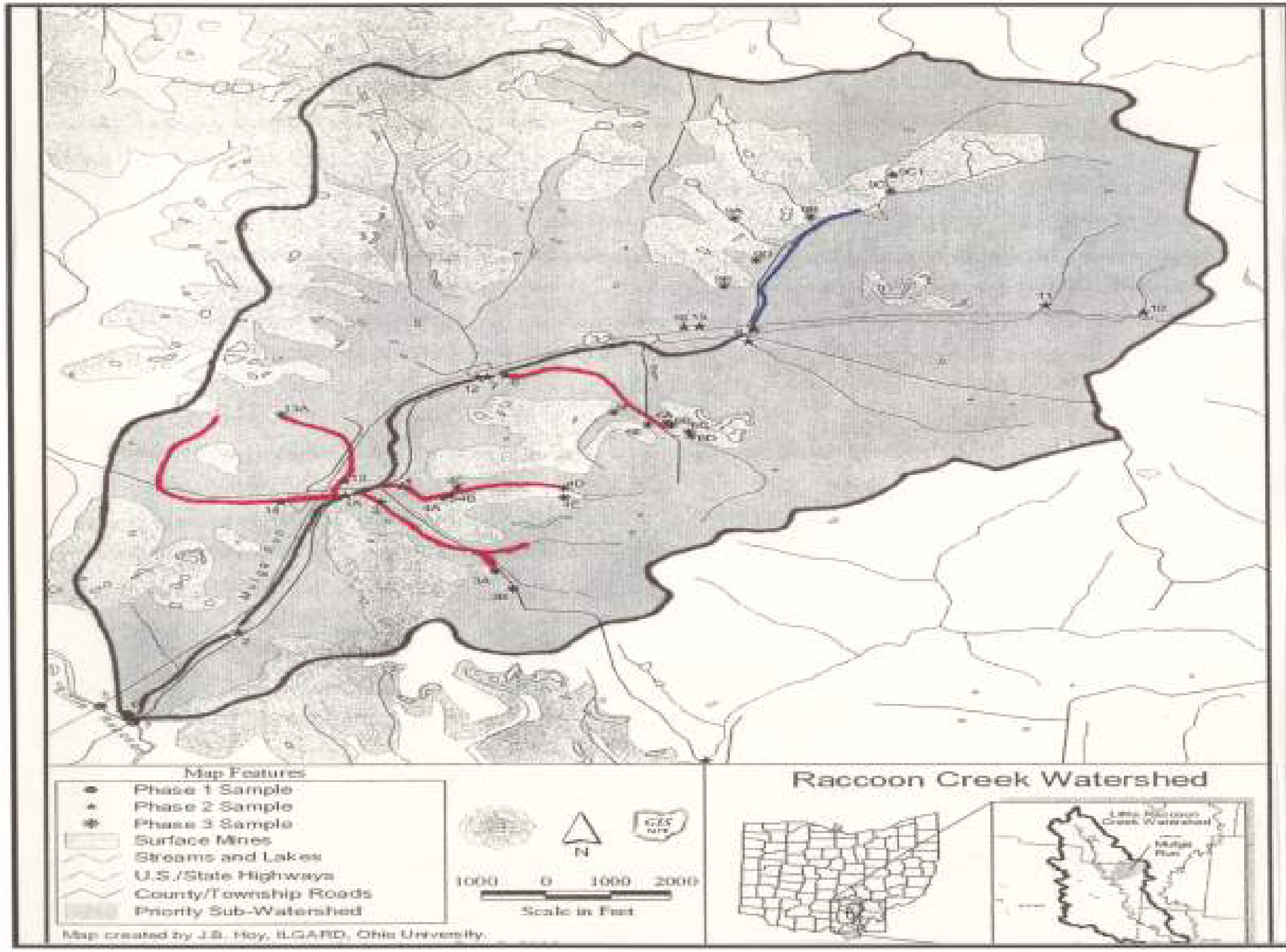


- 116 Square Miles (74,240 Acres)
- Provides 10% of Flow to the Hocking River
- Heavily Mined for Coal Over Last 180 Years (4,000 Surface Acres and 15,000 Underground Acres)
- Most Mines Abandoned Before Mining Laws in Affect

Grimmet Refuse Site



Site:	Grimmet					
Sample:	Tributary Mouth					
	pH	net acidity (mg/L)	acid load (tpy)	[Fe] (mg/L)	[Al] (mg/L)	[Mn] (mg/L)
pre construction	3.1	132.0	25.5	5.3	11.9	5.4
post construction	6.9	-22.7	-8.4	0.4	0.5	0.5
acid treated:			33.9	tons per year		
project cost:			$ 75,000			
efficiency:			$ 111	per ton of acid treated		



MULGA RUN RECLAMATION PROJECT WATERSHED MAP

ODNR — DMRM
JACKSON COUNTY, OHIO
(FIGURE OBTAINED FROM LITTLE RACCOON CREEK AMDAT PLAN)

Project Number: 88.32131.0003		Drn. By: CL
Drawing File: 32131_3A		Ckd. By: BM
Date: 10/04	Scale: AS SHOWN	App'd By:
		Figure: 1

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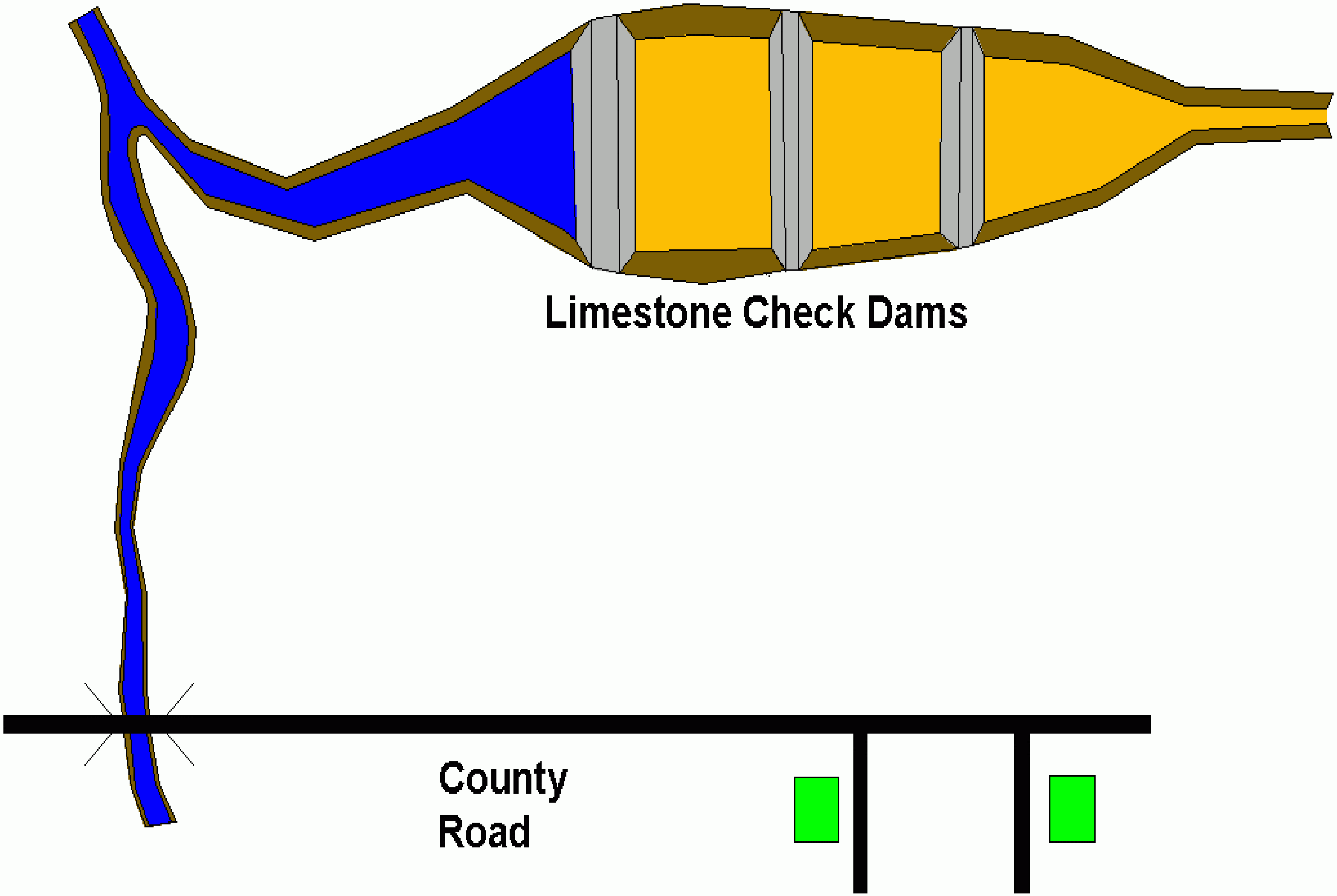
Slag Leach Bed

Slag leach bed: construction

Slag Leach Bed

Mulga Wetland with Limestone Check Dams



Aerobic wetland with check dam

Site:	Mulga Run					
Sample:	Tributary Mouth					
	pH	net acidity	acid load	[Fe]	[Al]	[Mn]
		(mg/L)	(tpy)	(mg/L)	(mg/L)	(mg/L)
pre construction	5.7	30.7	42.2	10.4	5.3	5.0
post construction	7.2	-75.6	-172.4	1.6	<0.25	2.9
acid treated:			215	tons per year		
project cost:			$ 600,000			
efficiency:			$ 140	per ton of acid treated		

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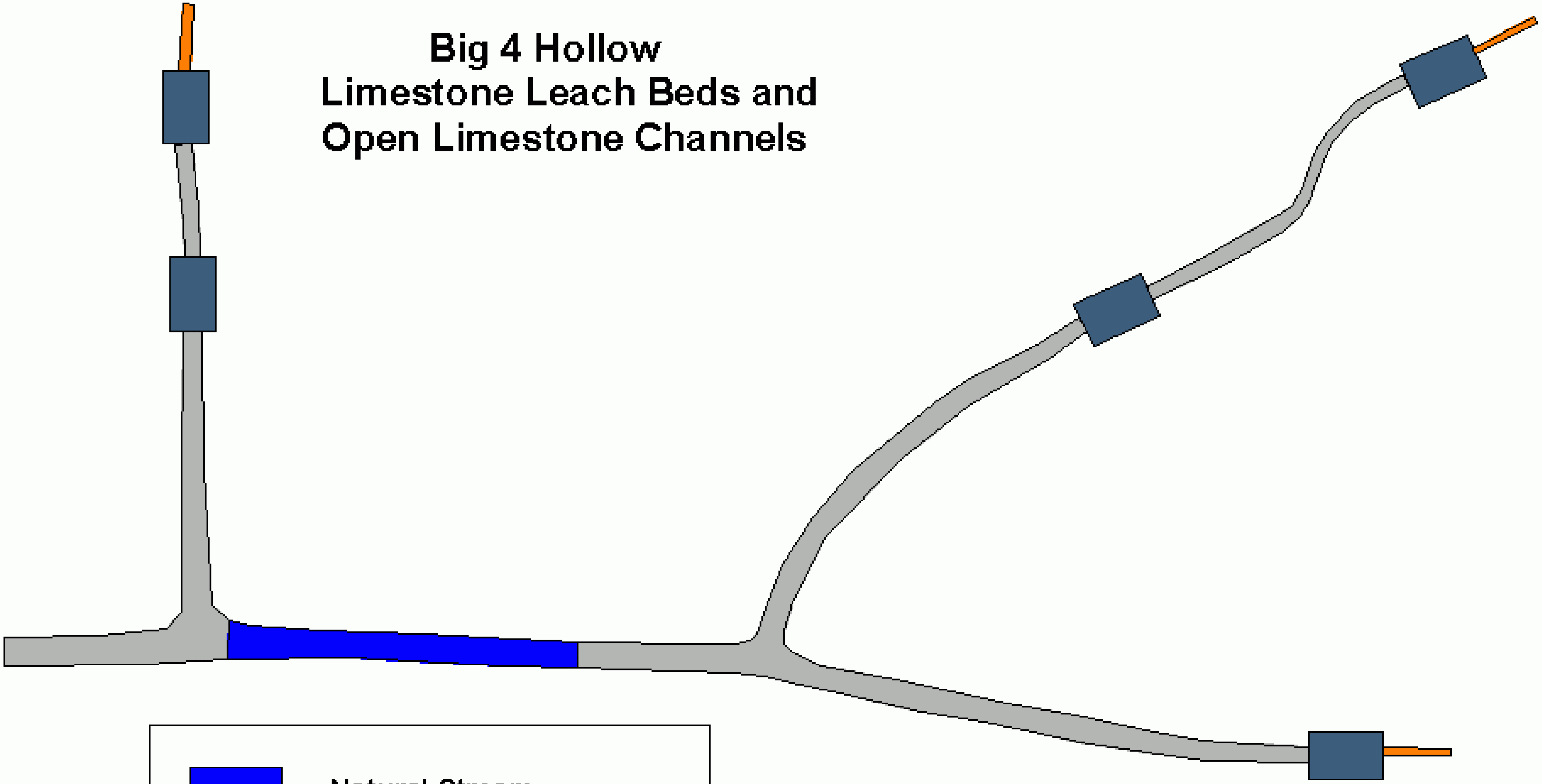
Big 4 Hollow
Limestone Leach Beds and Open Limestone Channels



