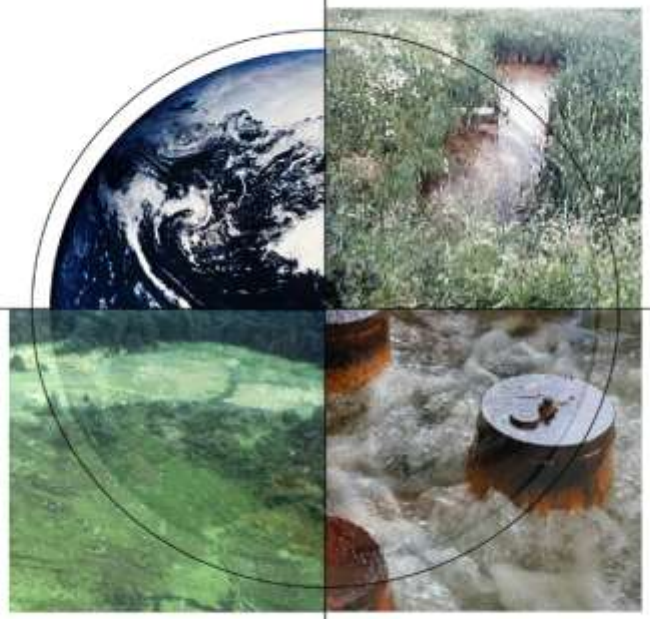
Manganese in Mine Water: A Historical Perspective



Bob Kleinmann
Director, Geosciences Division
NETL, U.S. Dept of Energy

How I Got Involved with Manganese

- U.S. Bureau of Mines involvement with mine water treatment in the early 1980's included trying to reduce the cost of removing Mn, and led to trying to understand the regulations.
- Understanding the regulations led to efforts to have the regulations re-evaluated.
- Subsequent research we conducted led to efforts on my part to have the regulations modified. It has been 15 years since I last addressed the topic.

Why is Manganese in Mine Water?

- Manganese is commonly present in sedimentary strata as a carbonate mineral, and is often associated with siderite. It is also sometimes associated with clay minerals, such as in shale.
- Manganese is soluble in acidic water and/or in a reducing environment.
- The oxidation of soluble Mn^{+2} to insoluble Mn^{+4} is slow at near-neutral pH, though it can be accelerated by bacteria. The reaction is autocatalytic at near-neutral pH if Fe^{+2} is not present; when both are present, Fe^{+2} oxidizes preferentially, and reduces any Mn^{+4} that forms.

Issues to be Discussed

- **Passage of the Clean Water Act led to regulation of manganese in mine water (this will probably be discussed in more detail by the next speaker)**
  - Best practicable technology currently available (BPT)
  - Best available technology economically achievable (BAT)
- **Drinking water concerns led to initial inclusion**
- **Toxicity concerns were considered**
- **Manganese as a surrogate for other, potentially more toxic metals**

BPT Standards

- **Initial regulation of manganese (and iron) were based on aesthetic considerations**
  - Taste of Mn detectable at 0.15 mg/L
  - Mn can stain plumbing and laundry at concentrations as low as 0.02 mg/L
- **Toxicity concerns subsequently considered as part of an EPA study of 129 “priority” pollutants potentially present in mine water**

Toxicity of Manganese

- Studies by the EPA and others have concluded that Mn toxicity is not an issue.
- Mn at normal concentrations is only toxic to aquatic life in very soft water.
- Mine water tends to be quite hard, especially after neutralization. The LC_{50} for Mn often exceeds 1,000 mg/L in freshwater species.
- The presence of Mn often ameliorates the toxicity of other metals by saturating extracellular metal-binding sites

Interesting Aspects of the 1976 BPT Regulations

- Untreated overflow from water treatment facilities caused by a 10 year storm event was exempted from the regulations.
- Drainage from a surface mine or a section thereof, which had been returned to final contour, was exempted from the regulations.
- Al, Ni, and Zn were not regulated because they were removed in the process of raising the pH and aerating the water to lower Fe concentrations to 3.5 mg/L.
- In alkaline mine water, manganese was not regulated because EPA found that it was not a significant problem.

Negative Aspects of Conventional Treatment for Mn

- Typically requires a high pH, which can resolubilize Al.
- Raising the pH that high is expensive, and if one has to reacidify the water, which is sometimes required, it is even more expensive.
- Though Mn is not typically toxic in hard water, alkaline, treated mine water can be, especially if it increases Al solubility.

Development of BAT Effluent Limitations

- The 114 organic compounds that EPA analyzed for were either not detected or were found at such low concentrations that no regulation was deemed necessary.
- Manganese was not found to be toxic, but 8 potentially toxic metals (arsenic, chromium, copper, lead, mercury, nickel, selenium, and zinc) were found to be elevated at some sites, though not at others.
- The existing BPT regulations were found to effectively control these metals.

More Negative Aspects of Regulating Mn

- As already pointed out, conventional neutralization and aeration to remove manganese to an average of 2 mg/L is both expensive and environmentally problematic.
- It is possible to remove both Fe and Mn passively, using methods that did not exist when these regulations were written, but depending on the method used, other more toxic metals may not be removed.

Manganese Removal Techniques

Method	Capital Costs	Operating Costs	Stability Of Sludge	Comments
Excess Alkalinity (high-pH)	🔴	🟡	🔴	Sludge becomes more stable with time
Chemical Oxidants (hypochlorite, permanganate)	🔴	🔴	🟢	Oxidants may not be permitted in all States
Passive (wetlands, limestone beds, etc.)	🟡	🟢	🟡	Requires large areas of land, inconsistent removal, may not remove more toxic metals

🟢 - GOOD 🟡 - FAIR 🔴 - POOR

Still More Negative Aspects of Regulating Mn

- By adding sufficient alkalinity to the mine spoil, it is possible to generate an alkaline discharge that may be elevated in Mn, but exempt from Federal regulation.
- It is common practice to dispose of water treatment sludge on a mine site or in an underground mine. The $Fe(OH)_3$ will be stable unless exposed to quite acidic water, but the Mn can redissolve, and thus be recycled.

A surface mine in Green County, PA that had high Mn and disposed of their sludge up-gradient of the seep. Mn concentrations were up to 200 mg/L.

Still More Negative Aspects of Regulating Mn

- Removal of the more toxic metals does not require a pH above 9; removal of Mn sometimes requires a pH of 10.5
- To summarize, the current Mn regulations, though well intended, significantly increase the cost of compliance at many mine sites, generally does not improve water quality, and at some sites, results in reduced water quality.

Manganese in Coal Mine Drainage: A Regulatory Perspective

William A. Telliard
Director of Analytical Methods
Office of Science and Technology
Office of Water

• Water Quality Improvement Act of 1970
• Federal Water Pollution Control Act Amendments of 1972
• Clean Water Act of 1977
Office of Water

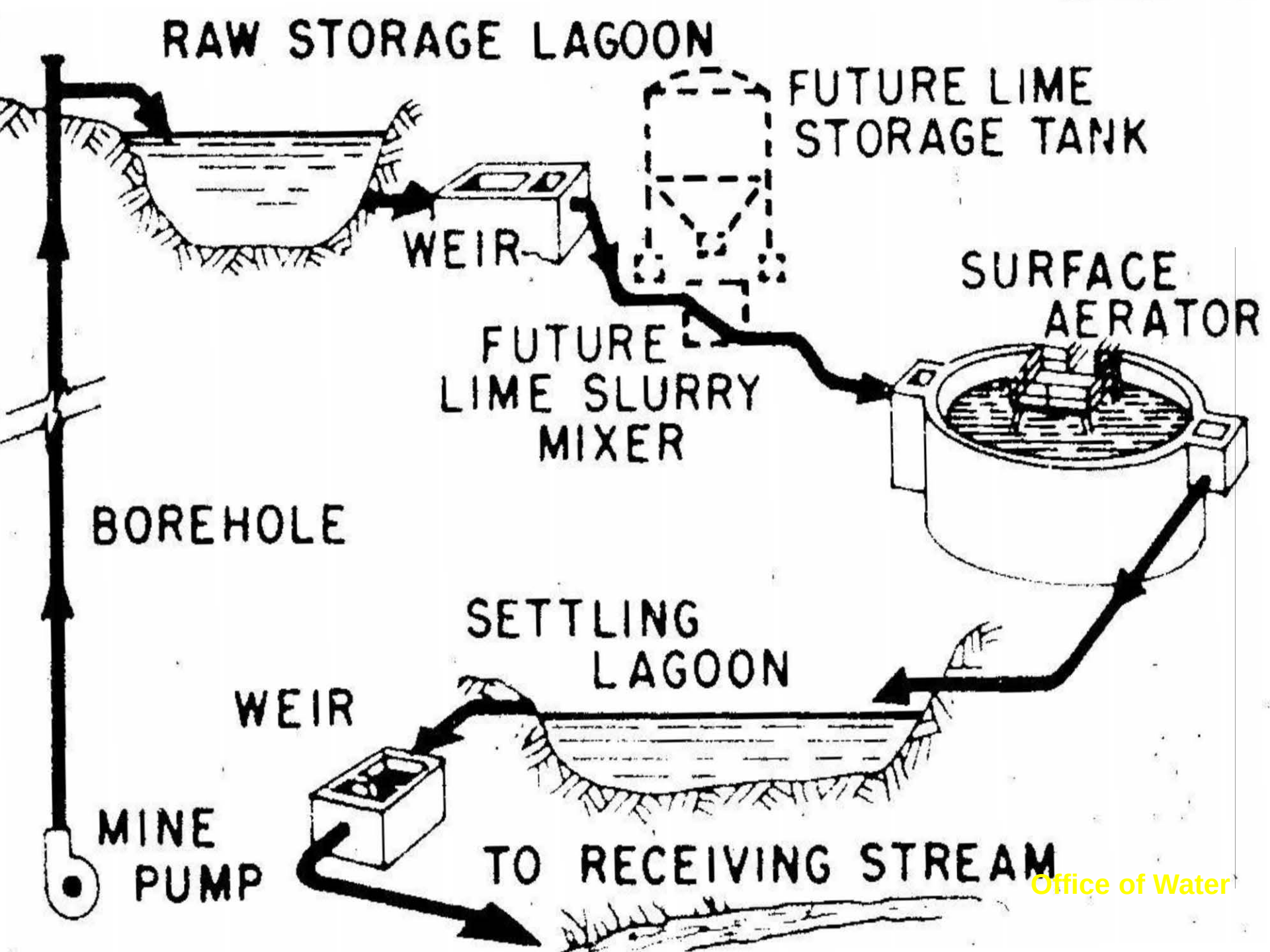
The Clean Water Act of 1977

- Controls Toxics
- Changes Deadlines/ Pretreatment Standards
- Creates New Categories of Industrial Pollutants

Office of Water

Coal Mine Pollutants of Concern - 1970s

- Total alkalinity
- Total acidity
- pH
- Total suspended solids
- Total iron
- Total manganese
- Sulfates


RAW STORAGE LAGOON
FUTURE LIME STORAGE TANK
WEIR
SURFACE AERATOR
FUTURE LIME SLURRY MIXER
BOREHOLE
SETTLING LAGOON
WEIR
MINE PUMP
TO RECEIVING STREAM
Office of Water

Best Practical Technology (BPT) - *Baseline Treatment*

- Total alkalinity
- Total acidity
- **pH**
- **Total suspended solids**
- **Total iron**
- **Total manganese**
- Sulfates
- **Settleable solids**

BPT parameter

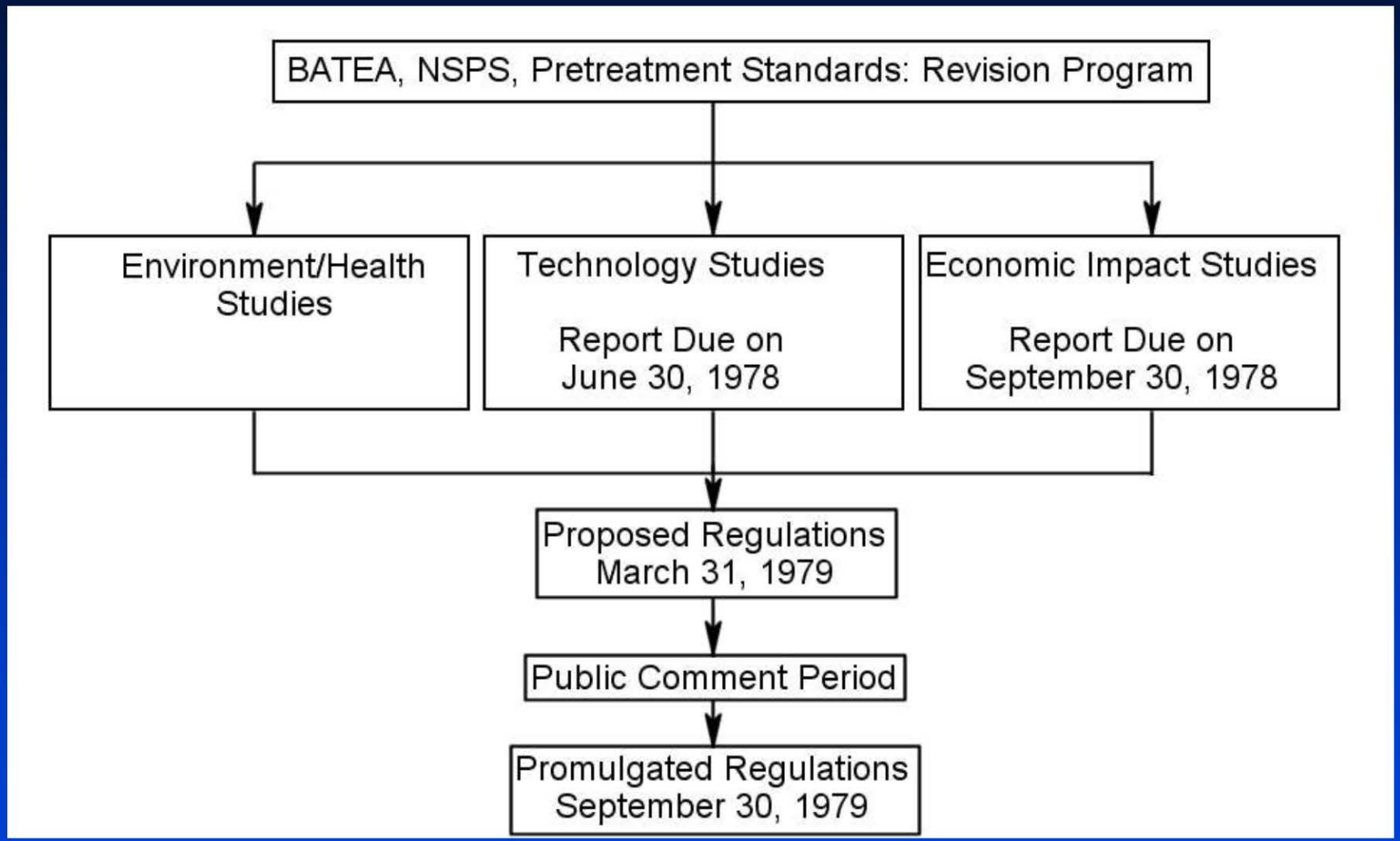
BAT Study

Office of Water

Classes of Pollutants in Regulations

- Conventional pollutants
  - BOD
  - pH
  - Total suspended solids (TSS)
  - Oil and grease
  - Fecal coliform bacteria
- Toxic pollutants (priority pollutants)
  - 129 total (15 inorganic and 114 organic)
- Nonconventional pollutants
  - Everything else

BATEA Revision Program



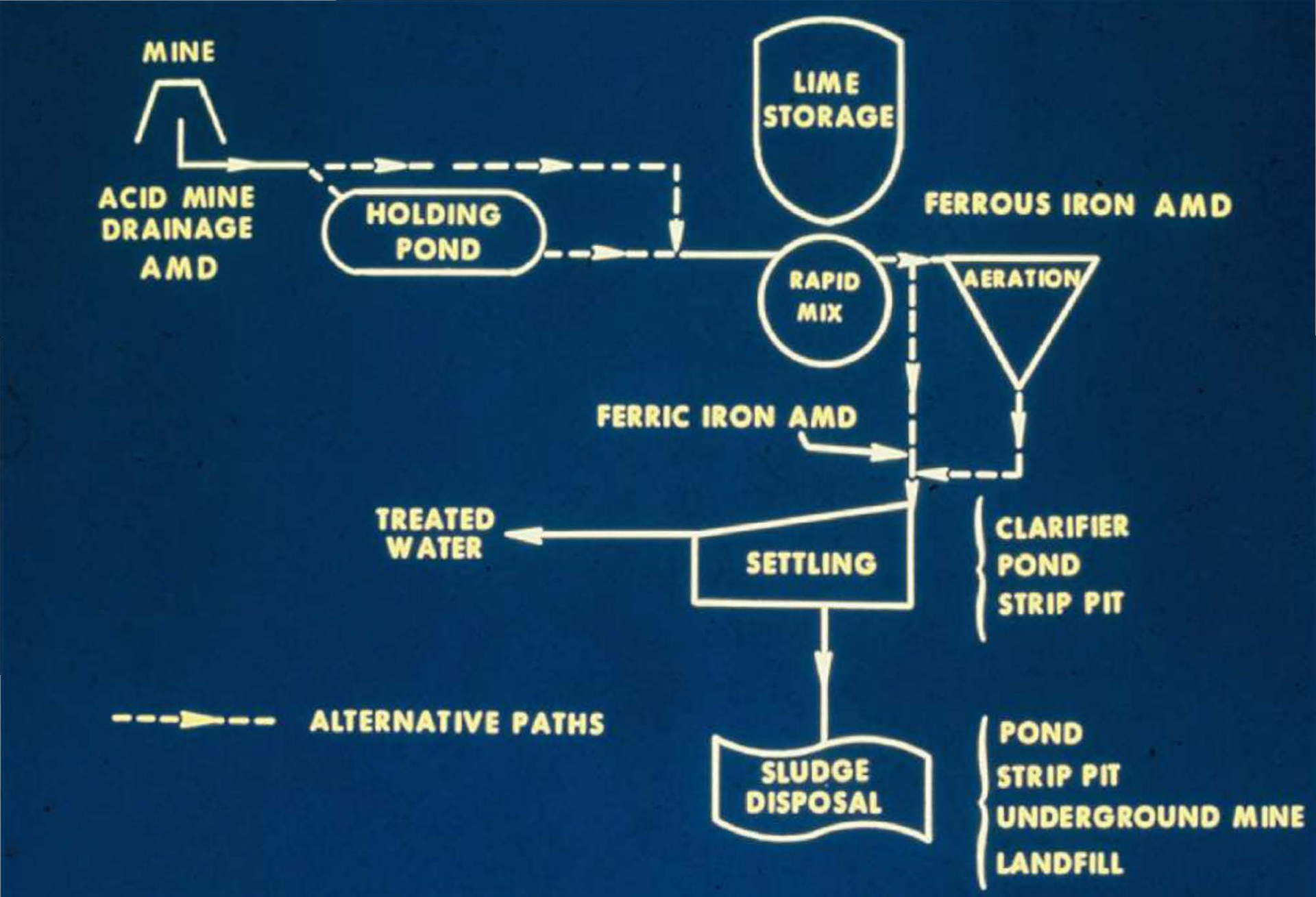


Figure 2. Typical lime treatment plant.

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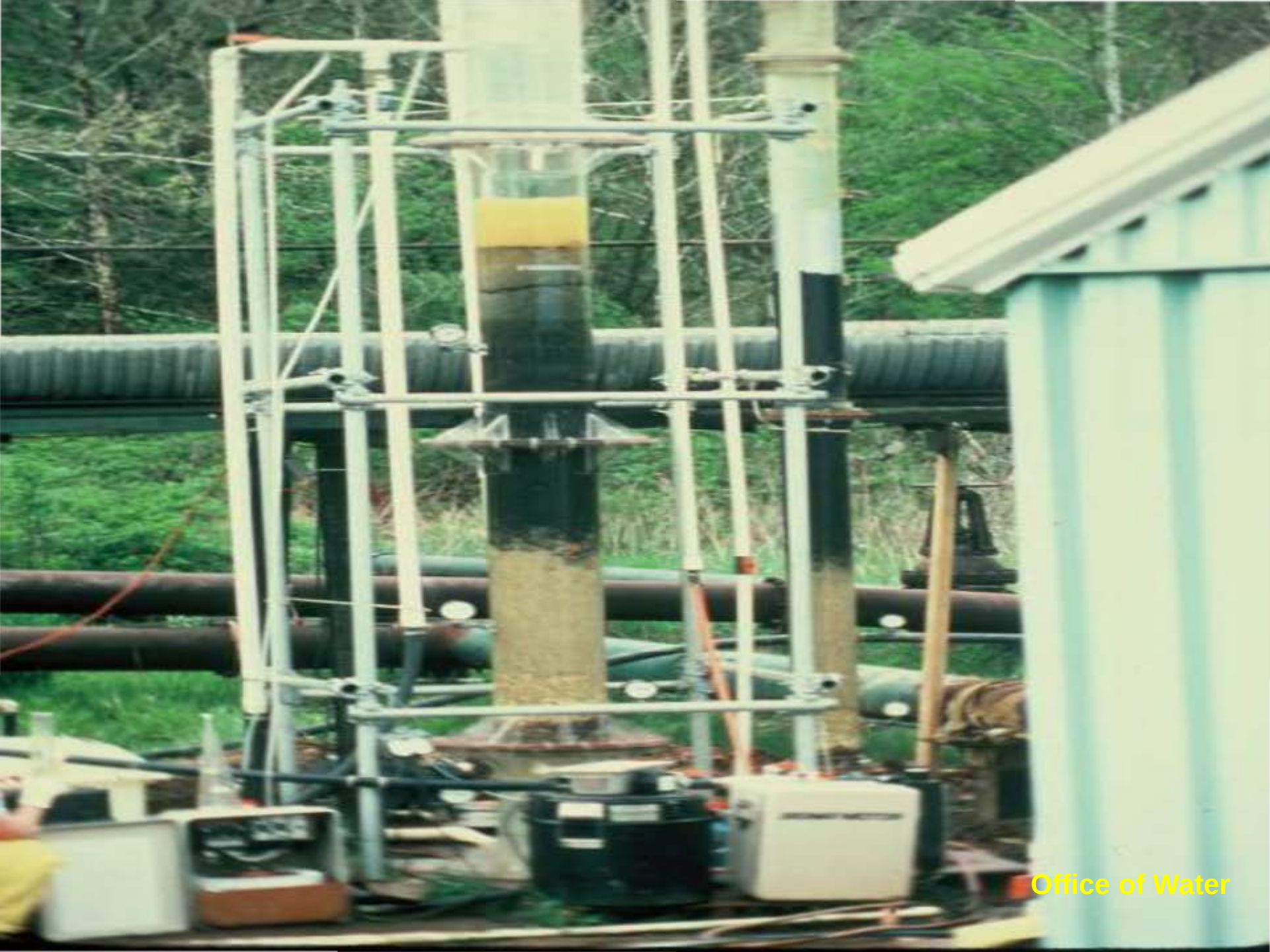
Office of Water

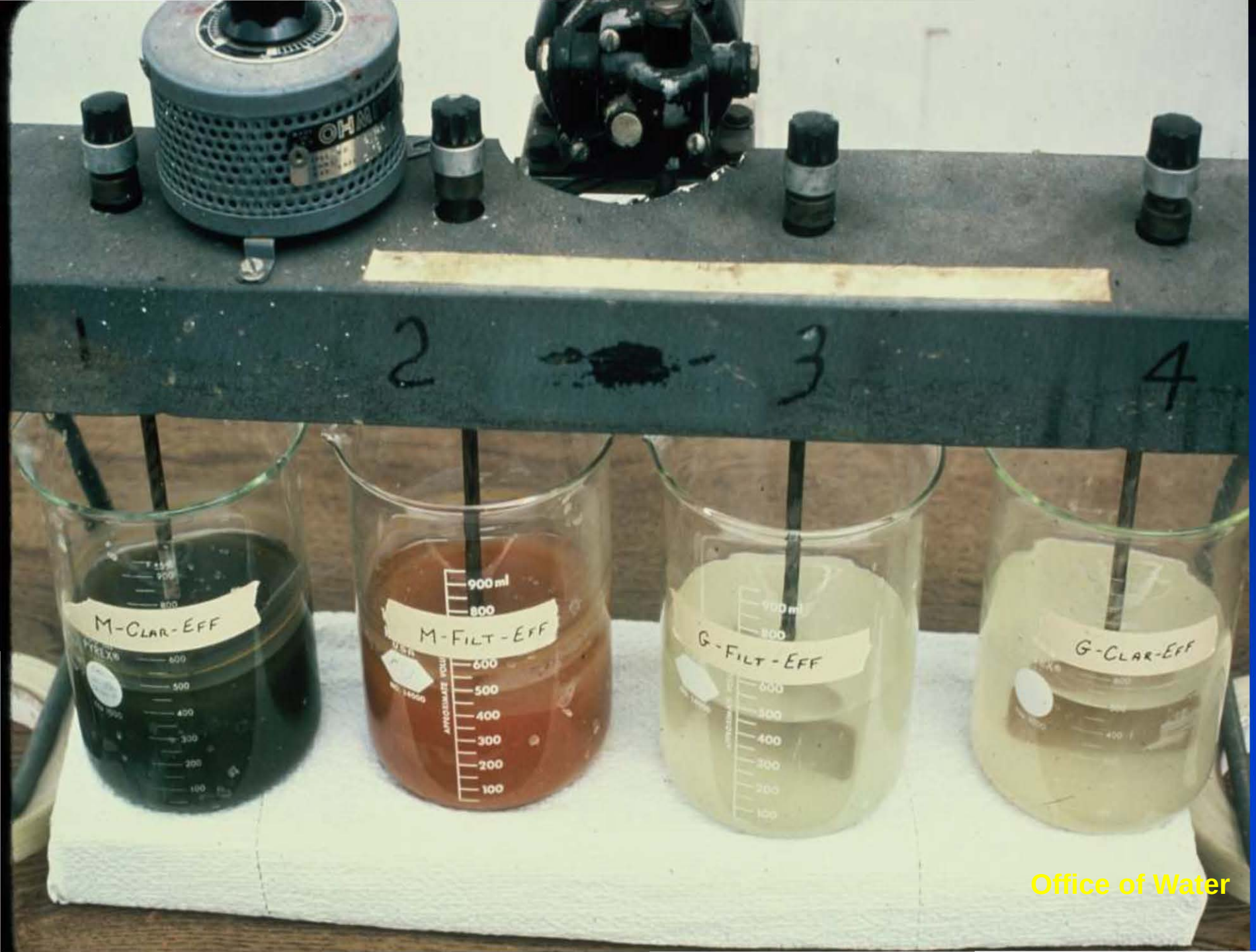

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FIGURE 1
SOLUBILITY OF Al, Mn, Fe III, Mg, Cu AND Zn
IN ACID MINE DRAINAGE AT VARIOUS pH'S

Office of Water

1985 Regulatory Summary

BAT = BPT

Manganese is ONLY regulated in:

- Coal preparation plants subcategory
- Acid or ferruginous mine drainage subcategory

What Process Does EPA Use to Revisit Its Existing Effluent Limitation Guidelines?

Section 304(b) and 304(m) Planning Requirements

- **Section 304(m) requires EPA to publish a plan every two years identifying:**
  - Its schedule for revising existing guidelines, per Section 304(b), and
  - Industrial categories for which EPA has not promulgated effluent guidelines
- The 2004 effluent guidelines program plan is EPA's first plan since 1990 outside the context of a consent decree

Section 304(m) Requirements

- Applies to industries with direct discharging facilities
  - Section 304(g) addresses annual review of pretreatment standards for indirect dischargers
- EPA must publish an effluent guidelines plan every even-numbered year after public comment
- For industry categories with an existing guideline
  - EPA must establish a schedule for the annual review and, if appropriate, revision of guidelines based on factors such as cost, nonwater quality environmental impacts, and *other factors the Administrator deems appropriate.*

Factors EPA Considers in 304 Planning

- Does an industry category discharge pollutants that pose a hazard to human health or the environment?
- Will any control technologies, process changes or pollution prevention approaches reduce these hazards?
- If so, what will the technology, process change or pollution prevention approach cost, how well will it perform, and is it affordable?
- Are there implementation or efficiency issues to consider?
  - Could other approaches (e.g., permit support, voluntary reductions) achieve the same or greater reductions more efficiently?

Phased review process

- Screening primarily based on hazard
- Further review hazard data and address other factors for industries that appear to pose the greatest hazard

434 Regulation

- Oral arguments for the amended 434 regulation covering:
  - Coal remining subcategory
  - Western alkaline coal mining subcategory

will occur in the 6th Circuit Court, Cincinnati, OH, on June 1, 2005.

For Further Information

- 304(m) procedure:

  Carey Johnston, Project Lead, 202-566-1014, johnston.carey@epa.gov

- Coal mining issues:

  William Telliard, Director, Analytical Methods, 202-566-1061, telliard.william@epa.gov

Manganese: What's all the Fuss about?

Brent Means
Office of Surface Mining

How common is Mn in mine drainage?

OSM

- Ca>Mg>Fe>Al>Mn>K>Zn>Ni>Co>Y (Na?)
- 62% of all discharges being treated in Appalachia are treating for Mn
- Average Mn is 20 mg/L
- Highest 454 mg/L
- Most of the discharges are in Pa and WV

Origins of Mn^{2+}

- As a rule of thumb, Mn is much more elevated in Surface Mine discharges than Underground mine discharges
- This provides some evidence that Mn is not associated with pyrite or coal (with overburden)
- It is unclear what stratigraphic unit Mn is associated with or the exact solid phase
- Large amounts have been found in black shales and in siderite (sub. for Fe)
- Research is needed to find Mn-rich strata so it can be tested for in OB analysis.

Chemistry of Manganese

- In mine drainage, Mn is known to exist as three Oxidation States:

$$Mn^{2+} \leftrightarrow Mn^{4+} + 2e^-$$

- Mn^{2+} – "Reduced Manganese"
  - $Mn(OH)_2$
- Mn^{3+} and Mn^{4+} "Oxidized Manganese"
  - MnO_2 (Pyrolusite)

Problems with Mn: Mn produces acidity when precipitated as an "oxidized" solid or a chemically "reduced" solid

Precipitating Mn as a chemically oxidized solid

$$Mn^{2+} + .5O_2 + 2\cancel{H^+} = \cancel{Mn^{4+}} + \cancel{H_2O}$$

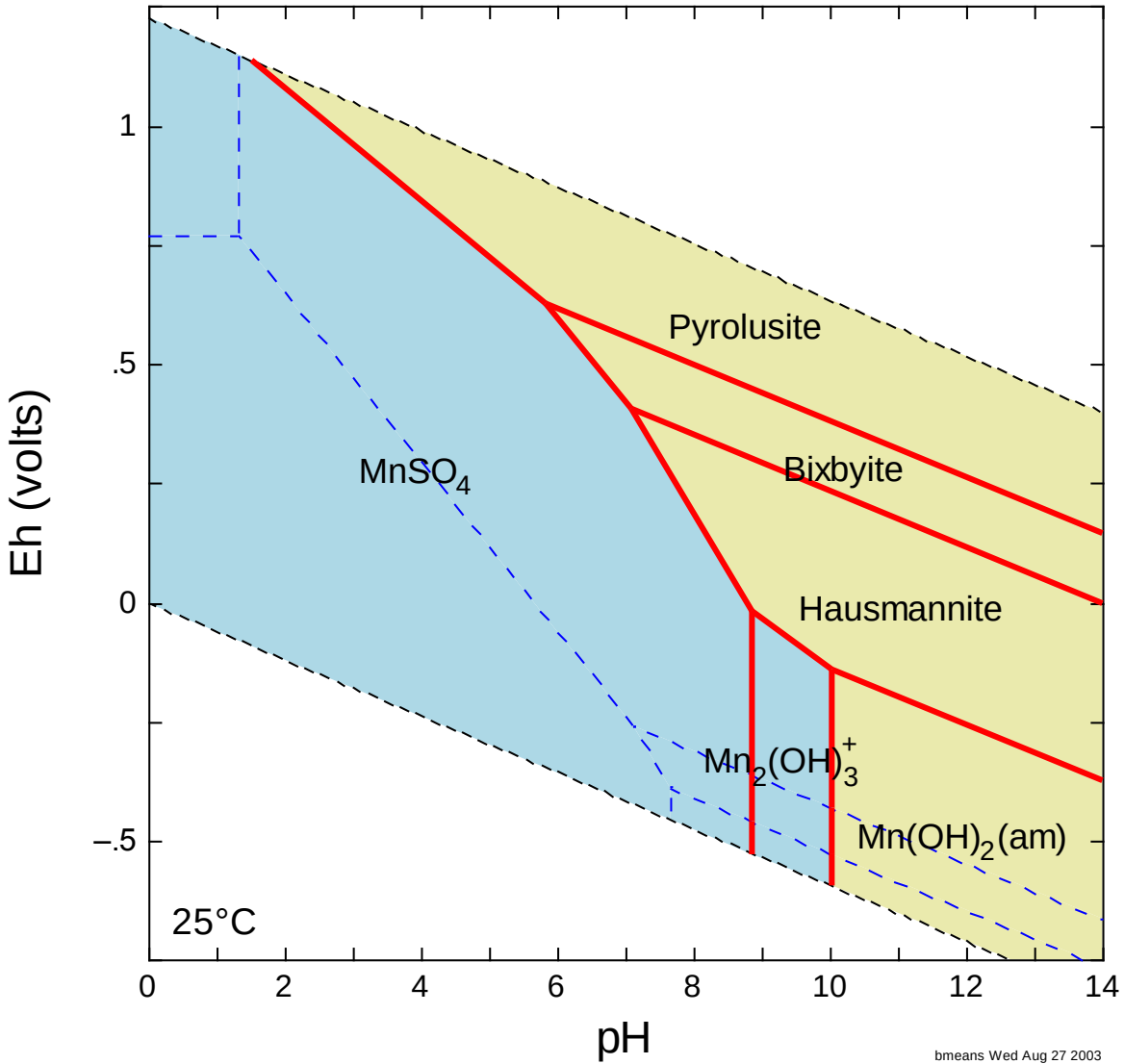
$$+ \quad \cancel{Mn^{4+}} + \cancel{2H_2O} = MnO_2\,(s) + 4\cancel{H^+}$$

$$Mn^{2+} + 0.5O_2 + H_2O = MnO_2\,(s) + 2\mathbf{H^+} \qquad E^o = +1.2 \text{ volts}$$

Precipitating Mn as a chemically reduced solid

$$Mn^{2+} + 2H_2O = Mn(OH)_2\,(s) + 2\mathbf{H^+}$$

Manganese Chemistry



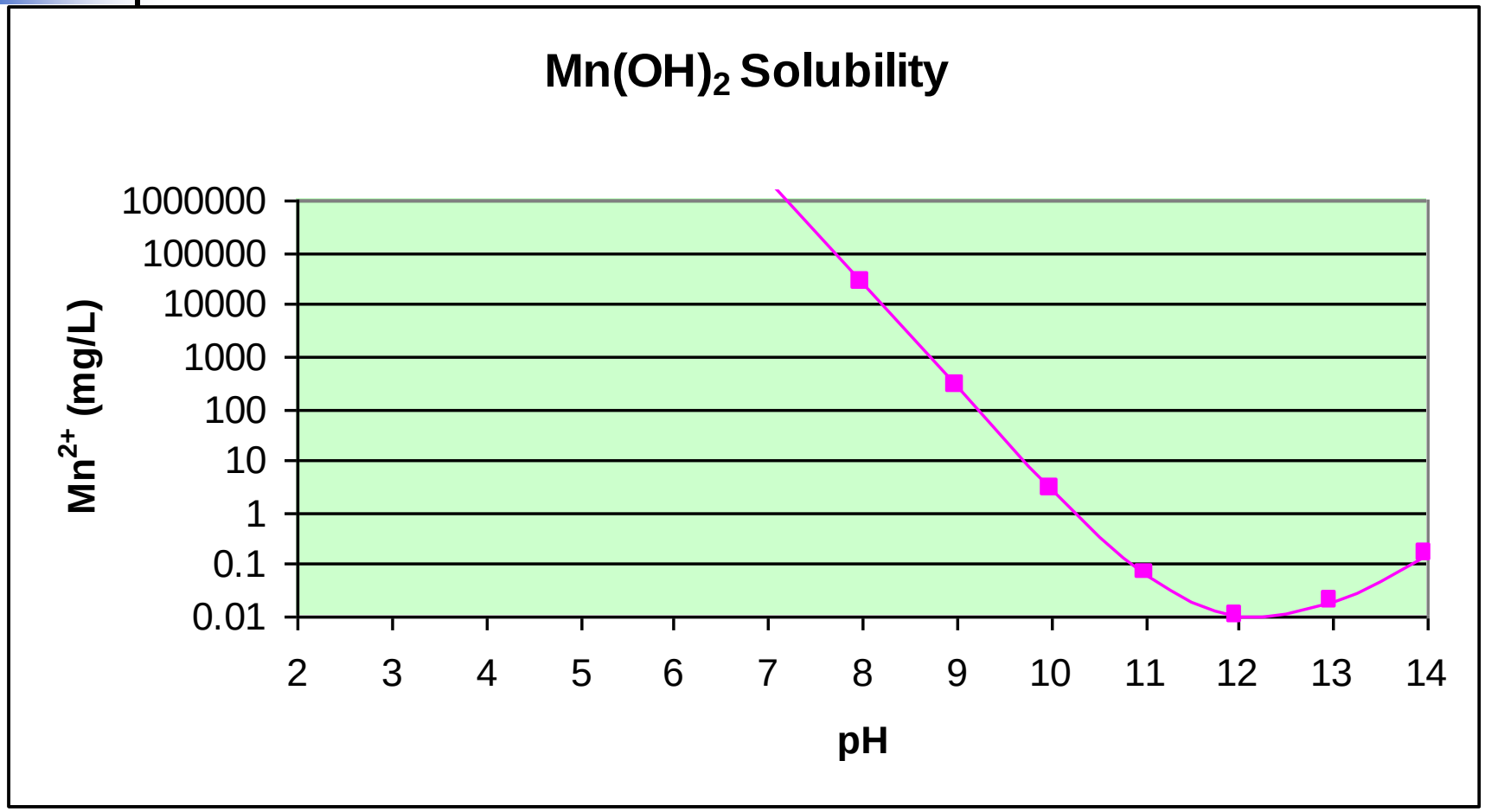
How long does it take to make Mn acidity?

- At pH of 8.4, Diem and Stumm (1984) found negligible abiotic precipitation in aerated solutions stored for 4 to 7 years.

- At pH of 9.5, abiotic oxidation is relatively instantaneous

How do you treat for Mn^{2+}

OSM



OSM

Mn Treatment Costs: Fact or Folklore?

- "I'm spending 200K/year treating for Mn"
- "Mn is doubling my treatment costs"
- "If I have to treat this discharge, I'm forfeiting my bonds and the State can deal with it"

- Money = Treatment chemical (NaOH)

- If we can estimate the amount of treatment chemical needed to treat for Mn, we can estimate the cost

Mn Treatment Costs: Fact or Folklore?