Natural Stream

Open Limestone Channel

Limestone Leach Bed

Mine Seep

Big 4 Hollow: Limestone channel and leachbed

Site:	Big 4 Hollow					
Sample:	Tributary Mouth					
	pH	net acidity (mg/L)	acid load (tpy)	[Fe] (mg/L)	[Al] (mg/L)	[Mn] (mg/L)
pre construction	3.5	150.5	82.2	3.9	16.0	4.4
post construction	5.7	48.8	26.5	0.9	7.5	3.5
acid treated:			56	tons per year		
project cost:			$ 300,000			
efficiency:			$ 269	per ton of acid treated		

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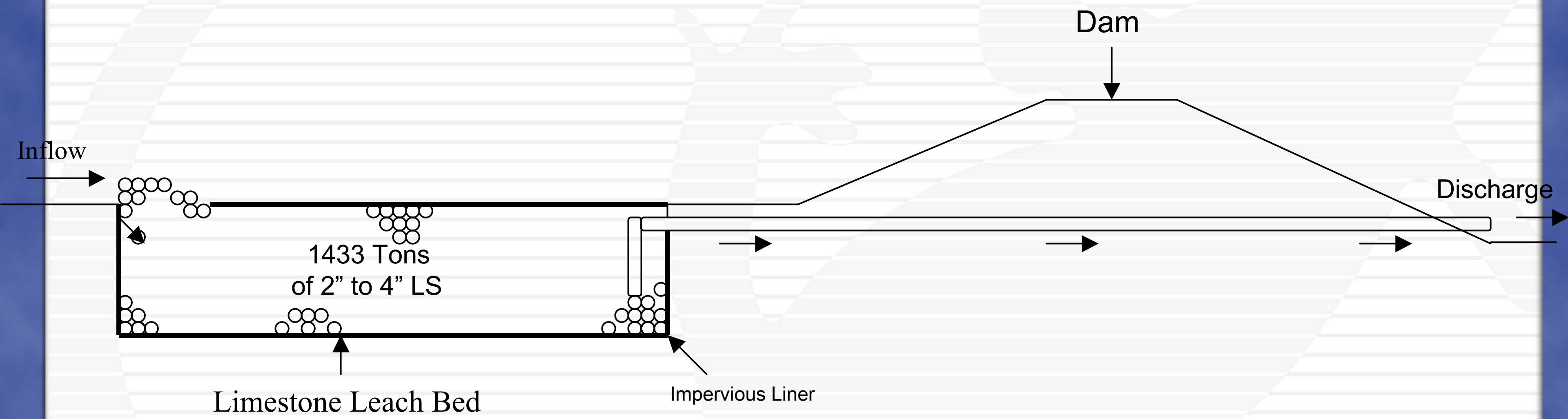
Freshwater Limestone Leach bed

Result of Limestone Leach beds
pH was 4.2; now 7.1

Limestone Leachbed
Site Prior to Reclamation

Internal Limestone Leach Bed



Acmar Internal Leachbed

Improved Discharge (mg/L)

	Before	After
pH	3.8	7.3
Acidity	91.7	0
Alkalinity	0	50.3
Fe	8.4	0
Al	8.1	0

Steel Slag cap on Refuse Pile

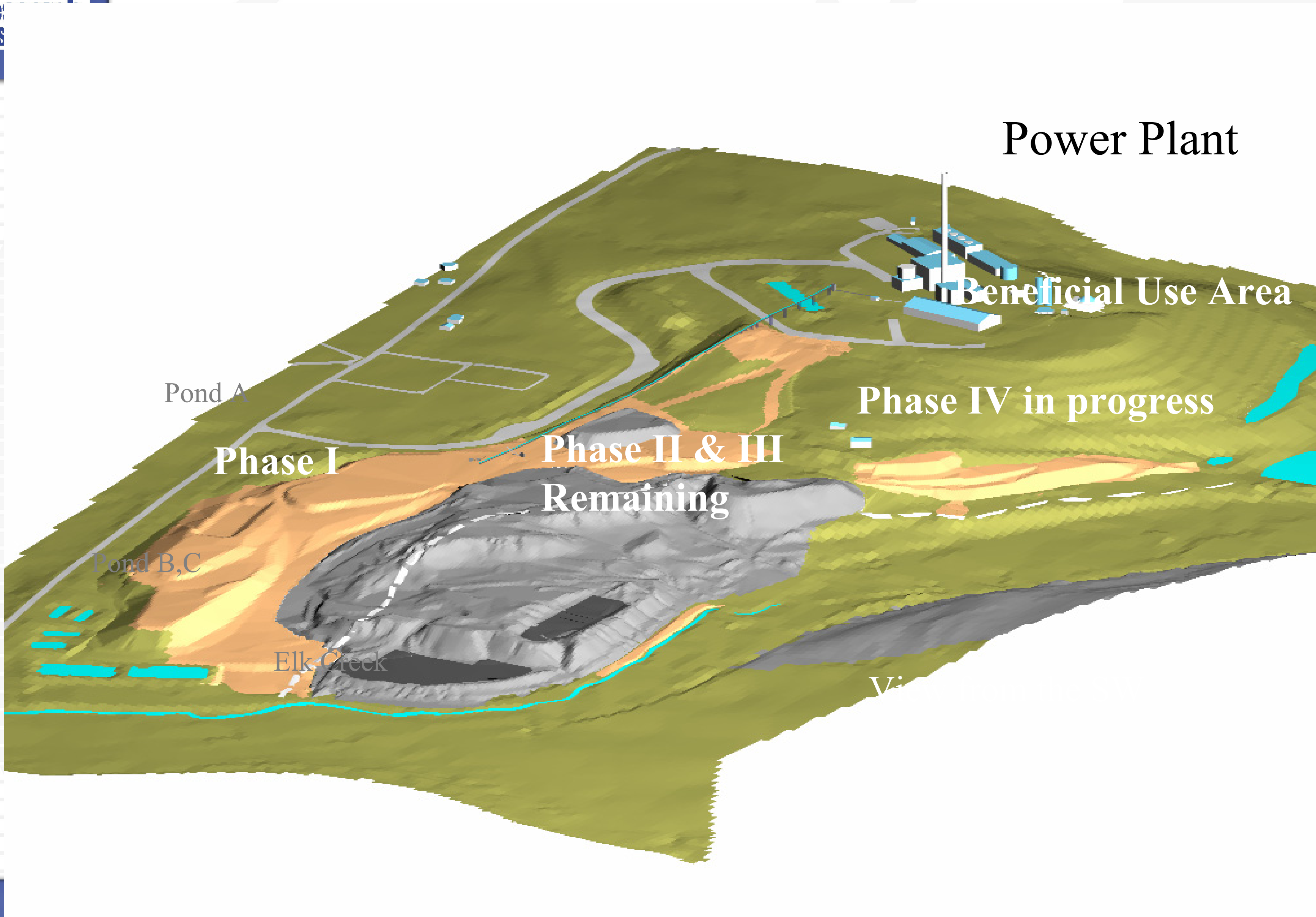
Soil

Steel slag

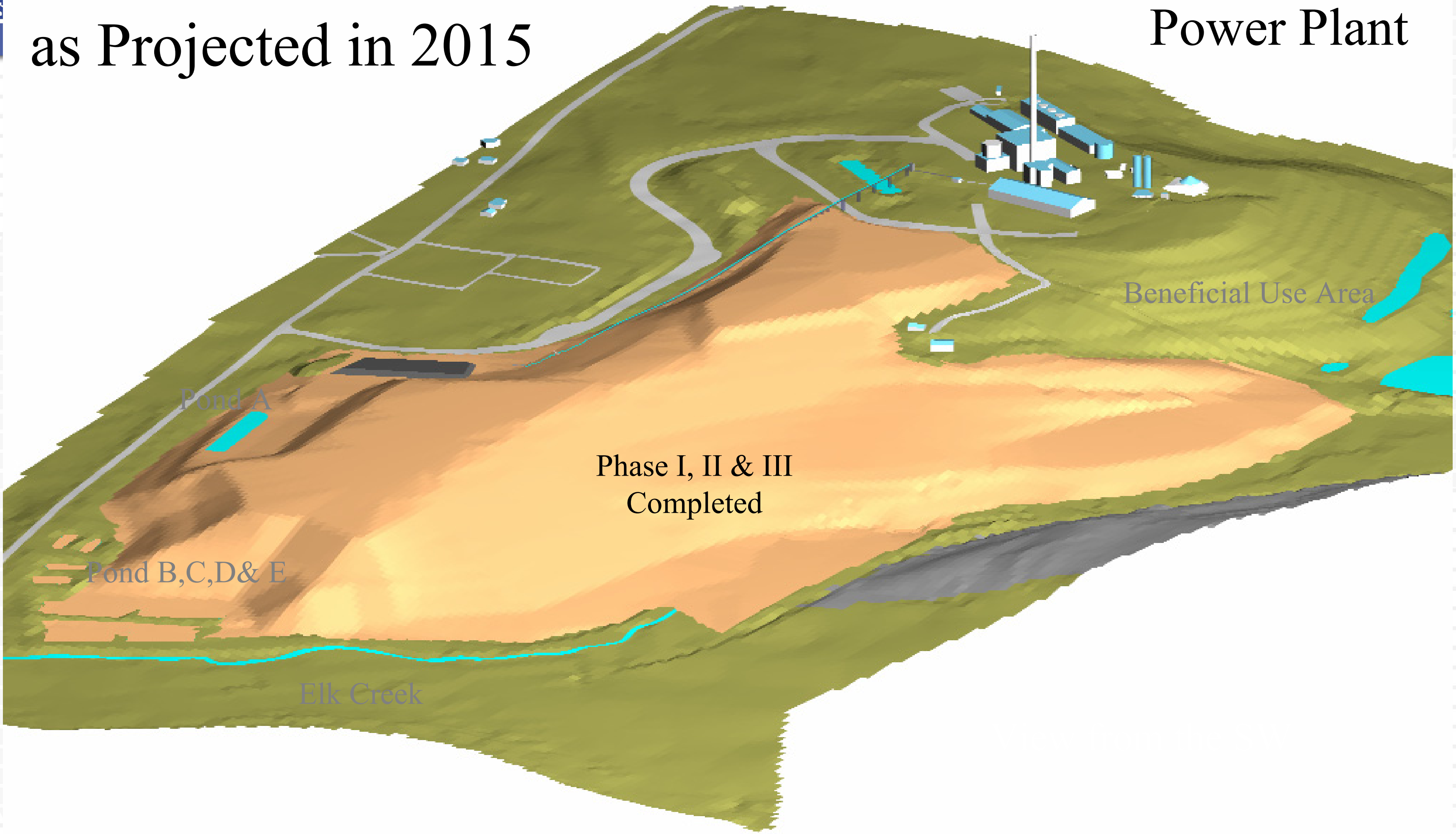
Refuse

Pond Now in Compliance

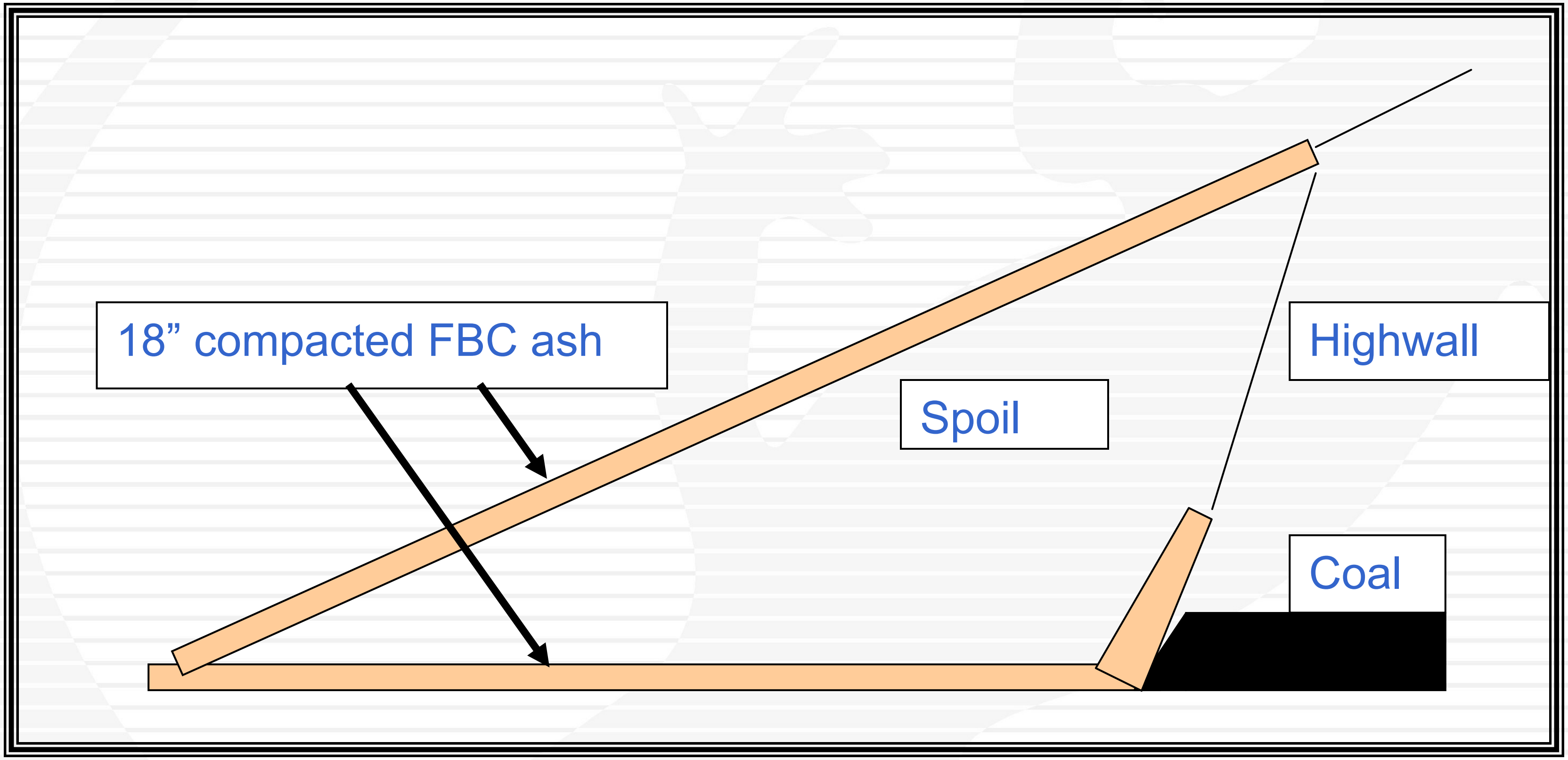
Replacement of Coal Tailings with FBC Ash



Colver Refuse Site as Projected in 2015



FBC ash barrier at Crown East



Pit Floor and Highwall Barrier – FBC Ash

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FBC Ash being delivered to pit floor

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Maryland In-Stream Lime Dosers

Boxholm

Pumpkonsult

Aquafix

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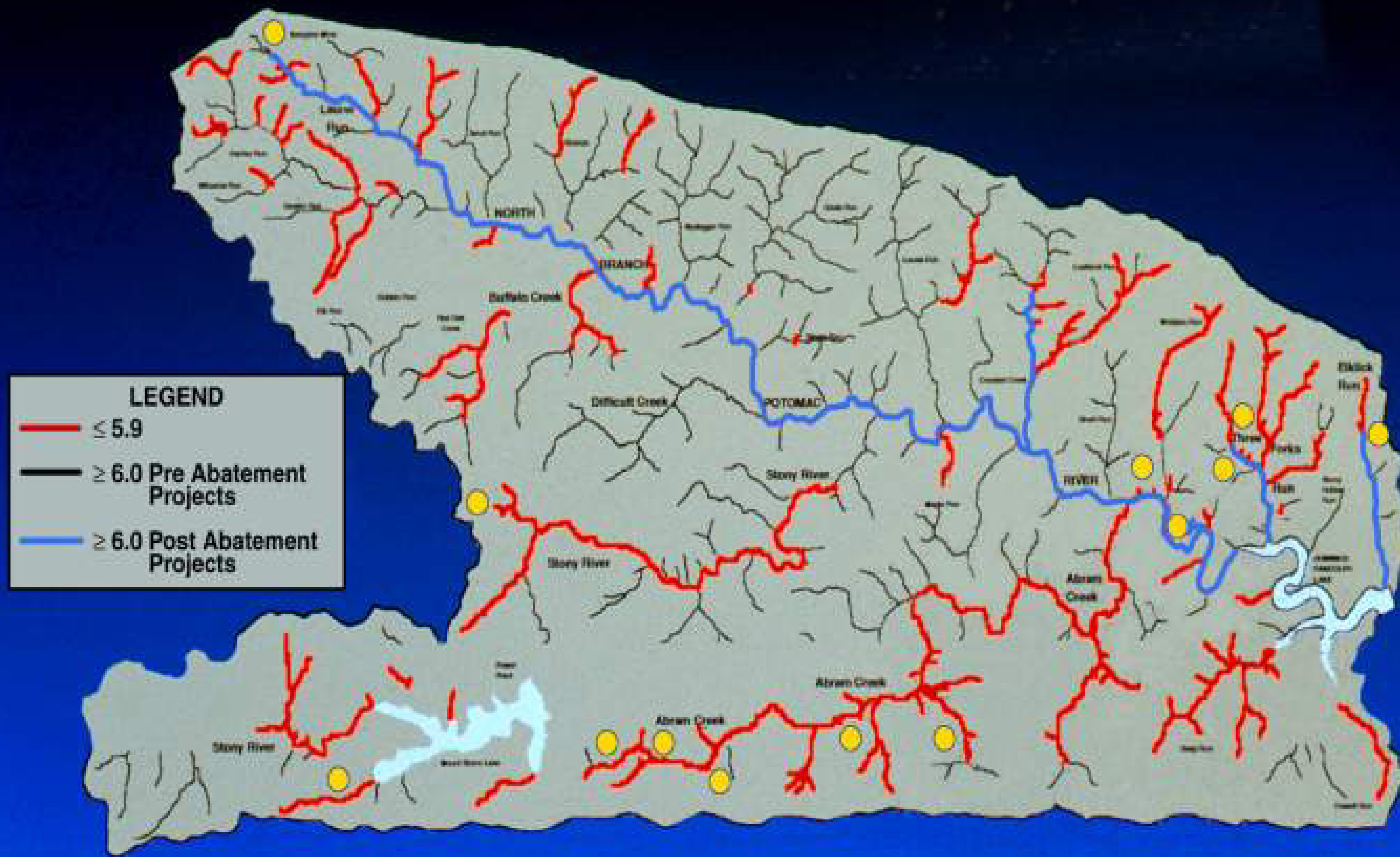
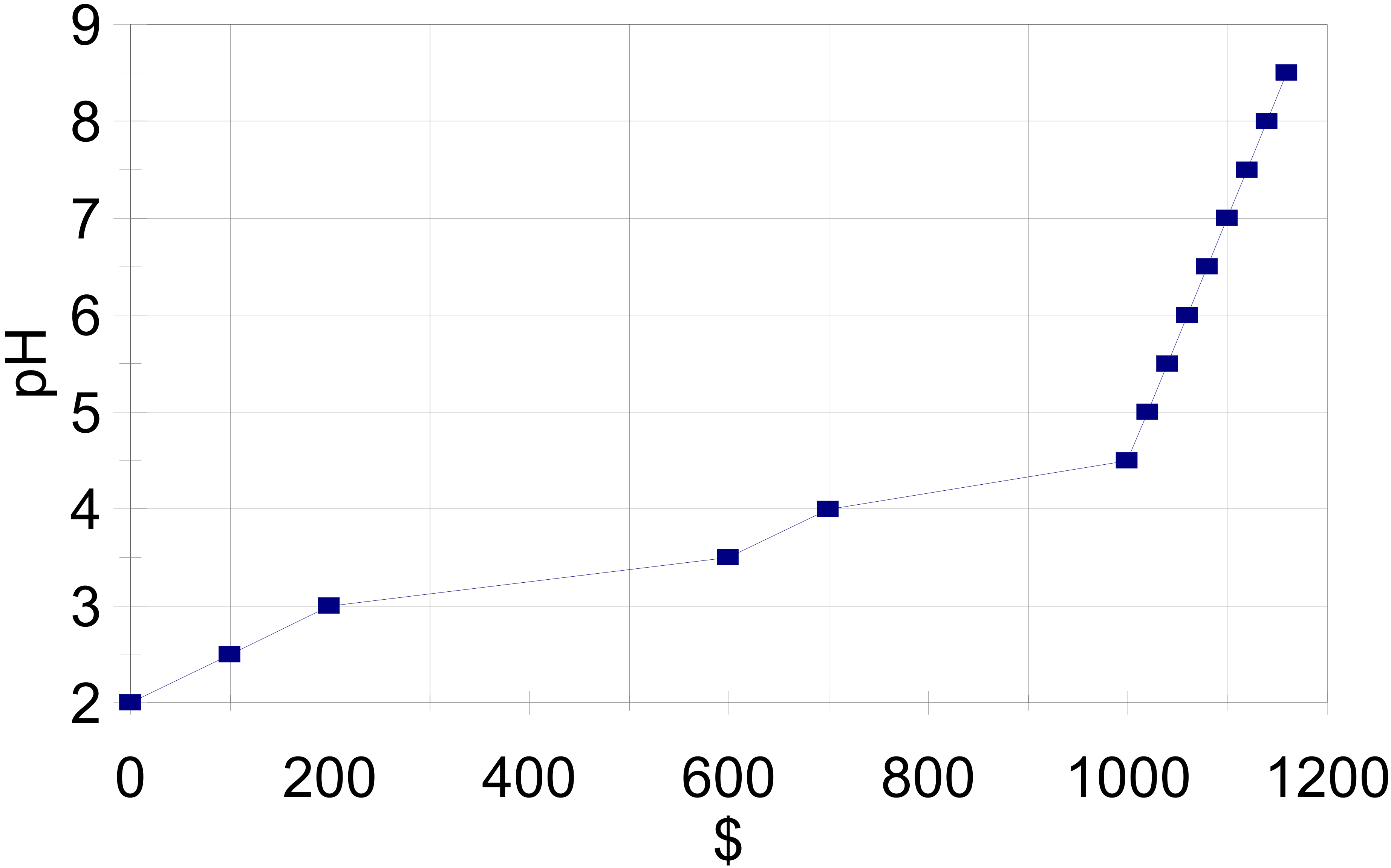
N. Branch Potomac River: pH Before Doser Project