OSM

$$NaOH = [50000*(10^{-(STARTpH)} + 10^{-(14-FINALpH)}) + 1.8*Mn\ (mg/L)]*1.7$$

(gal/year of 20%))

- pH = 5, Mn = 58 mg/L, treatment pH = 10.5
  - ~ 204 gal NaOH/year for each gpm of flow
  - ~ $102/year for each gpm of flow

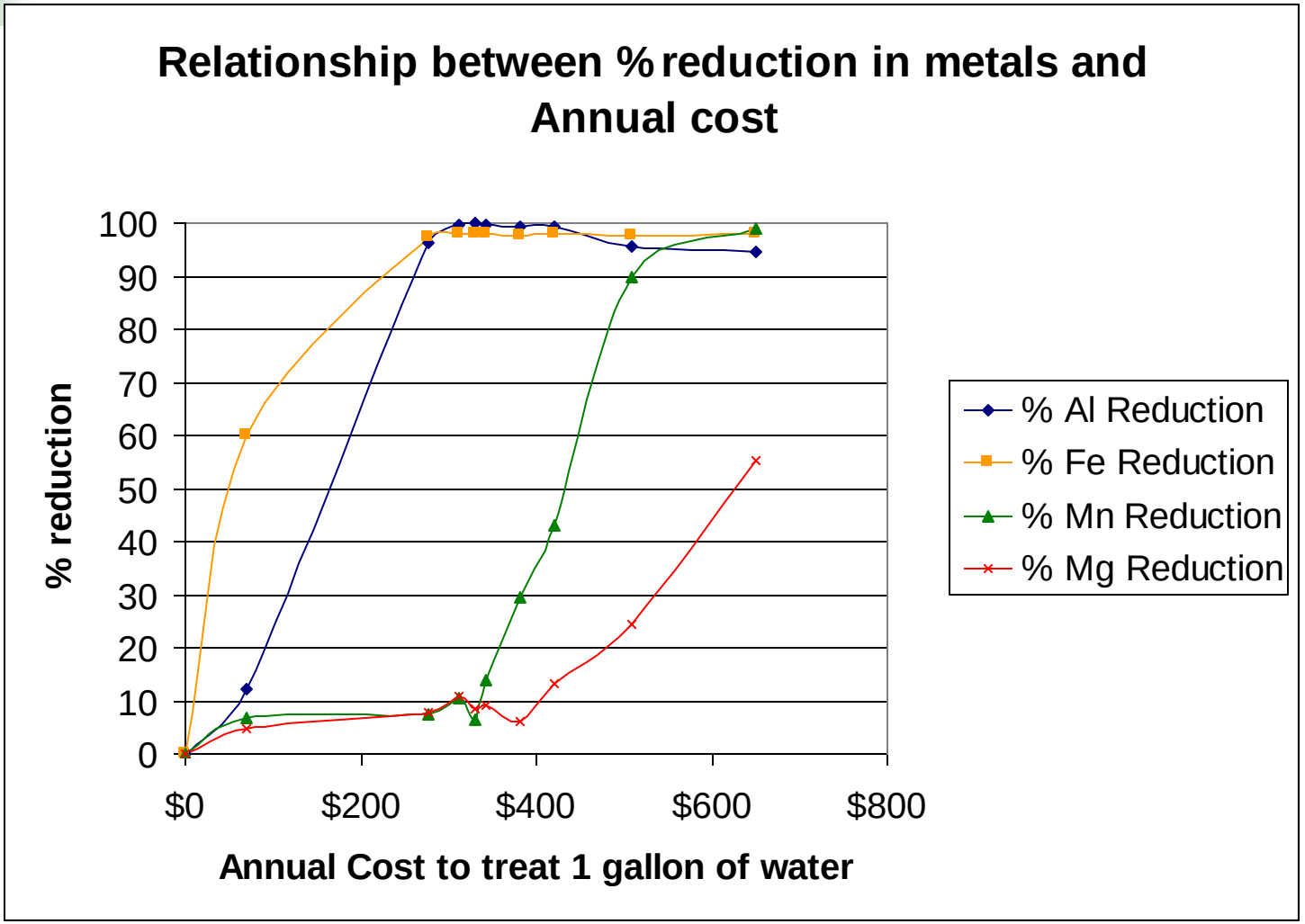
Titration Results

OSM

- Treatment Chemical (e.g. NaOH) is added to reach various pH levels and the water is sampled at each level
  - The amount of chemical consumed to reach each pH level is recorded
  - The water is analyzed to evaluate metal removal rates at various pH levels.

- These results are used to estimate annual chemical consumption rates and determine Treatment pH

Titration Results



Treatment Cost/Benefit Analysis

OSM

pH	Al (mg/L)	% Al reduction	Fe (mg/L)	% Fe reduction	Mn (mg/L)	%Mn reduction	Mg (mg/L)	%Mg reduction	Annual Cost for a 1 gpm discharge assuming caustic soda = $.50/gal
3.01	65.3	0.00	11.2	0.00	62	0.00	130	0.00	$0
4.43	57.3	12.25	4.49	59.91	57.8	6.77	124	4.62	$70
4.93	2.54	96.11	0.317	97.17	57.4	7.42	120	7.69	$277
5.83	0.215	99.67	0.242	97.84	55.4	10.65	116	10.77	$312
7.74	0.0303	99.95	0.241	97.85	58	6.45	119	8.46	$330
8.24	0.162	99.75	0.236	97.89	53.3	14.03	118	9.23	$342
8.47	0.507	99.22	0.255	97.72	43.7	29.52	122	6.15	$382
9.48	0.454	99.30	0.214	98.09	35.4	42.90	113	13.08	$421
9.97	2.81	95.70	0.249	97.78	6.2	90.00	98.4	24.31	$509
10.41	3.44	94.73	0.229	97.96	0.543	99.12	58.3	55.15	$651

Flow Rate (gpm)	Annual Cost if Treatment pH = 7.74	Annual Cost if Treatment pH = 10.41	Difference in Annual Cost
10	$3,300	$6,510	$3,210
20	$6,600	$13,020	$6,420
30	$9,900	$19,530	$9,630

Treatment Cost/Benefit Analysis

OSM

- Example: Assume a Coal Co. is able to give $100,000 for a trust fund
  - Assume the Trustee promises the investment will return 6%
  - Assume an inflation rate of 3%

How many years of treatment can I expect?

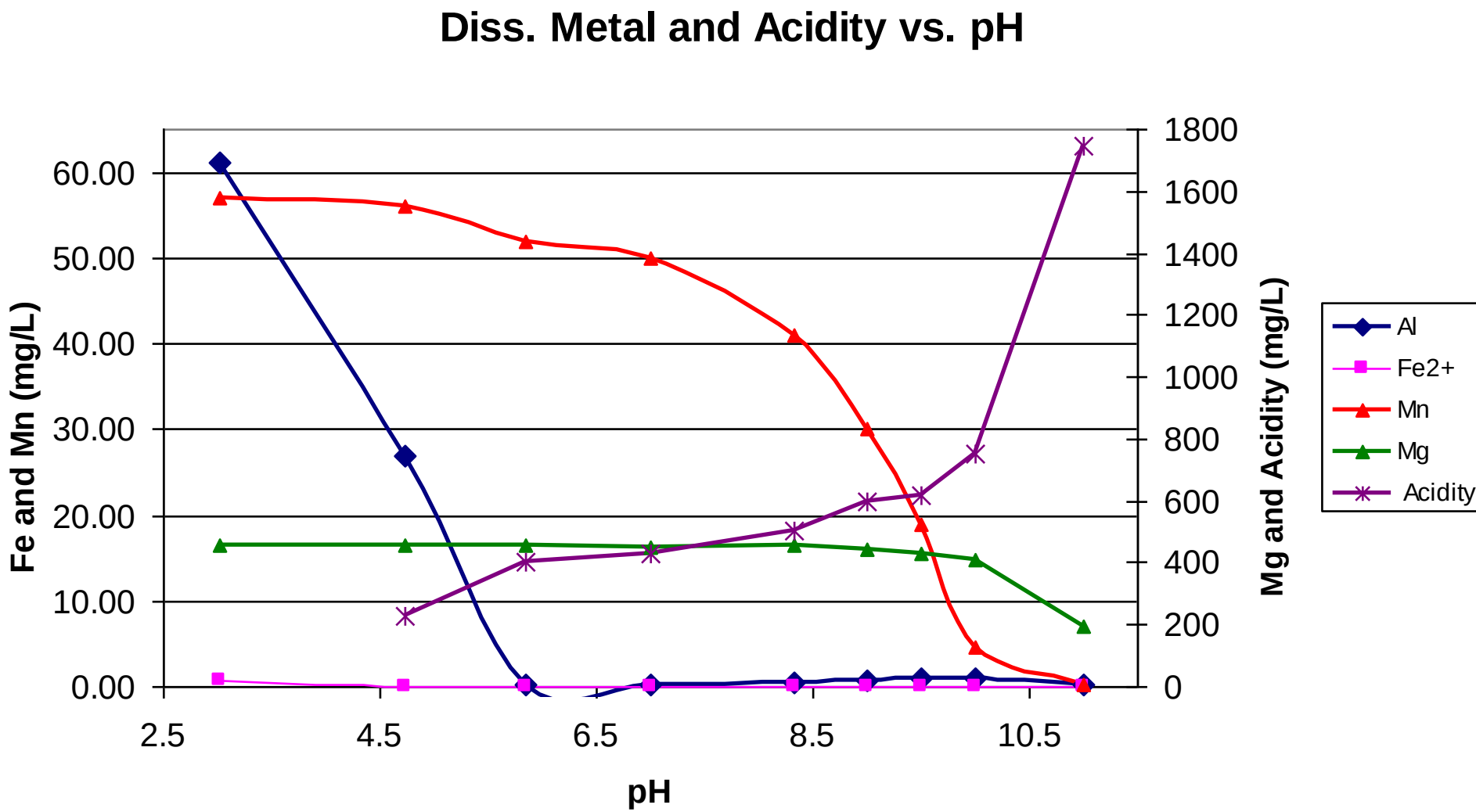
Flow Rate (gpm)	pH	Al (mg/L)	% Al reduction	Fe (mg/L)	% Fe reduction	Mn (mg/L)	%Mn reduction	Annual Cost	Years of Treatment
10	7.74	0.0303	99.95	0.241	97.85	58	6.45	$3,300	66
10	10.41	3.44	94.73	0.229	97.96	0.543	99.12	$6,510	17.8
20	7.74	0.0303	99.95	0.241	97.85	58	6.45	$6,600	17.5
20	10.41	3.44	94.73	0.229	97.96	0.543	99.12	$13,020	6.5
30	7.74	0.0303	99.95	0.241	97.85	58	6.45	$9,900	9.7
30	10.41	3.44	94.73	0.229	97.96	0.543	99.12	$19,530	3.4

Why is it so expensive to treat for Manganese?

OSM

Hot Acidity = 547 mg/L

pH	Ca	Al	Fe^{2+}	Mn	Mg	Treatment Acidity
3.01	186	61	1	57	460	
4.73	189	27	0.07	56	460	226
5.84	188	ND	ND	52	460	401
7.00	184	ND	ND	50	452	432
8.33	191	0.53	0.02	41	457	506
9.00	174	0.70	0.02	30	442	595
9.50	174	0.92	0.03	19	430	619
10.00	173	0.97	0.03	5	412	749
11.00	173	ND	0.03	0.18	194	1743



1 mg/L Mn^{2+} = 1.8 mg/L Acidity

1 mg/L Fe^{2+} = 1.8 mg/L Acidity

1 mg/L Fe^{3+} = 2.7 mg/L Acidity

1 mg/L Mg^{2+} = 4.1 mg/L Acidity

1 mg/L Al^{3+} = 5.5 mg/L Acidity

OSM

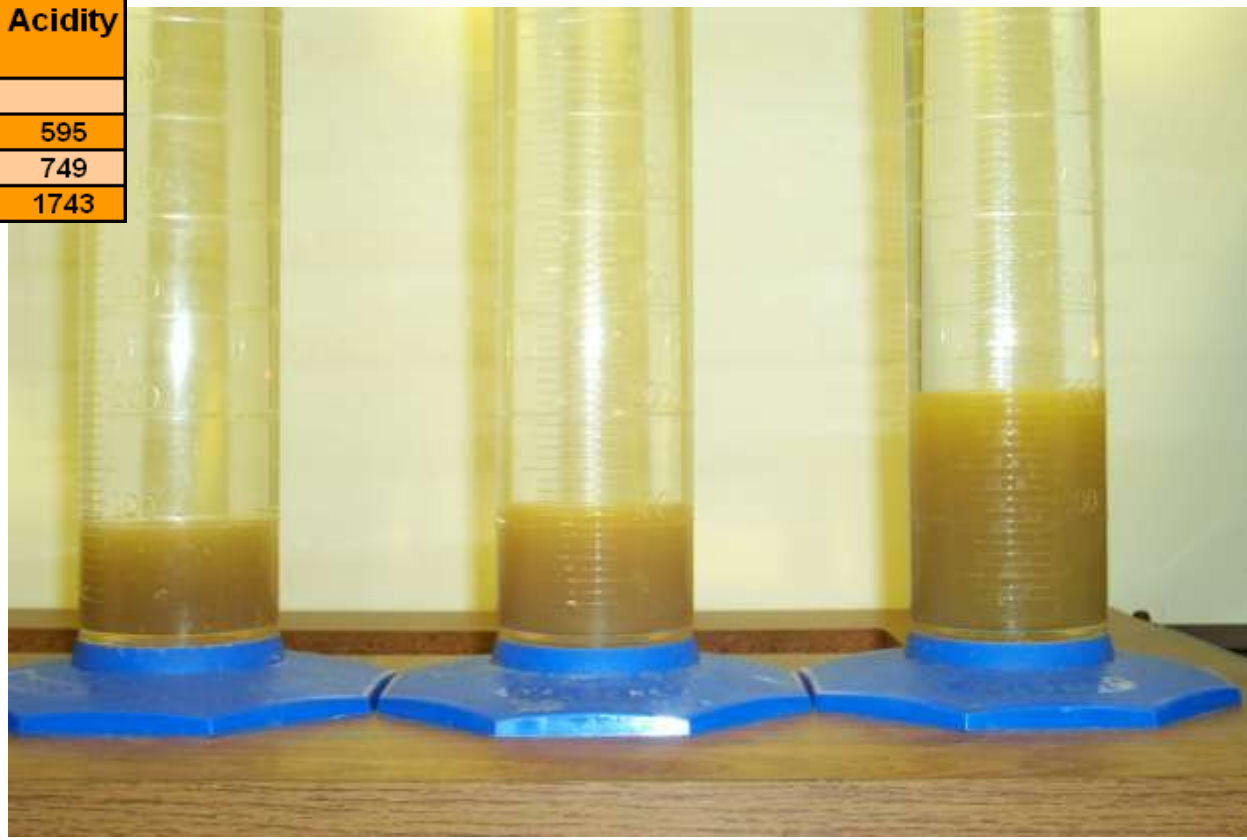
Effect of Mg on Treatment Costs

pH	Al	Ca	Fe^{3+}	Fe^{2+}	Na	Mg	Mn	Treatment Acidity as CaCO3	Titration Annual Cost assuming $.50/gal and 1 gpm
4.8	8.49	239	ND	0.022	43.7	260	136		
8.8	0.395	243	ND	0.028	189	261	118	328	$341
9.55	0.2	218	ND	0.149	262	261	46.6	437	$455
10.1	0.2	226	ND	0.025	374	243	10.3	686	$714
10.5	0.2	234	ND	0.055	430	194	5.45	864	$900
11	0.2	213	ND	0.025	579	57.6	0.431	1306	$1,360
11.5	0.2	158	ND	0.02	800	6.33	0.163	1709	$1,780

Effect of Mg on sludge volume

OSM

pH	Ca	Al	Fe^{2+}	Mn	Mg	Acidity
3.01	186	61	1	57	460	
9.00	174	0.70	0.02	30	442	595
10.00	173	0.97	0.03	5	412	749
11.00	173	ND	0.03	0.18	194	1743



pH 9 pH 10 pH 11

Research Needs

$$Rate\left(\frac{mole}{L^{-}s}\right)=\frac{dMn^{2+}}{dTime}=-k_1[Mn][MnO_2]-k_2[Mn]C_{bact}$$

Mn Summary

- When you treatment for Manganese…You really treat for Mg and Ca.

- Treating for Mg can double or triple chemical costs since it produces so much acidity

- Treating for Mg can double or triple sludge volumes, which will significanty increase sludge removal costs

- Treating for Mn in waters void of Mg (some deep mines) is no more expensive than treating for Fe^{3+} or Al^{3+}.

Manganese produces Acidity upon hydrolosis

OSM

$$Mn^{2+} + 2H_2O = Mn(OH)_2(s) + 2\mathbf{H^+}$$

$$+ \quad 2H^+ + 2NaOH = 2Na^+ + 2H_2O$$

Acidity

$$Mn^{2+} + 2NaOH = Mn(OH)_2(s) + 2Na^+$$ **(Overall Reaction)**

If you know the concentration of this

You can calculate the concentration of this

Sources of Acidity when treating for Mn

OSM

- pH Acidity

$$pH = -\log [H^+]$$

Caustic Soda

$$H^+ + NaOH = Na^+ + H_2O$$

Acid

Base

If you know the concentration of this

You can calculate the concentration of this

Sources of Acidity when treating for Mn

OSM

- pH Acidity

$$pH = -\log [\mathbf{H^+}]$$

$$\mathbf{H^+} + NaOH = Na^+ + H_2O$$

- Mineral Acidity

$$Mn^{2+} + 2H_2O = Mn(OH)_2\,(s) + 2\mathbf{H^+}$$ ← Acidity

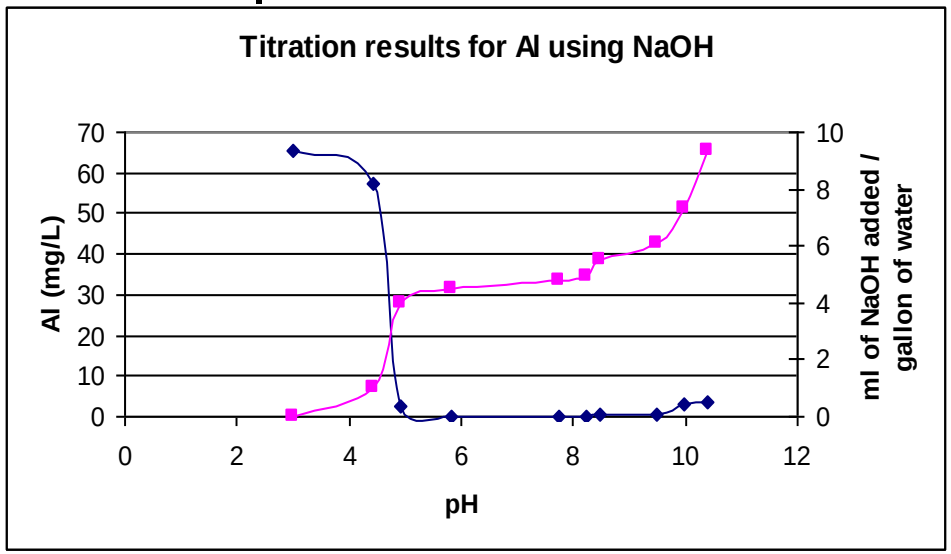
$$+\quad 2H^+ + 2NaOH = 2Na^+ + 2H_2O$$

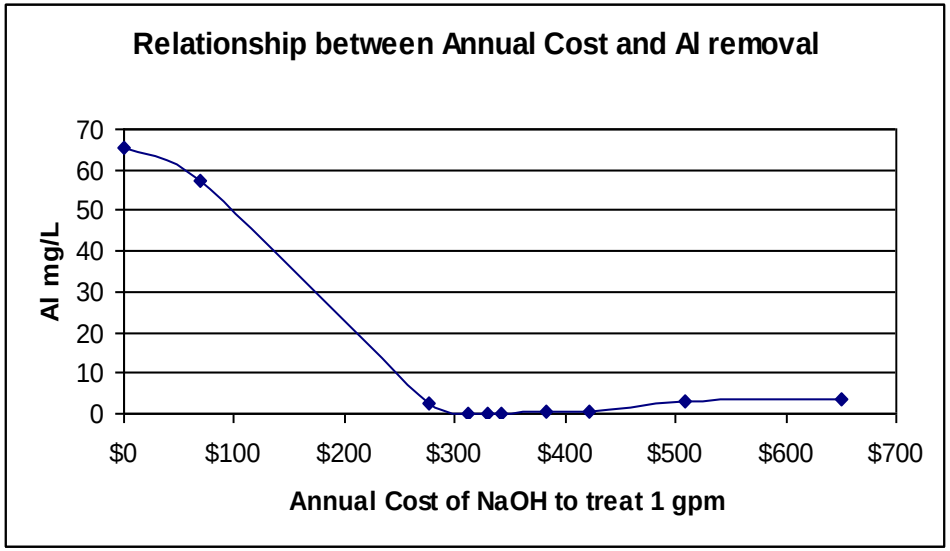
$$Mn^{2+} + 2NaOH = Mn(OH)_2(s) + 2Na^+$$ **(Overall Reaction)**

If you know the concentration of this

You can calculate the concentration of this

Titration Results for Coalition Coal





$$Al^{3+} + 3H_2O = Al(OH)_3(s) + 3H^+$$ ← Acidity

$$+ \quad 3H^+ + 3NaOH = 3Na^+ + 3H_2O$$

$$Al^{3+} + 3NaOH = Al(OH)_3(s) + 3Na^+$$ **(Overall Reaction)**

Manganese as an Aquatic Pollutant

Workshop on Manganese in Coal Mine Drainage

US Department of the Interior
Office of Surface Mining

Pittsburgh, PA
May 18, 2005

Presented by Richard Grippo, Ph.D.

Outline of Talk

- Chemical Characteristics as they Relate to Toxicity
- Toxicity
  - Effects and mechanisms
  - Toxic levels
  - Allowable levels vs toxic levels
  - Effect of hardness on toxicity
- Manganese-related research in the Grippo laboratory
  - AMD
    - Trout – biomarker of AMD?
    - Stonefly – sentinel species for AMD?
  - Aquaculture therapeutant (potassium permanganate)
- Biological Monitoring
  - Why?
  - Why not?

Chemistry of Manganese related to toxicity

- Occurs in 11 oxidation states but primarily as

Oxidation state	Example	Solubility
Mn(II)	$MnCl_2$	high
Mn(IV)	MnO_2	low
Mn(VII) until oxidation occurs	$KMnO_4$	high

The most biologically active (toxic) form is Mn^{2+} which increasingly occurs as water pH drops below 6.0 and/or becomes anaerobic

Mechanisms of Manganese Toxicity

Direct Effect	Indirect effect	Affected level
Reduction in calcium uptake	Reduced bone mineralization	Larval fish
Disruption of body ion levels	Osmoregulatory imbalance	Most organisms with gills (?)
Reproduction	Population decrease	Invertebrates, fish
Reduced growth rate	Survival, fecundity	Fish

Toxicity of Manganese

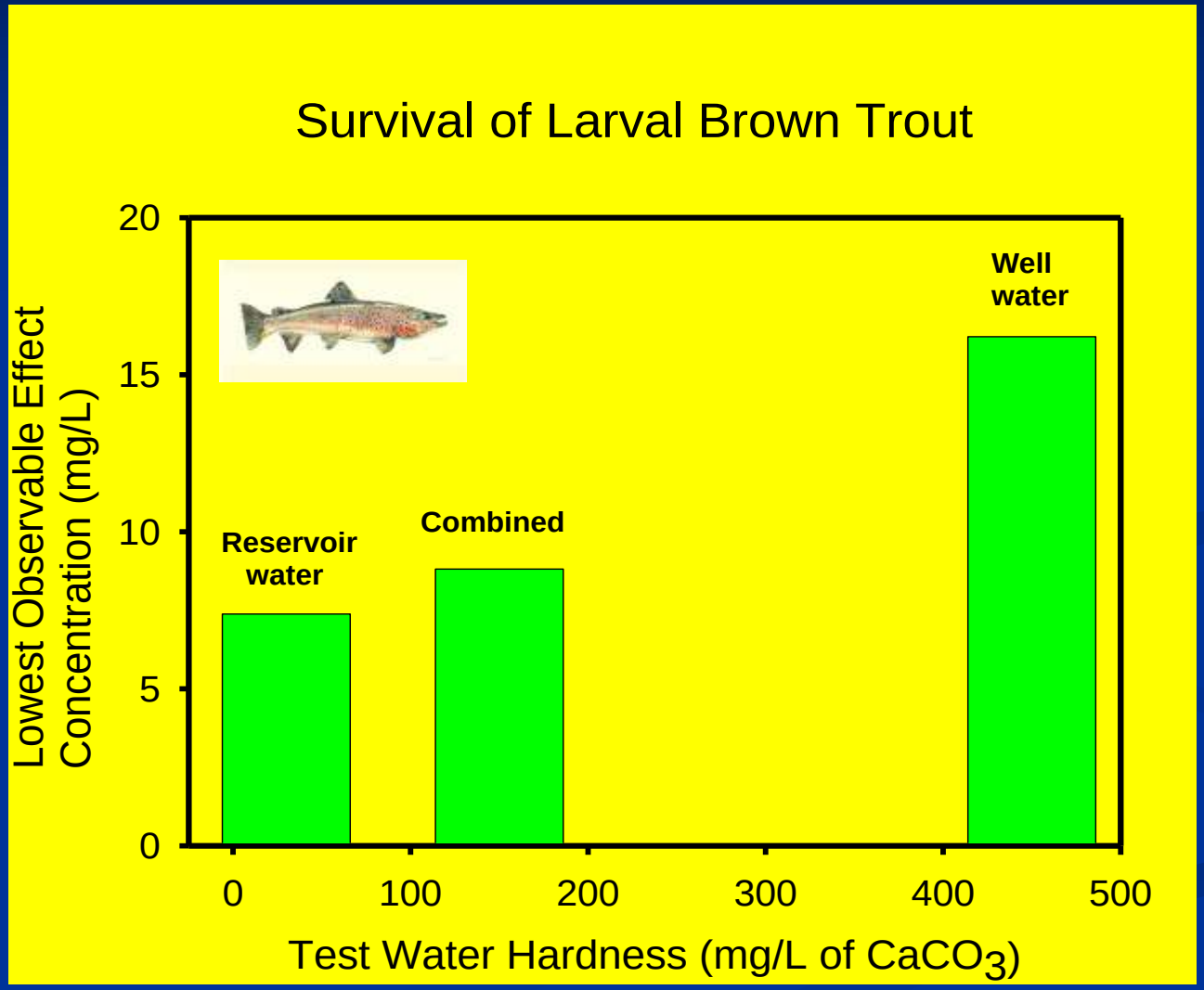
Organism	Toxic value (mg/L)	Test	Endpoint
Marine diatom	1.5	5-d EC_{50}	growth
FW alga	1.9	12-d EC_{50}	chlorophyll production
FW invertebrates			
Water flea	0.8	48-h LC_{50}	mortality
Amphipod	1.4	48-h LC_{50}	mortality
Fishes			
Coho salmon	2.4	96-h LC_{50}	mortality
Brook trout	269	96-h LC_{50}	mortality
Indian catfish	3350	96-h LC_{50}	mortality

Allowable levels of manganese and toxicity

	PA DER Mine Discharge Effluent Limits	96h LC_{50} for brook trout*
Iron	7.0	1.9
Manganese	4.0	269

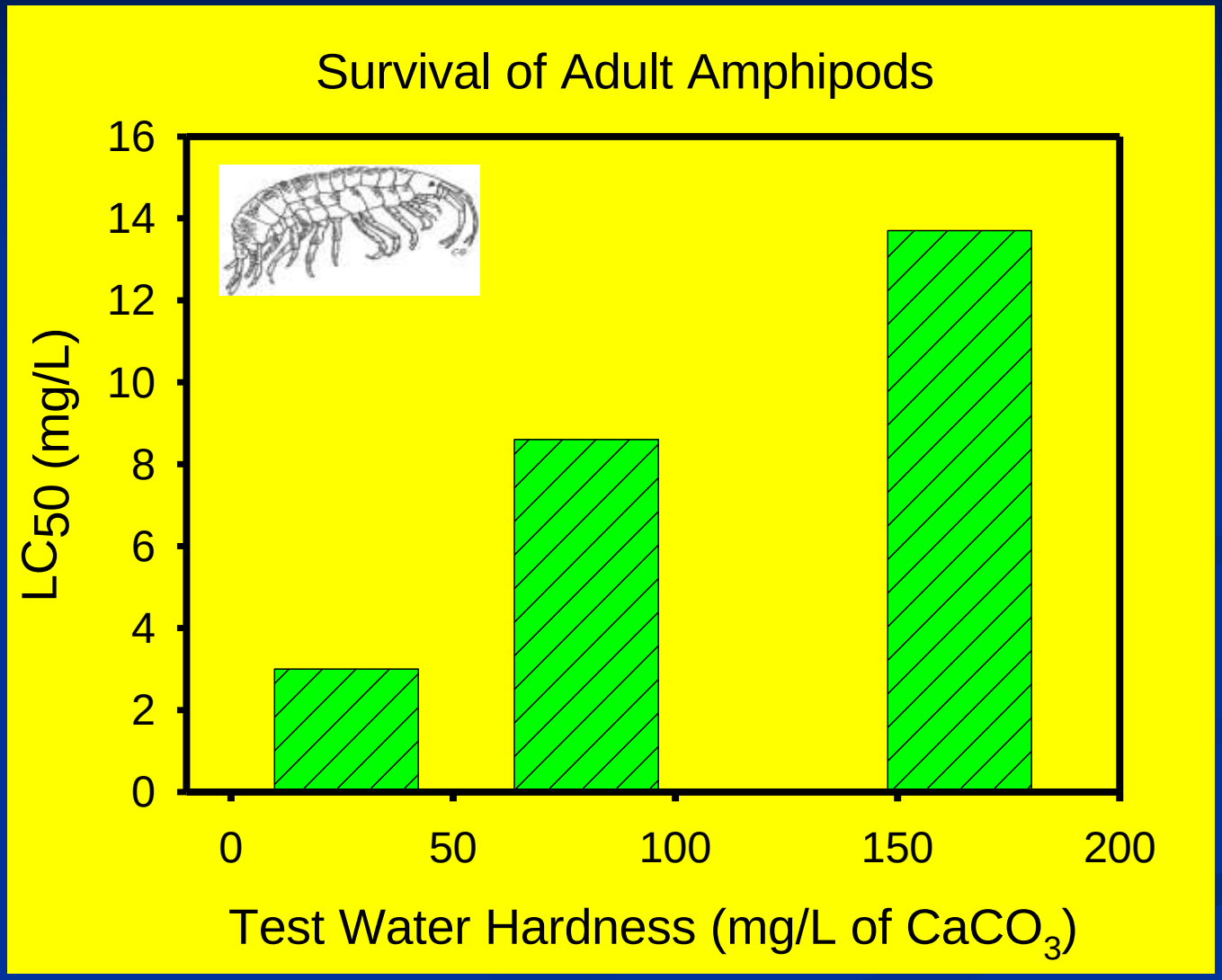
(*Gonzalez, Grippo & Dunson, 1990)

Effect of Hardness on Mn Toxicity



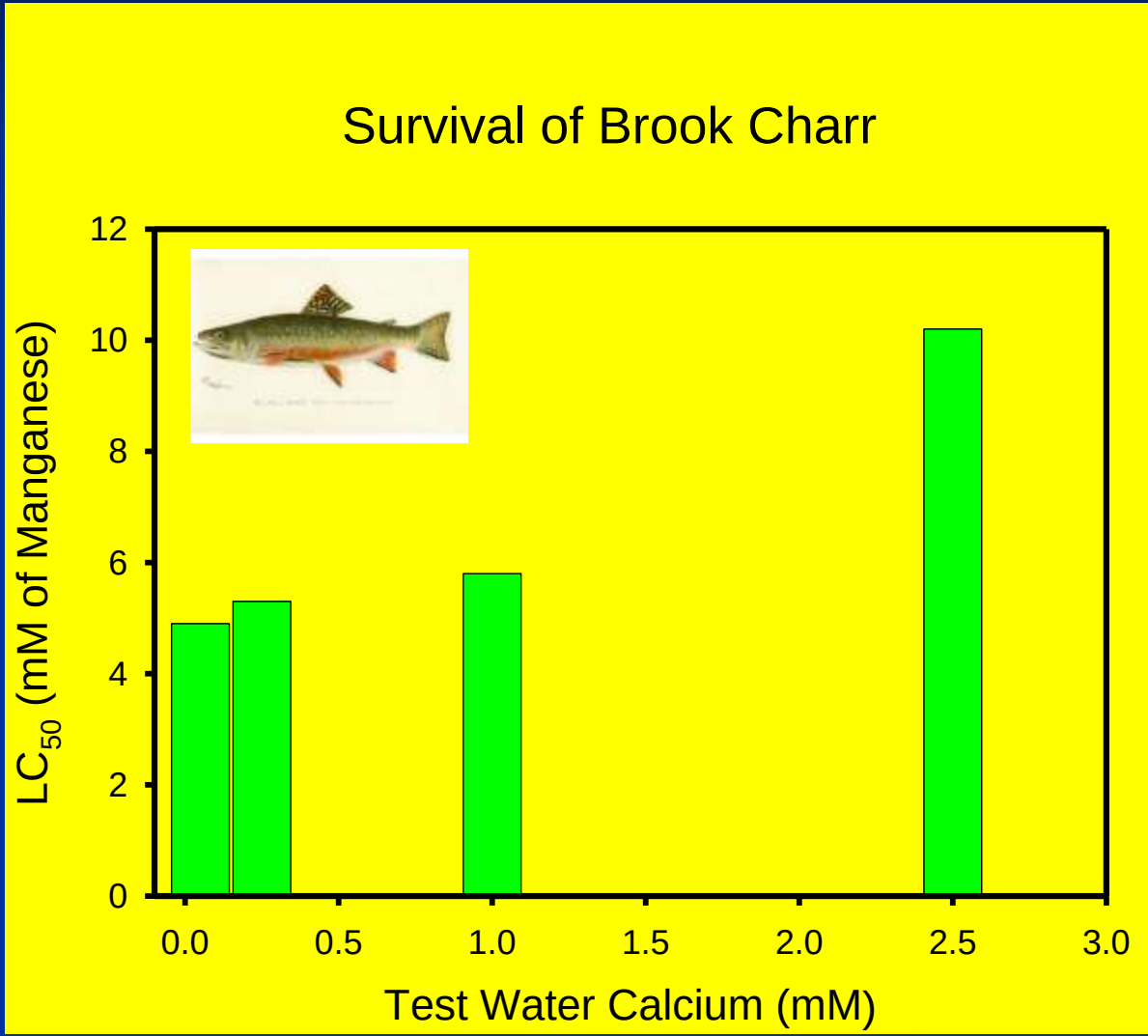
from Stubblefield *et al,* 1997

Effect of Hardness on Mn Toxicity



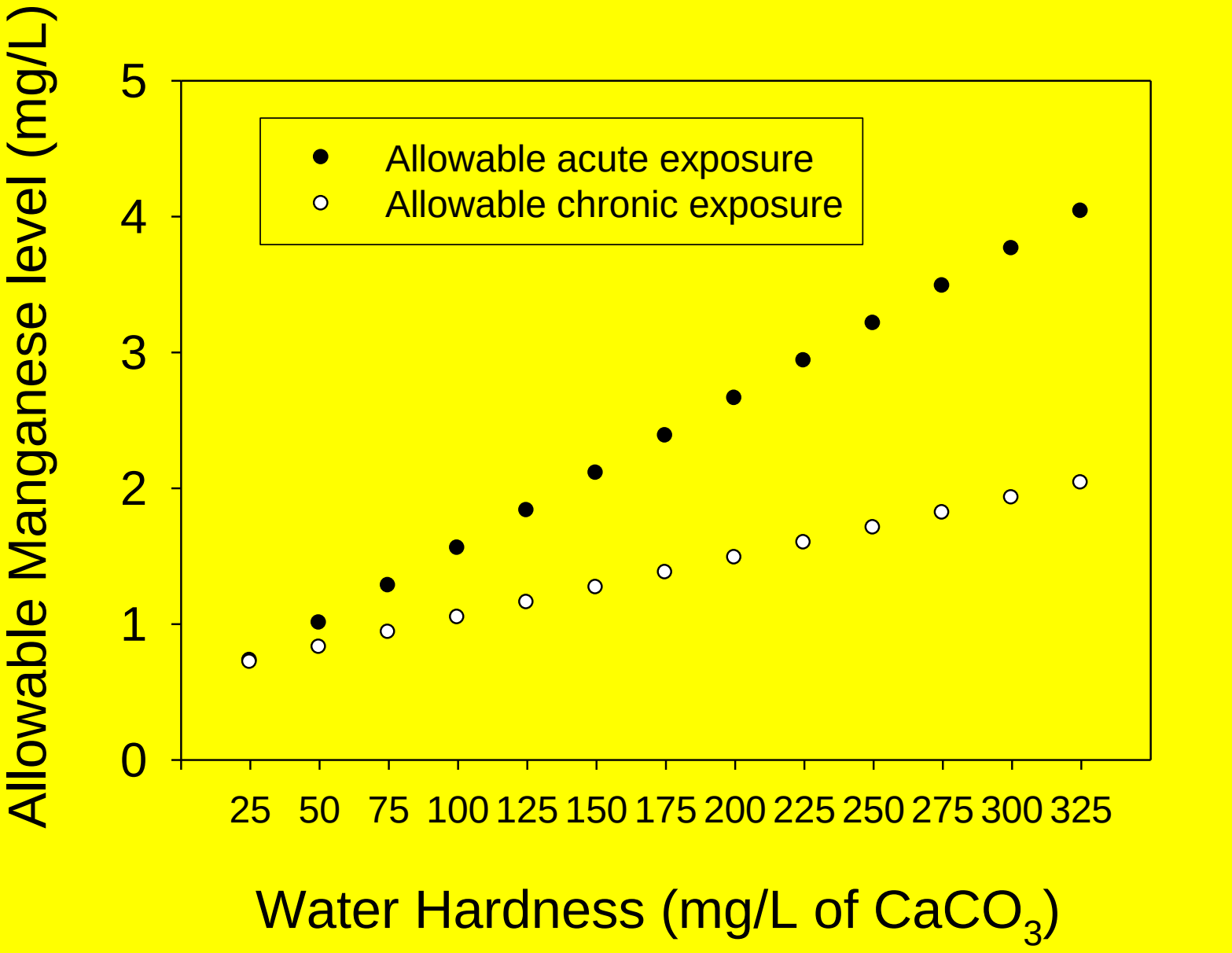
From Lasier *et al* , 2000

Effect of Calcium on Mn Toxicity



From Gonzalez, Grippo and Dunson, 1990

British Columbia Guidelines for Adjusting Allowable Mn Levels Based on Water Hardness



Manganese-related Research in the Grippo Laboratory

or

How I Spend Your Tax Dollars

Background

- A primary mechanism of toxicity of exposure of aquatic organisms to acidity and some toxic trace metals is disruption of body ion balance
- The body ion loss biomarker can be used to indicate sub-lethal exposure to acid mine drainage

Stream enclosures

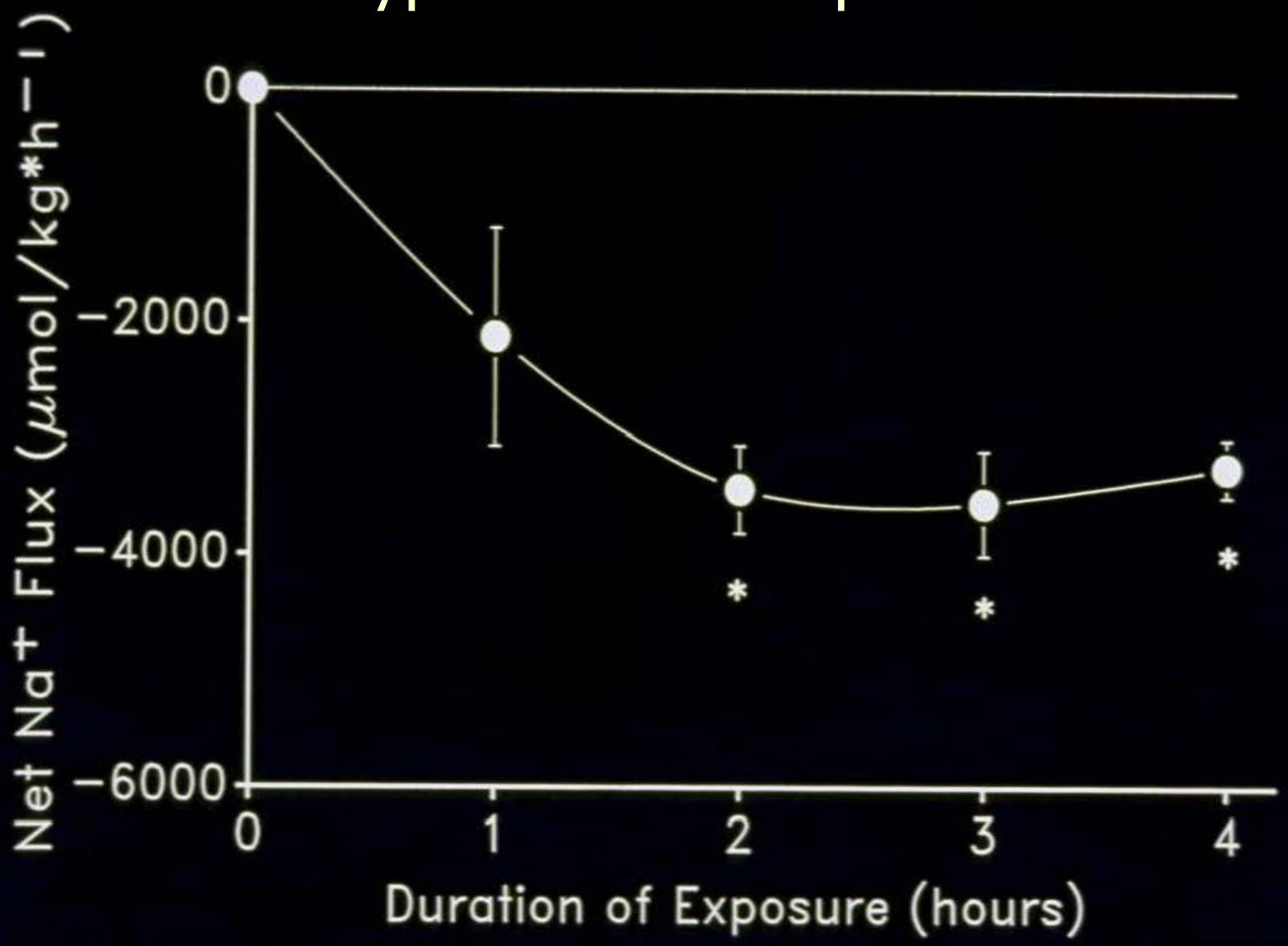
Waiting for body ions to change

Calculation of Body Ion Flux

$$\text{Ion flux} = \frac{[\text{final ion}] - [\text{initial ion}]}{\text{Exposure time}}$$