Post Doser Map



Objective: Return of Aquatic Life

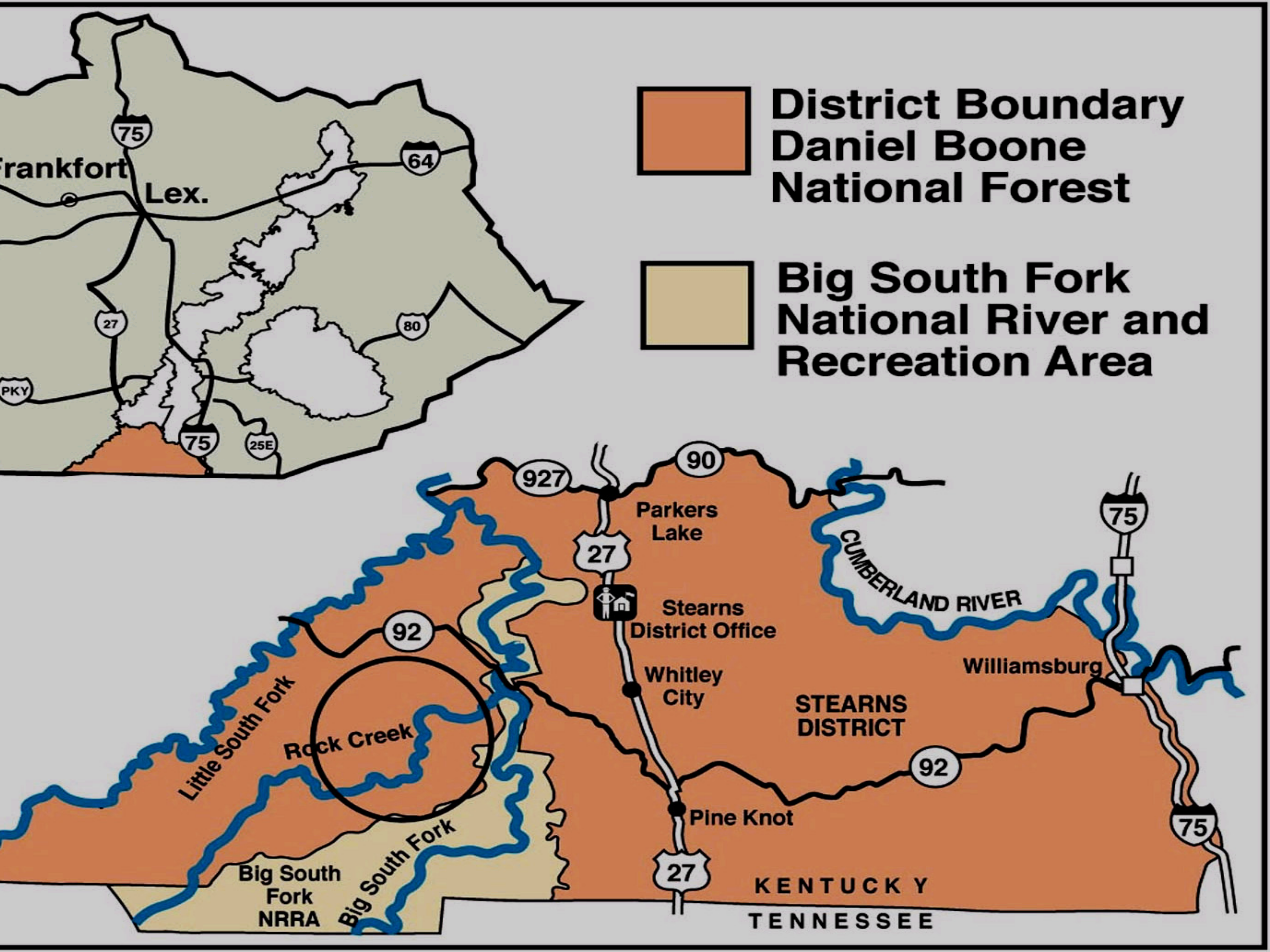
AMD Treatment Cost vs. Change in pH



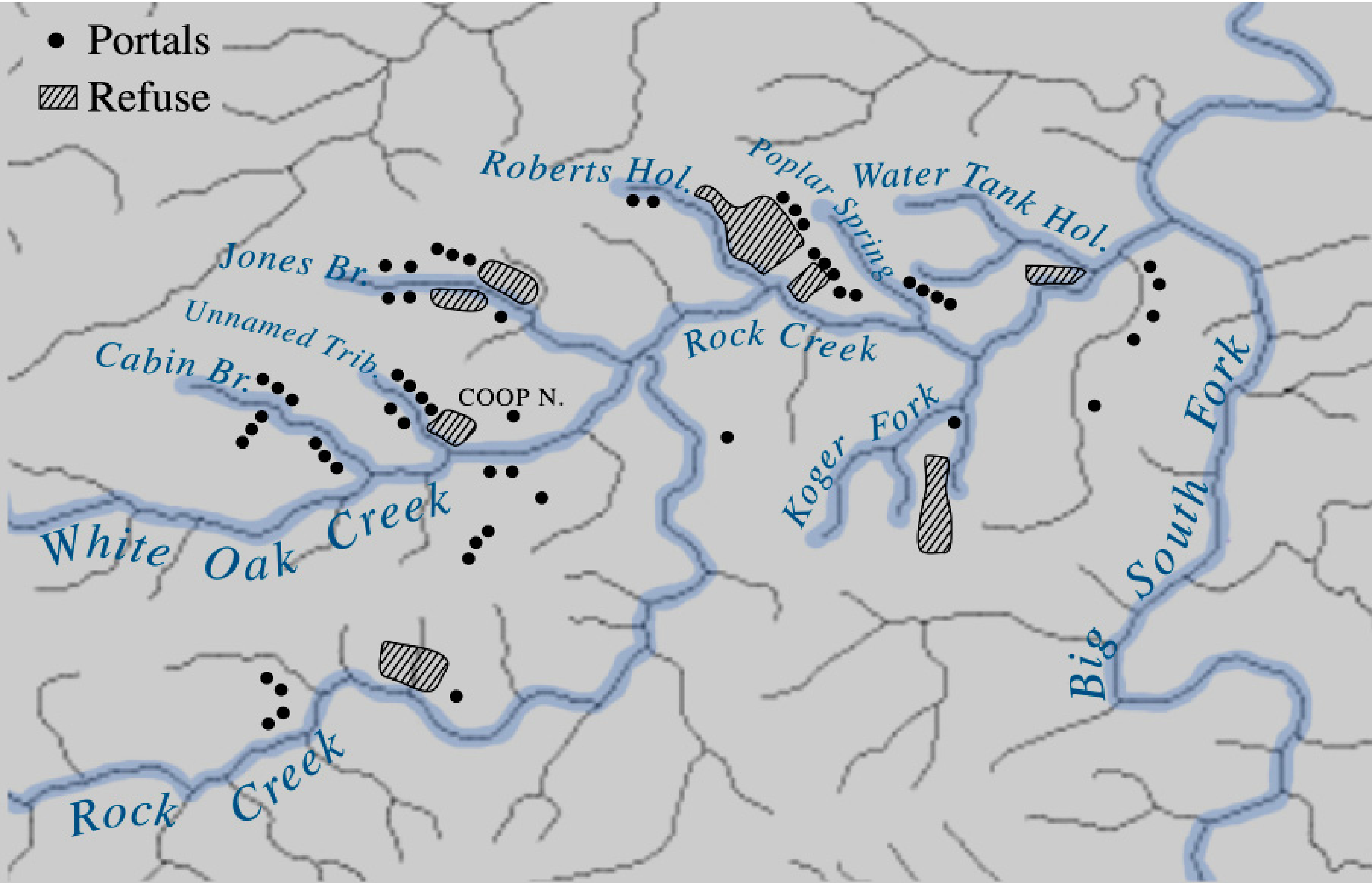
Passive Treatment of AMD with Open Limestone Channels in the

Lower Rock Creek Watershed

McCreary County, Kentucky


District Boundary Daniel Boone National Forest
Big South Fork National River and Recreation Area
Frankfort
Lex.
75
64
27
80
PKY
25E
927
90
Parkers Lake
27
Stearns District Office
Cumberland River
75
92
Whitley City
Williamsburg
STEARNS DISTRICT
Little South Fork
Rock Creek
92
Pine Knot
75
Big South Fork
Big South Fork NRRA
27
KENTUCKY
TENNESSEE

AMD Sources


• Portals
Refuse
Roberts Hol.
Poplar Spring
Water Tank Hol.
Jones Br.
Unnamed Trib.
Cabin Br.
COOP N.
Rock Creek
Koger Fork
Big South Fork
White Oak Creek
Rock Creek

Selected AMD Treatment Methods

- Limestone Sand Dosing
- Refuse Removal and Treatment
- Open Limestone Channels

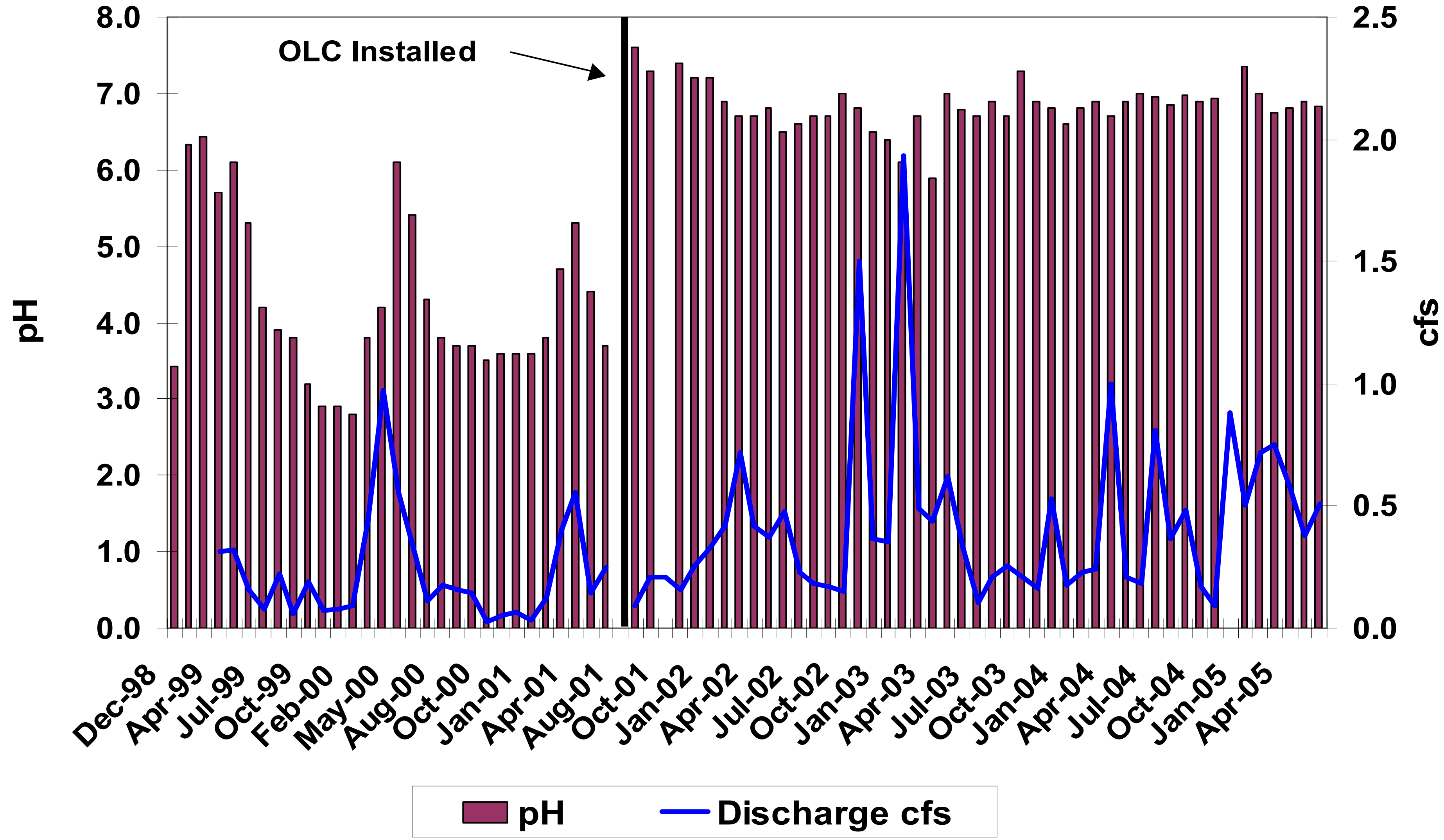
Rock Creek Project
AMD Abatement Methodology

- Treat AMD with limestone sand at rates based on acid loading calculations
- Utilize passive treatment and mine reclamation techniques as funding allows
- Reduce limestone sand dosing as sites are reclaimed and passive treatment systems are installed

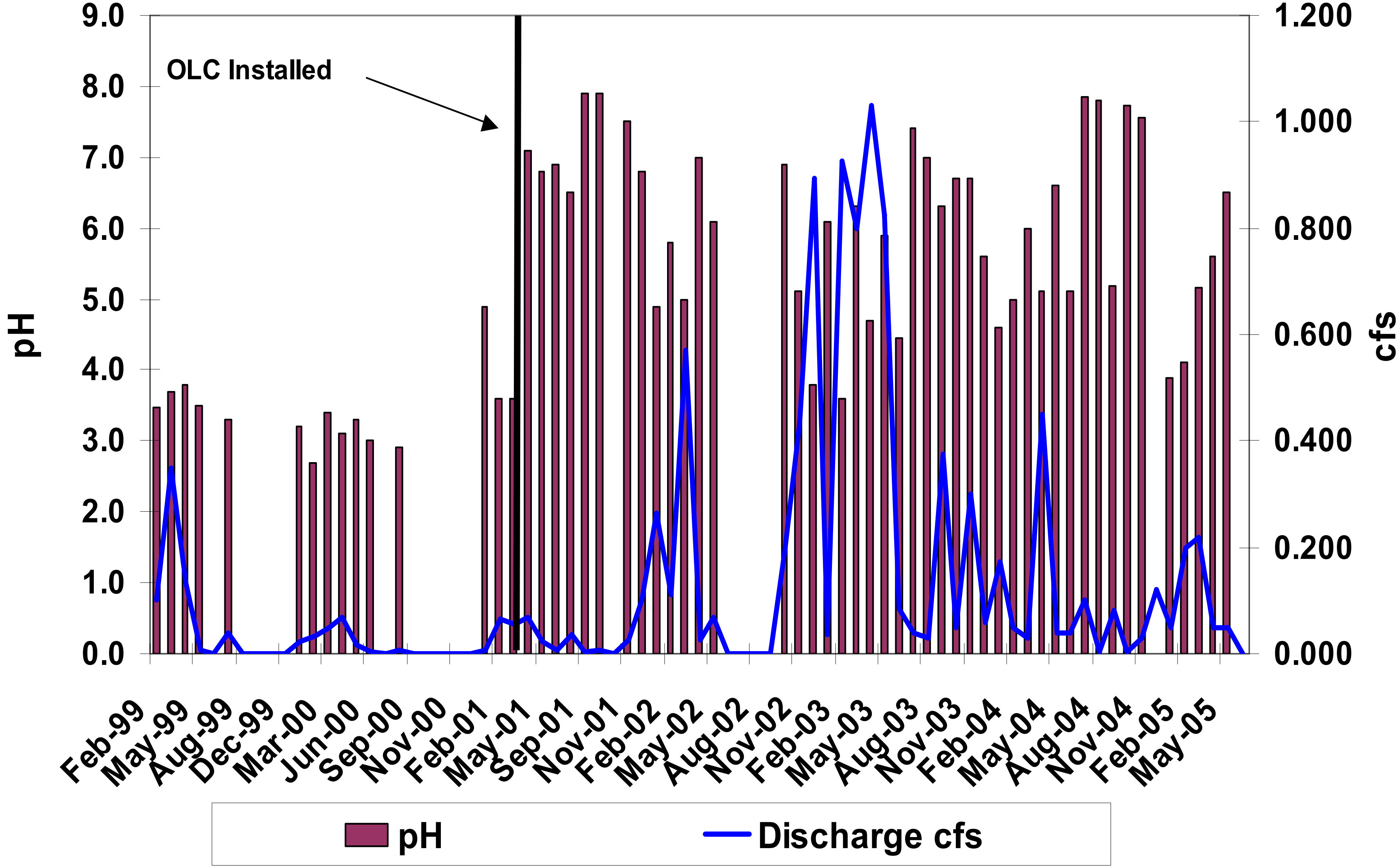
Limestone Sand Dosing

Open Limestone Channels

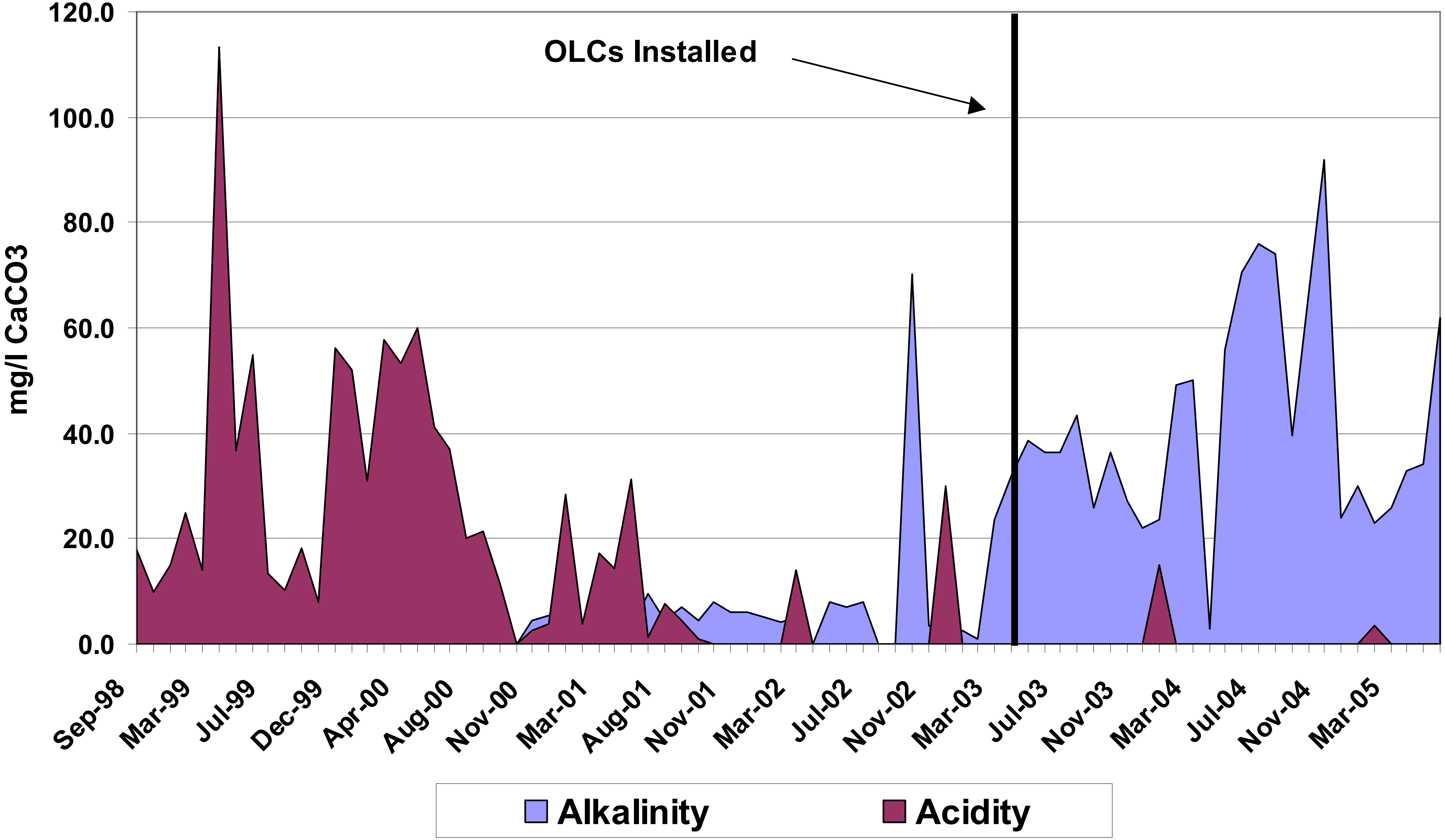
pH: Coop North



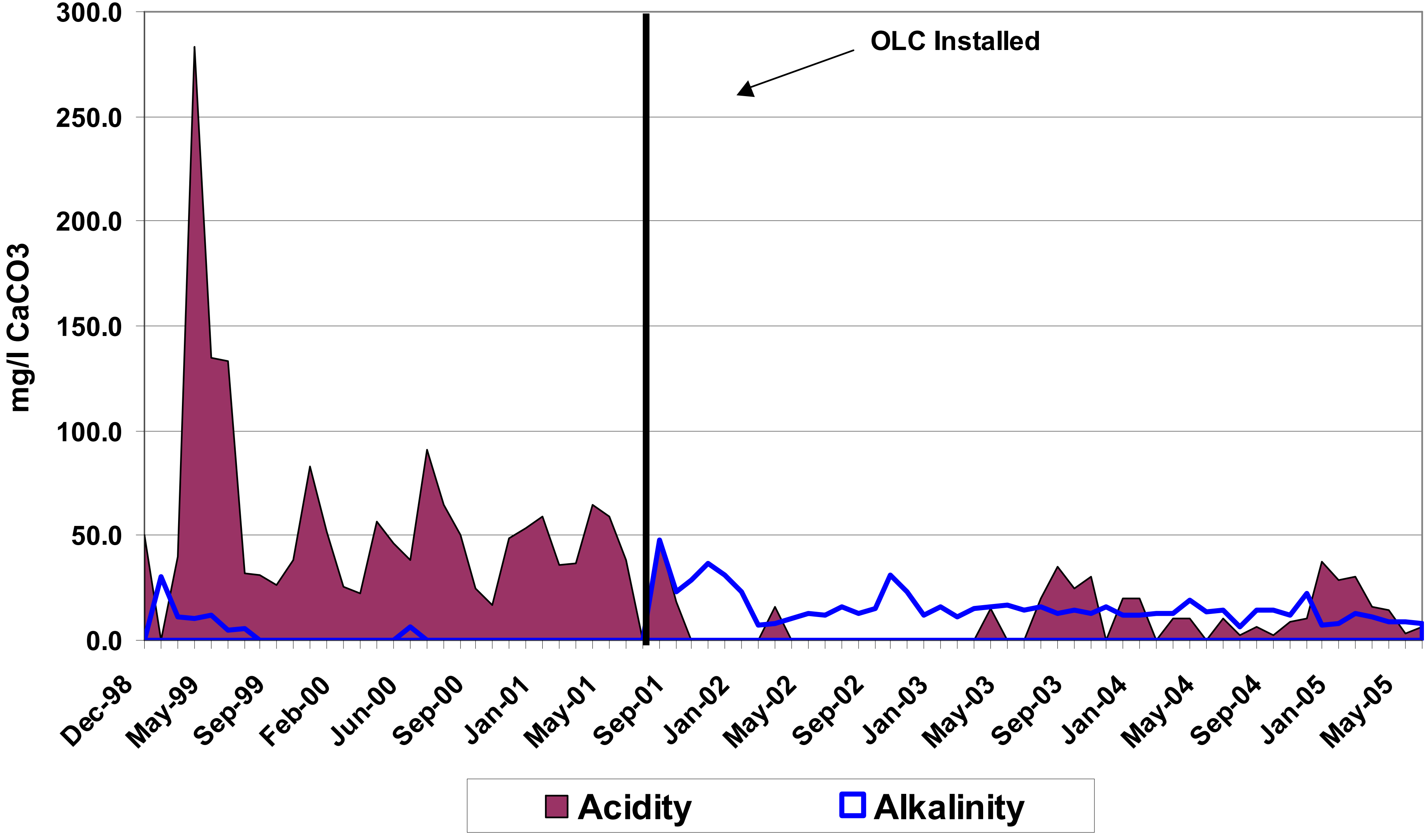
pH: Roberts Hollow



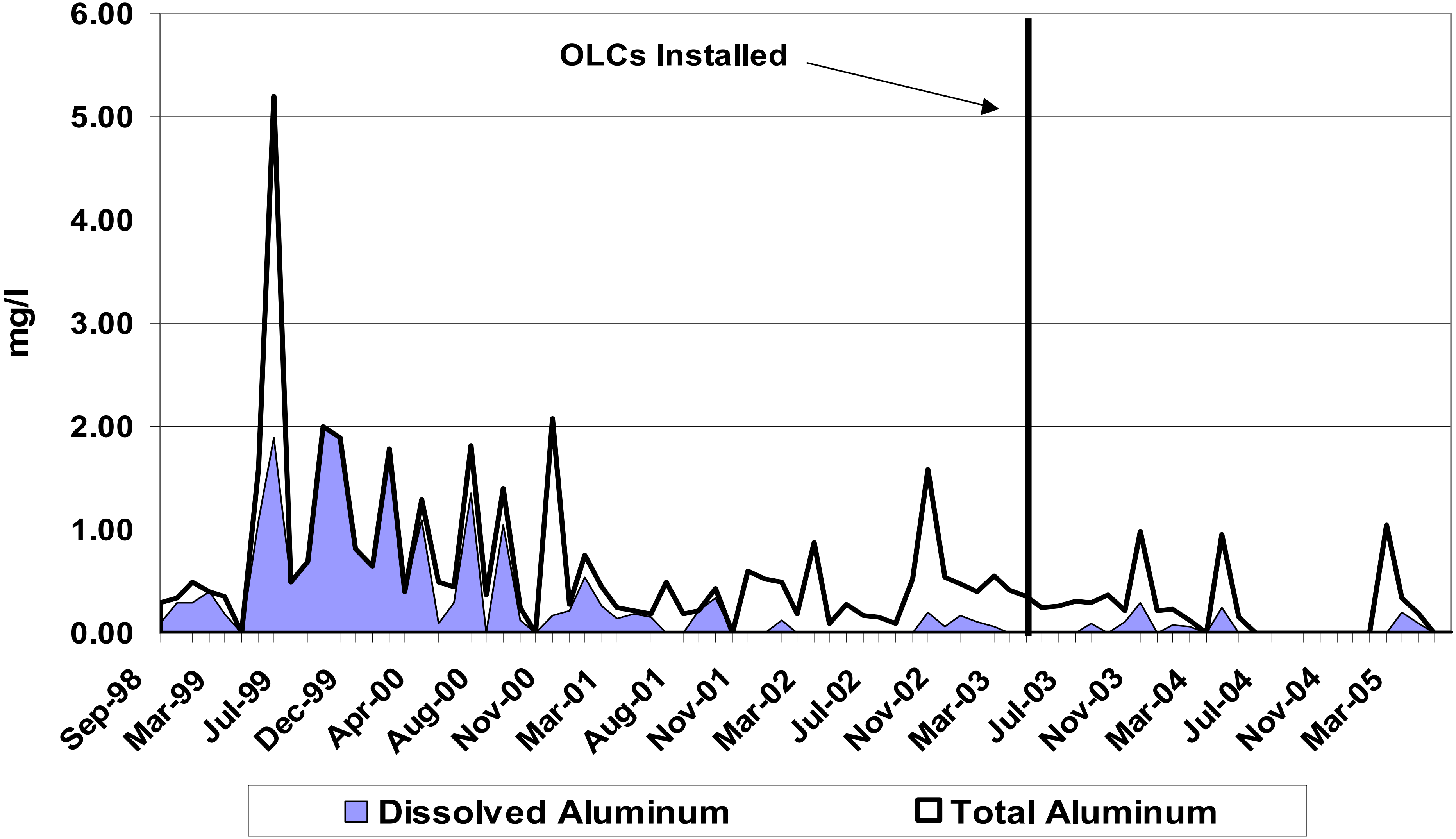
Acidity: Unnamed Tributary



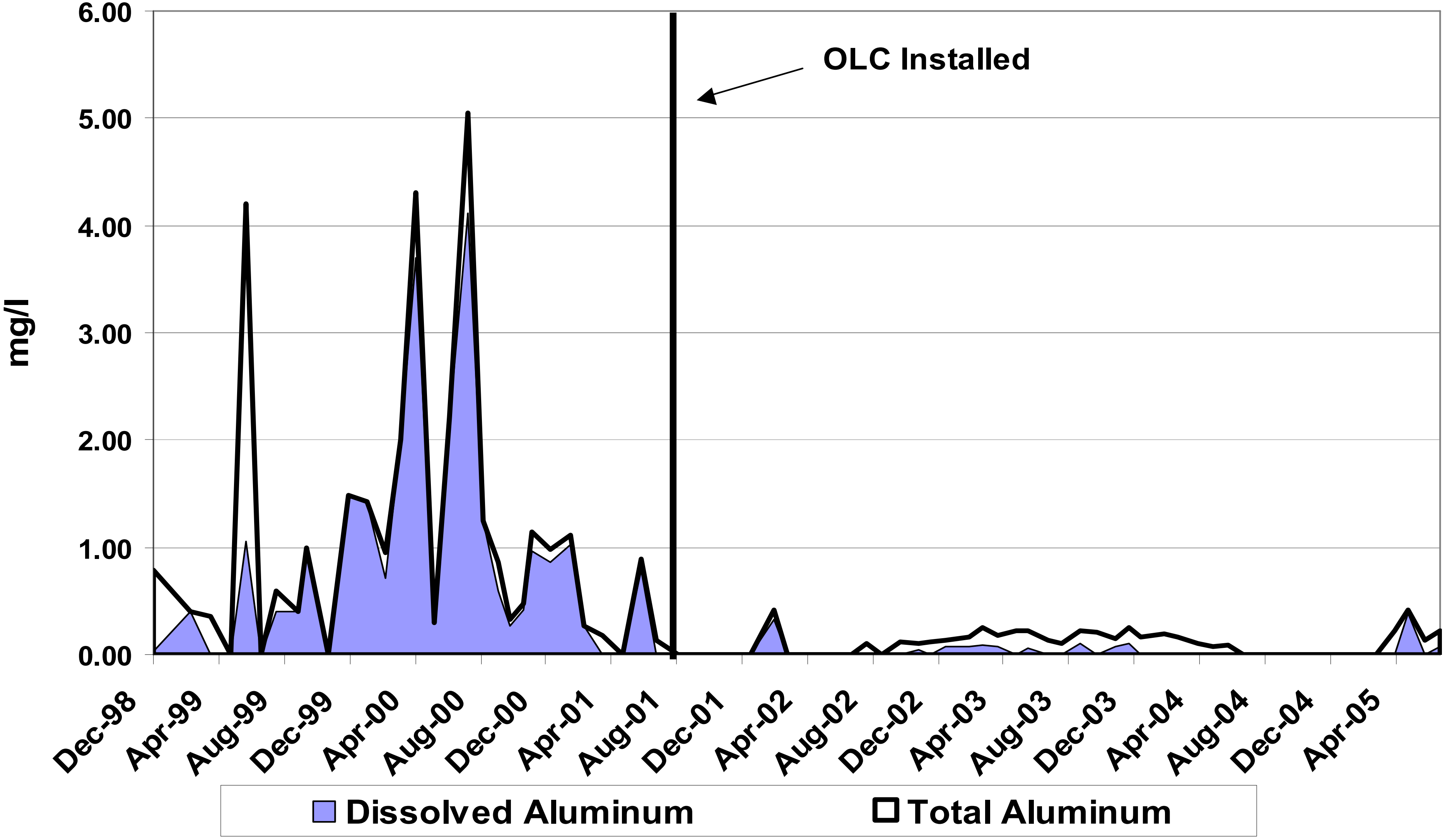
Acidity: Cooperative North



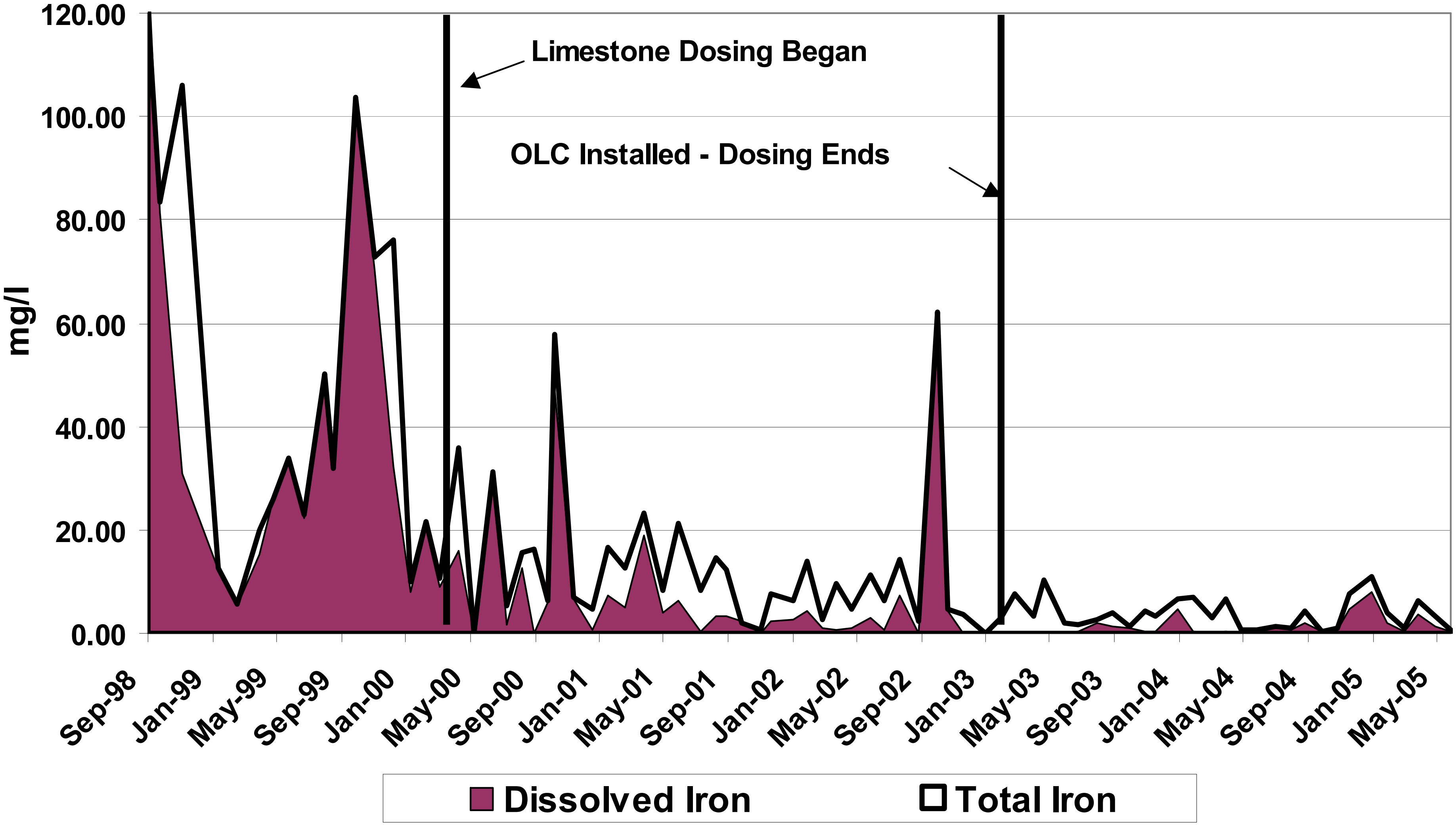
[Al]: Unnamed Tributary



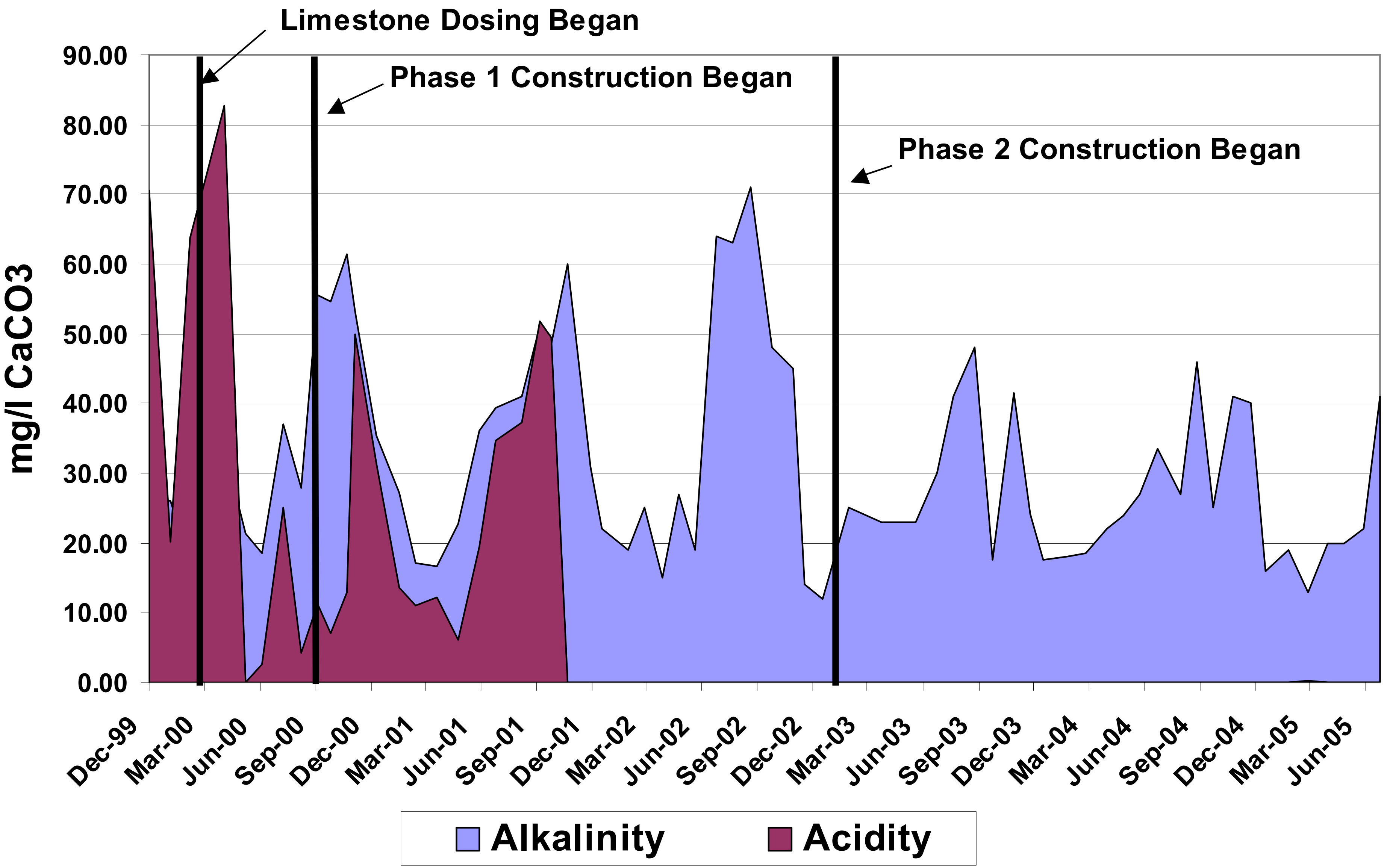
[Al]: Cooperative North



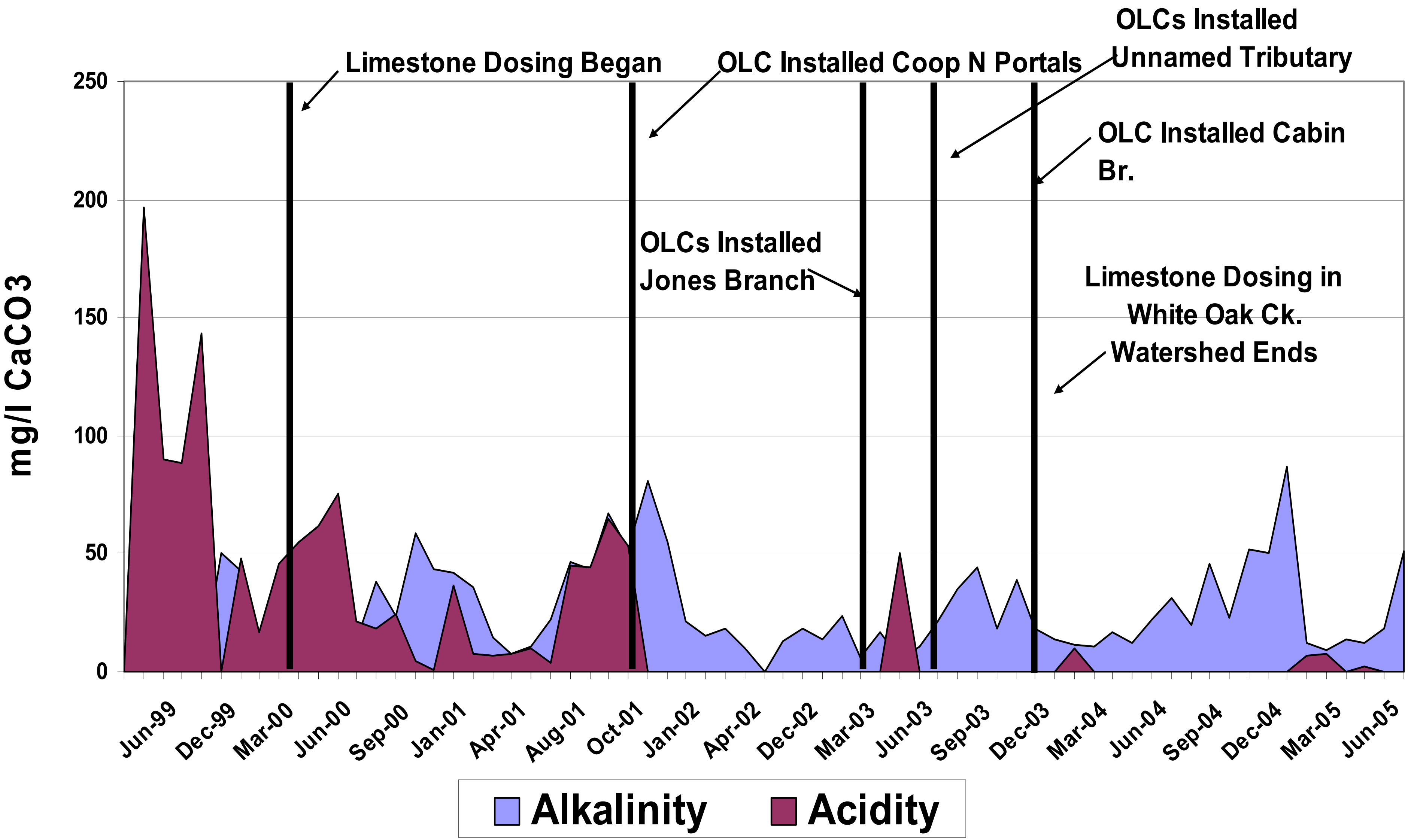
[Fe]: Jones Branch



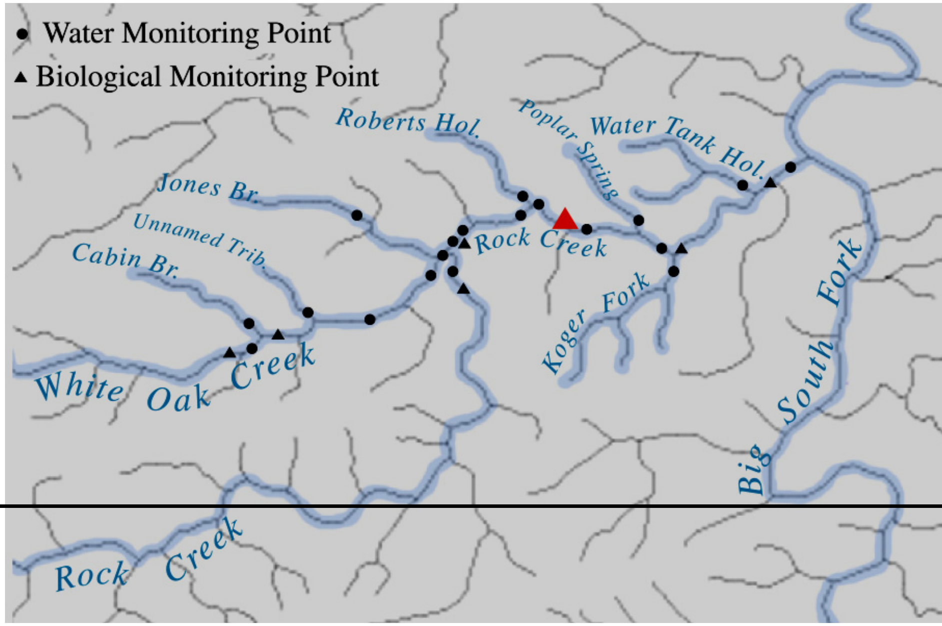
Acidity: Rock Creek Mouth

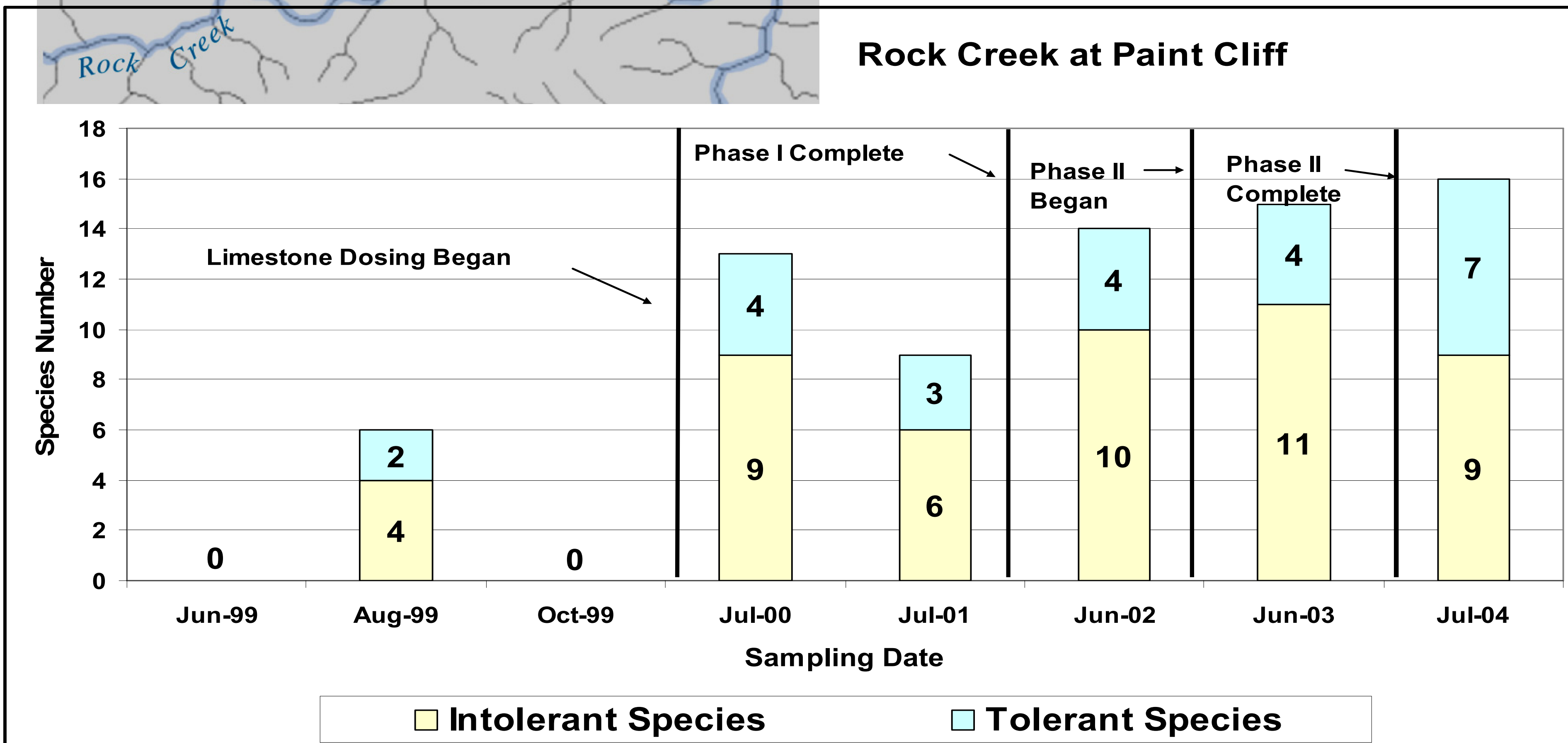


Acidity: White Oak Creek Mouth

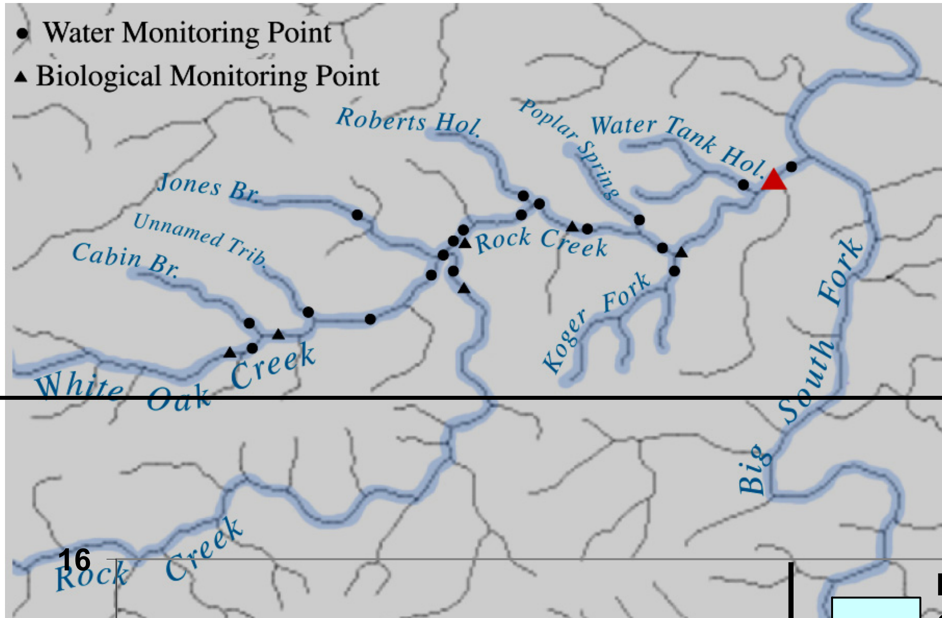