Note: final and initial ion concentrations are determined in different groups of test animals

Typical Field Response



Field assistants

STREAM PARAMETERS

pH	Al
Temperature	Fe
Alkalinity	Mn
Conductivity	Cd
Sulfate	Ni
Hardness	Cu
Na, K, Ca, Mg	Zn

Curwensville
Philipsburg
Houtzdale
State College
Allentown
Pittsburgh
Harrisburg
Philadelphia

Regression of Body Ion Loss on Stream Variables

Sodium flux = -15 [Mn] - 253 [Zn] – 2 [Mg] + 7 [Al] + 9 [Fe] + 13 [Na] – 1611

Calcium flux = -18 [H^+] – 14 [Ca] +19 [Na] – 170 [Mn] + 44 [Al] + 4225 [Ni] + 16 [Mg] – 493 [Zn] - 617

MULTIPLE REGRESSION OF NET SODIUM FLUX ON WATER PARAMETERS FROM DIFFERENT DATA BASES

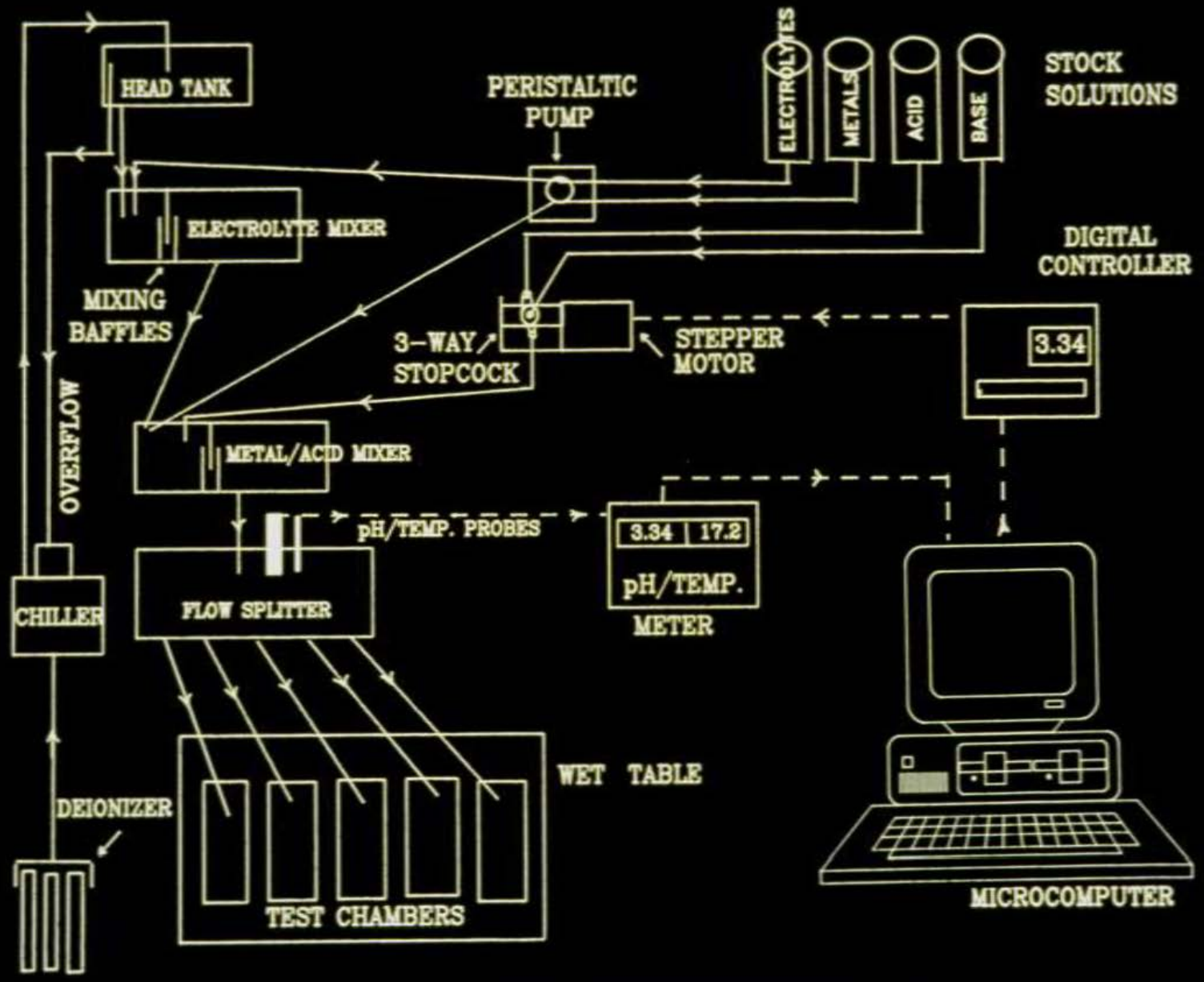
Data Base	Number of Parameters	$R^2_{adj.}$	p–value
WATSTORE	11	0.793	0.004
STORET	14	0.768	0.036
PA DER	3 (pH, Fe, Mn)	0.743	0.0001

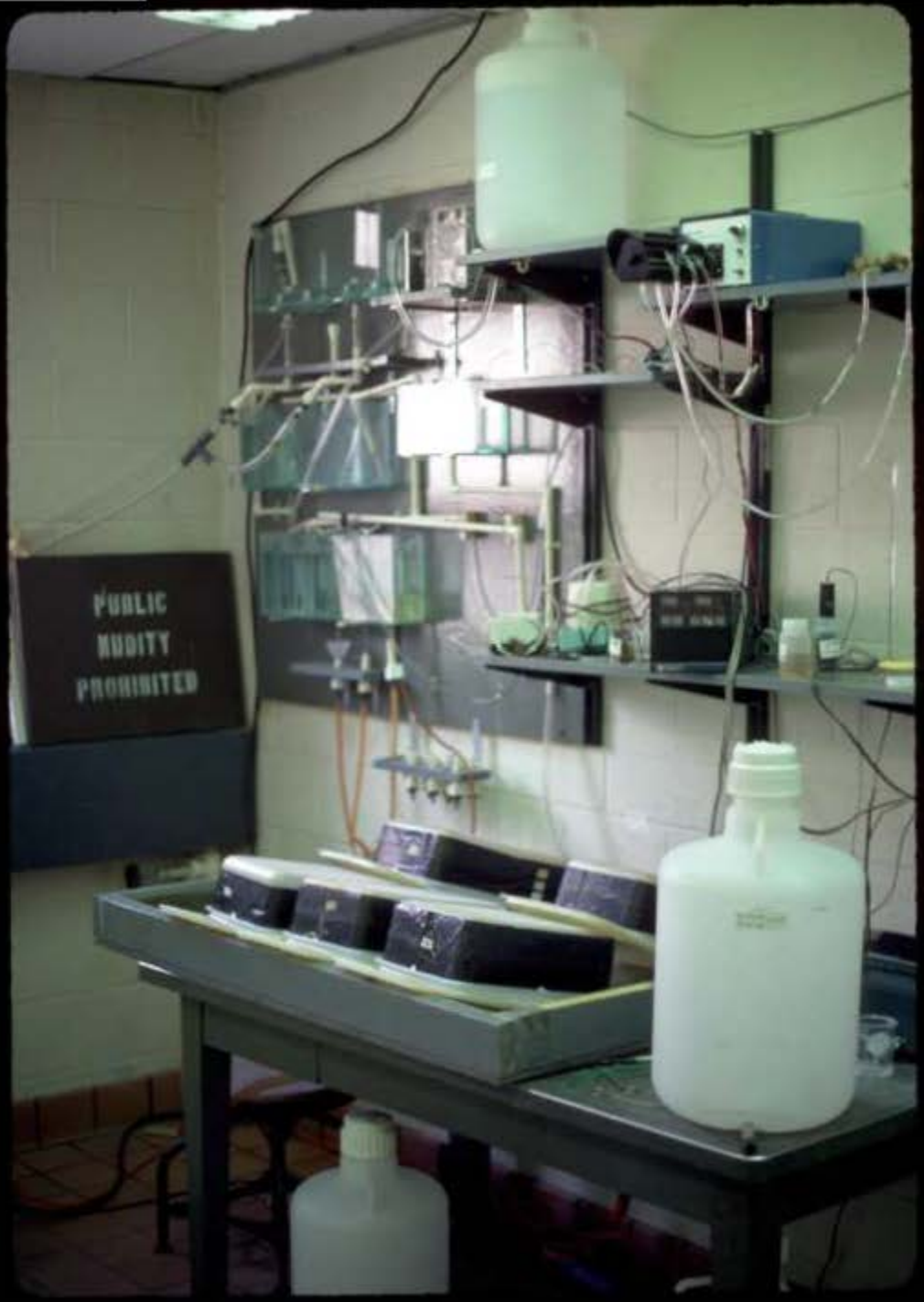
The Need for Controlled Laboratory Studies

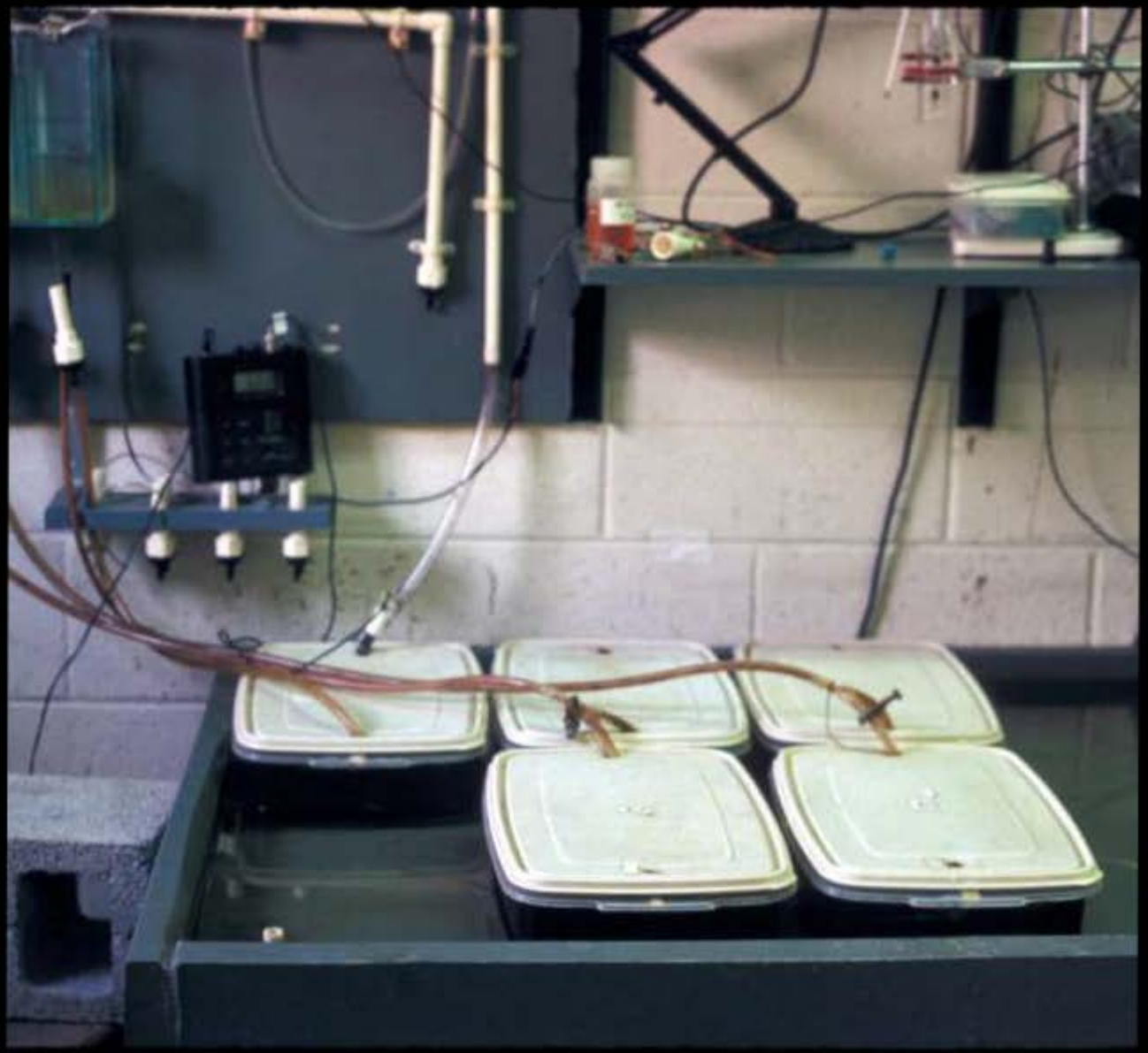
What is the true contribution of each of the measured AMD water quality variables to total toxicity?

How do they each interact with acidity?

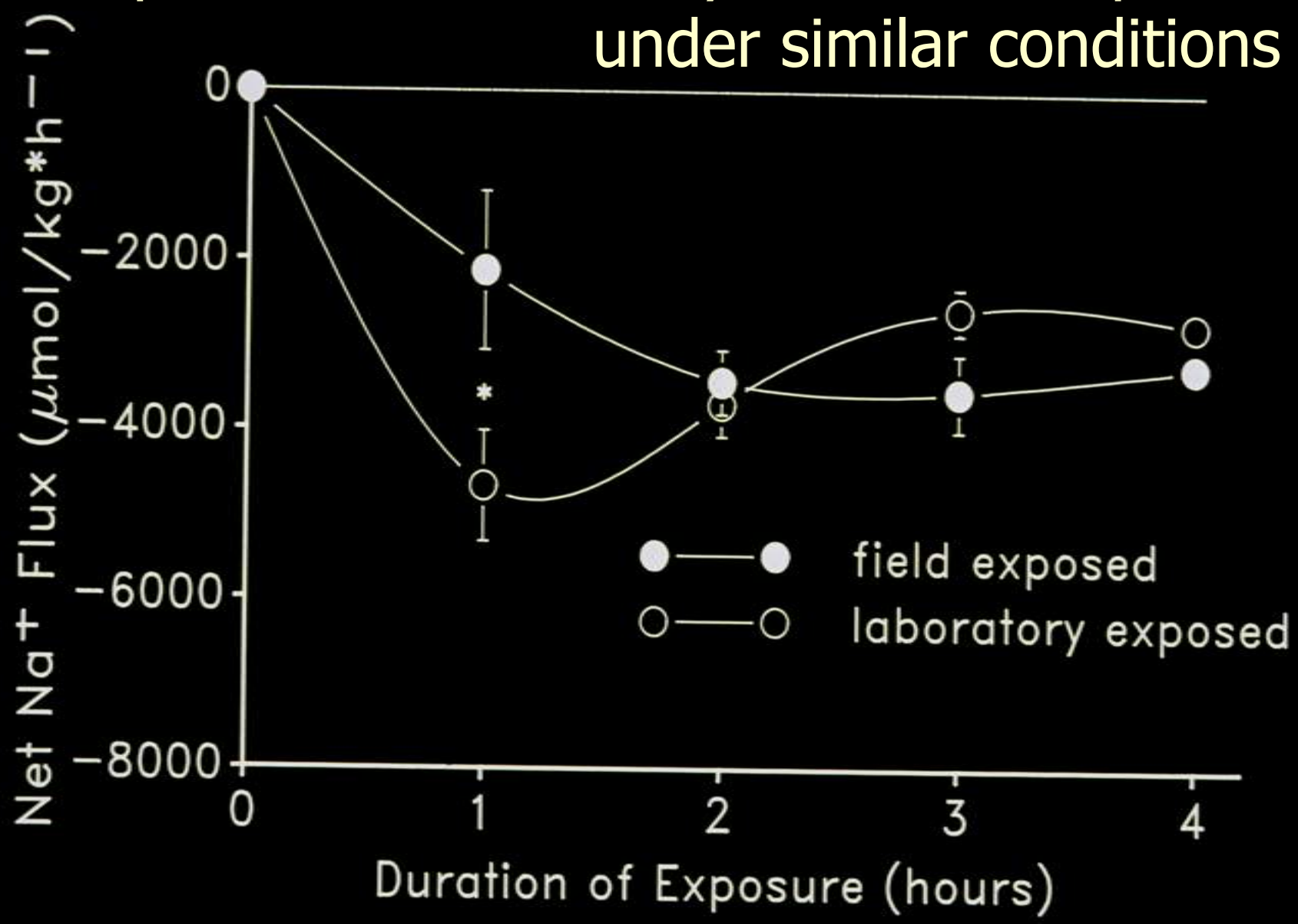
Schematic of Flow-Through System for Simulating Acid Mine Drainage in the lab



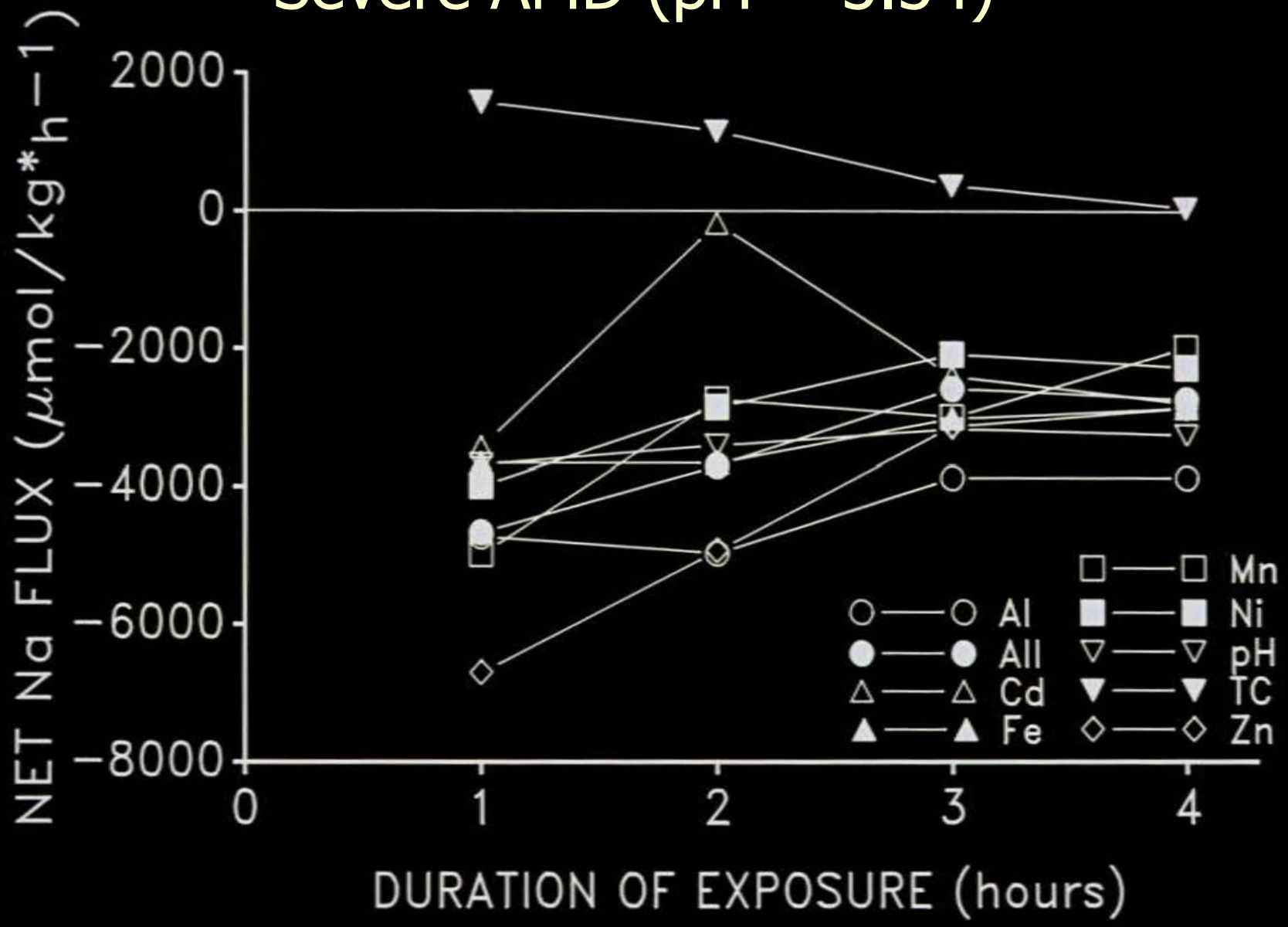

PUBLIC
NUDITY
PROHIBITED



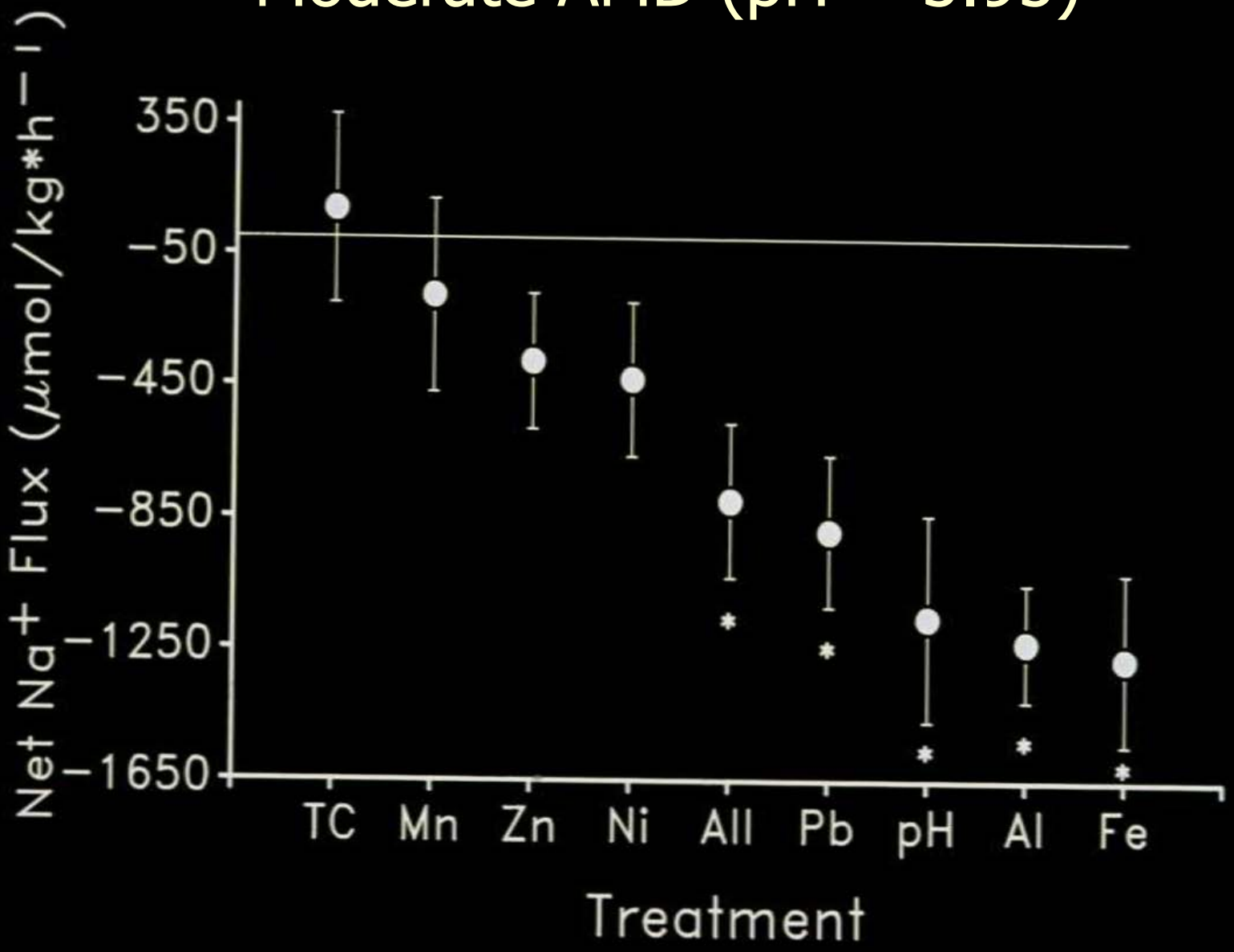
Comparison of laboratory and field response under similar conditions



Severe AMD (pH = 3.34)



Moderate AMD (pH = 3.95)



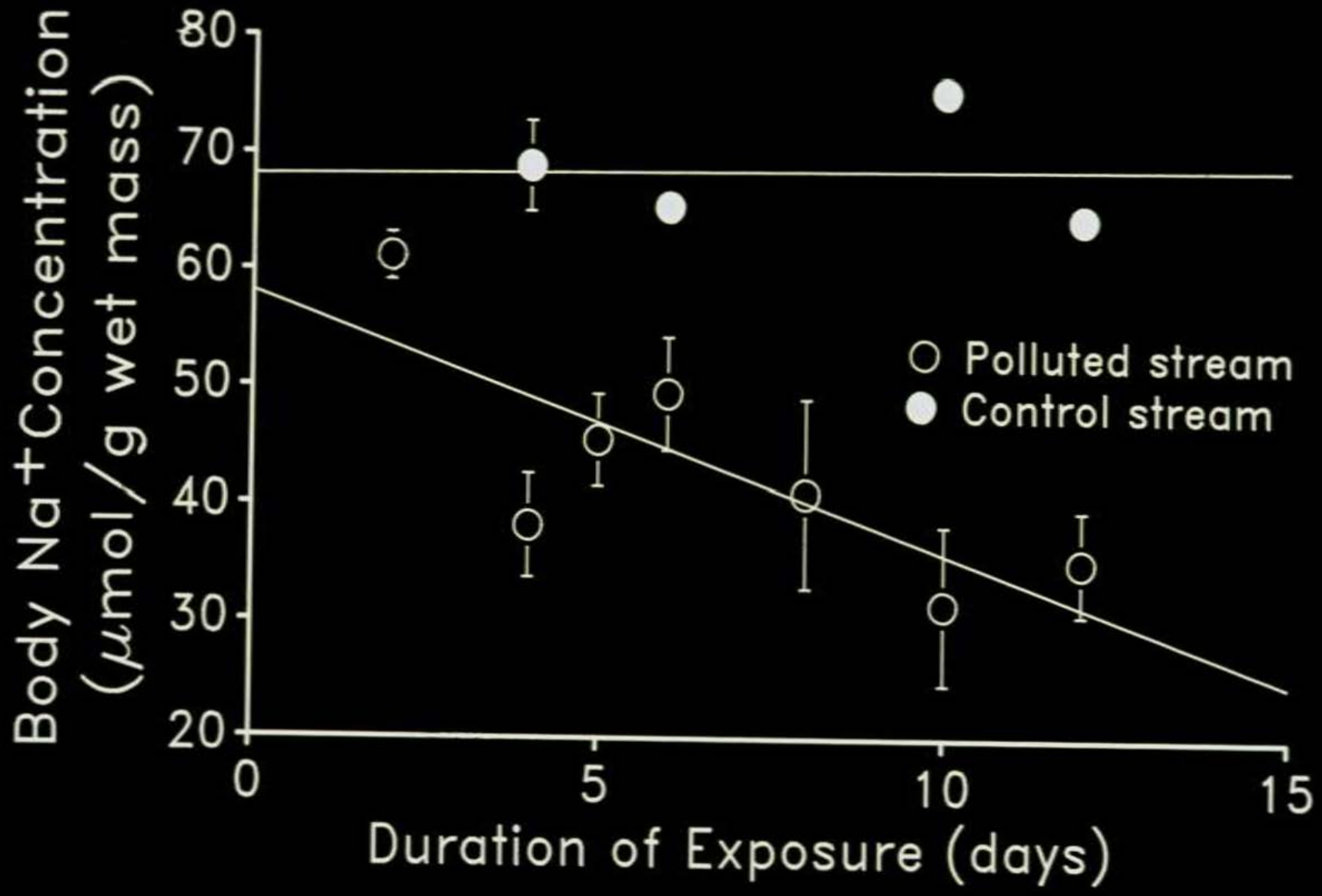
Stoneflies as Long-term Monitoring Sentinels of Acid Mine Drainage

Acroneuria carolinensis (stone fly)

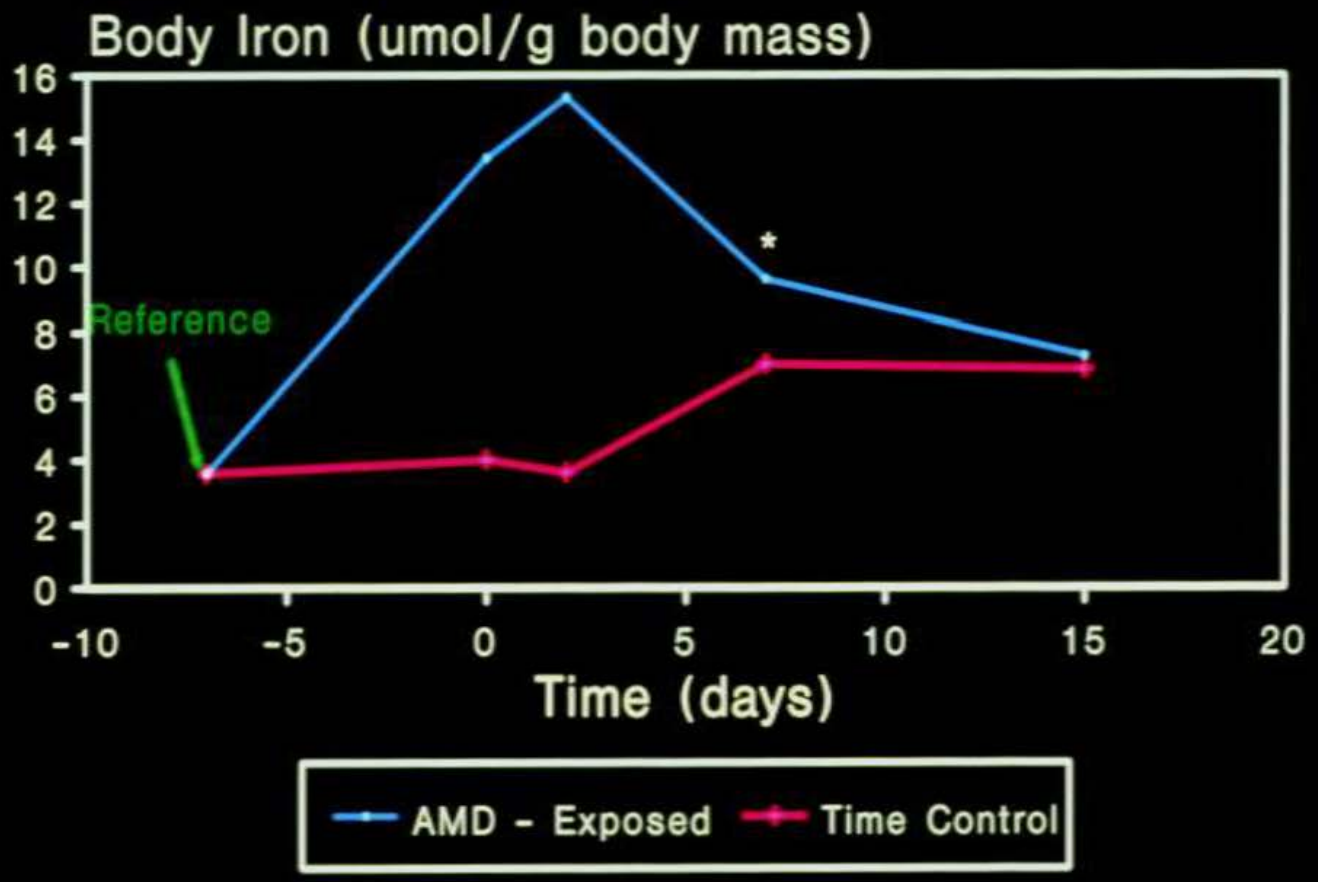
Stonefly exposure chamber

Will work for food

Body Na levels of stoneflies exposed to severe AMD)

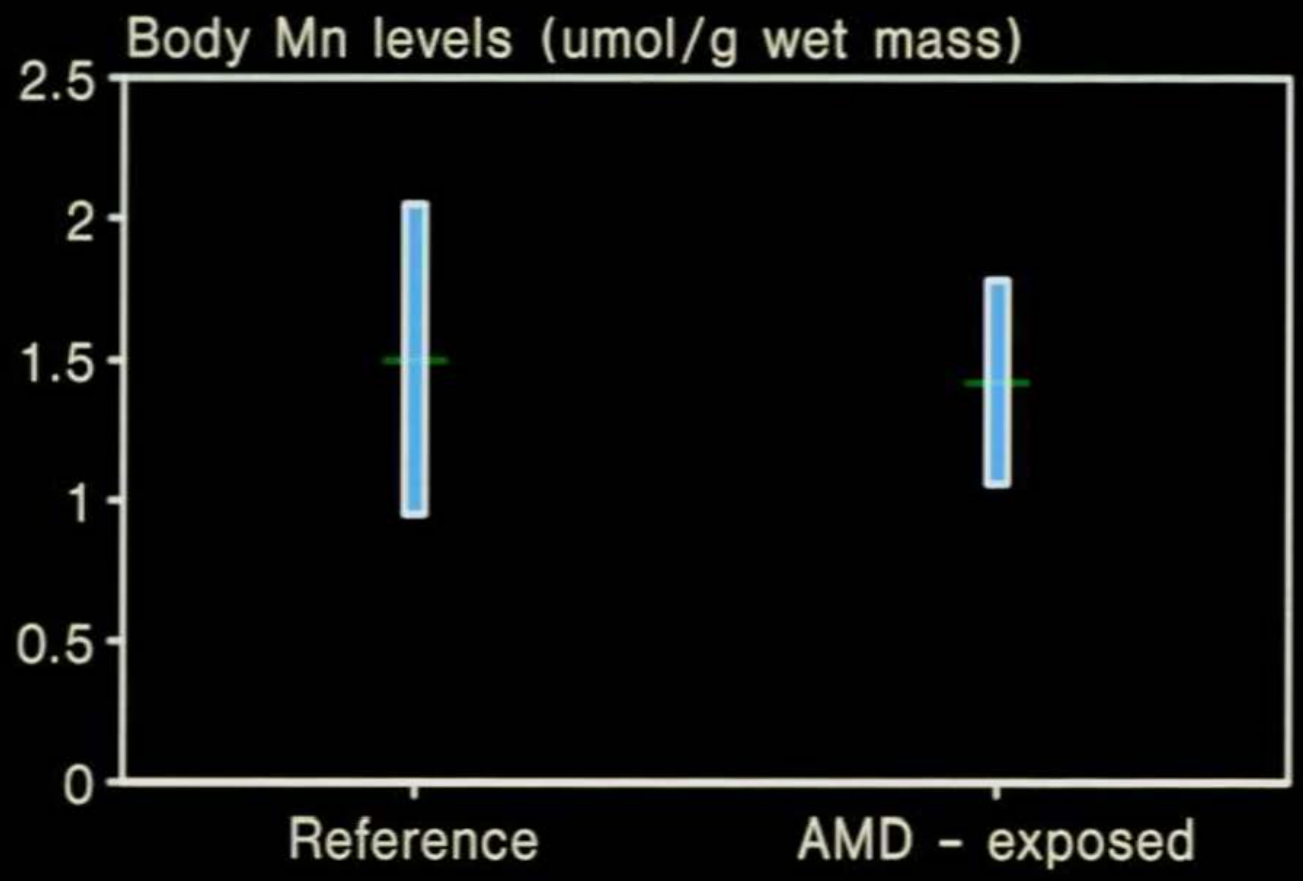


BODY IRON LOSS
OF STONEFLIES



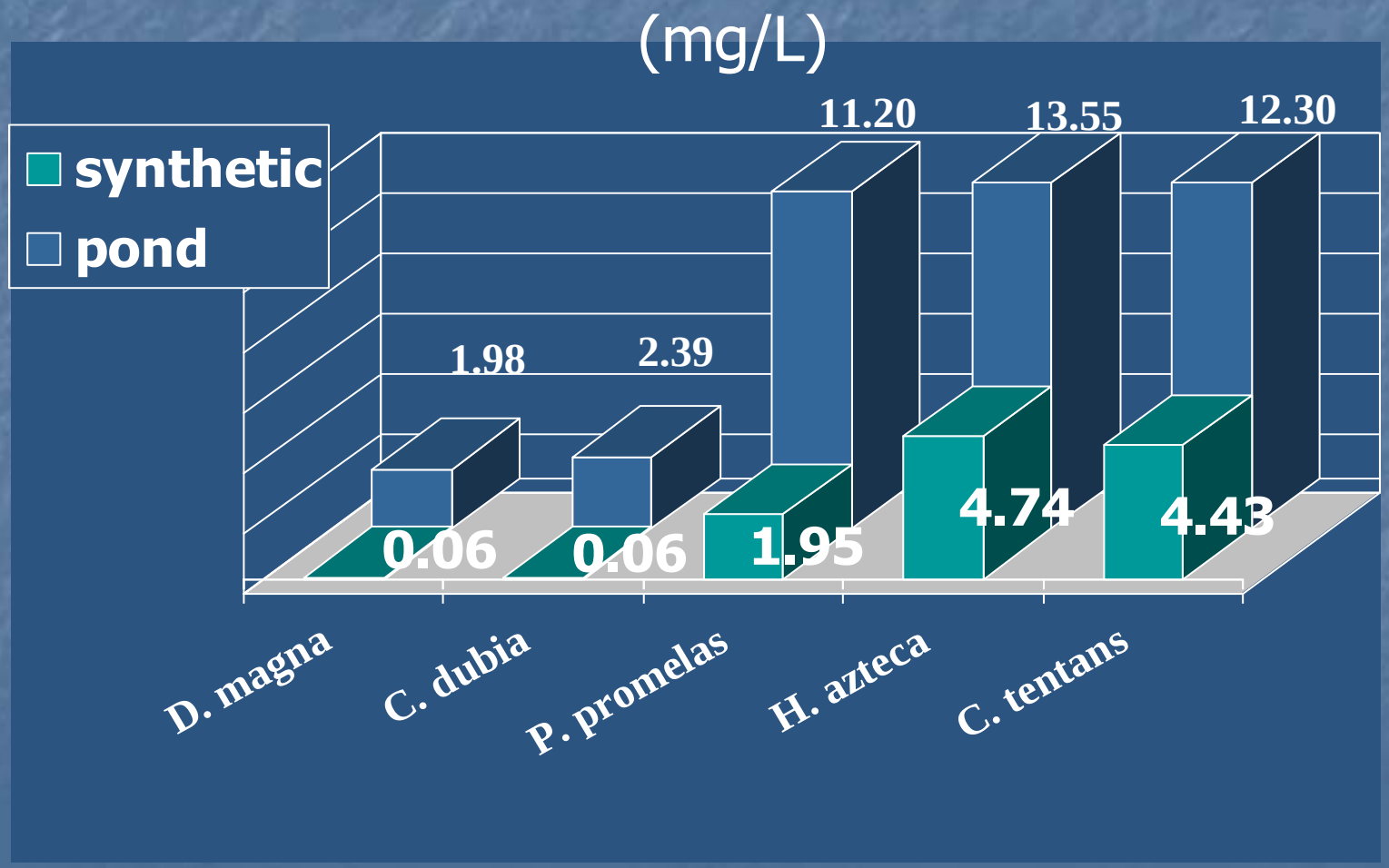
* - Significantly different from reference

BODY MANGANESE LEVELS
OF STONEFLIES



Environmental Risk of Potassium Permanganate

Laboratory vs Field Toxicity of $KMnO_4$



Acute Toxicity (% survival) of $KMnO_4$ in Mesocosms at Dosing (X, 3X, 5X) and Two Weeks Post-dosing

Species	Initial (96 h)	Total [Mn]*	Two weeks later (48h)	Total [Mn]*
C. dubia	0.0	0.979	80.0	0.397
P. promelas	0.0	4.436	100.0	0.397
H. azteca	24.0	6.233 (pore water)	73.0	0.850 (pore water)

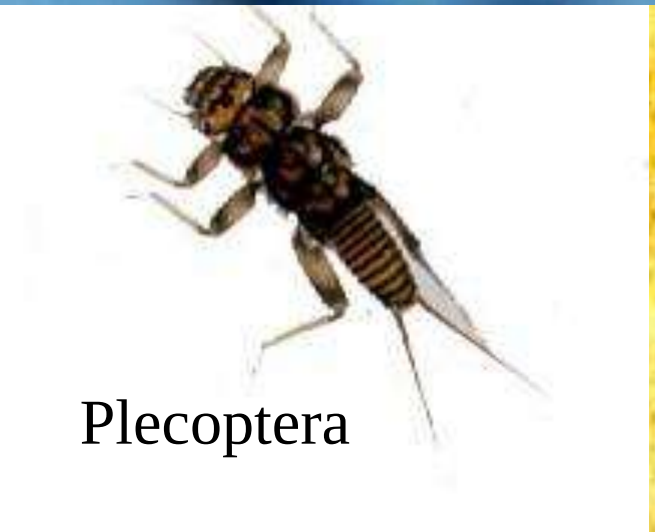
* mg/L

Biological Monitoring to Evaluate Environmental Health

Dictyophora duplicata (Stinkhorn)

Chironomidae

Trichoptera


Plecoptera

Ephemeroptera

Approaches to Monitoring Water Quality

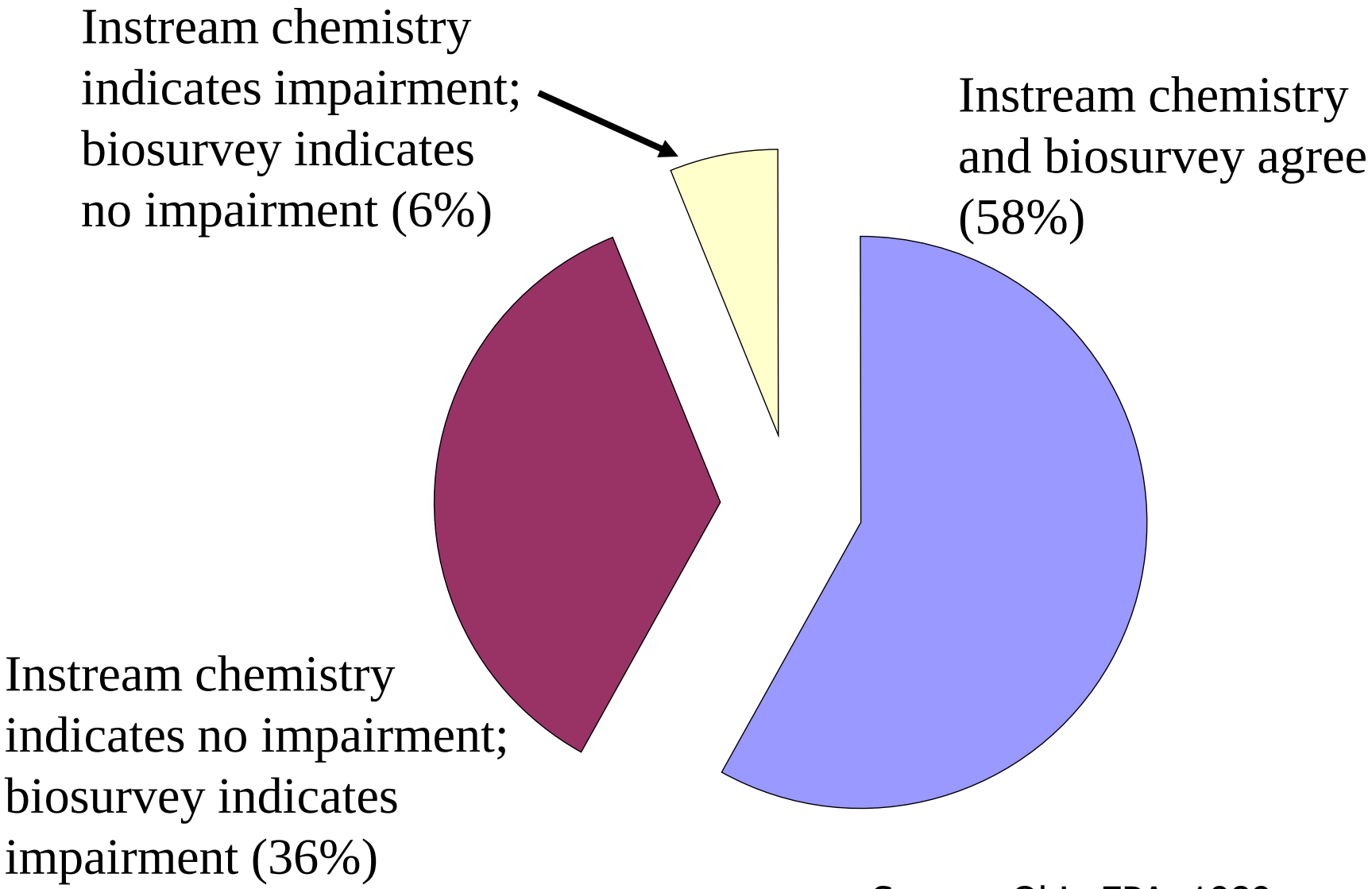
Low

Cost, Time, Sensitivity, Variability

High

- Direct physical/chemical measurements—e.g., temperature, pH, dissolved oxygen, clarity, nutrient concentrations

- Biological measurements—e.g., indicator species, community structure



Source: Ohio EPA 1989

Why measure biological communities?

- Reflect overall ecological integrity—the primary goal of the CWA
- Integrate the effects of different stressors, and can measure aggregate impacts
- Integrate stresses over time and fluctuating environmental conditions
- For nonpoint-source impacts such as habitat, they may be the only practical means of evaluation

Why measure invertebrate communities?

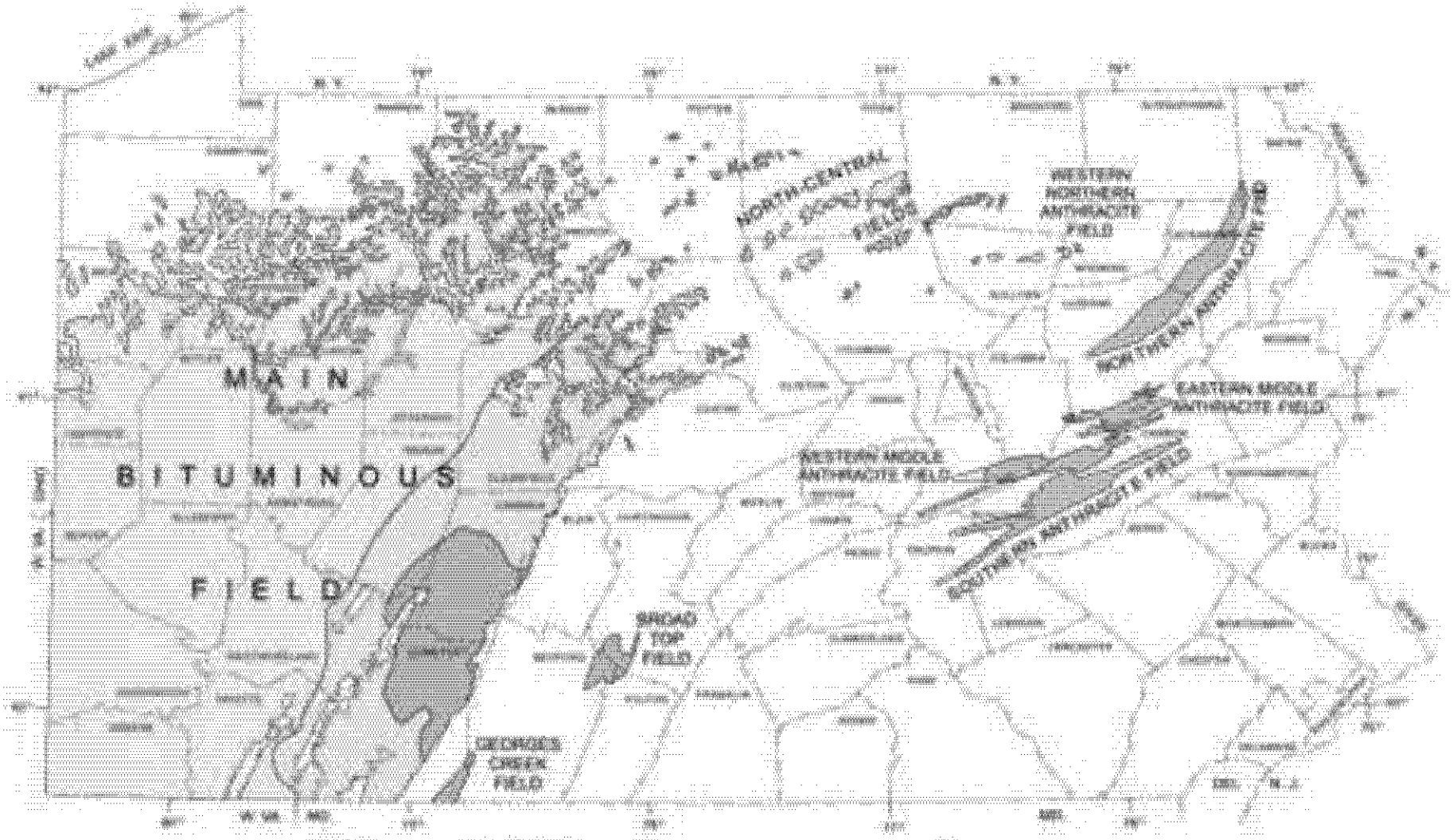
- Ubiquitous and abundant
- Complex assemblages offer variety of responses to environmental stresses
- Not as mobile as fish, allowing spatial analysis of disturbance effects (upstream vs downstream)
- Relatively long life cycles, allowing examination of temporal disturbance effects and integration of long-term impacts

Problems with Biomonitoring

- High level of training/experience needed for accurate identification
- Relatively time consuming
- Relatively expensive

STOP

OTTER RUN, LYCOMING COUNTY PENNSYLVANIA



high-volatile | medium-volatile | low-volatile | semi-anthracite | anthracite

Bituminous **Anthracite**

Flatiron
Pt
Oxbow
Strip Mines
Strip Mines
Strip Mine
Ridge
Chestnut
Jack
Camp
Run
Branch
GAME LANDS BDY
Copyright (C) 2001, Maptech, Inc.

SITE HISTORY(PRE 1980)

- MINING BEGAN IN EARLY 1900’S
- SURFACE AND DEEP MINES
- FISHER MINES
- THOMAS MINES
- OTTER RUN IMPACTS-1977 DER STUDY

SITE HISTORY(MID1970'S PRESENT)

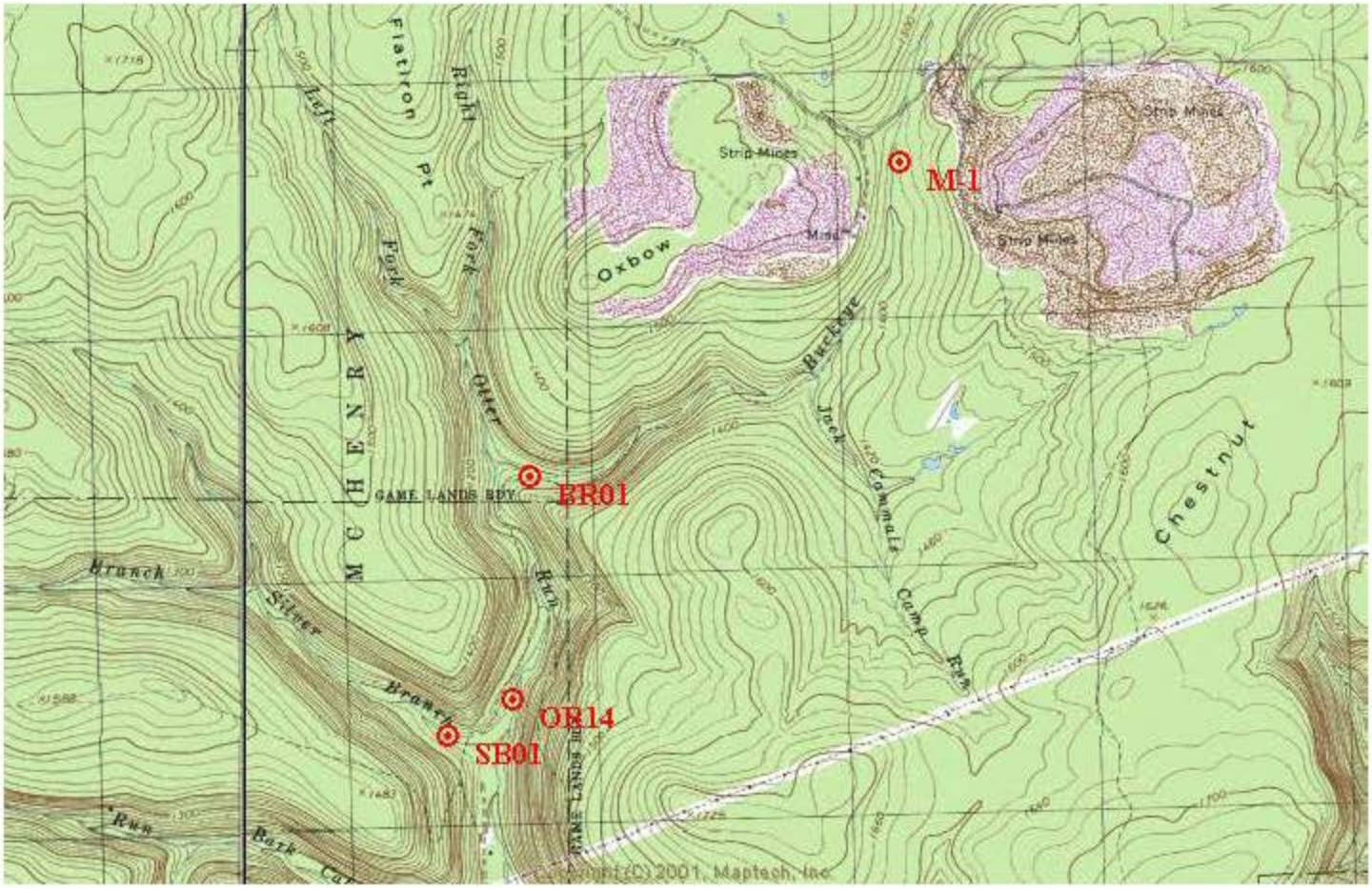
- FISHER MINE SITE ISSUED WITH MN EXEMPTION
- COOPERATIVE SAMPLING BETWEEN PFBC, PGC, DEP AND FISHER MINING BEGINNING IN 1983
- THOMAS MINE PERMIT APPLICATION IN 1994 REQUESTING MN EXEMPTION

Good Water Quality Indicators

OTTER RUN ELECTROFISHING

BIOMONITORING STUDY

- DETERMINATION OF BASELINE INFORMATION FOR AQUATIC COMMUNITY.
- TOTAL OF EIGHT SITES WERE SAMPLED FOR BASELINE.
- BENTHIC COMMUNITIES WERE SAMPLED USING A VARIETY OF METHODS


M-1
BR01
OR14
SB01
Strip Mines
Strip Mines
Strip Mines
Oxbow
Mine
Flatiron Pt
Left Fork
Right Fork
Otter Run
Buckeye
Jack Camp Run
Chestnut
Branch
Silver Branch
Run
Bark
GAME LANDS BDY
MCHENRY
Copyright (C) 2001, Maptech, Inc.

OTTER RUN STATION OR14

ARTIFICIAL SUBSTRATE

BASELINE AND METRIC DEVELOPMENT

- EVALUATIONS OF BENTHIC INFORMATION COLLECTED
- COMPARE TO WATER QUALITY
- FINAL SAMPLING PROTOCOL FOR DETERMINATION OF SIGNIFICANT IMPACT

FIGURE 6B. FISHER MINING BIOMONITORING DATA, Silver Branch SB01, Feeding Guilds

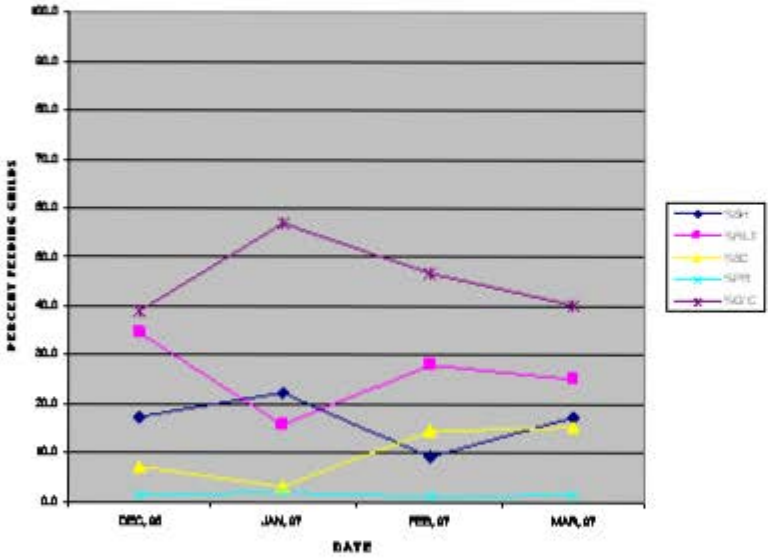


FIGURE 7B. FISHER MINING BIOMONITORING DATA, Otter Run OR14, Feeding Guilds

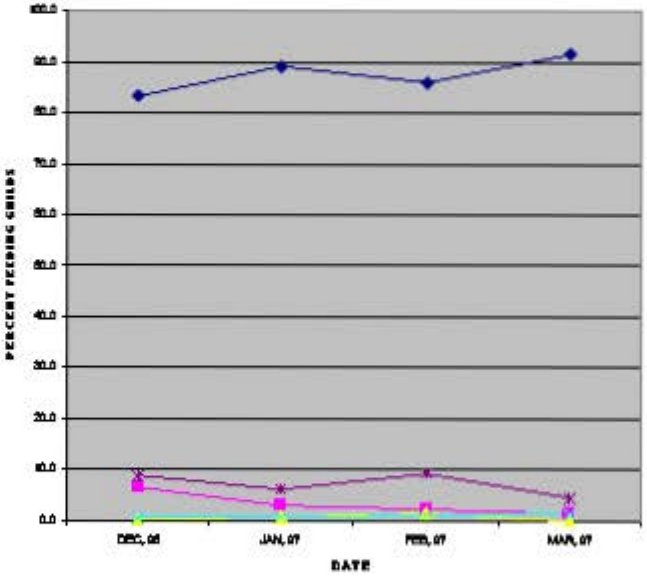
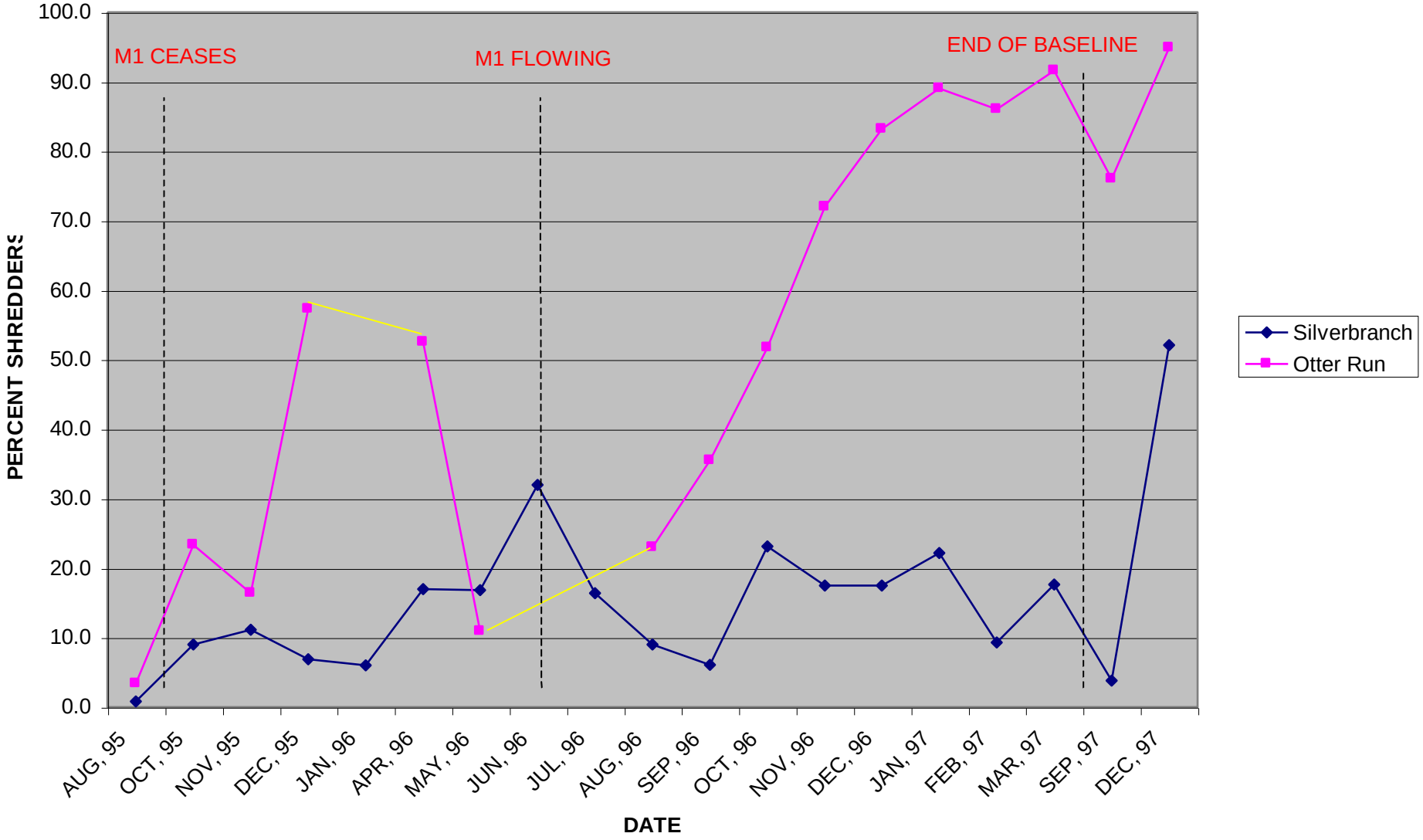
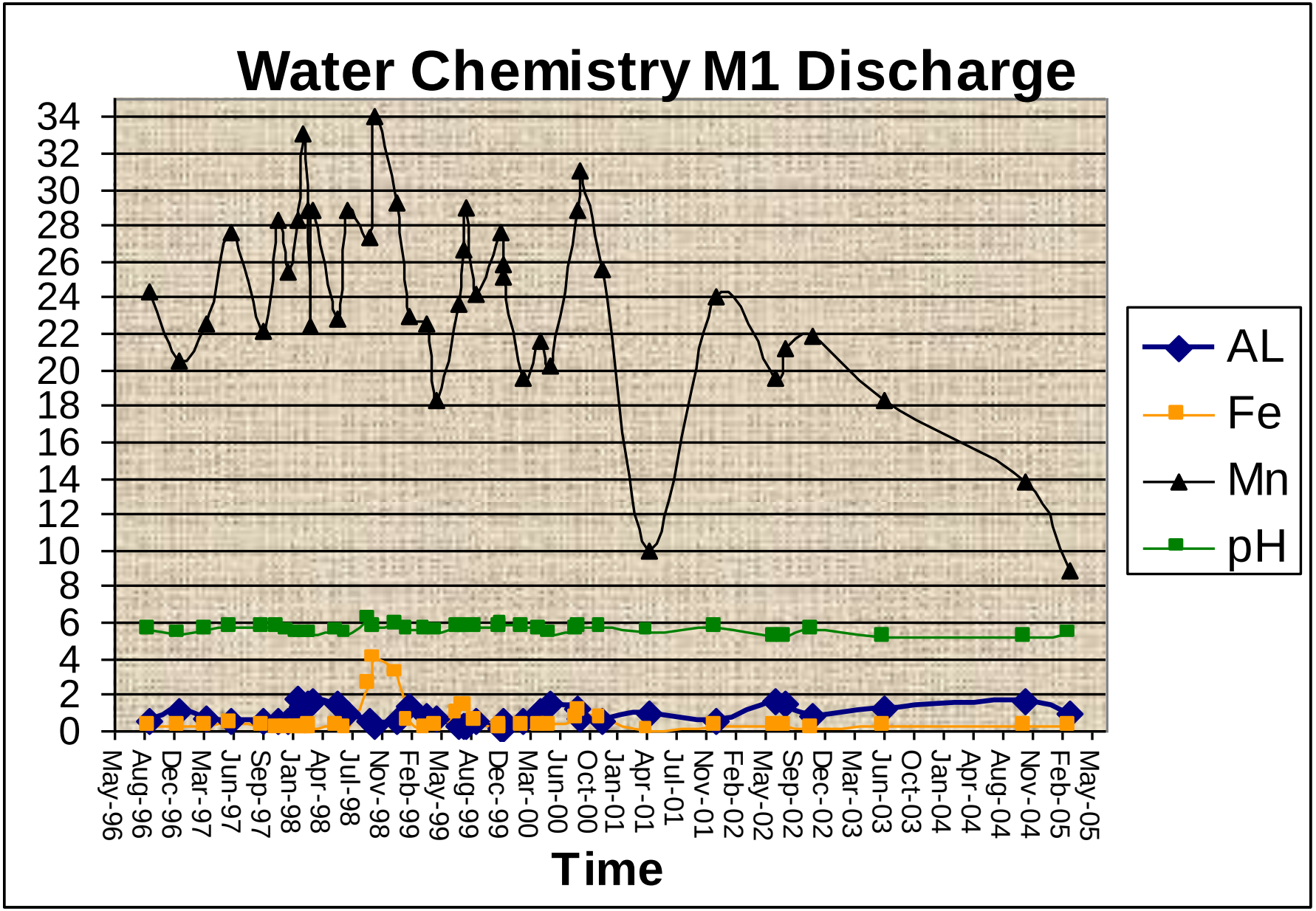
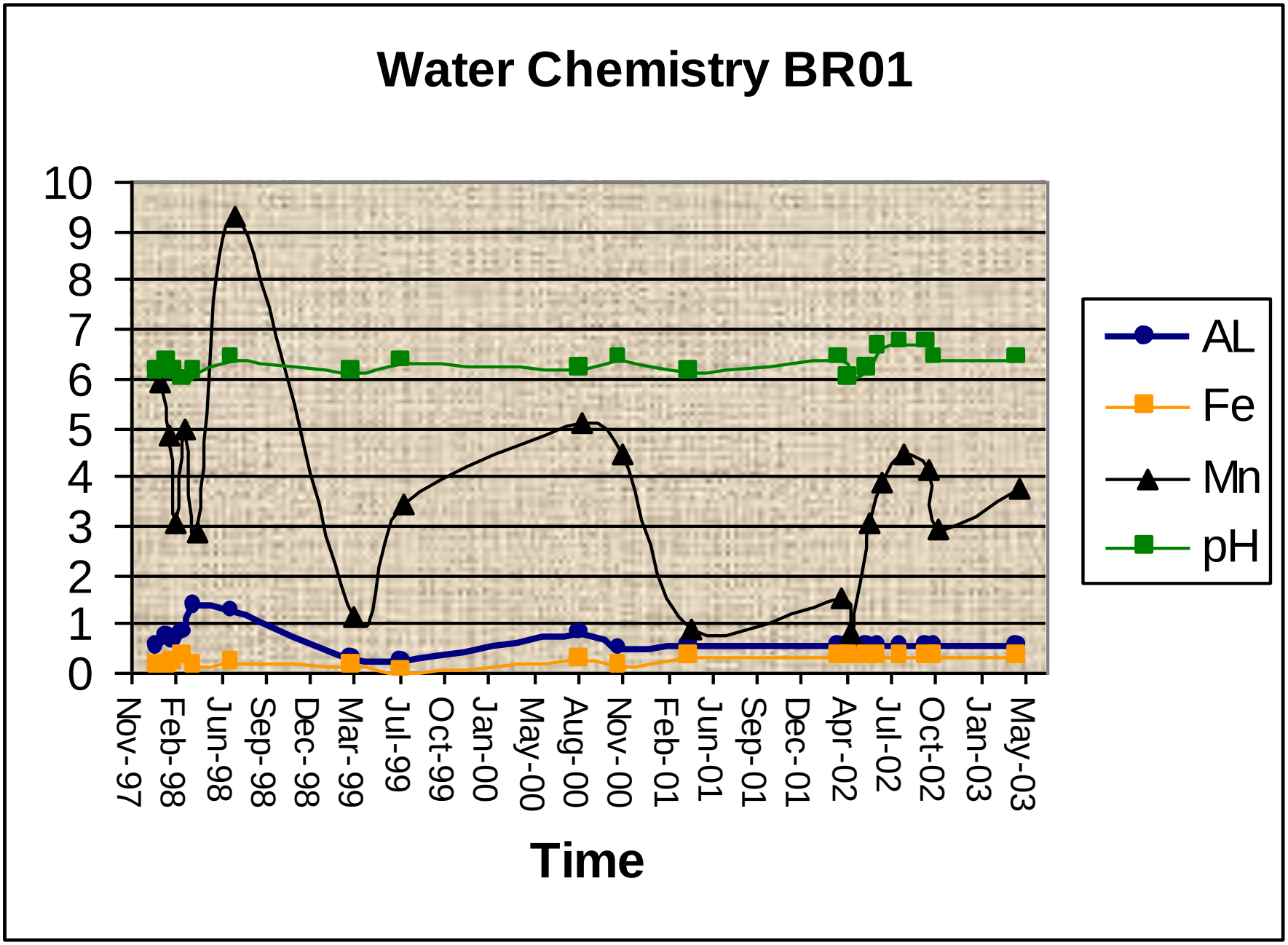
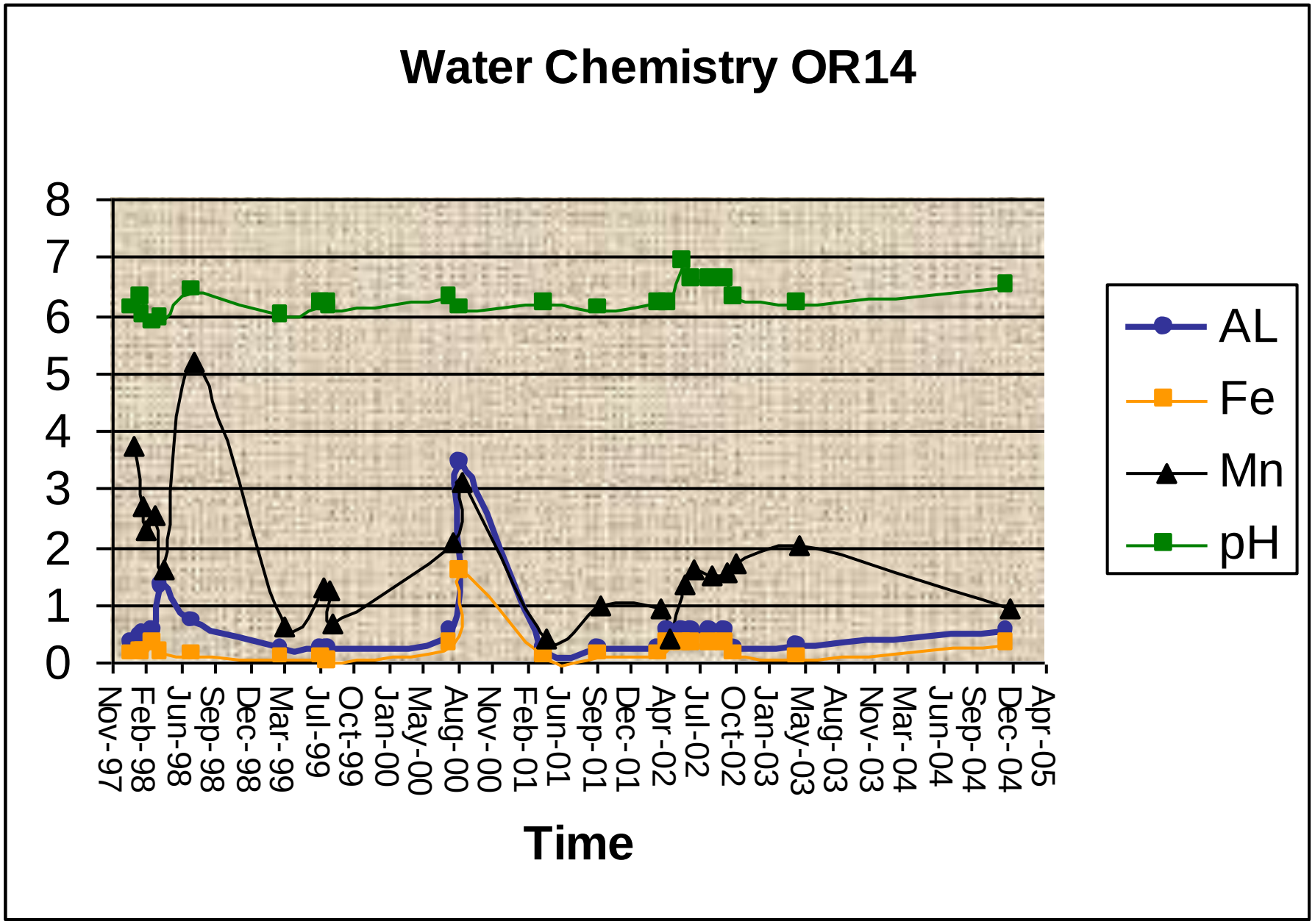


FIGURE 1. Percent shredders, Otter (OR14) vs. Silverbranch (SB01)




Water Chemistry M1 Discharge
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
May-96
Aug-96
Dec-96
Mar-97
Jun-97
Sep-97
Jan-98
Apr-98
Jul-98
Nov-98
Feb-99
May-99
Aug-99
Dec-99
Mar-00
Jun-00
Oct-00
Jan-01
Apr-01
Jul-01
Nov-01
Feb-02
May-02
Sep-02
Dec-02
Mar-03
Jun-03
Oct-03
Jan-04
Apr-04
Aug-04
Nov-04
Feb-05
May-05
Time
AL
Fe
Mn
pH


Water Chemistry BR01
10
9
8
7
6
5
4
3
2
1
0
Nov-97
Feb-98
Jun-98
Sep-98
Dec-98
Mar-99
Jul-99
Oct-99
Jan-00
May-00
Aug-00
Nov-00
Feb-01
Jun-01
Sep-01
Dec-01
Apr-02
Jul-02
Oct-02
Jan-03
May-03
Time
AL
Fe
Mn
pH


Water Chemistry OR14
8
7
6
5
4
3
2
1
0
Nov-97
Feb-98
Jun-98
Sep-98
Dec-98
Mar-99
Jul-99
Oct-99
Jan-00
May-00
Aug-00
Nov-00
Feb-01
Jun-01
Sep-01
Dec-01
Apr-02
Jul-02
Oct-02
Jan-03
May-03
Aug-03
Nov-03
Mar-04
Jun-04
Sep-04
Dec-04
Apr-05
Time
AL
Fe
Mn
pH

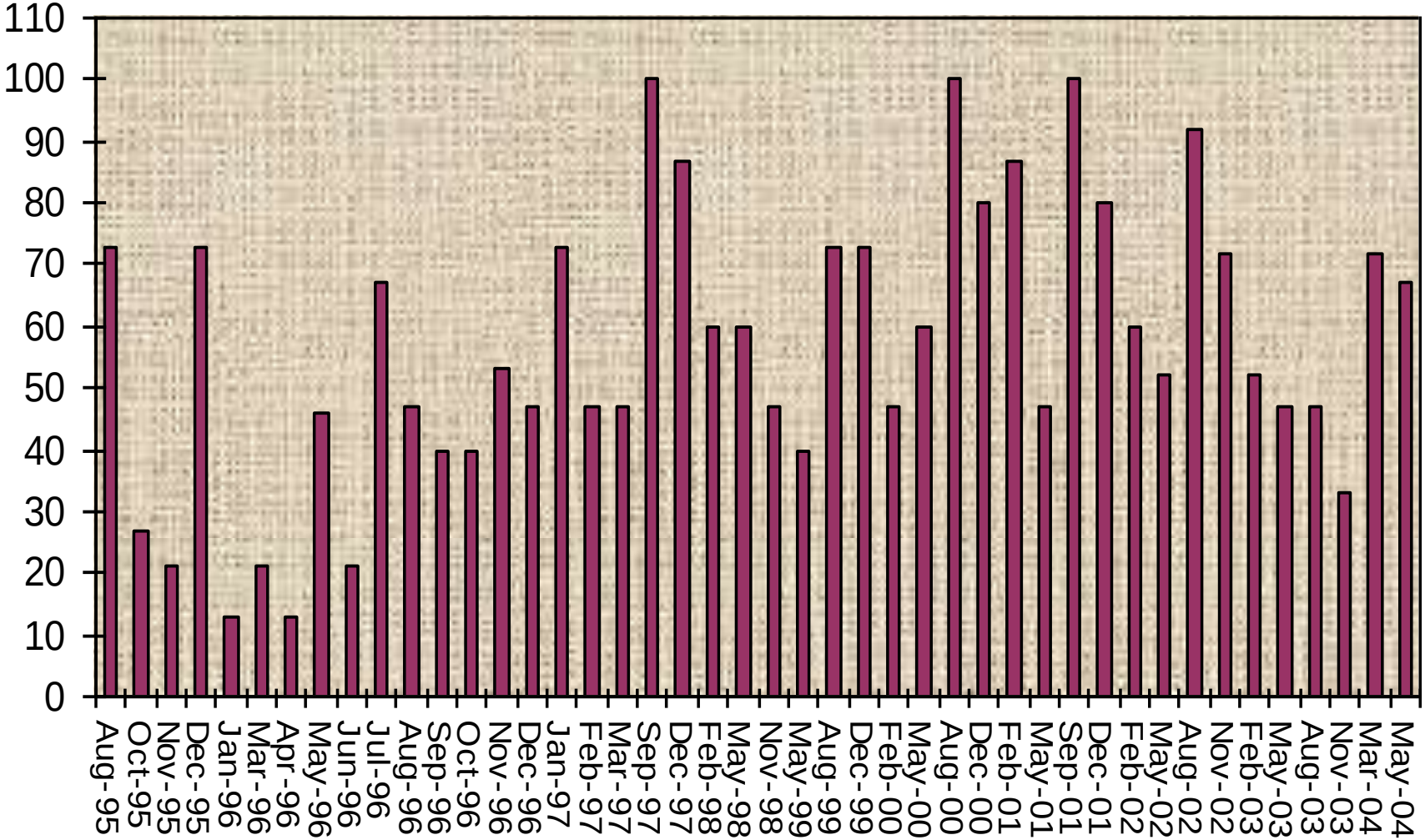
Season	Sample Collecection Dates
Summer	July 18, 1996
	August 21, 1996
Fall	September 23, 2005
	September 25, 1996
	October 26, 1996
	November 23, 1996
	December 18, 1997
Winter	December 21, 1996
	January 8, 1997
	February 20, 1997
	February 16, 1998
Spring	March 25, 1997
	May 27, 1998

METRIC	BIOLOGICAL CONDITION SCORING CRITERIA				
	Calculation	6	4	2	0
DENSITY (Mean)	(S/R)	≥51%	36-50%	21-35%	≤20%
TAXA RICHNESS	(S/R)	>80%	60-80%	40-59%	<40%
EPT DENSITY (Mean)	(S/R)	>51%	36-50%	21-36%	≤20%
EPT TAXA	(S/R)	>90%	80-90%	70-79%	<70%
COMMUNITY LOSS		,0.5	0.5-1.5	1.6-4.0	>4.0

Season	Biological Condition Score (mean % of reference)
Summer	67%
Fall	60%
Winter	55%
Spring	53%

Season	Biological Alarm Trigger
Summer	34%
Fall	30%
Winter	28%
Spring	27%

Percent of Reference OR14



Study problems

- Sedimentation events
- Water quality fluctuations
- Other metals
- Droughts and floods

	M1		BR01		OR14	
	2/9/1998	*4/14/1998*	*2/9/1998*	*4/14/1998*	*2/9/1998*	*4/14/1998*
pH	5.3	5.5	6.3	6.1	6.3	5.9
Alkalinity	48	48	12.8	12	11	10.4
Mn	33100	25200	4810	2860	2710	1620
Cobalt	796	813	141	102	88	61
Nickel	1420	1390	294	181	167	113
Zinc	1270	1190	265	160	207	99

8 23 00

Benthic Evaluations on Sites with Elevated Manganese Concentrations West Virginia Case Studies

Randall R. Maggard
Manager of Environmental Compliance
Argus Energy WV, LLC

Clean Water Act

“The objective of this act is to restore and maintain the chemical, physical, and biological integrity of the nation’s waters”

Quotes from Karr, J. R. and E. W. Chu: Restoring Life in Running Waters, 1999

- "Despite the Clean Water Act's clear mandate and lofty language, the condition of living aquatic systems says we have failed to achieve the act's objectives."
- "Water resource management has been dominated by outdated legal doctrines, weak implementations of good laws, and a focus on water chemistry."