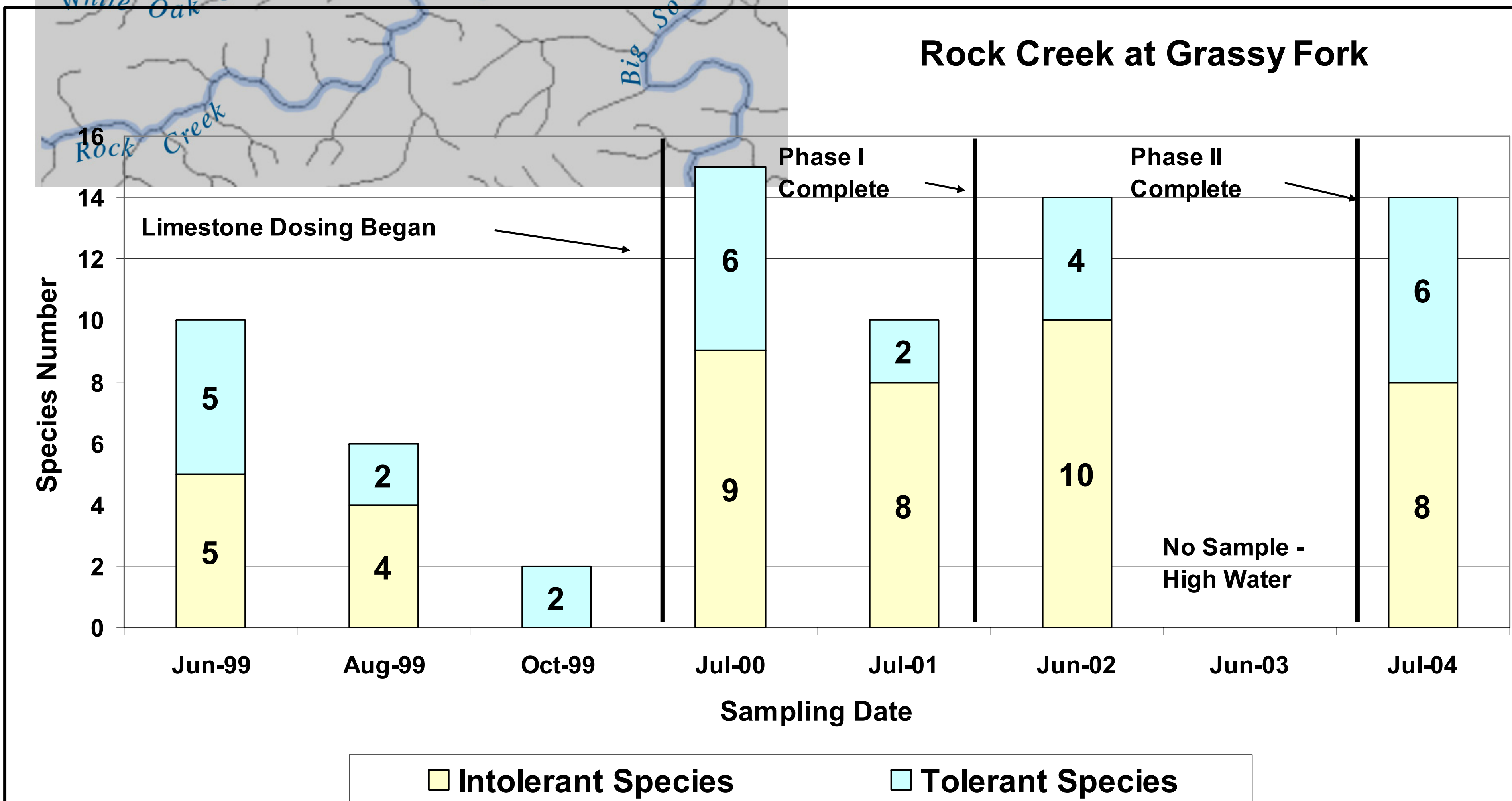
Fish Species





Fish Species





6,500 m of limestone channel
80,000 tons of limestone

Fish Populations are Increasing in Numbers and Diversity

Acid Loading into Big South Fork reduced from 1,400 tons annually to zero

Watershed-based versus At-source-based AMD Treatment: Costs and Benefits

Or:

Remind Me Why We’re Spending All This Money

Or:

Is AMD Treatment a Financial Problem Looking for a Technical Solution?

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Methods

- A comparison of AMD treatment costs was made related to the following scenarios:
  - Single AMD sources
  - Multiple AMD sources
  - Manganese sources.

Cost Factors

• Site access	S
• Construction	C
• Alkalinity addition	A
• Oxidation	O
• Sludge disposal	D

Parameters

- *AMD Cost = S+C+A+O+D*
- *Environmental efficiency = AMD Cost/ Recovered stream miles*
- *Treatment efficiency= AMD Cost/Tons of acid load removed*