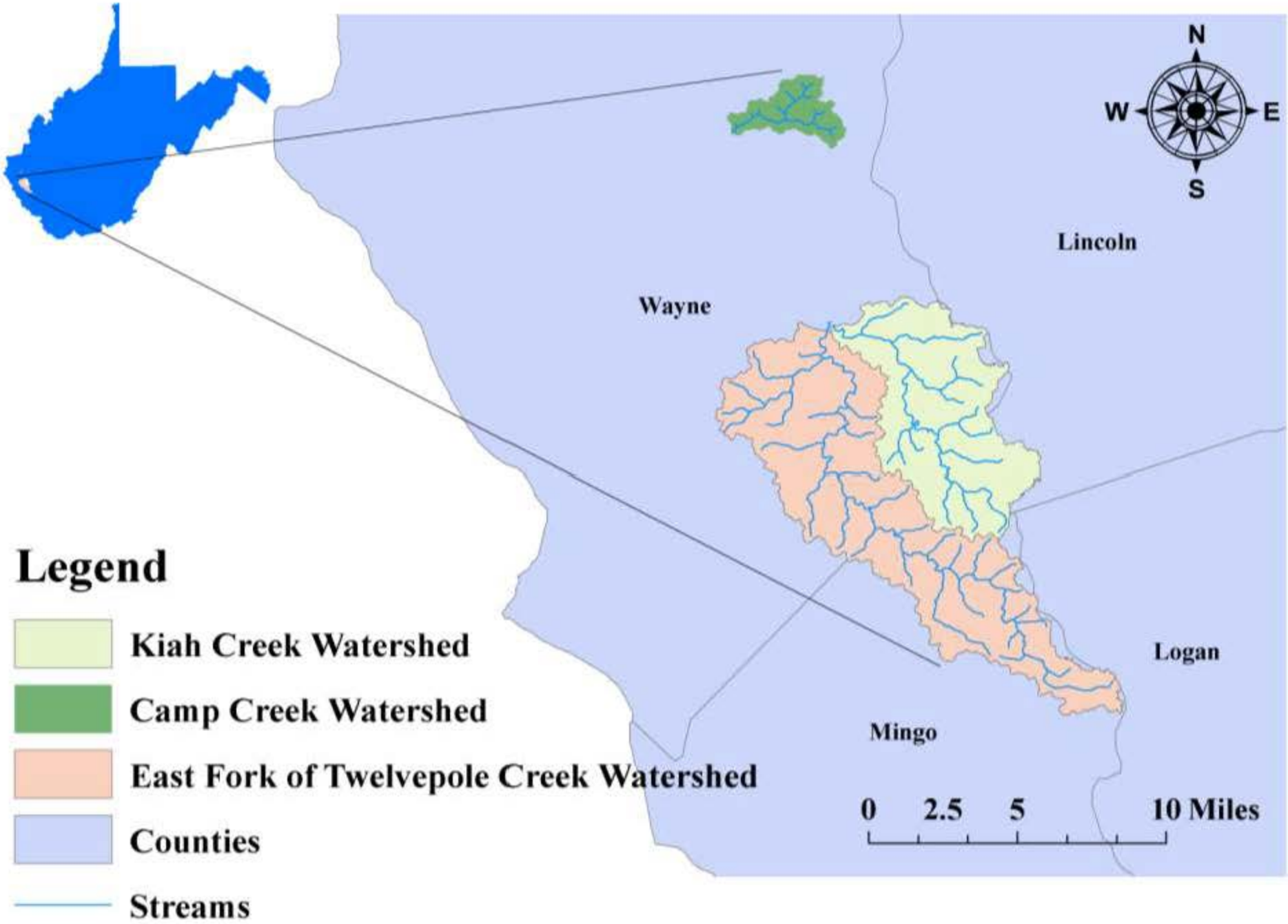
Quotes from Karr, J. R. and E. W. Chu: Restoring Life in Running Waters, 1999

- "Biological integrity may be damaged by too narrow a focus on chemical criteria"
- "Narrow use of chemical criteria can damage water resources and waste money."

Biological Monitoring

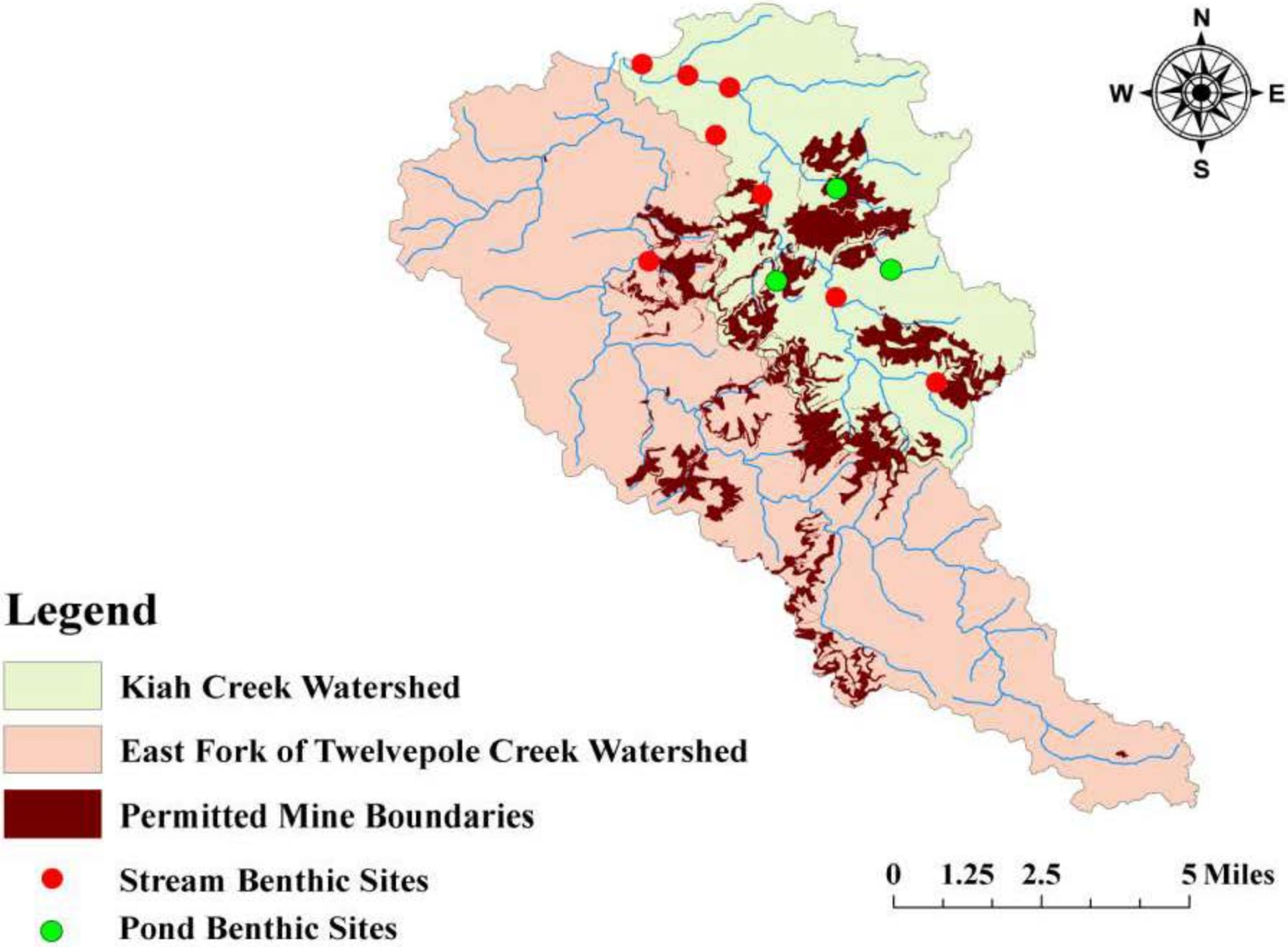
- Argus Energy and its predecessor, Pen Coal, have conducted biological monitoring on a regular basis since the spring of 1995

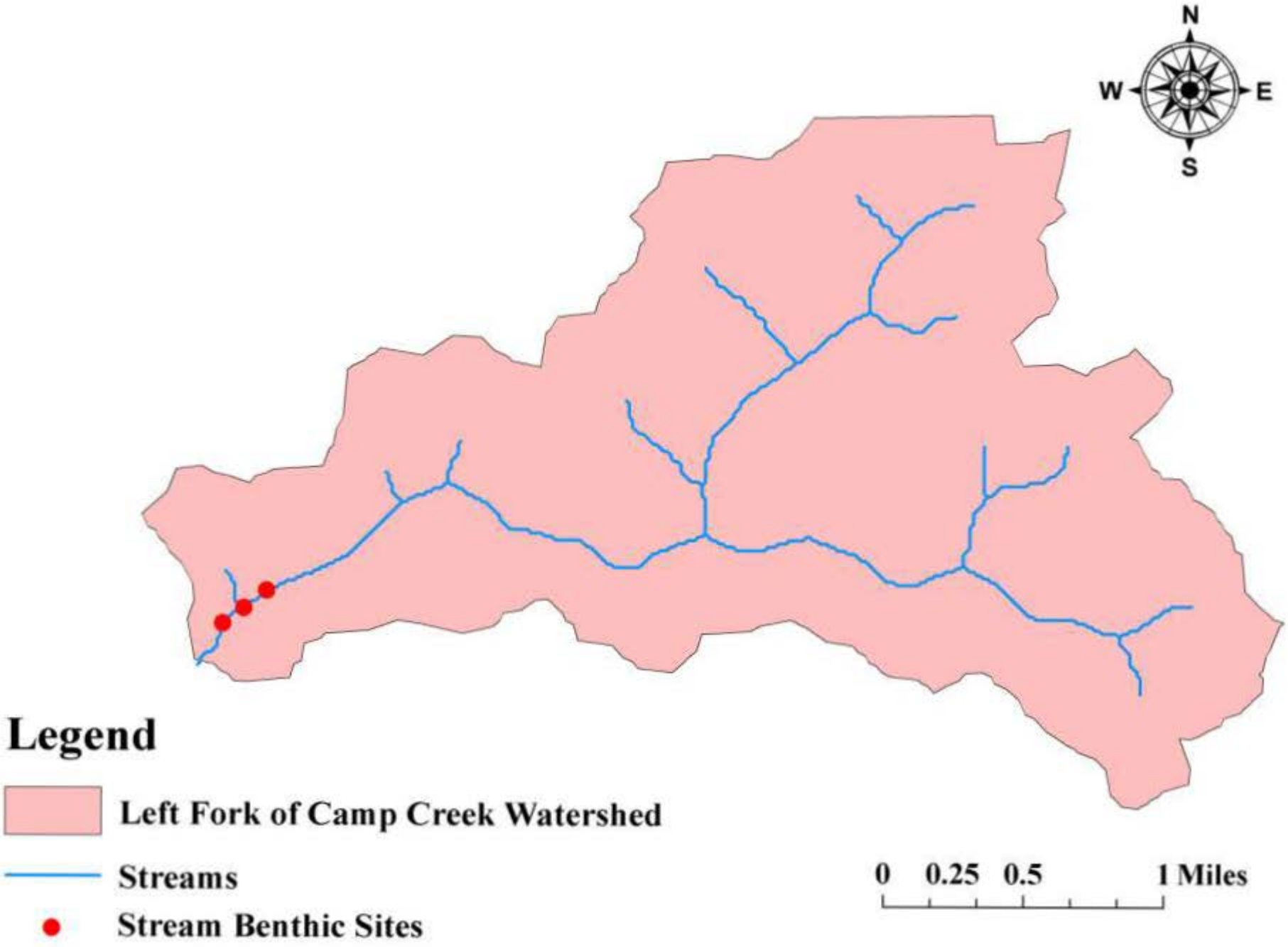
- Physical + Chemical = Biological


N
W
E
S
Lincoln
Wayne
Logan
Mingo
0
2.5
5
10 Miles
Legend
Kiah Creek Watershed
Camp Creek Watershed
East Fork of Twelvepole Creek Watershed
Counties
Streams

Study Sites

1. Vance Branch Pond
2. Rollem Fork Pond
3. Left Fork of Parker Branch Pond
4. Maynard Branch
5. Left Fork of Camp Creek
6. Kiah Creek


N
W
E
S
Legend
Kiah Creek Watershed
East Fork of Twelvepole Creek Watershed
Permitted Mine Boundaries
Stream Benthic Sites
Pond Benthic Sites
0
1.25
2.5
5 Miles


N
W
E
S
Legend
Left Fork of Camp Creek Watershed
Streams
Stream Benthic Sites
0 0.25 0.5 1 Miles

Collection Methods - Ponds

Physical Water Quality:

•Marsh McBirney Model 2000 portable flow meter. Width, depth, and velocity measured at outfall.

Water temperature and pH measured on-site with Orion 250a portable pH meter

•Conductivity measured on-site with Orion Model 122 conductivity meter

•Dissolved oxygen measured on-site with YSI Model 57 meter

Water Quality Samples:

•Collected at each pond outlet and processed by a certified water quality laboratory

Benthic Macroinvertebrates:

•Modified Hester-Dendy multiplate samplers

•Gravel basket samplers

•Kick-net samplers

•Collections preserved in 10% formalin

Collection Methods - Streams

Physical Water Quality:

- Hydrolab™ Minisonde multi-parameter probe to measure dissolved oxygen, pH, and conductivity
- Marsh-McBirney™ Model 2000 portable flow meter to determine discharge

Water Quality Samples:

- Collected at each station and processed by a certified water quality laboratory

Benthic Macroinvertebrates:

- Rapid bioassessment protocols for use in streams and wadeable rivers (EPA 841-B-99-002)
- 0.1 m^2 Surber sampler (500-µm mesh size net)
- 0.25 m2 D-frame kick-net (500-µm mesh size net)
- Collections preserved in 35% formalin

Habitat:

Rapid bioassessment protocols for use in streams and wadeable rivers (EPA 841-B-99-002)

Benthic Metrics - Ponds

- Taxa Richness
- Modified Hilsenhoff Biotic Index
- Ratio of Scraper and Filtering Collector Functional Feeding Groups
- Ratio of Ephemeroptera, Plecoptera, Trichoptera (EPT), and Chironomidae Abundances
- Percent Contribution of Dominant Family
- EPT Index
- Ratio of Shredder Functional Feeding Group and Total Number of Individuals Collected

Benthic Metrics - Streams

- Taxa Richness
- Modified Hilsenhoff Biotic Index
- Ratio of Scraper and Filtering Collector Functional Feeding Groups
- Ratio of Ephemeroptera, Plecoptera, Trichoptera (EPT), and Chironomidae Abundances
- Percent Contribution of Mayflies
- Percent Contribution of Dominant Family
- EPT Index

Benthic Metrics - Streams

- Ratio of Shredder Functional Feeding Group and Total Number of Individuals Collected
- Simpson's Diversity Index
- Shannon-Wiener Diversity Index
- Shannon-Wiener Eveness
- West Virginia Stream Condition Index

Results - Vance Branch Pond

Physical Water Quality	Pond No. 1
Flow (ft^3/s)	0.68
Temperature, (C)	15.2
Dissolved Oxygen (mg/l)	8.92
pH (SI units)	7.26
Conductivity	701
Total Manganese	1.76

Results - Vance Branch Pond

Benthic Metrics	Pond No. 1
Taxa Richness	16
Total Individuals	1,291
Modified Hilsenhoff Biotic Index	5.67
Ratio of Scraper to Collectors/Filterers	4:33
Ratio of EPT and Chironomidae Abundances	149:1006
% Contribution of Dominant Family	77.9
EPT Index	7.0
% of Shredders to Total	0.0
% Sensitive Individuals	0.4
% Facultative Individuals	13.5
% Tolerant Individuals	86.1

Results - Rollem Fork Pond

Physical Water Quality	Upstream	Downstream	Pond
Flow (ft^3/s)	0.33	0.71	NA
Temperature, (C)	7.4	9.5	13.0
Dissolved Oxygen (mg/l)	10.82	10.27	9.51
pH (SI units)	6.72	7.68	7.68
Conductivity	67.6	310.0	551.0
Total Manganese	0.007	0.474	1.52

Results - Rollem Fork Pond

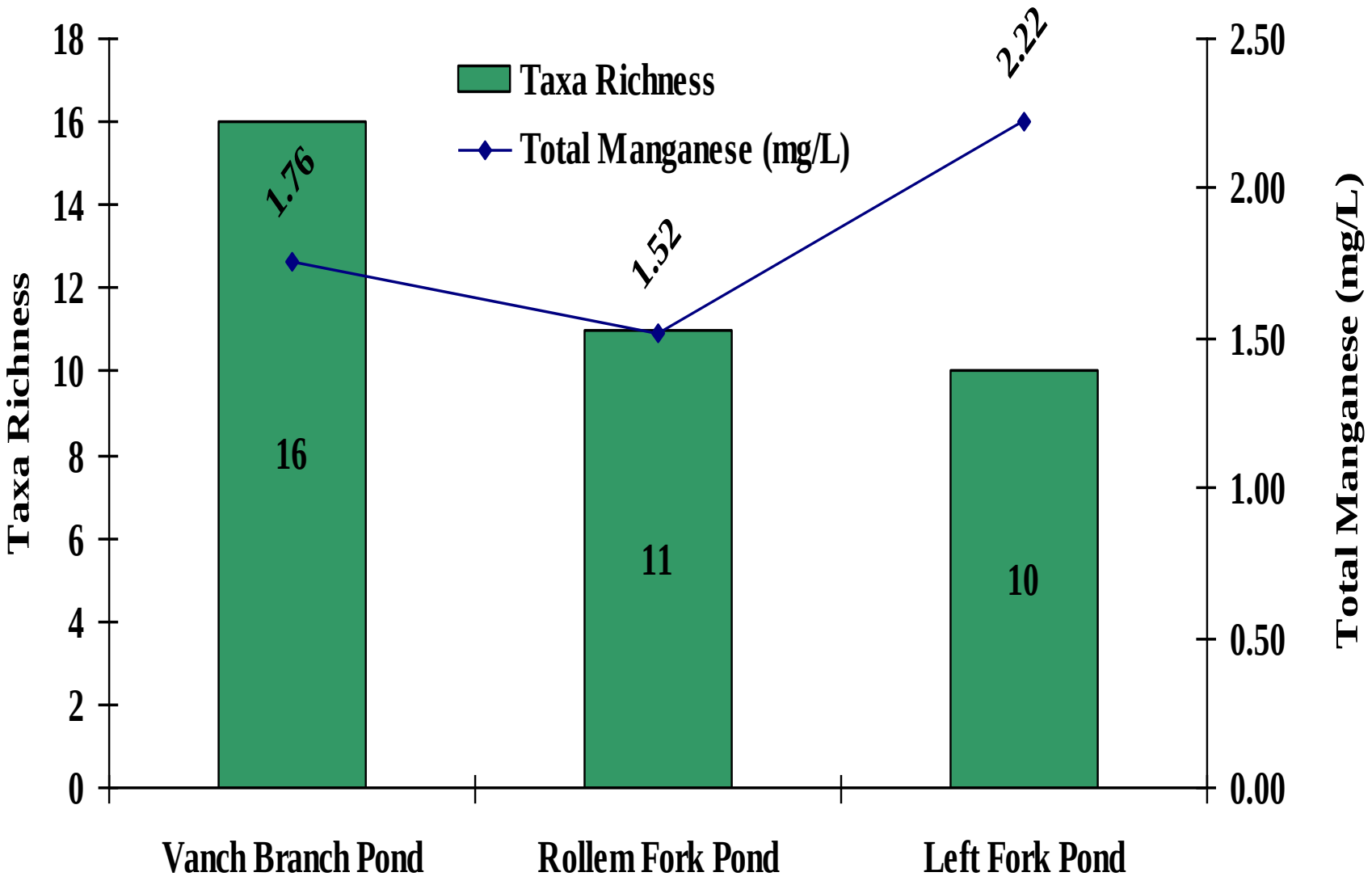
Benthic Metrics	Upstream	Downstream	Pond
Taxa Richness	24	24	11
Total Individuals	785	1,429	649
Modified Hilsenhoff Biotic Index	4.55	4.66	5.93
Ratio of Scraper to Collectors/Filterers	49:2	37:38	0:0
Ratio of EPT and Chironomidae Abundances	378:371	595:733	18:288
% Contribution of Dominant Family	47.3	51.3	47.9
EPT Index	15	16	3
% of Shredders to Total	11.8	12.3	0.0
% Sensitive Individuals	13.5	5.2	0.0
% Facultative Individuals	36.2	41.1	5.7
% Tolerant Individuals	50.3	53.7	94.3

Results – Left Fork of Parker Branch Pond

Physical Water Quality	Pond
Flow (ft^3/s)	0.30
Temperature, (C)	13.2
Dissolved Oxygen (mg/l)	9.71
pH (SI units)	7.92
Conductivity	603.0
Total Manganese	2.22

Results – Left Fork of Parker Branch Pond

Benthic Metrics	Pond
Taxa Richness	10
Total Individuals	303
Modified Hilsenhoff Biotic Index	6.06
Ratio of Scraper to Collectors/Filterers	0:0
Ratio of EPT and Chironomidae Abundances	6:111
% Contribution of Dominant Family	46.9
EPT Index	1.0
% of Shredders to Total	0.0
% Sensitive Individuals	0.0
% Facultative Individuals	2.0
% Tolerant Individuals	98.0


Taxa Richness vs Total Manganese for Pond Collections
Taxa Richness
Total Manganese (mg/L)
Taxa Richness
Total Manganese (mg/L)
18
16
14
12
10
8
6
4
2
0
2.50
2.00
1.50
1.00
0.50
0.00
1.76
1.52
2.22
16
11
10
Vanch Branch Pond
Rollem Fork Pond
Left Fork Pond

Results – Maynard Branch

Physical Water Quality	Maynard Branch at Mouth
Temperature, (C)	20.8
Dissolved Oxygen (mg/l)	7.80
pH (SI units)	7.40
Conductivity (µs)	1,106
Discharge (ft^3/sec)	1.33
Total Dissolved Solids (mg/L)	658
Sulfate (mg/l)	366
Dissolved Aluminum (mg/L)	<0.030
Total Manganese (mg/L)	1.45
Habitat Assessment Score	147

Results – Maynard Branch

Metric	Maynard Branch
Taxa Richness	13
Modified Hilsenhoff Biotic Index	5.34
Ratio of Scrapers to Collectors/Filterers	7:38
Ratio of EPT and Chironomidae Abundances	36:21
% Contribution of Mayflies	0
% Contribution of Dominant Taxa	26.5
EPT Index	2
% of Shredders to Total	4.1
Simpson's Diversity Index	0.84
Shannon-Wiener Diversity Index	3.05
Shannon-Wiener Eveness	0.82
WV-SCI	**53.38**

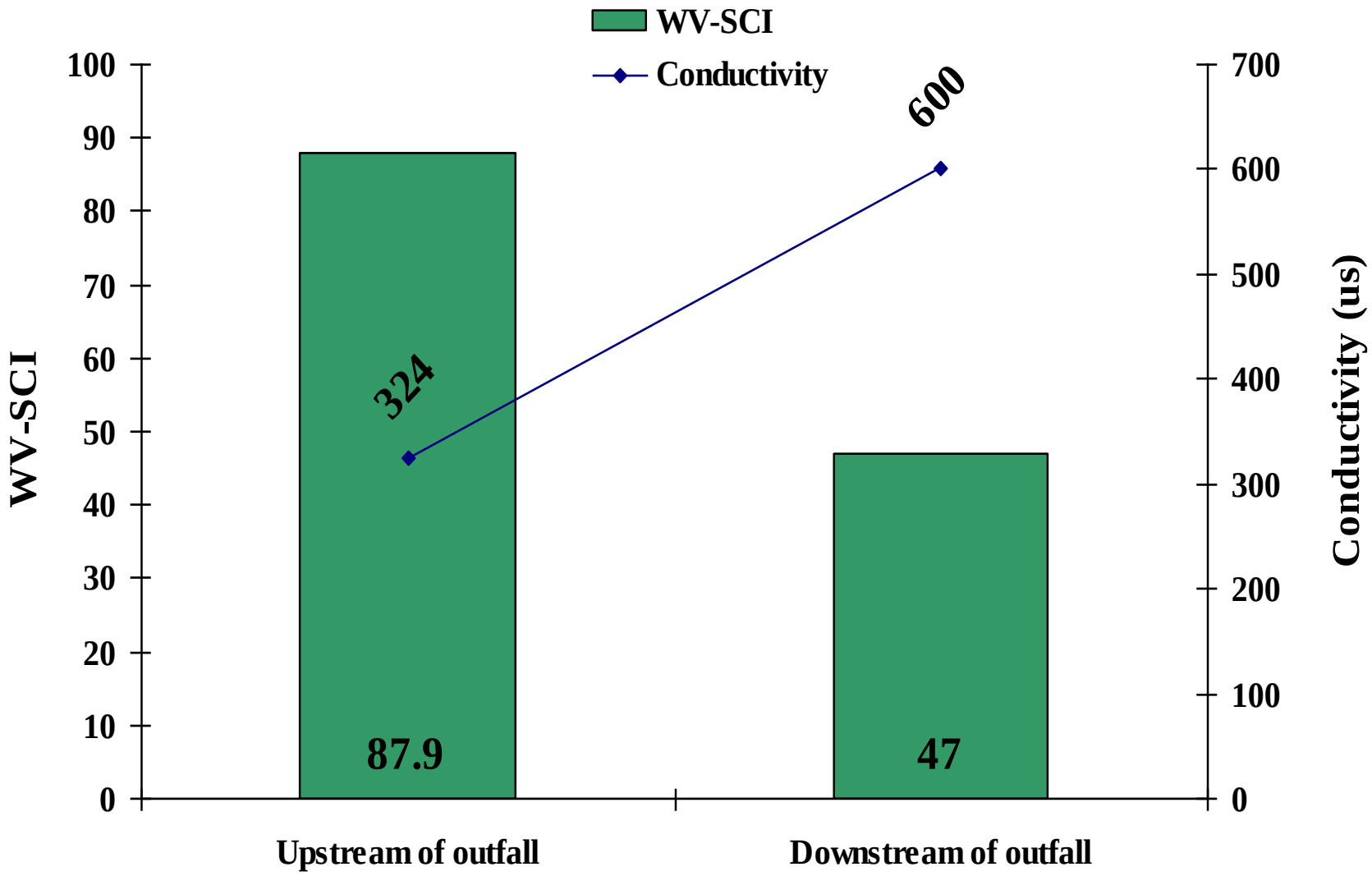
Results – Left Fork of Camp Creek

Physical Water Quality	LFCC-Outfall	LFCC Upstream of Outfall	LFCC Downstream of Outfall
Temperature, (C)	16.0	16.0	16.0
Dissolved Oxygen (mg/l)	7.95	6.04	6.55
pH (SI units)	2.98	6.55	4.16
Conductivity (µs)	1,396	324	600
Discharge (ft^3/sec)	0.011	0.028	0.158
Sulfate (mg/l)	647	56.8	245
Total Dissolved Solids (mg/l)	1,040	186	421
Dissolved Aluminum (mg/l)	32.7	0.030	9.78
Total Manganese (mg/L)	4.55	0.237	1.86
Habitat Assessment Score	N/A	154	159

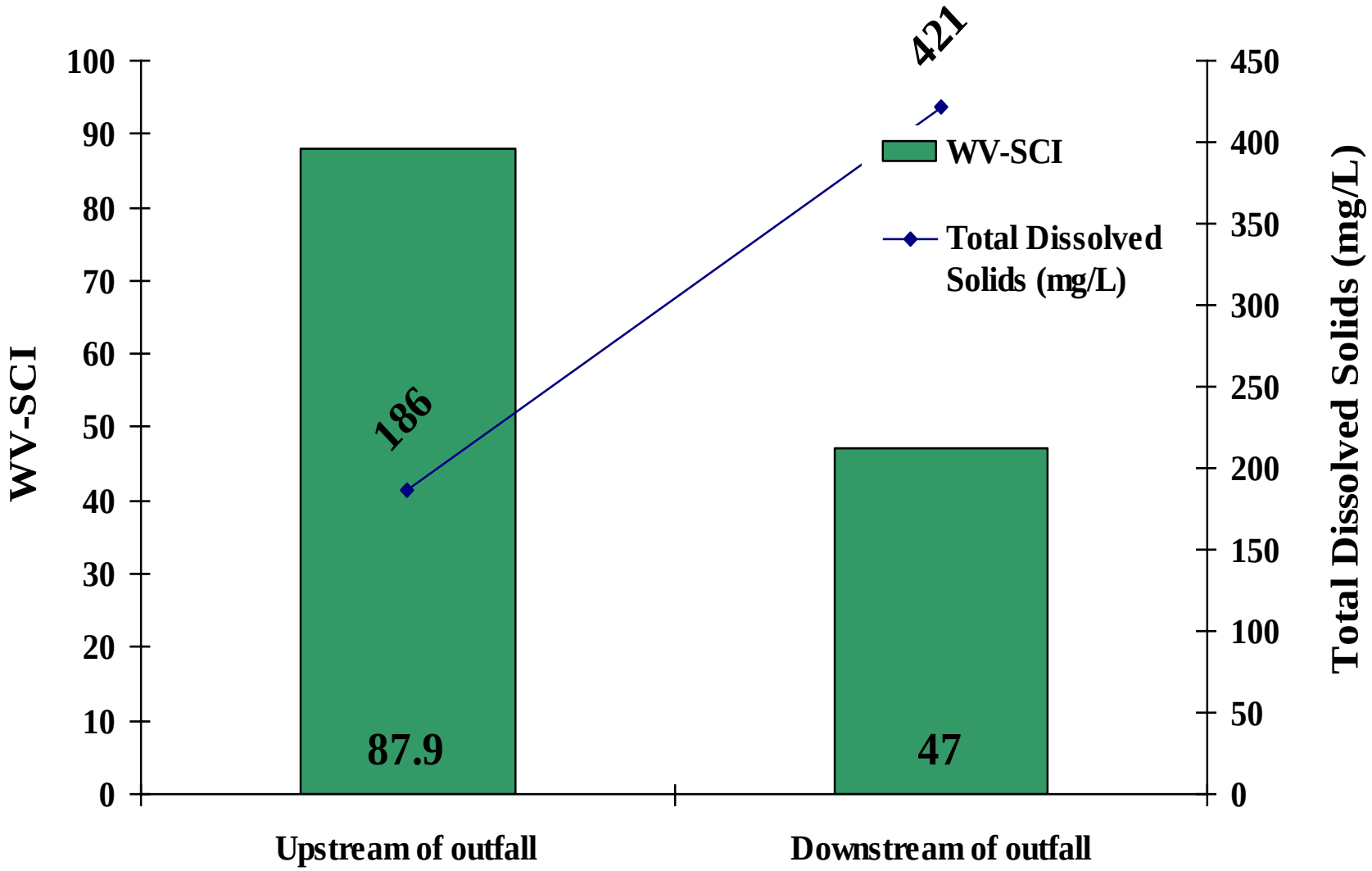
Results – Left Fork of Camp Creek

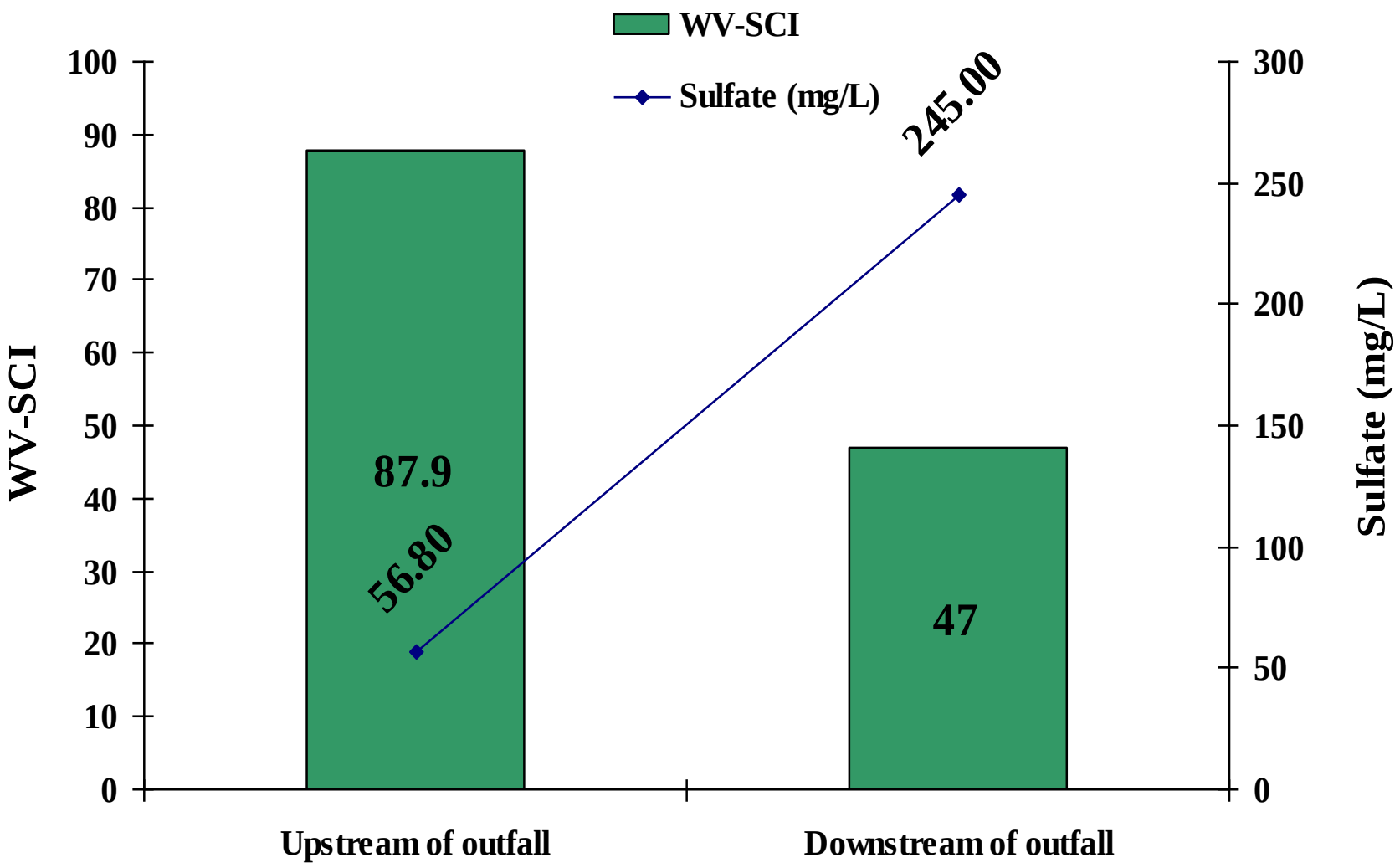
Metric	LFCC Upstream of Outfall	LFCC Downstream of Outfall
Taxa Richness	32	14
Modified Hilsenhoff Biotic Index	3.68	4.77
Ratio of Scrapers to Collectors/Filterers	170:58	42:9
Ratio of EPT and Chironomidae Abundances	226:47	16.39
% Contribution of Mayflies	37.9	1.7
% Contribution of Dominant Taxa	24.2	34.5
EPT Index	18	4
% of Shredders to Total	9.5	7.6
Simpson's Diversity Index	0.89	0.76
Shannon-Wiener Diversity Index	3.76	2.64
Shannon-Wiener Eveness	0.75	0.69
WV-SCI	**87.9**	**47**

WV-SCI Scores vs Conductivity for Stations on Left Fork of Camp Creek Fall 2001

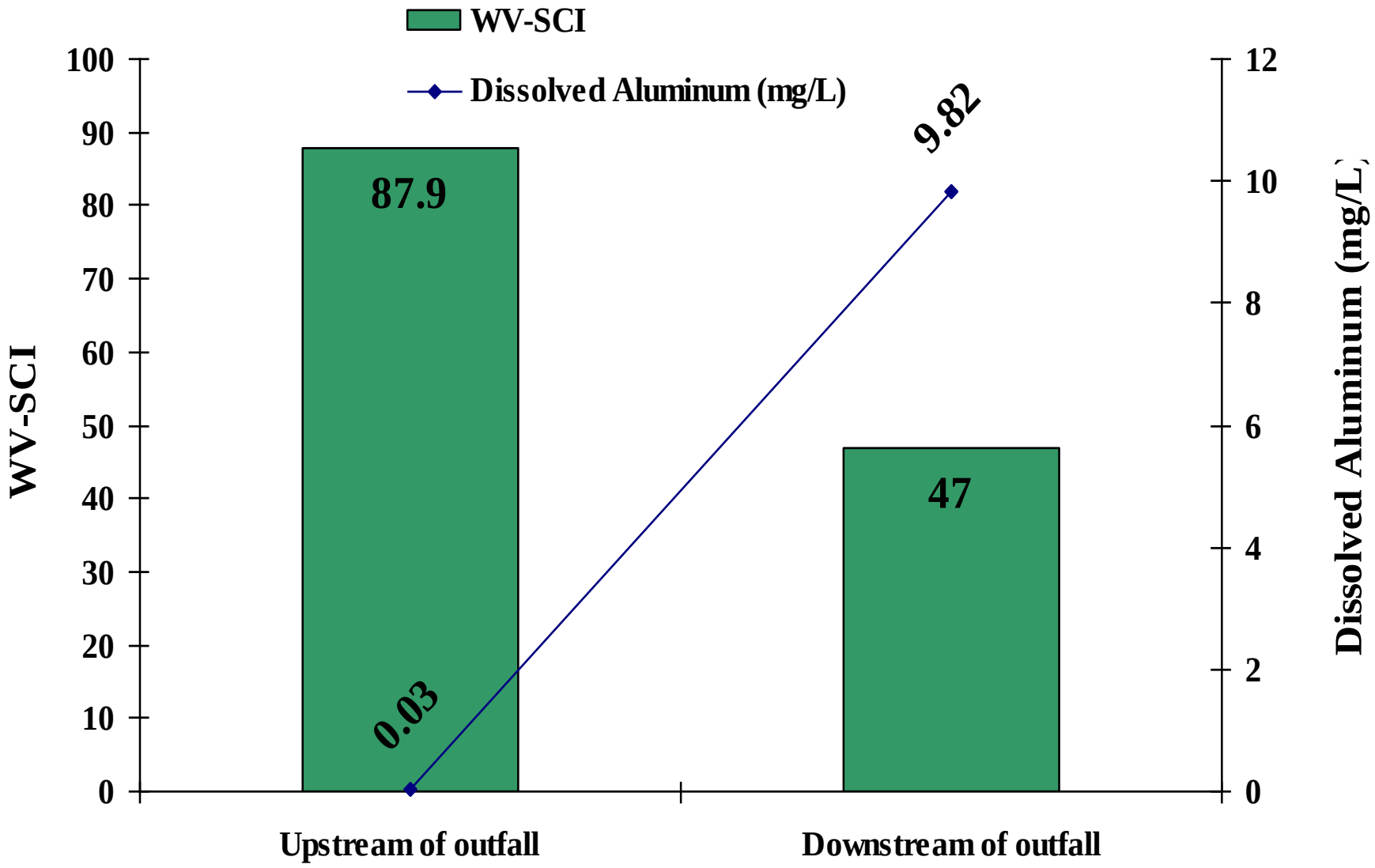


WV-SCI Scores vs Total Dissolved Solids for Stations on Left Fork of Camp Creek Fall 2001

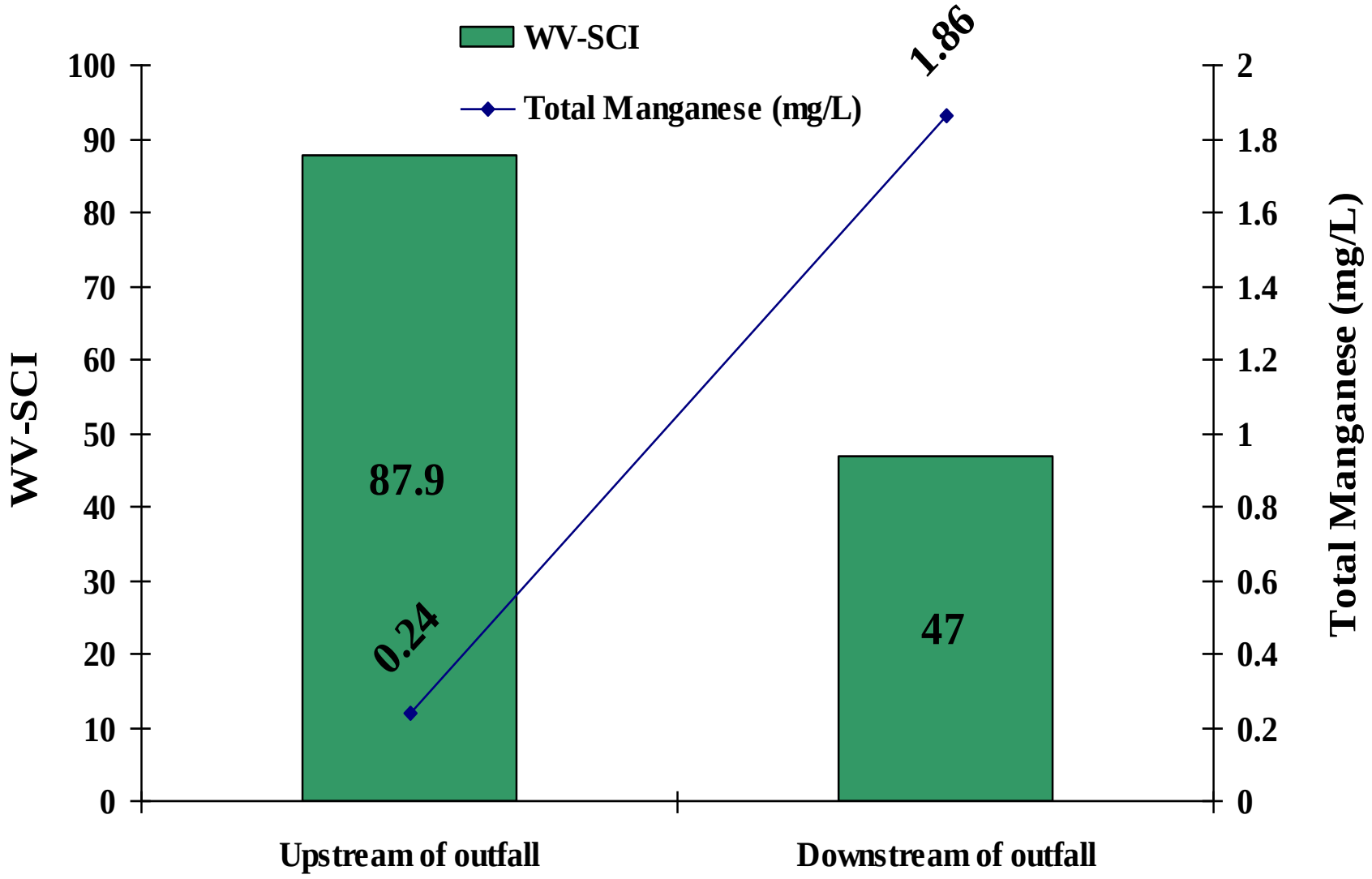


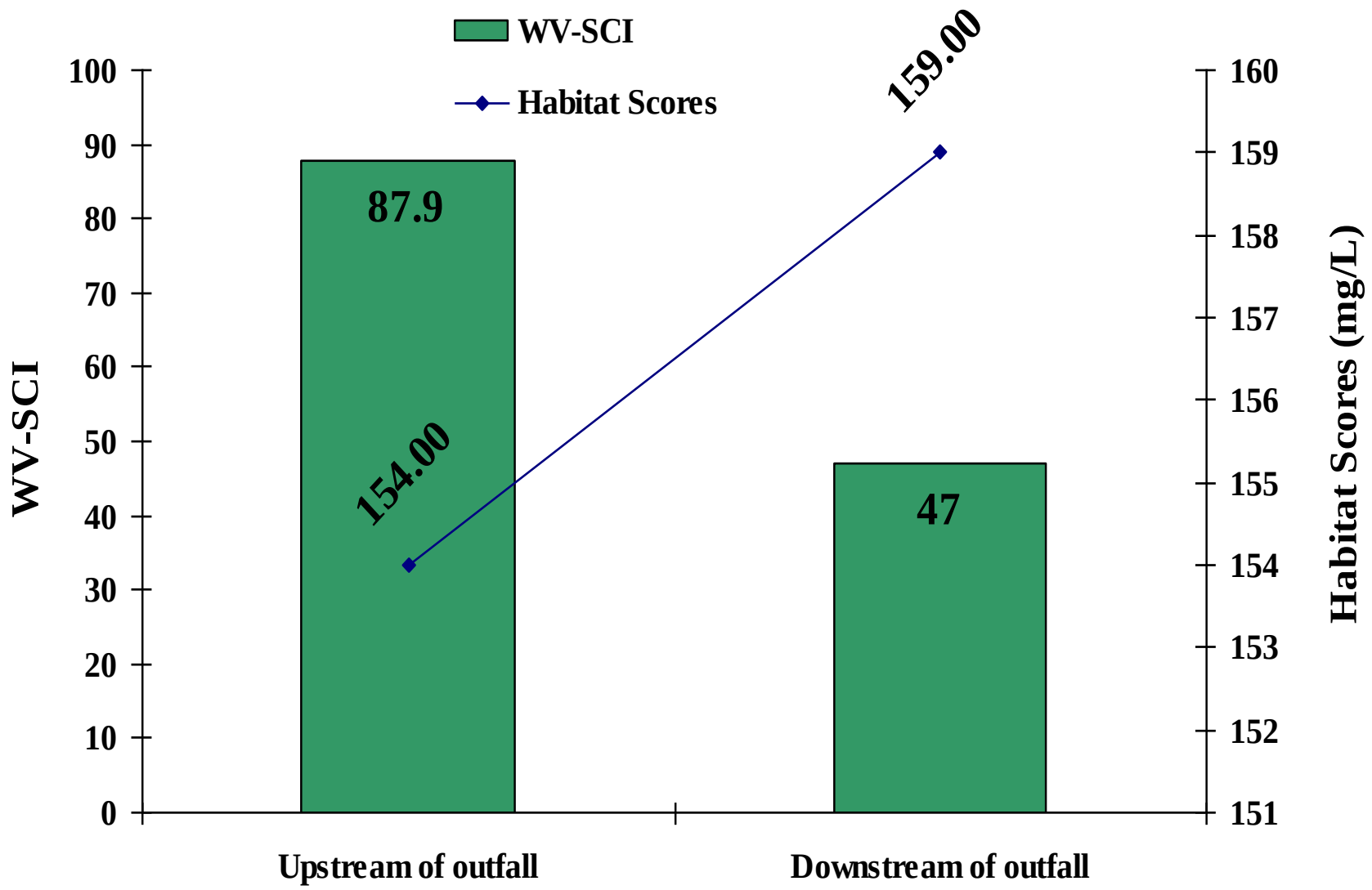

WV-SCI Scores vs Sulfate for
Stations on Left Fork of Camp Creek Fall 2001
WV-SCI
Sulfate (mg/L)
WV-SCI
Sulfate (mg/L)
100
90
80
70
60
50
40
30
20
10
0
300
250
200
150
100
50
0
87.9
47
56.80
245.00
Upstream of outfall
Downstream of outfall

WV-SCI Scores vs Dissolved Aluminum for Stations on Left Fork of Camp Creek Fall 2001



WV-SCI Scores vs Total Manganese for Stations on Left Fork of Camp Creek Fall 2001



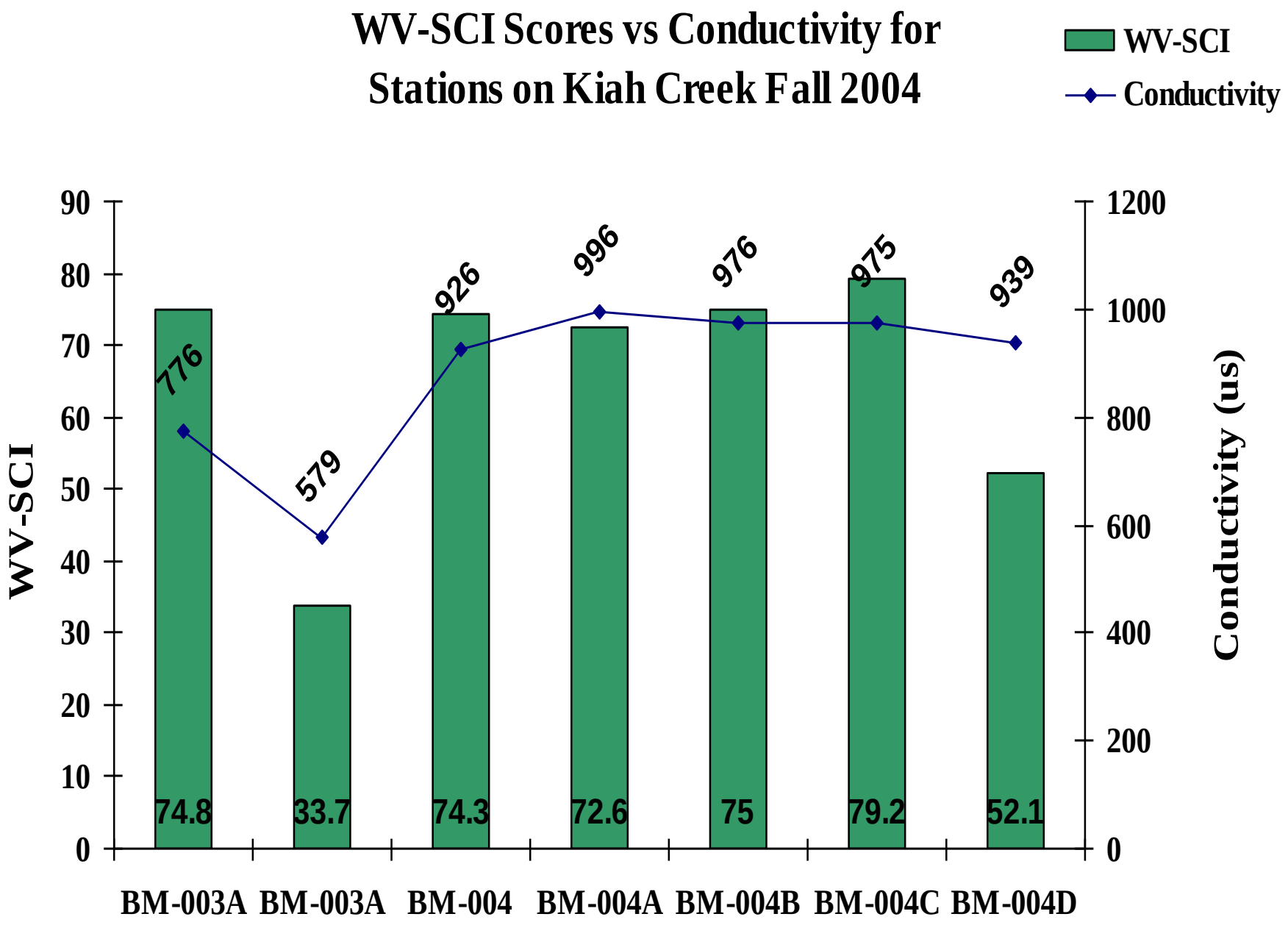

WV-SCI Scores vs Habitat Scores for
Stations on Left Fork of Camp Creek Fall 2001
WV-SCI
Habitat Scores
100
90
80
70
60
50
40
30
20
10
0
WV-SCI
160
159
158
157
156
155
154
153
152
151
Habitat Scores (mg/L)
87.9
47
154.00
159.00
Upstream of outfall
Downstream of outfall

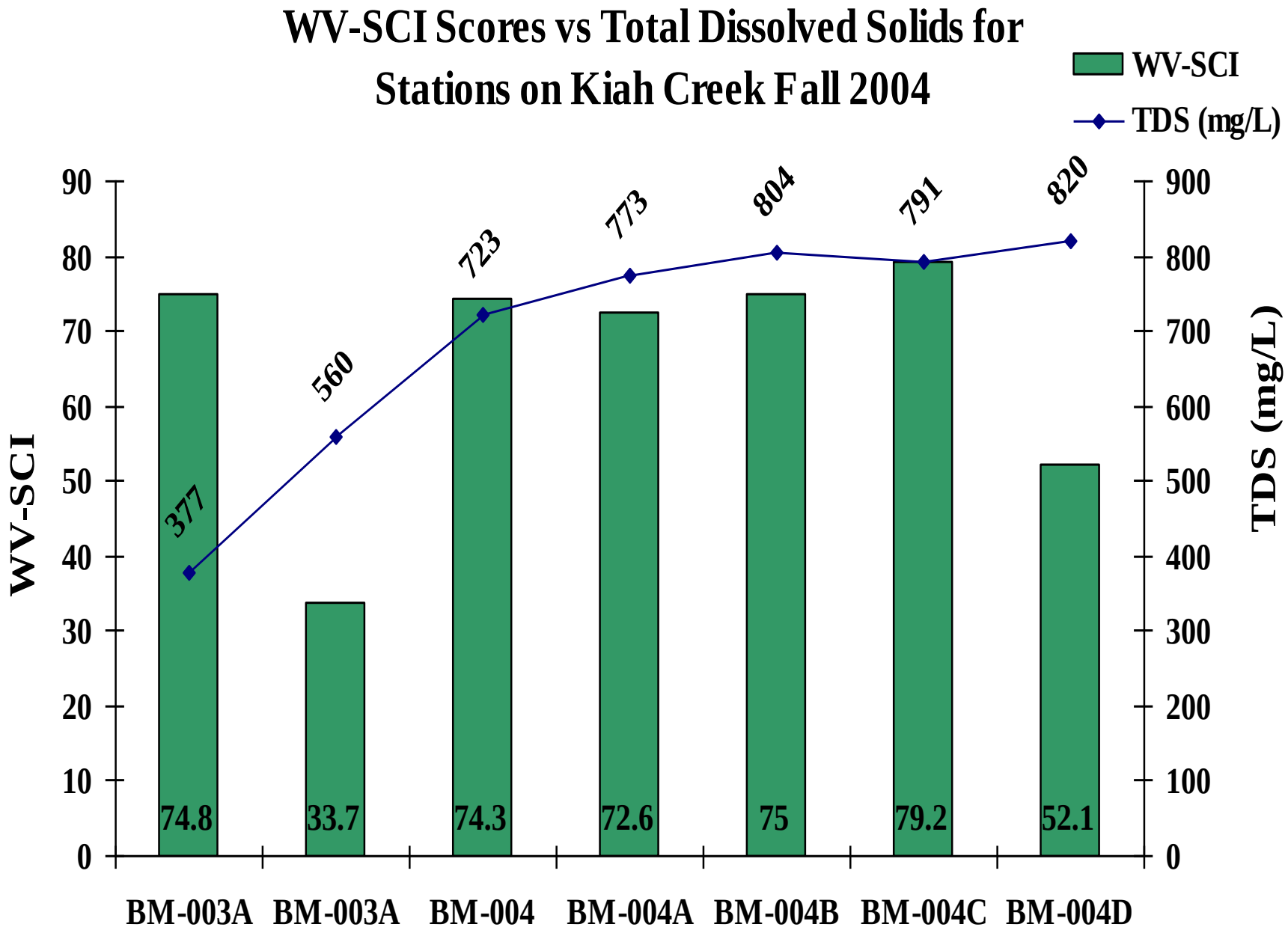
Results – Kiah Creek

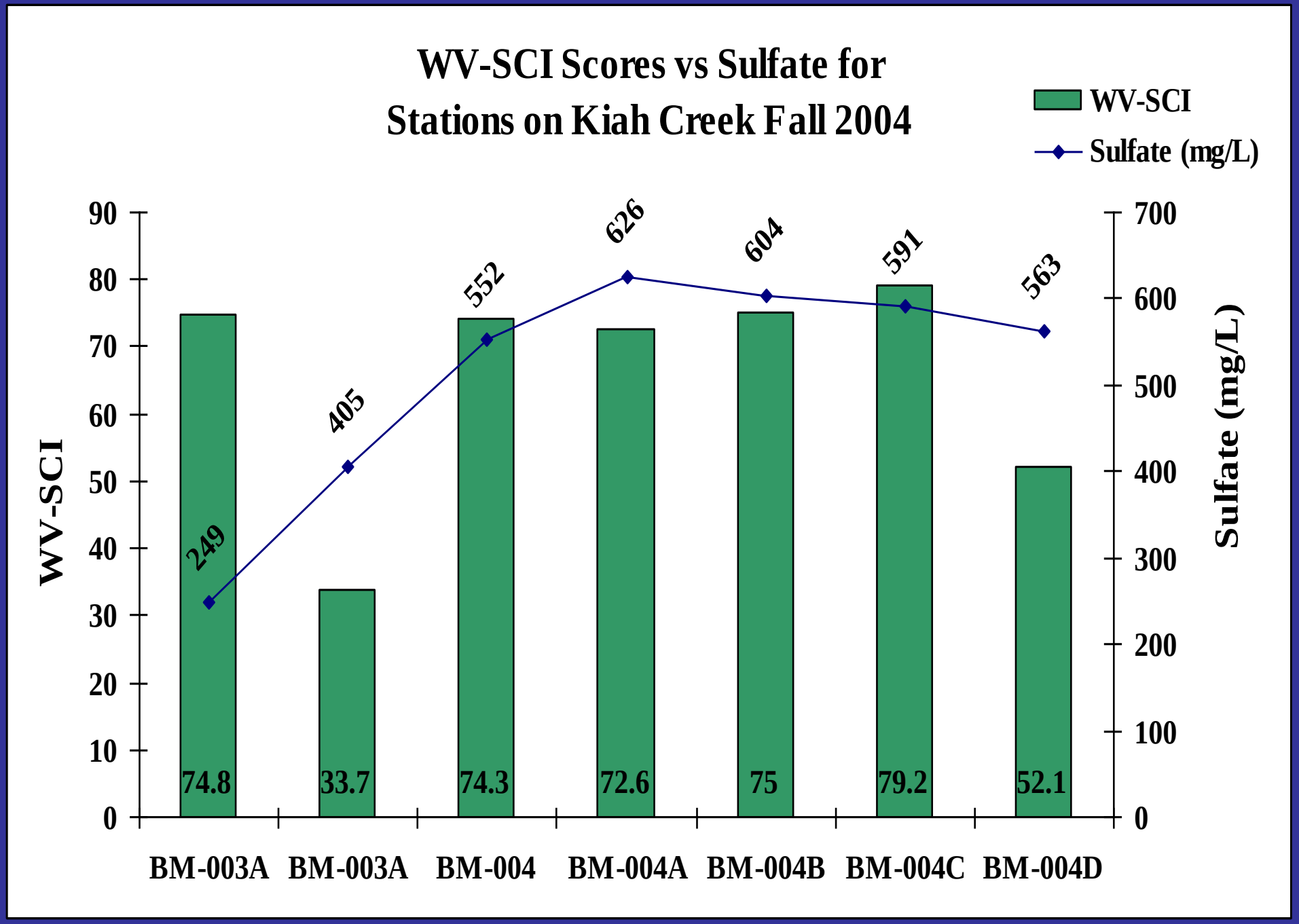
Physical Water Quality	BM-003A	BM-003	BM-004	BM-004A	BM-004B	BM-004C	BM-004D
Temperature, (C)	14.2	14.6	13.0	12.2	11.5	11.2	10.9
Dissolved Oxygen (mg/l)	8.51	10.16	9.63	9.78	9.74	8.53	9.14
pH (SI units)	7.42	7.86	7.48	7.77	7.57	7.37	7.07
Conductivity (µs)	579	776	926	996	976	975	939
Discharge (ft^3/sec)	0.47	2.88	5.42	5.83	6.15	7.56	8.06
Sulfate (mg/l)	249	405	552	626	604	591	563
Total Dissolved Solids (mg/l)	377	560	723	773	804	791	820
Dissolved Aluminum (mg/l)	<0.020	<0.020	0.039	<0.020	<0.020	<0.020	<0.020
Total Manganese (mg/L)	0.104	0.384	2.110	1.890	1.050	0.767	0.411
Habitat Assessment Score	170	136	145	160	161	152	117

Results – Kiah Creek

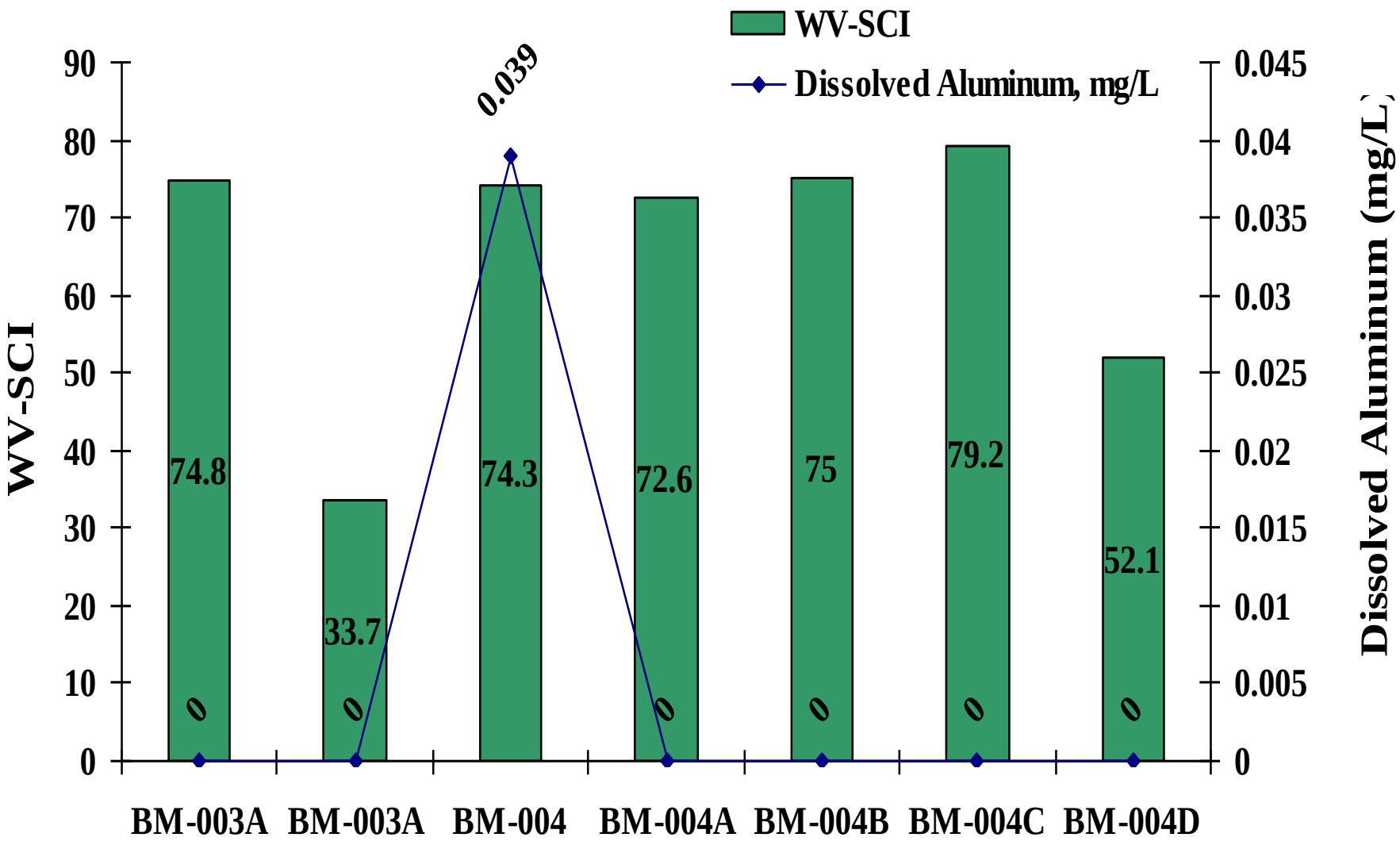
Metric	BM-003A	BM-003	BM-004	BM-004A	BM-004B	BM-004C	BM-004D
Taxa Richness	22	13	15	17	18	21	10
Modified Hilsenhoff Biotic Index	3.3	5.7	4.2	4	3.7	3.4	4.4
Ratio of Scrapers to Collectors/Filterers	30:62	34:16	54:42	582:232	298:78	100:248	6:10
Ratio of EPT and Chironomidae Abundances	634:358	42:874	152:52	582:232	298:78	546:150	32:40
% Contribution of Mayflies	2	0.8	22	4	7	6	2
% Contribution of Dominant Taxa	41	89	17	31	27	29	39
EPT Index	12	7	7	11	9	10	4
% of Shredders to Total	44	1	15	15	22	35	25
Simpson's Diversity Index	0.73	0.22	0.88	0.8	0.84	0.83	0.76
Shannon-Wiener Diversity Index	2.58	0.85	3.36	2.76	3.1	2.99	2.43
Shannon-Wiener Eveness	0.55	0.21	0.83	0.66	0.74	0.67	0.71
WV-SCI	**74.8**	**33.7**	**74.3**	**72.6**	**75**	**79.2**	**52.1**

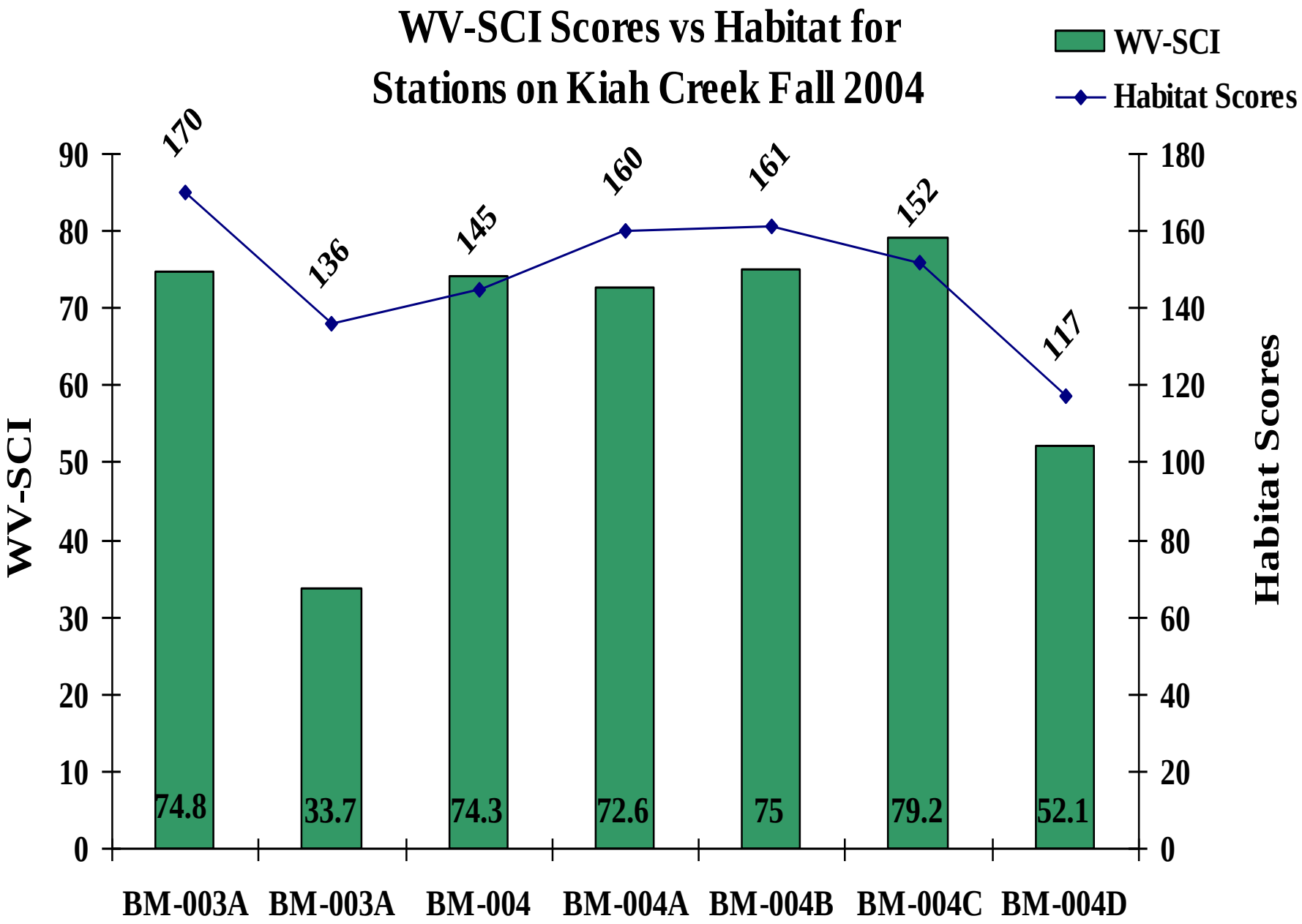

WV-SCI Scores vs Conductivity for Stations on Kiah Creek Fall 2004
WV-SCI
Conductivity
WV-SCI
Conductivity (us)
90
80
70
60
50
40
30
20
10
0
1200
1000
800
600
400
200
0
776
579
926
996
976
975
939
74.8
33.7
74.3
72.6
75
79.2
52.1
BM-003A
BM-003A
BM-004
BM-004A
BM-004B
BM-004C
BM-004D


WV-SCI Scores vs Total Dissolved Solids for Stations on Kiah Creek Fall 2004
WV-SCI
TDS (mg/L)
WV-SCI
TDS (mg/L)
90
80
70
60
50
40
30
20
10
0
900
800
700
600
500
400
300
200
100
0
377
560
723
773
804
791
820
74.8
33.7
74.3
72.6
75
79.2
52.1
BM-003A
BM-003A
BM-004
BM-004A
BM-004B
BM-004C
BM-004D

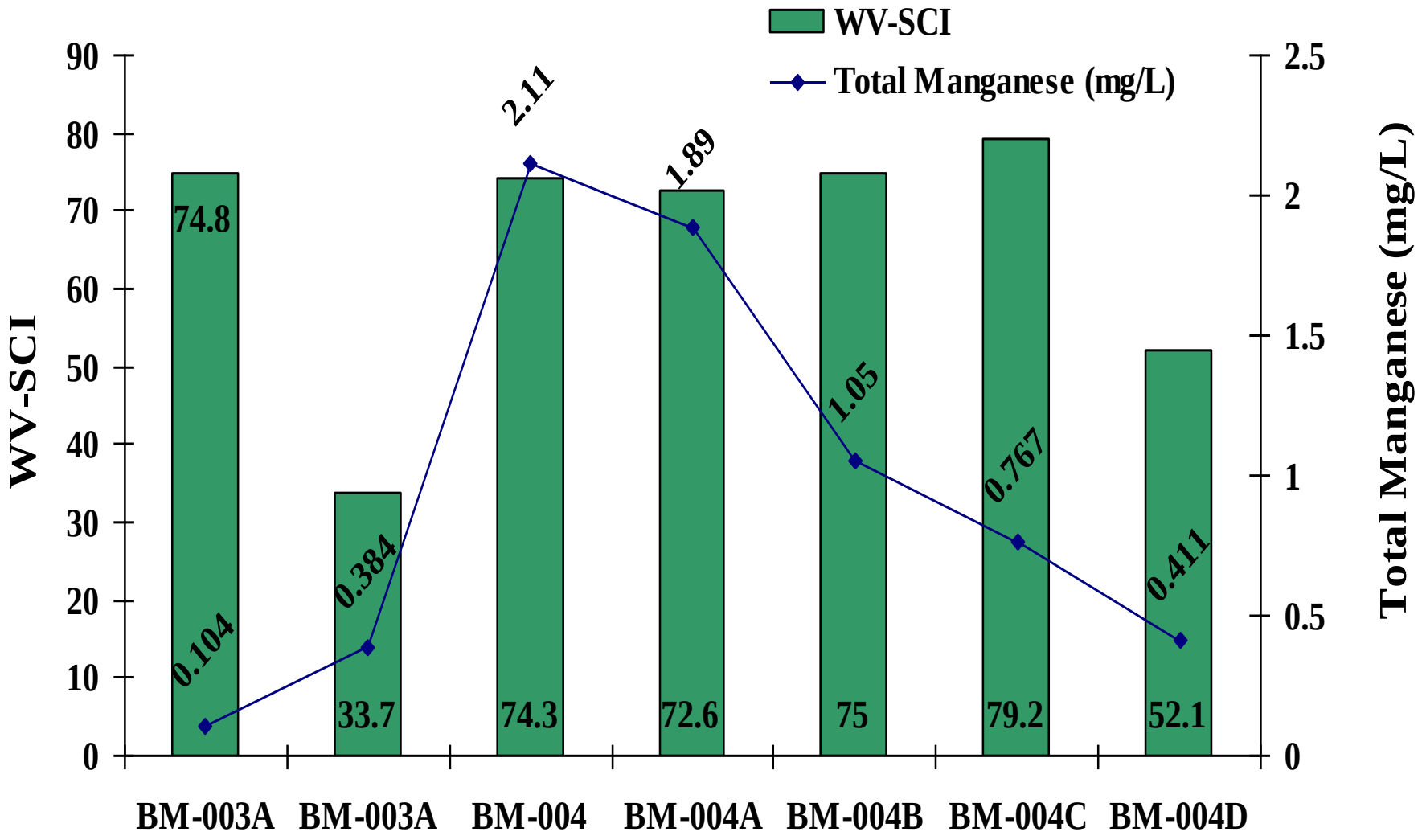

WV-SCI Scores vs Sulfate for
Stations on Kiah Creek Fall 2004
WV-SCI
Sulfate (mg/L)
WV-SCI
Sulfate (mg/L)
90
80
70
60
50
40
30
20
10
0
700
600
500
400
300
200
100
0
249
405
552
626
604
591
563
74.8
33.7
74.3
72.6
75
79.2
52.1
BM-003A
BM-003A
BM-004
BM-004A
BM-004B
BM-004C
BM-004D

WV-SCI Scores vs Dissolved Aluminum for Stations on Kiah Creek Fall 2004

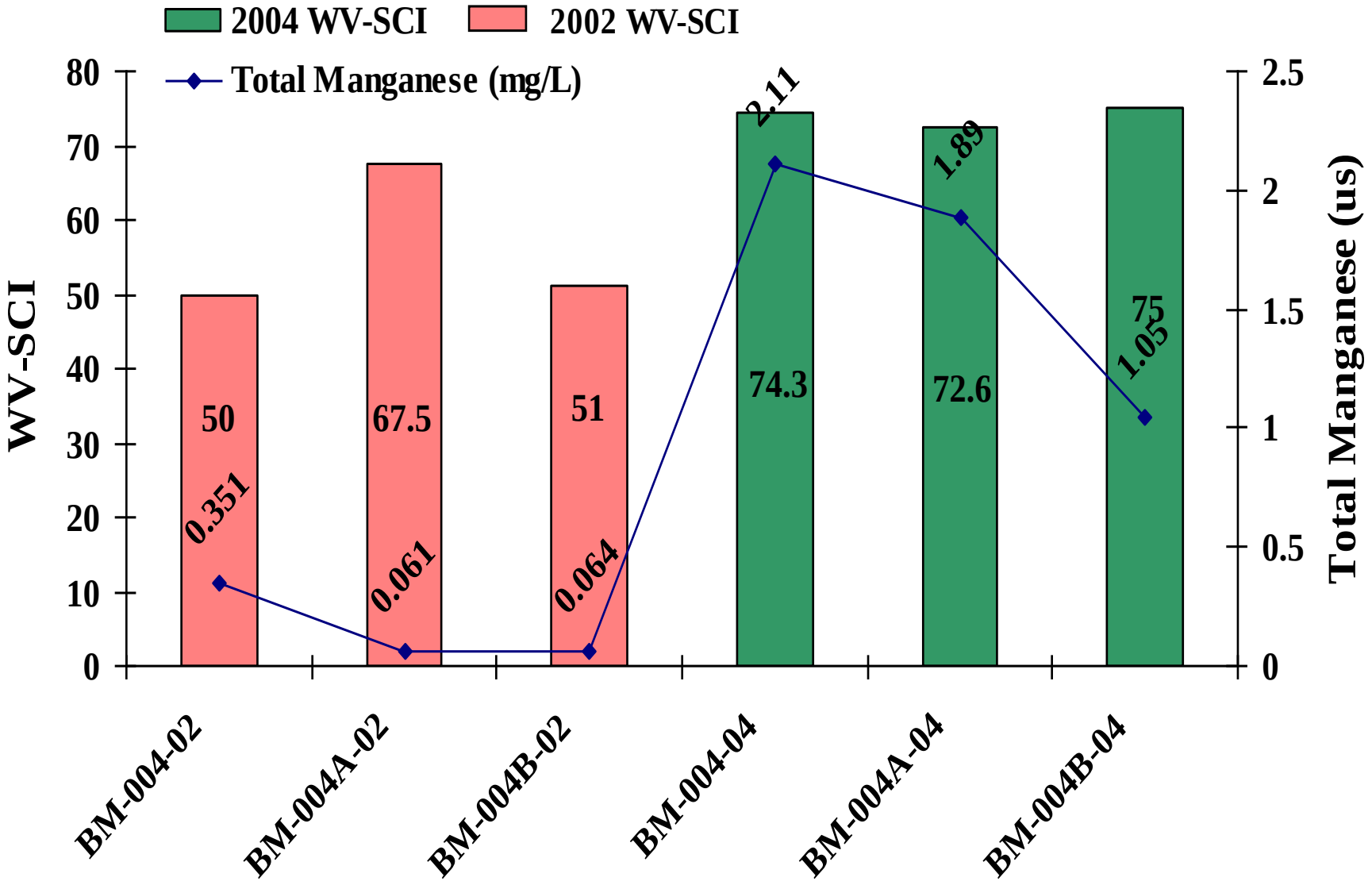


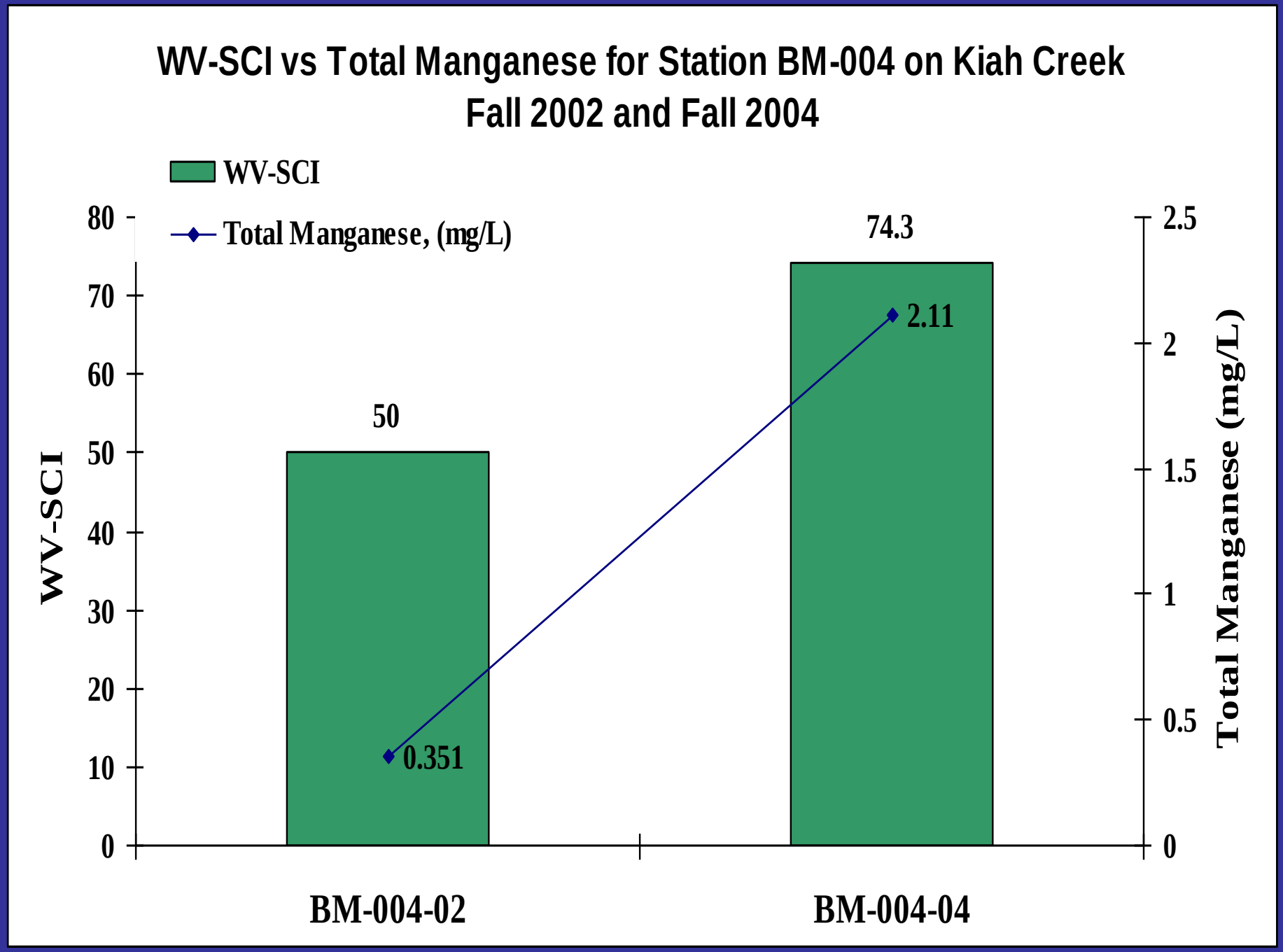

WV-SCI Scores vs Habitat for
Stations on Kiah Creek Fall 2004
WV-SCI
Habitat Scores
WV-SCI
Habitat Scores
0
10
20
30
40
50
60
70
80
90
0
20
40
60
80
100
120
140
160
180
170
136
145
160
161
152
117
74.8
33.7
74.3
72.6
75
79.2
52.1
BM-003A
BM-003A
BM-004
BM-004A
BM-004B
BM-004C
BM-004D