Completed WVDEP Special Reclamation Project

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M&O: Charging the Lime Bin

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M&O: Sludge Cleanout

At-source vs. In-stream costs

Treatment Scenario	acid load (tpy)	20-yr Trt. ($)	Stream Rec. (mi.)	Stream Recovery Cost ($/mi/yr)	Acid Load Removal Efficiency ($/ton)
A. single AMD, in stream	253	885,171	2.0	22,129	175
A. single AMD, at source	12	532,569	0.3	106,514	2,211
B. multiple AMD, in stream	330	1,926,345	2.5	38,527	291
B. multiple AMD, at source	58	2,858,650	0.5	285,865	2,468

Conclusions: In-stream AMD Treatment vs. At-source treatment

- Always treated more acid load
- Recovers more stream miles
- More expensive than at-source, single AMD
- Less expensive than multiple at-source treatment

With In-Stream Treatment We Need to Know:

- How many miles of stream are actually restored to biological health with in-stream treatment?
- How quickly metal floc comes out of the water column
- Effects of metal loading, stream hydraulics: oxidation and floc settlement

Conventional Wisdom

- Treat Till You Drop
  - When the money runs out turn all residual liabilities over to the taxpayer
- Punitive: only negative incentives
- Inefficient: high cost, low return
- Does not address legacy sites

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There might be a watershed-based alternative

- Adopt-a-watershed: the one you're about to buy
- AMD bond based on perpetual watershed treatment
  - Predictable results, proven technology
  - Reasonable cost
- Pay into interest-bearing escrow account during mining
- Fund and treatment administered by Province
- If at end of operations site discharge results in no impact to the watershed you get your bond back

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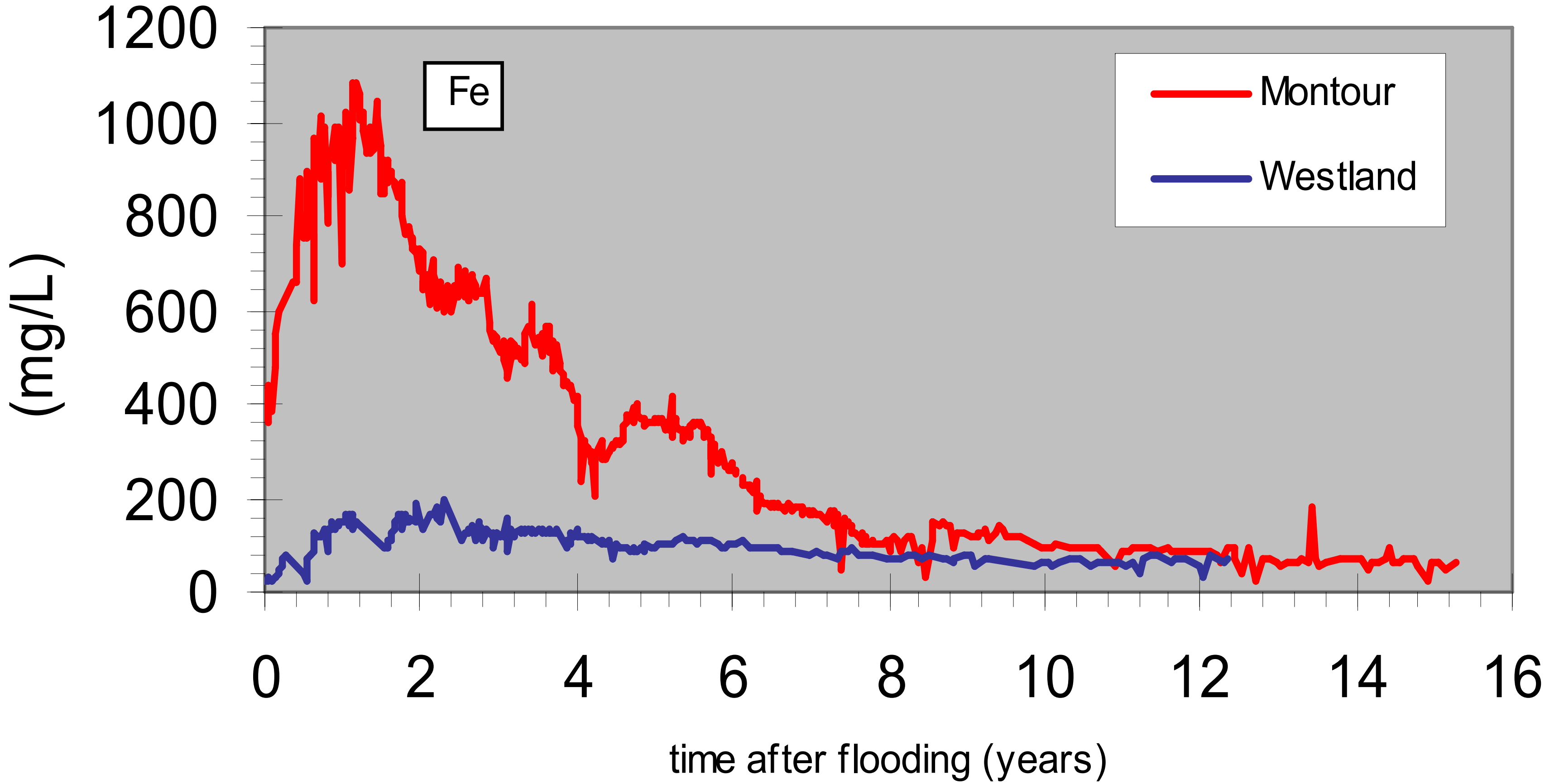
AMD Liabilities Can Change Dramatically, yet unpredictably



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