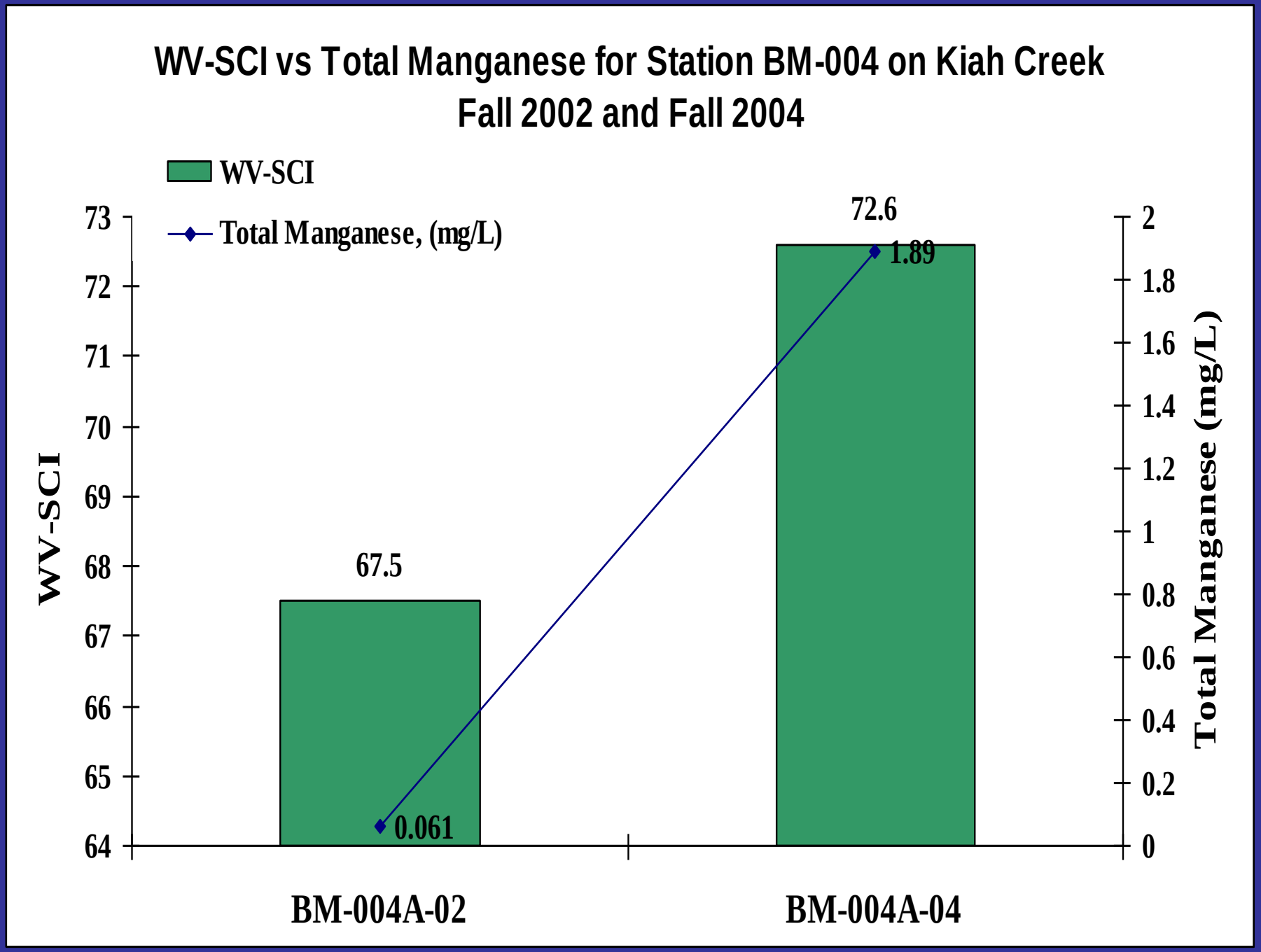
WV-SCI Scores vs Total Manganese for Stations on Kiah Creek Fall 2004

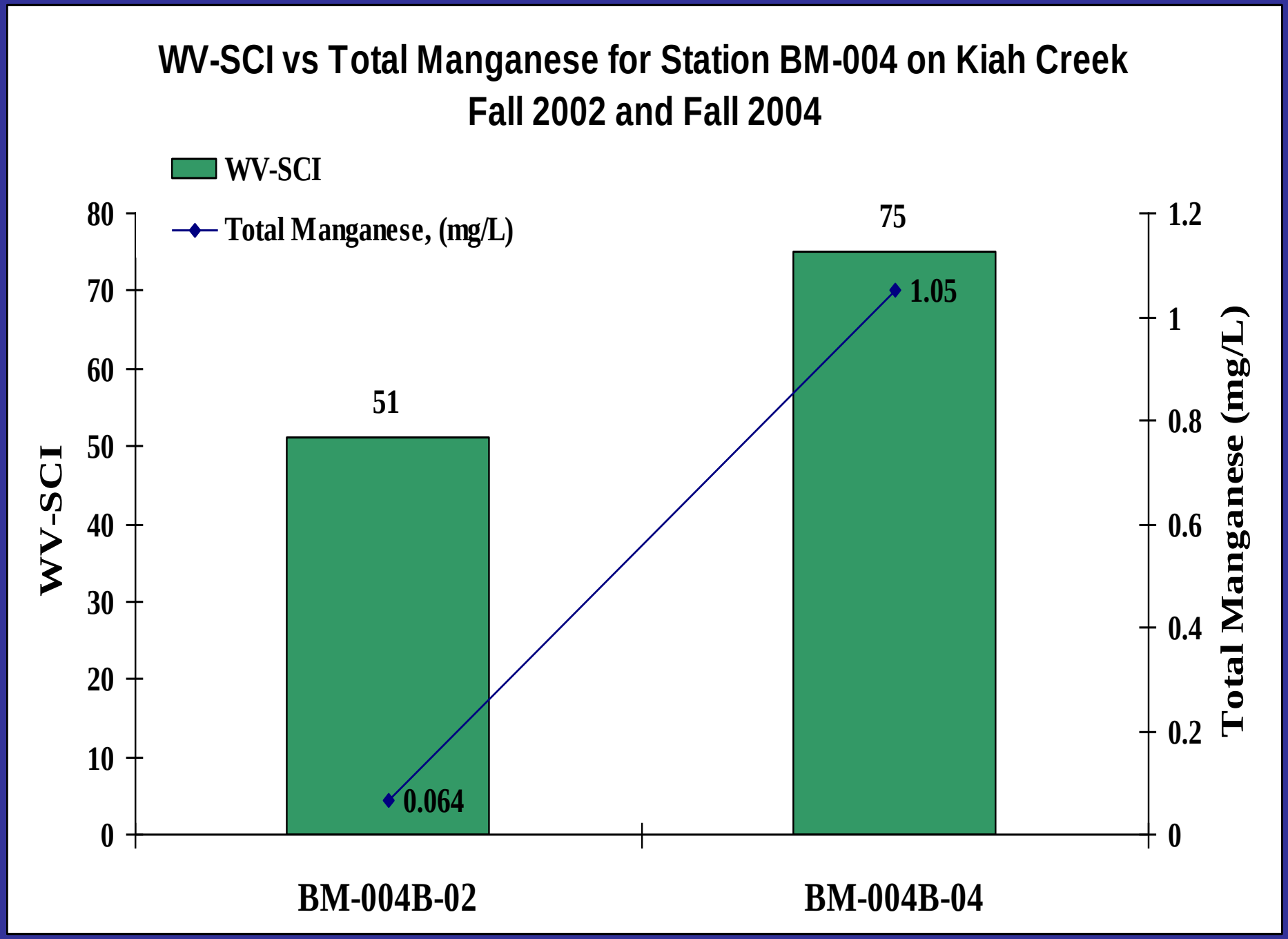


WV-SCI vs Total Manganese for Station BM-004 on Kiah Creek Fall 2002 and Fall 2004

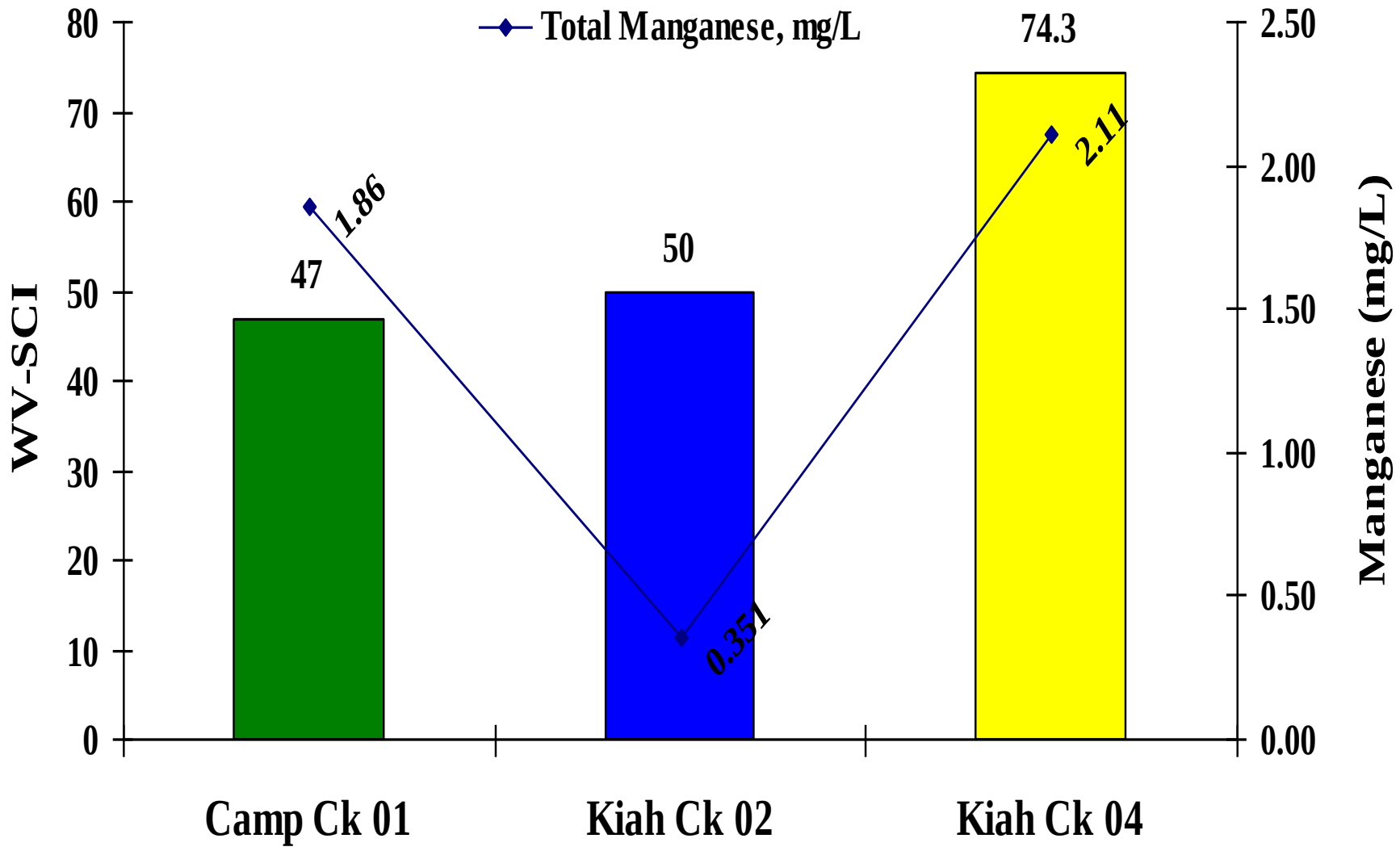



WV-SCI vs Total Manganese for Station BM-004 on Kiah Creek
Fall 2002 and Fall 2004
WV-SCI
Total Manganese, (mg/L)
80
70
60
50
40
30
20
10
0
WV-SCI
50
74.3
0.351
2.11
2.5
2
1.5
1
0.5
0
Total Manganese (mg/L)
BM-004-02
BM-004-04


WV-SCI vs Total Manganese for Station BM-004 on Kiah Creek
Fall 2002 and Fall 2004
WV-SCI
Total Manganese, (mg/L)
WV-SCI
Total Manganese (mg/L)
73
72
71
70
69
68
67
66
65
64
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
67.5
72.6
0.061
1.89
BM-004A-02
BM-004A-04


WV-SCI vs Total Manganese for Station BM-004 on Kiah Creek
Fall 2002 and Fall 2004
WV-SCI
Total Manganese, (mg/L)
WV-SCI
Total Manganese (mg/L)
80
70
60
50
40
30
20
10
0
1.2
1
0.8
0.6
0.4
0.2
0
51
75
0.064
1.05
BM-004B-02
BM-004B-04

WV-SCI vs Total Manganese



Conclusions

- **The strict regulation and treatment for Manganese appears to have negative effects on benthic macroinvertebrates.**
- **The water quality regulations for Manganese need to be revised as soon as possible to minimize adverse aquatic impacts.**

WV Case Study: Laurel Creek Treatment Sites

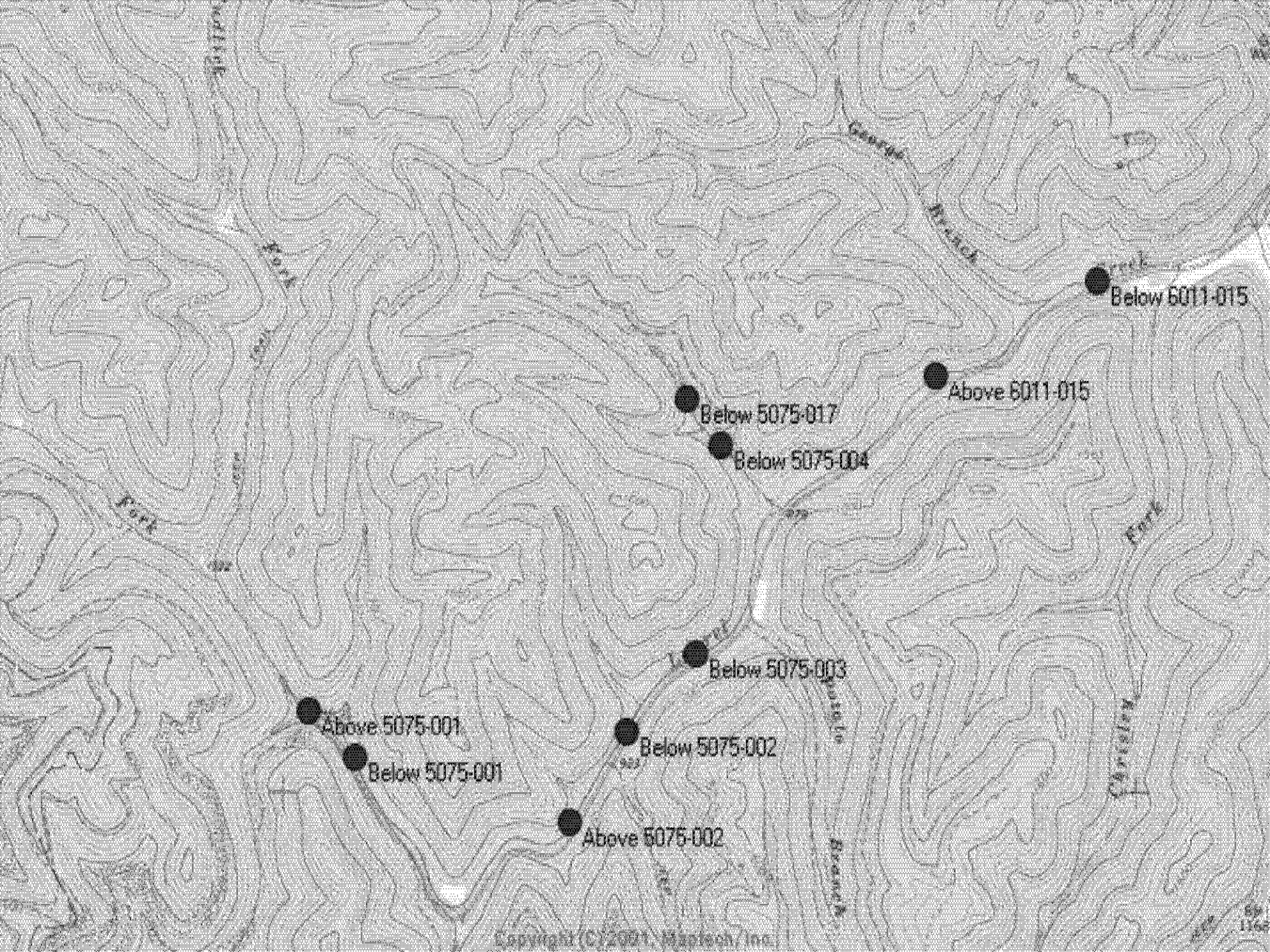
Ed J. Kirk, REI Consulting, Inc.
Tiff Hilton, WOPEC

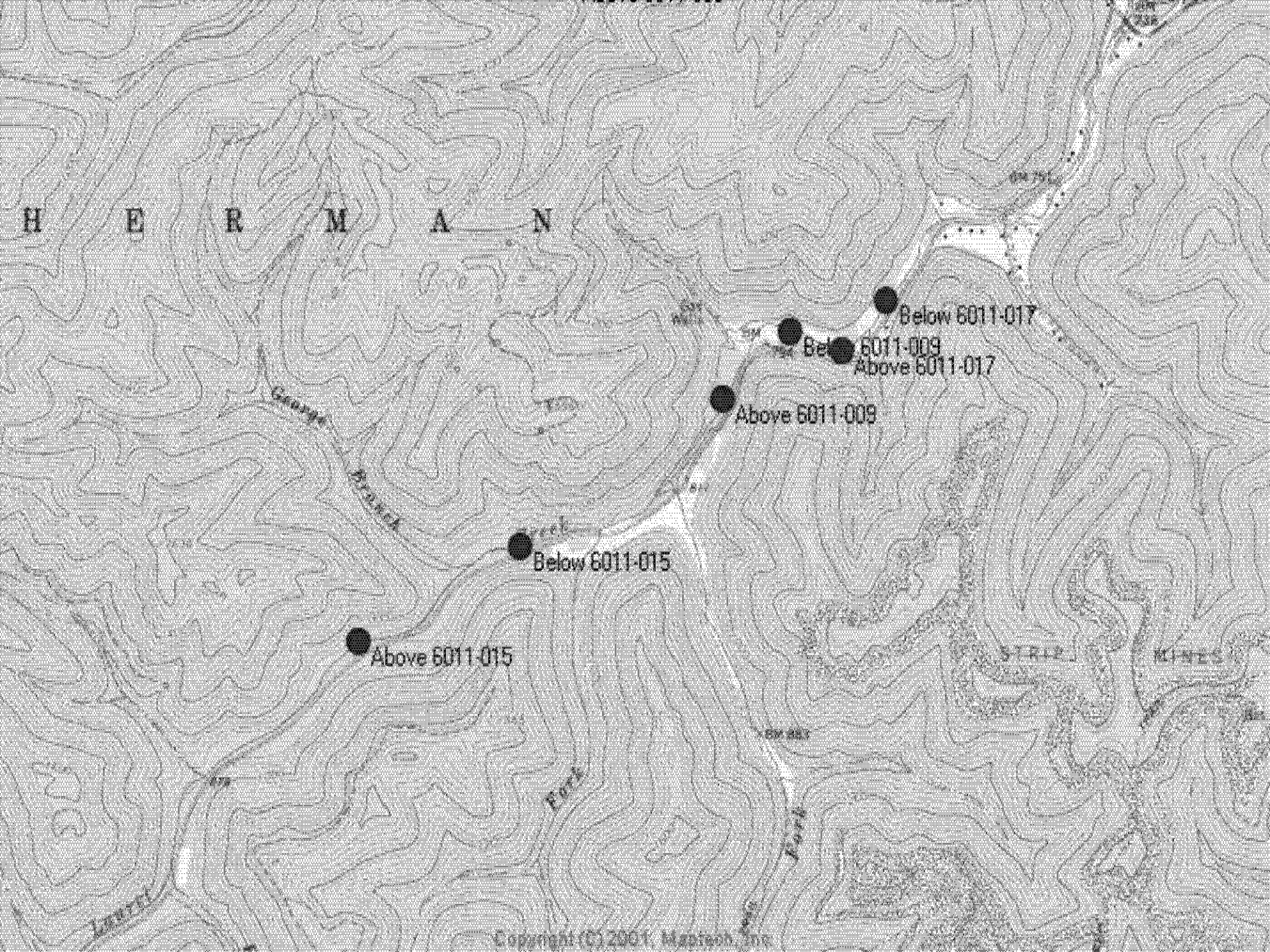
Objective:

- Study benthic communities in response to elevated levels of Mn, Mg, sulfates, conductivity, TDS.

H
B
Oh
Mar
Wetzel
Monong
Mario
Prest
Tyler
Pt
Harri
Tayl
Dod
Wood
Ritchi
Barbo
Tucker
Grant
Min
Hamps
Mo
Berk
Jef
Hardy
Wirt
Lewis
Jack
Cal
Gilm
Ups
Maso
Roan
Braxto
Randolp
Pendl
Putn
Clay
Webst
Cabel
Kanawha
Nicholas
Pocaho
Way
Lincol
Boone
Fayette
Greenbrier
Loga
Raleigh
Mi
Wyomi
Sq
Monro
McDowe
Mercer

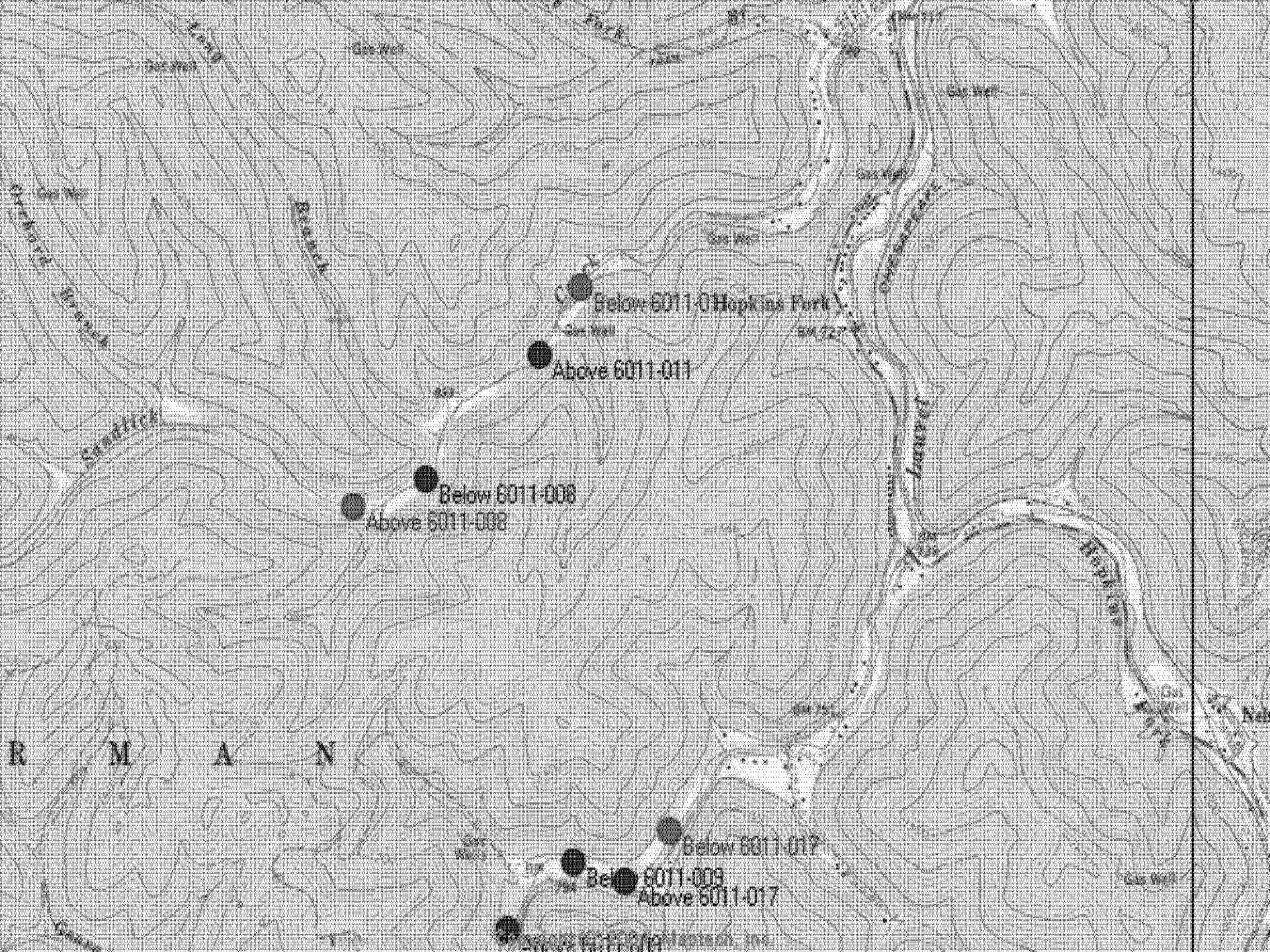
Below 6011-011
Hopkins Fork
Above 6011-011
Below 6011-008
Above 6011-008
Gas Well
Copyright (C) 2001, Maptech, Inc.


Below 6011-015
Above 6011-015
Below 5075-017
Below 5075-004
Below 5075-003
Above 5075-001
Below 5075-001
Below 5075-002
Above 5075-002
Copyright (C) 2001 Maptech, Inc.


H E R M A N
Below 6011-017
Below 6011-009
Above 6011-017
Above 6011-009
Below 6011-015
Above 6011-015
Copyright (C) 2001, Maptech, Inc.

Sandlick Creek Sites

- Outfall 6011-008 Above = “Upper SLC”
- Outfall 6011-011 Below = “Lower SLC”



Below 6011-01
Hopkins Fork
Above 6011-011
Below 6011-008
Above 6011-008
Below 6011-017
Below 6011-009
Above 6011-017
Gas Well
Sandlick
Branch
Orchard
Land
Hopkins
R M A N

Laurel Creek Sites

- Outfall 5075-002 Above = “Upper LC”
- Outfall 6011-008 Above = “Mid LC”
- Outfall 6011-017 Below = “Lower LC”

Below 6011-017
Below 6011-009
Above 6011-017
Above 6011-009
George Branch
Below 6011-015
Above 6011-015
Below 5075-017
Below 5075-004
Below 5075-003
Below 5075-002
Below 5075-001
Above 5075-002
Copyright (C) 2001, Maptech, Inc.

Sandlick & Laurel Creek Habitat

- Scores 154 – 175 out of 200
- Limited by “riparian zone widths”, “channel alterations”, some “deposition”.
- Water chemistry is considerably more limiting than habitat.

Water Chemistry

- Temperature, DO, pH, conductivity, flow, acidity, alkalinity, hardness, chloride, sulfates, TDS, TSS, total and dissolved aluminum, calcium, iron, manganese, magnesium, sodium, & fecal coliforms.

Upper Sandlick Creek

- pH 7.36 - 7.89
- Cond. 293 - 736
- Acidity < 2.0
- Alk 16 - 36
- Hard 126 - 327
- Sulfate 107 - 176
- TDS 194 - 274
- Tot. Al < 0.01
- Tot. Fe 0.01–0.02
- Tot. Mg 16 - 57
- Tot. Mn 0.01
- Diss. Mn 0.01

Lower Sandlick Creek

- pH 6.67 - 7.42
- Cond. 380 - 1198
- Acidity < 2.0
- Alk 22 - 34
- Hard 142 - 870
- Sulfate 161 - 466
- TDS 246 - 933
- Tot. Al < 0.01
- Tot. Fe < 0.01
- Tot. Mg 24 - 147
- Tot. Mn 0.3 – 1.2
- Diss. Mn 0.2 – 1.2

Upper Laurel Creek

- pH 7.41 - 7.77
- Cond. 764 - 1285
- Acidity < 2.0
- Alk 68 - 83
- Hard 355 - 1010
- Sulfate 252 - 470
- TDS 552 - 996
- Tot. Al <0.01- 0.63
- Tot. Fe 0.18 - 1.09
- Tot. Mg 51 - 167
- Tot. Mn 0.65 -1.89
- Diss. Mn 0.57-1.83

Mid Laurel Creek

- pH 7.32 - 7.89
- Cond. 961 - 1728
- Acidity < 2.0
- Alk 52 - 58
- Hard 408 - 1217
- Sulfate 333 - 876
- TDS 679 -1503
- Tot. Al <0.07- 0.35
- Tot. Fe 0.02 - 0.20
- Tot. Mg 58 - 190
- Tot. Mn 1.49- 3.78
- Diss. Mn 1.00-3.71

Lower Laurel Creek

- pH 7.02 - 7.98
- Cond. 736 - 1631
- Acidity < 2.0
- Alk 34 - 50
- Hard 321 - 1171
- Sulfate 257 - 766
- TDS 541 -1329
- Tot. Al 0.01 –0.21
- Tot. Fe 0.01 –0.06
- Tot. Mg 51 - 186
- Tot. Mn 0.80 -2.39
- Diss. Mn 0.78-2.34

Benthic Metrics

- Total Individuals
- Total Taxa
- % S, F, & T
- mHBI
- Ratio of Scrapers: Collector/Filterers
- EPT:Chiro ratio
- % Dominant Taxa
- EPT Index
- % Shredders
- Simpson's Diversity
- Shannon-Wiener Div.
- Shannon-Wiener Evenness
- WV-SCI

WV-SCI

- EPT Taxa
- Total Taxa
- % EPT
- % Chiro
- % Top 2 Taxa
- mHBI

- 78 –100 “Very Good”
- 68 – 78 “Good”
- 45 – 68 “Fair”
- 22 – 45 “Poor”
- 0 – 22 “Very Poor”

Upper Sandlick Creek

- Taxa Richness 29 - 34
- EPT Index 16 - 18
- % Mayflies 10.4 – 20.2%
- WV-SCI 74.2 - 87.7 “G - VG”

Lower Sandlick Creek

- Taxa Richness 16 - 24
- EPT Index 6 - 14
- % Mayflies 0.0 - 13.1%
- WV-SCI 64.4 - 81.4 “F - VG”

Upper Laurel Creek

- Taxa Richness 15 - 17
- EPT Index 5 - 11
- % Mayflies 0.0 - 14.7%
- WV-SCI 37.9 - 68.0 “Poor - Good”

Mid Laurel Creek

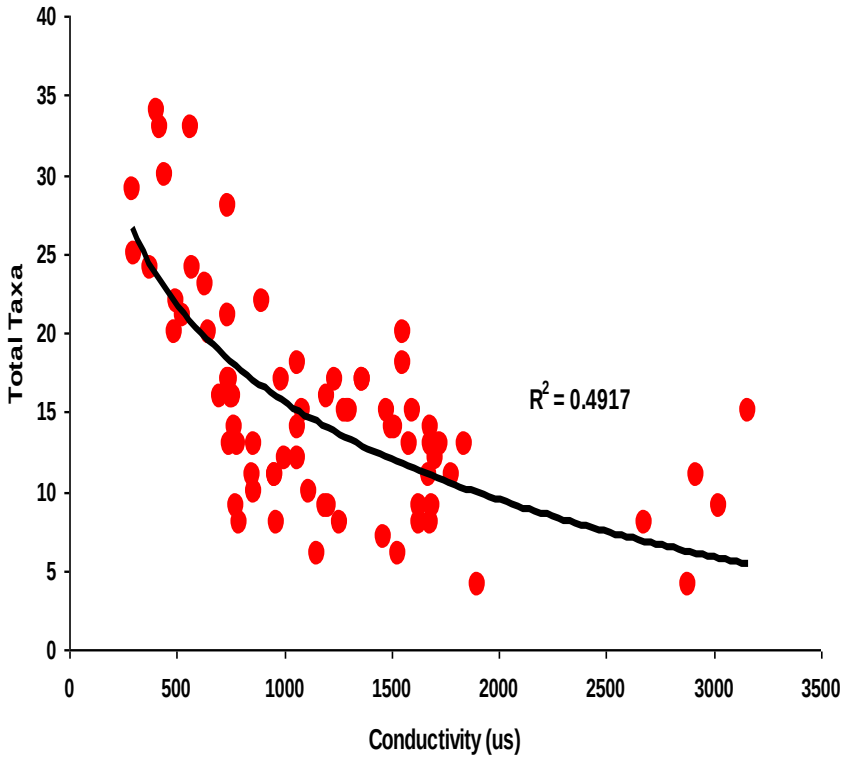
- Taxa Richness 6 - 13
- EPT Index 2 - 5
- % Mayflies 0.0 - 17.3%
- WV-SCI 17.7 - 61.9 “VP - F”

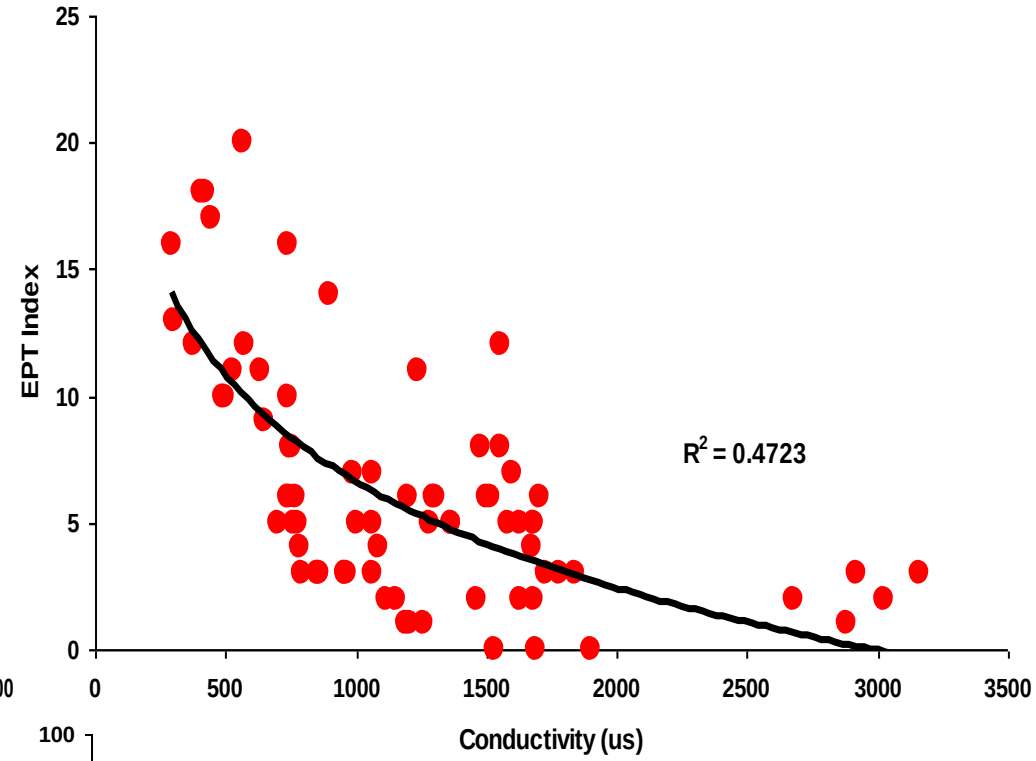
Lower Laurel Creek

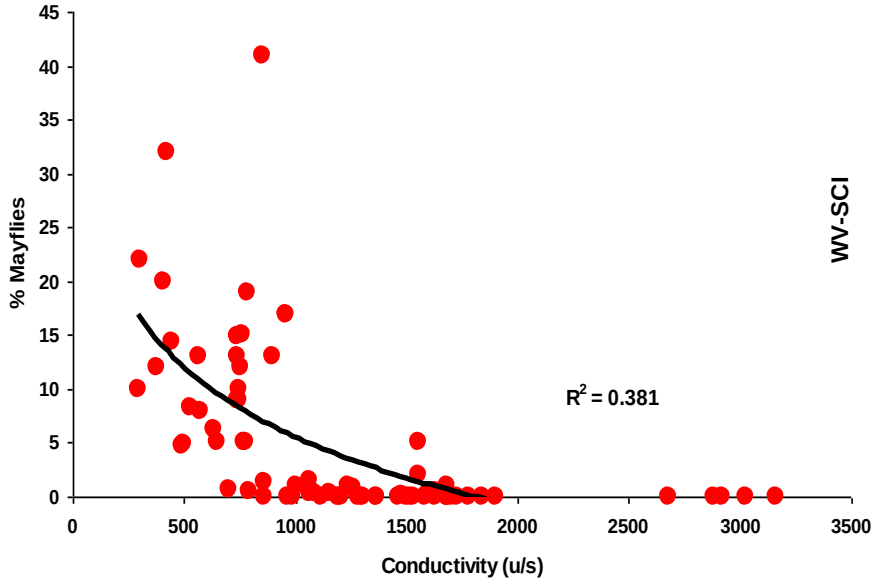
- Taxa Richness 9 - 20
- EPT Index 3 - 12
- % Mayflies 0.3 - 12.8%
- WV-SCI 25.8 - 75.9 “P - G”

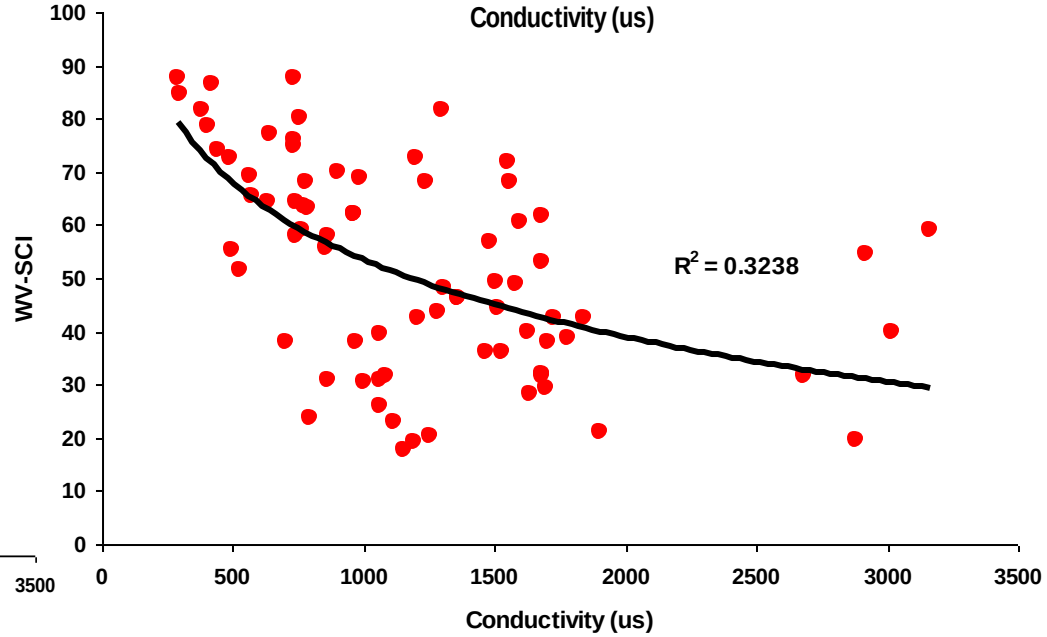
Comparisons

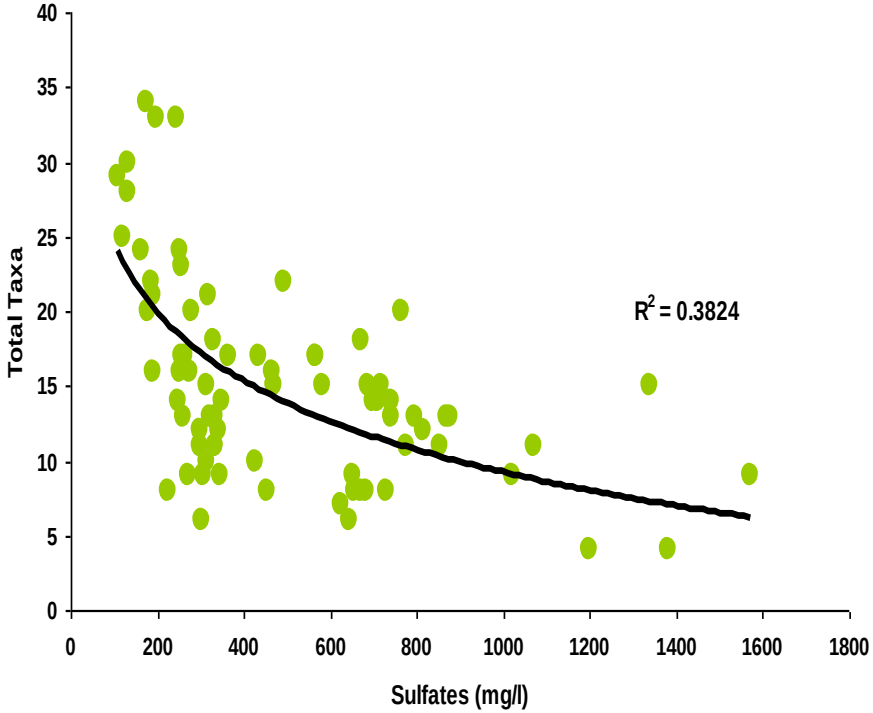
- Conductivity
- Sulfates
- Magnesium
- Aluminum
- Manganese
- Total Taxa
- EPT Taxa
- % Mayflies
- WV-SCI

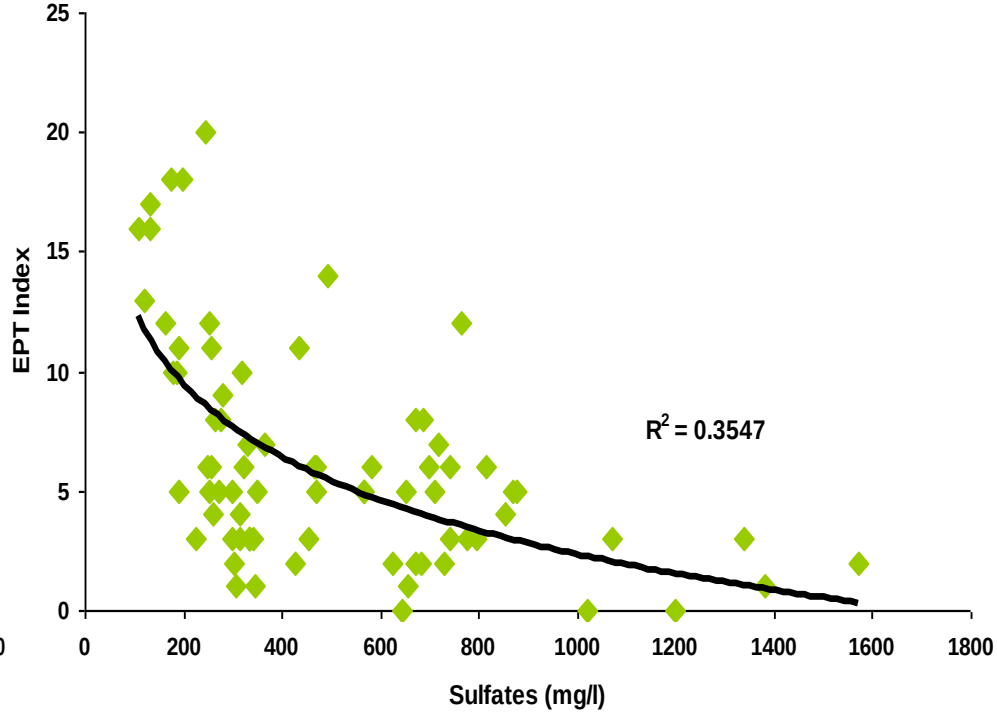

Total Taxa
Conductivity (us)
$R^2 = 0.4917$
0
5
10
15
20
25
30
35
40
0
500
1000
1500
2000
2500
3000
3500

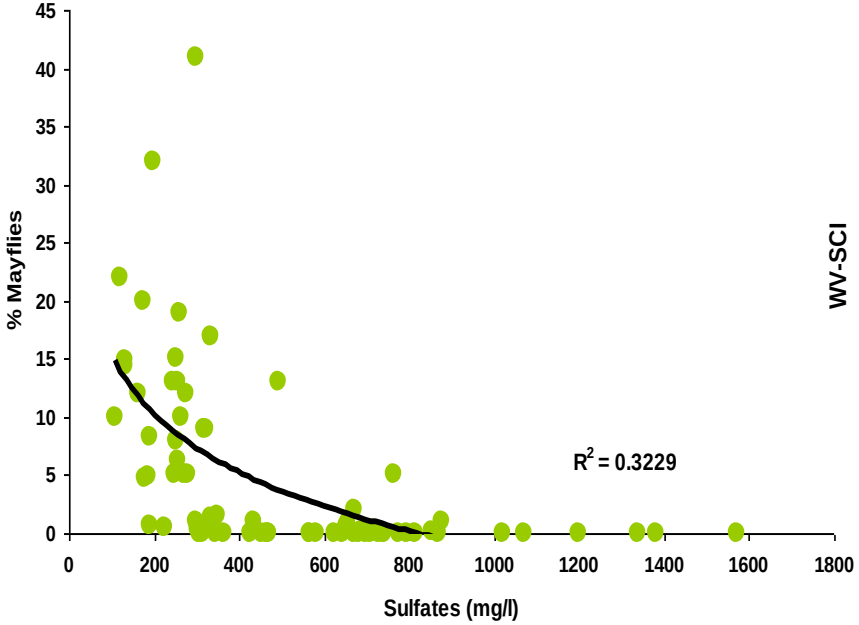

EPT Index
Conductivity (us)
$R^2 = 0.4723$
0
5
10
15
20
25
0
500
1000
1500
2000
2500
3000
3500

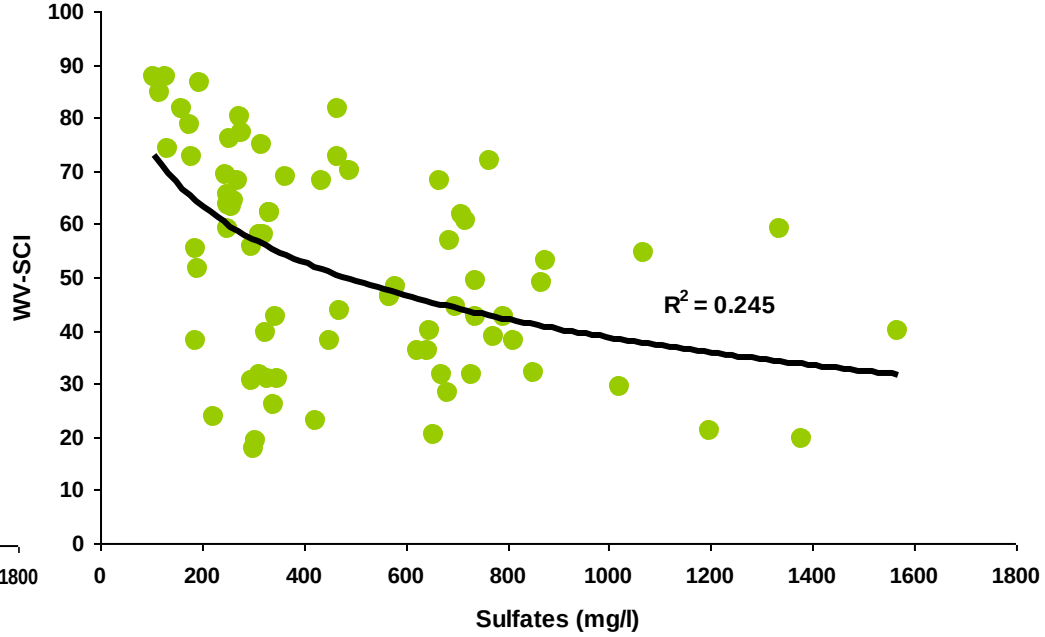

% Mayflies
Conductivity (u/s)
$R^2 = 0.381$
0
5
10
15
20
25
30
35
40
45
0
500
1000
1500
2000
2500
3000
3500

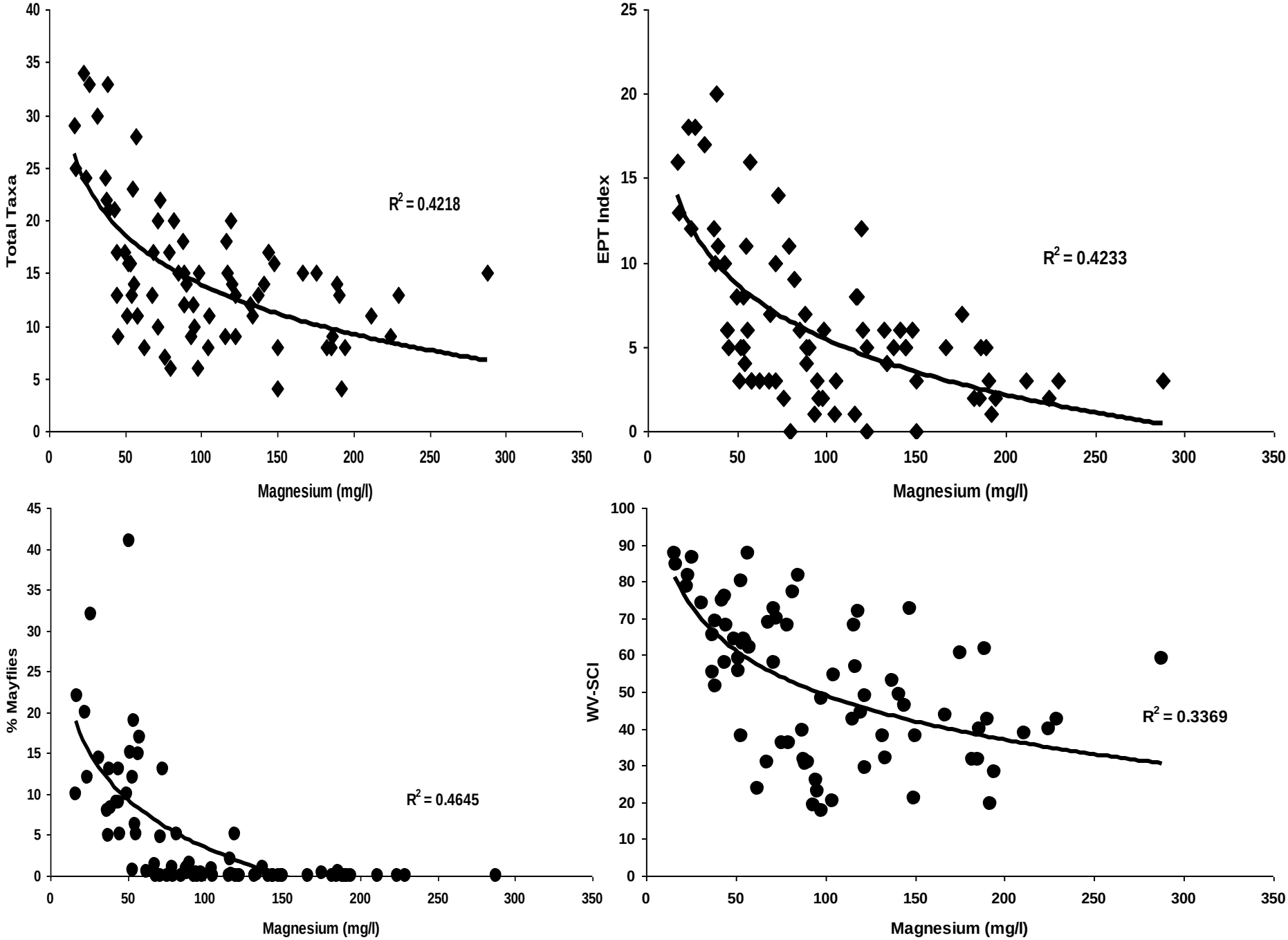

WV-SCI
Conductivity (us)
$R^2 = 0.3238$
0
10
20
30
40
50
60
70
80
90
100
0
500
1000
1500
2000
2500
3000
3500

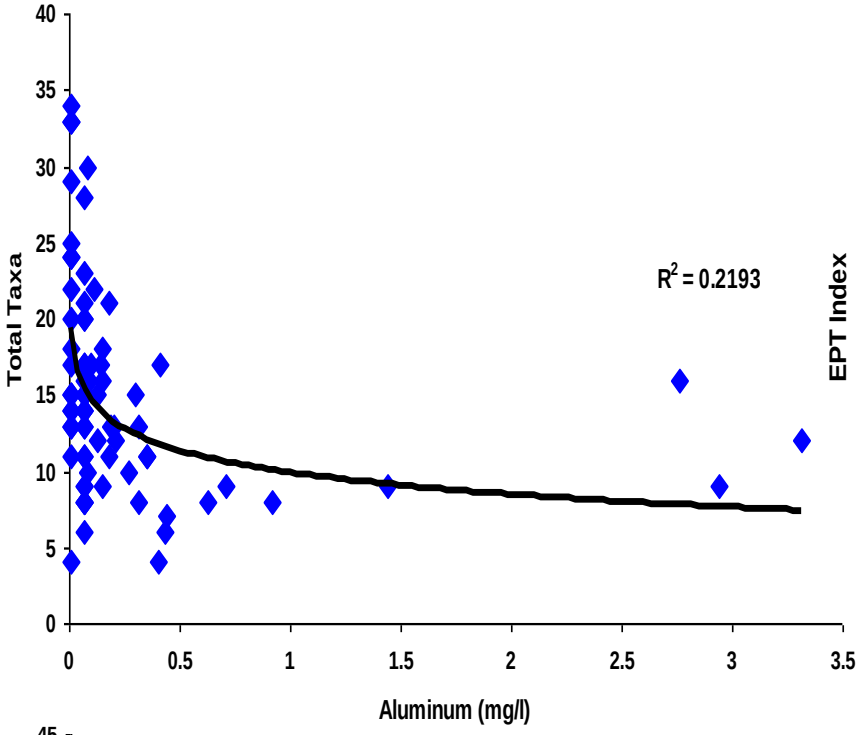

Total Taxa
Sulfates (mg/l)
$R^2 = 0.3824$
0
5
10
15
20
25
30
35
40
0
200
400
600
800
1000
1200
1400
1600
1800

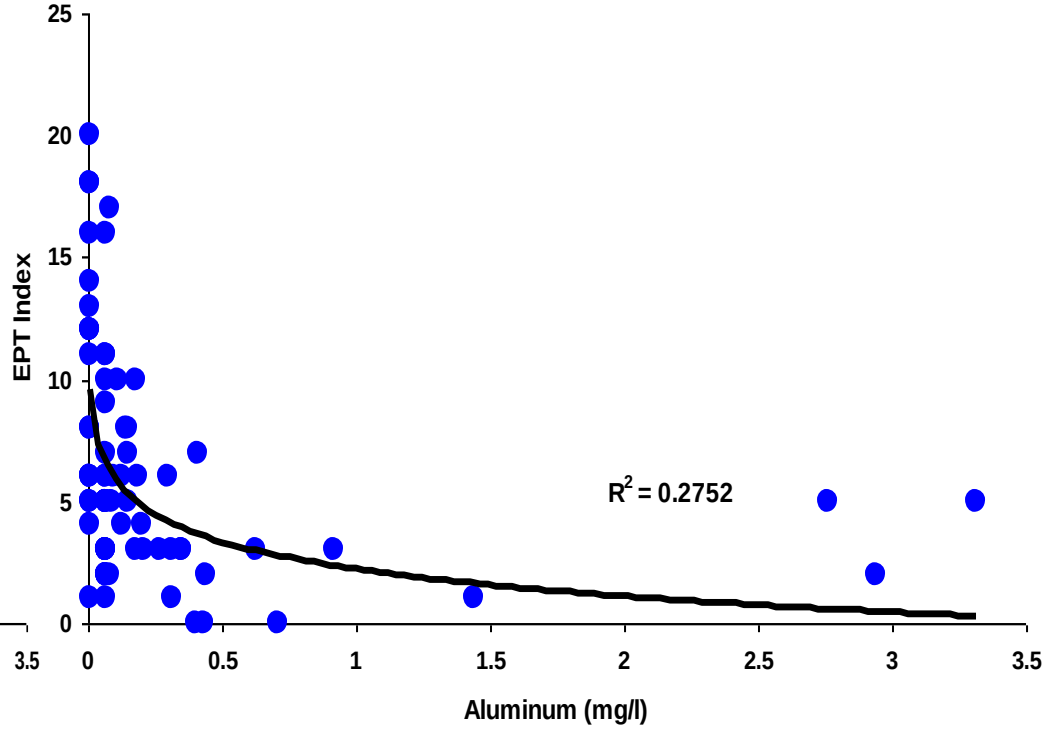

EPT Index
Sulfates (mg/l)
$R^2 = 0.3547$
0
5
10
15
20
25
0
200
400
600
800
1000
1200
1400
1600
1800

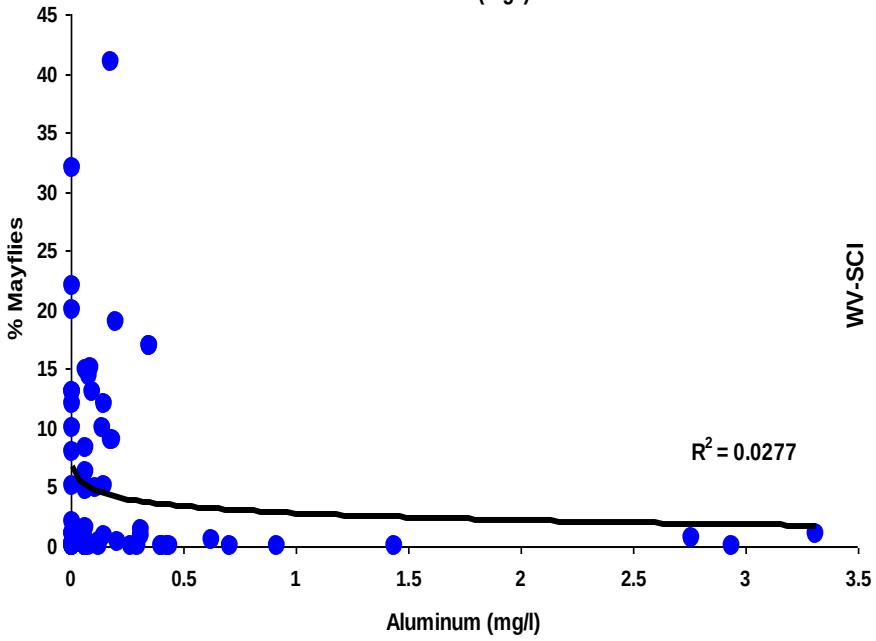

% Mayflies
Sulfates (mg/l)
$R^2 = 0.3229$
0
5
10
15
20
25
30
35
40
45
0
200
400
600
800
1000
1200
1400
1600
1800

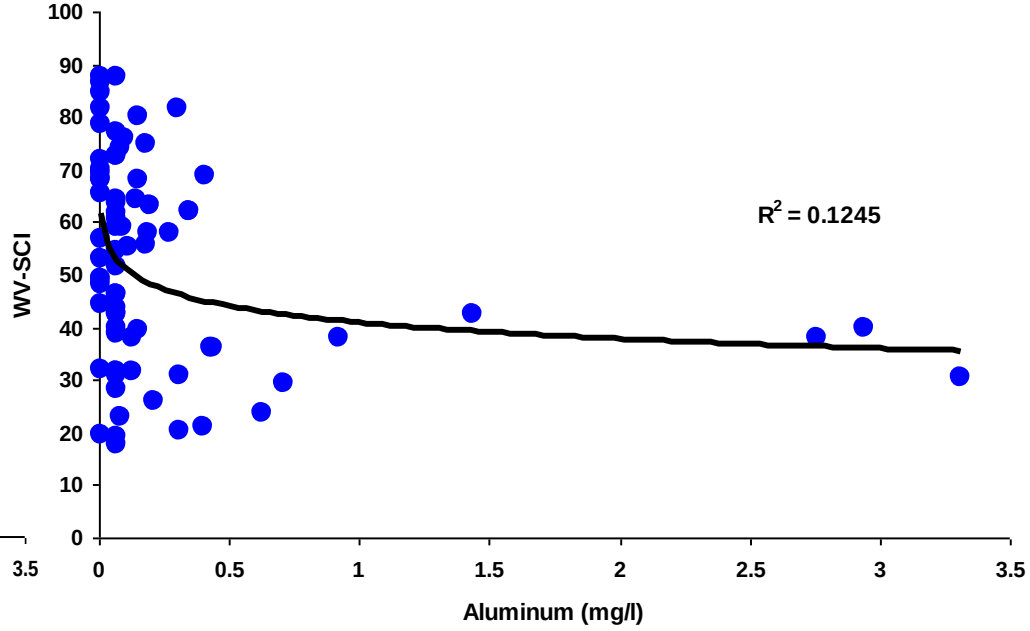

WV-SCI
Sulfates (mg/l)
$R^2 = 0.245$
0
10
20
30
40
50
60
70
80
90
100
0
200
400
600
800
1000
1200
1400
1600
1800

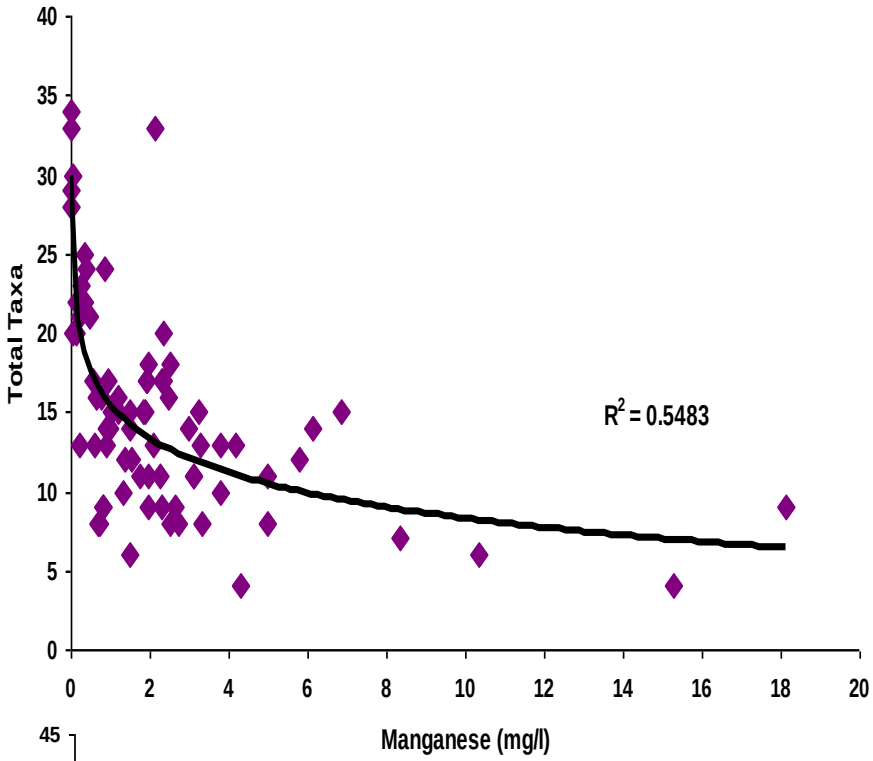

Total Taxa
Magnesium (mg/l)
$R^2 = 0.4218$
EPT Index
Magnesium (mg/l)
$R^2 = 0.4233$
% Mayflies
Magnesium (mg/l)
$R^2 = 0.4645$
WV-SCI
Magnesium (mg/l)
$R^2 = 0.3369$

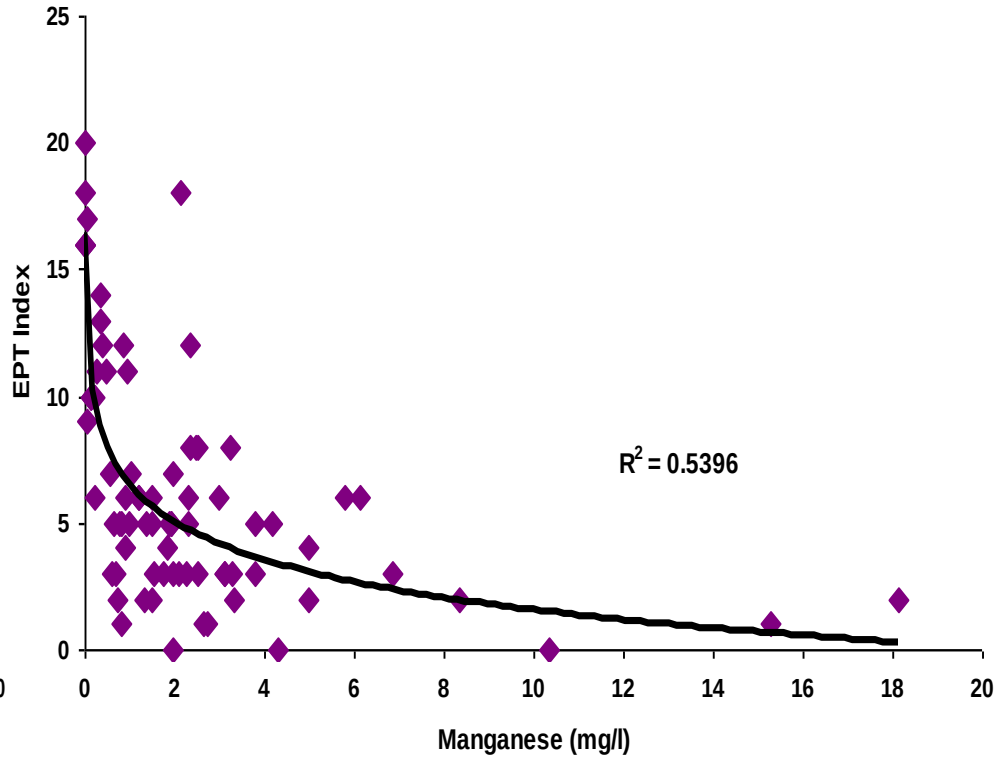

Total Taxa
Aluminum (mg/l)
$R^2 = 0.2193$
0
5
10
15
20
25
30
35
40
0
0.5
1
1.5
2
2.5
3
3.5

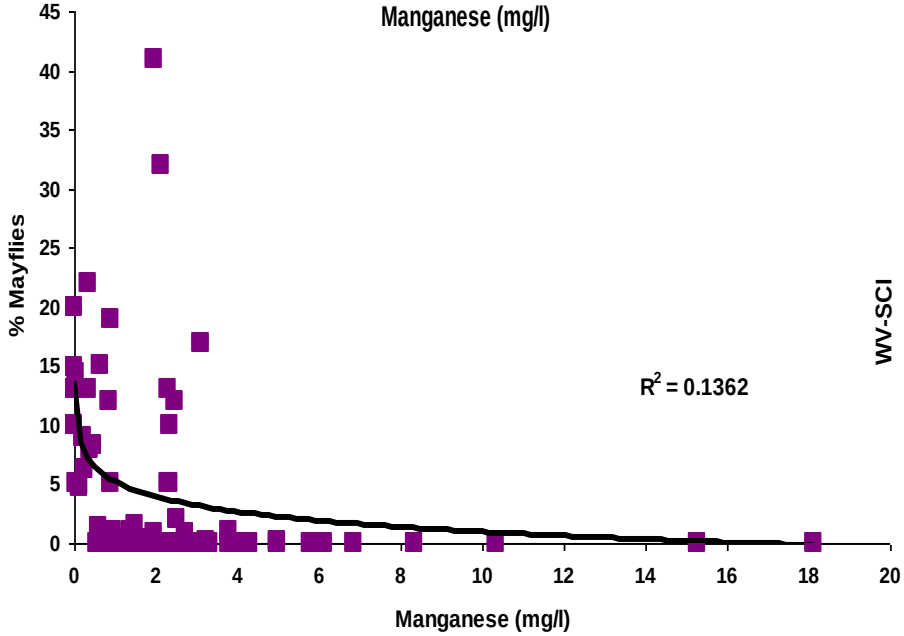

EPT Index
Aluminum (mg/l)
$R^2 = 0.2752$
0
5
10
15
20
25
0
0.5
1
1.5
2
2.5
3
3.5

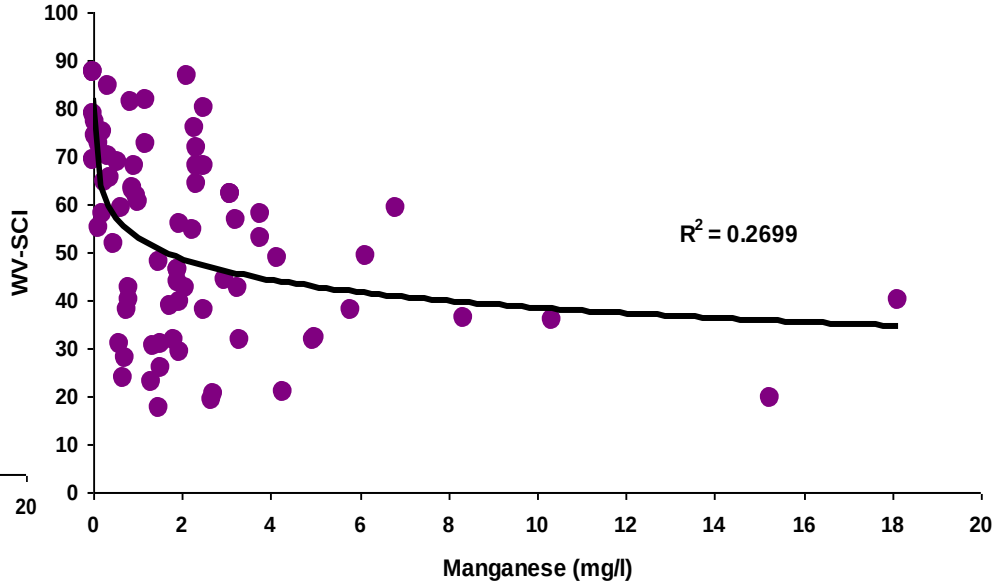

% Mayflies
Aluminum (mg/l)
$R^2 = 0.0277$
0
5
10
15
20
25
30
35
40
45
0
0.5
1
1.5
2
2.5
3
3.5


WV-SCI
Aluminum (mg/l)
$R^2 = 0.1245$
0
10
20
30
40
50
60
70
80
90
100
0
0.5
1
1.5
2
2.5
3
3.5


Total Taxa
Manganese (mg/l)
$R^2 = 0.5483$


EPT Index
Manganese (mg/l)
$R^2 = 0.5396$


% Mayflies
Manganese (mg/l)
$R^2 = 0.1362$


WV-SCI
Manganese (mg/l)
$R^2 = 0.2699$

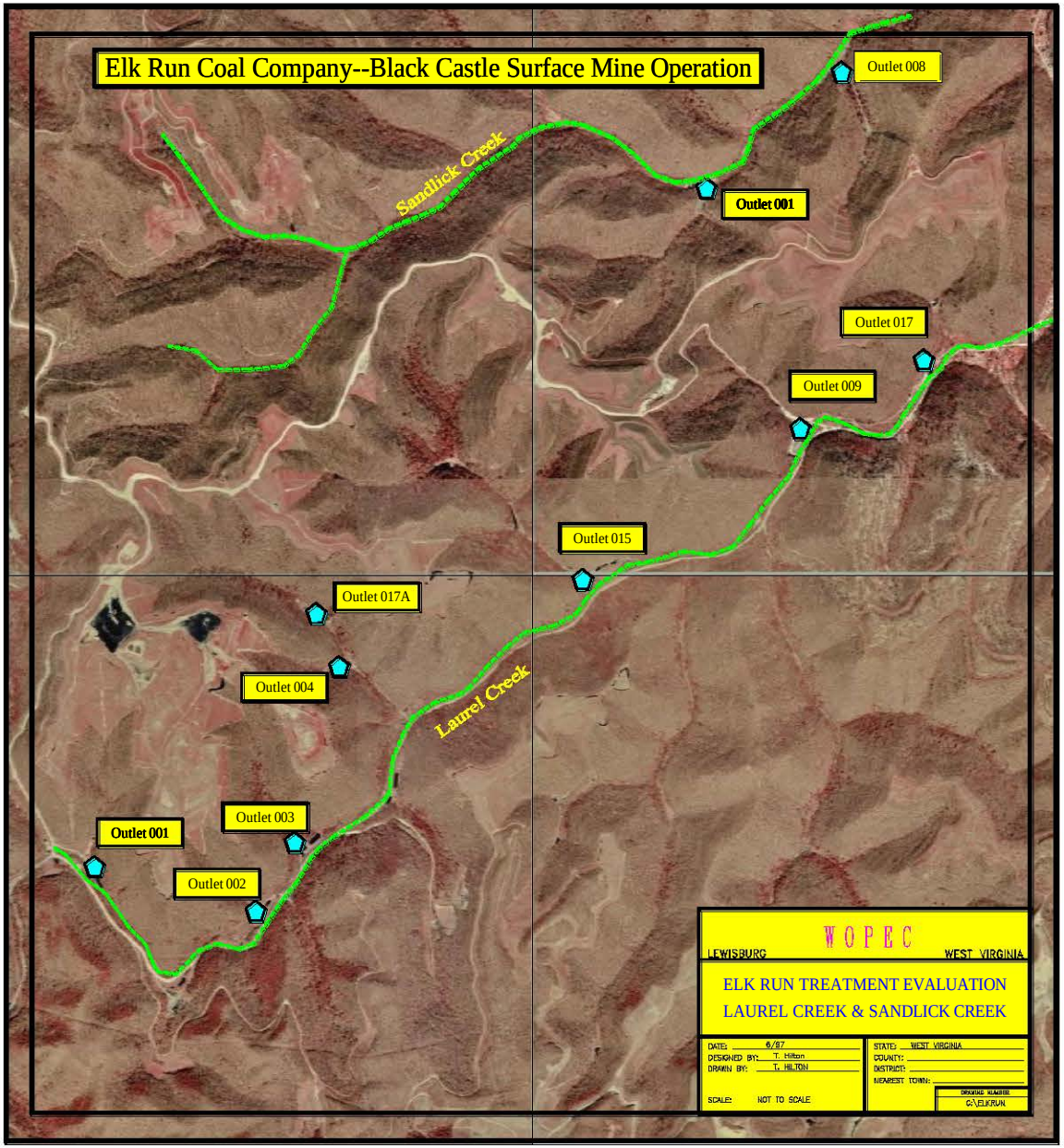
Important Last Point

- Hard to separate out relationships between benthic responses to individual water quality constituents when several are at elevated levels. Ex.: streams with higher levels of Mn also contained higher levels of conductivity, sulfates, magnesium, etc.

Acknowledgements

- Danny Cox of Massey Energy Company
- Tiff Hilton II (WOPEC)

ELK RUN COAL COMPANY MN TREATMENT EVALUATION



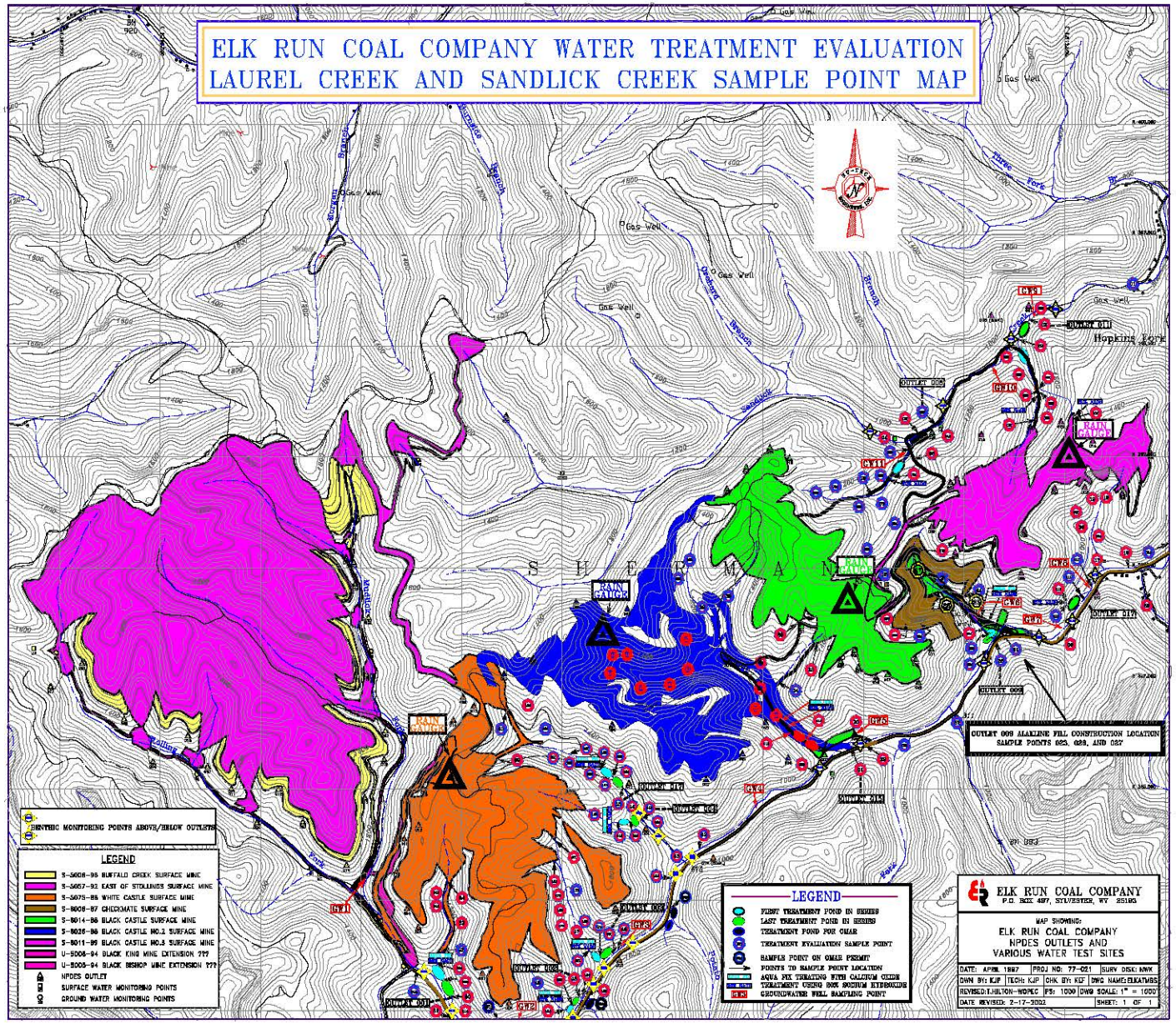
ELK RUN COAL COMPANY—BLACK CASTLE SURFACE MINE

BLACK CASTLE CAO/NAOH TREATMENT SYSTEM

BLACK CASTLE MN TREATMENT SETTLING POND

BLACK CASTLE ALUMINUM RESOLUBILIZATION

ELK RUN COAL COMPANY WATER TREATMENT EVALUATION
LAUREL CREEK AND SANDLICK CREEK SAMPLE POINT MAP



ELK RUN COAL CO. INCREMENTAL MANGANESE REDUCTION STUDY

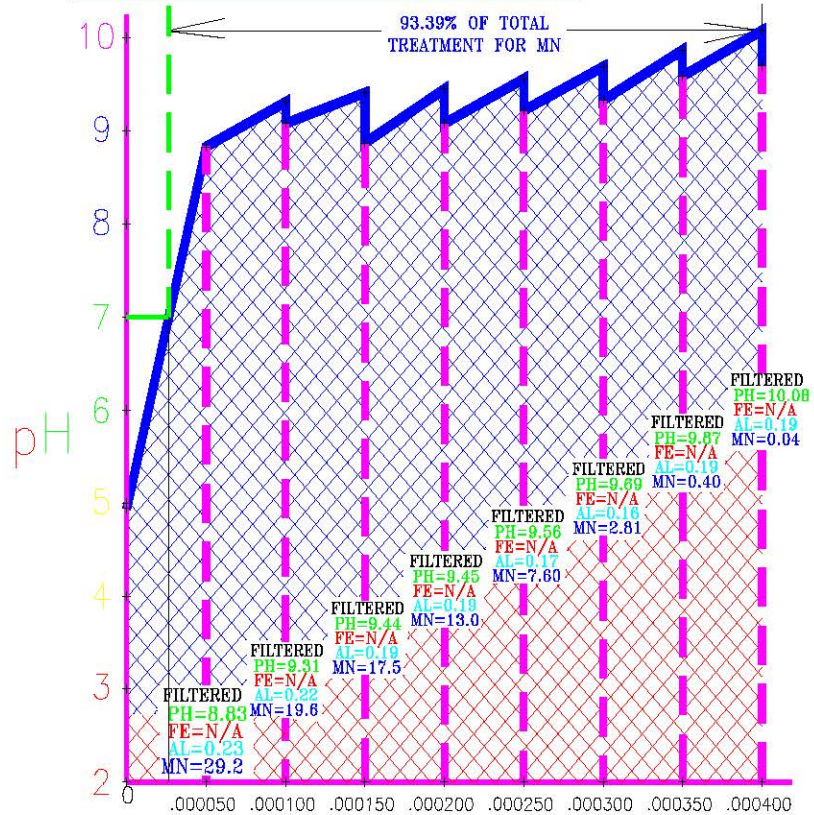
ARTICLE III PERMIT S-5075-92 WVNPDES PERMIT WV1013441

SITE 002-- TOTAL TITRATION

NOTE: MG/L READINGS WERE OBTAINED BY FILTERING AT THE LISTED PH POINTS TO DETERMINE MG/L STILL IN SOLUTION

INDIVIDUAL PRECIPITATION POINTS

pH	Fe	Al	Mn
10.08	N/A	0.19	0.04
9.87	N/A	0.19	0.40
9.69	N/A	0.16	2.81
9.56	N/A	0.17	7.60
9.45	N/A	0.19	13.00
9.44	N/A	0.19	17.50
9.31	N/A	0.22	19.60
8.83	N/A	0.23	29.20
4.94	0.09	1.18	31.30



TITRATION CURVE BY WOPEC

GALLONS OF 20% SODIUM HYDROXIDE PER GALLON OF RAW WATER

FINAL PH UPON COMPLETE PRECIPITATION = 8.80

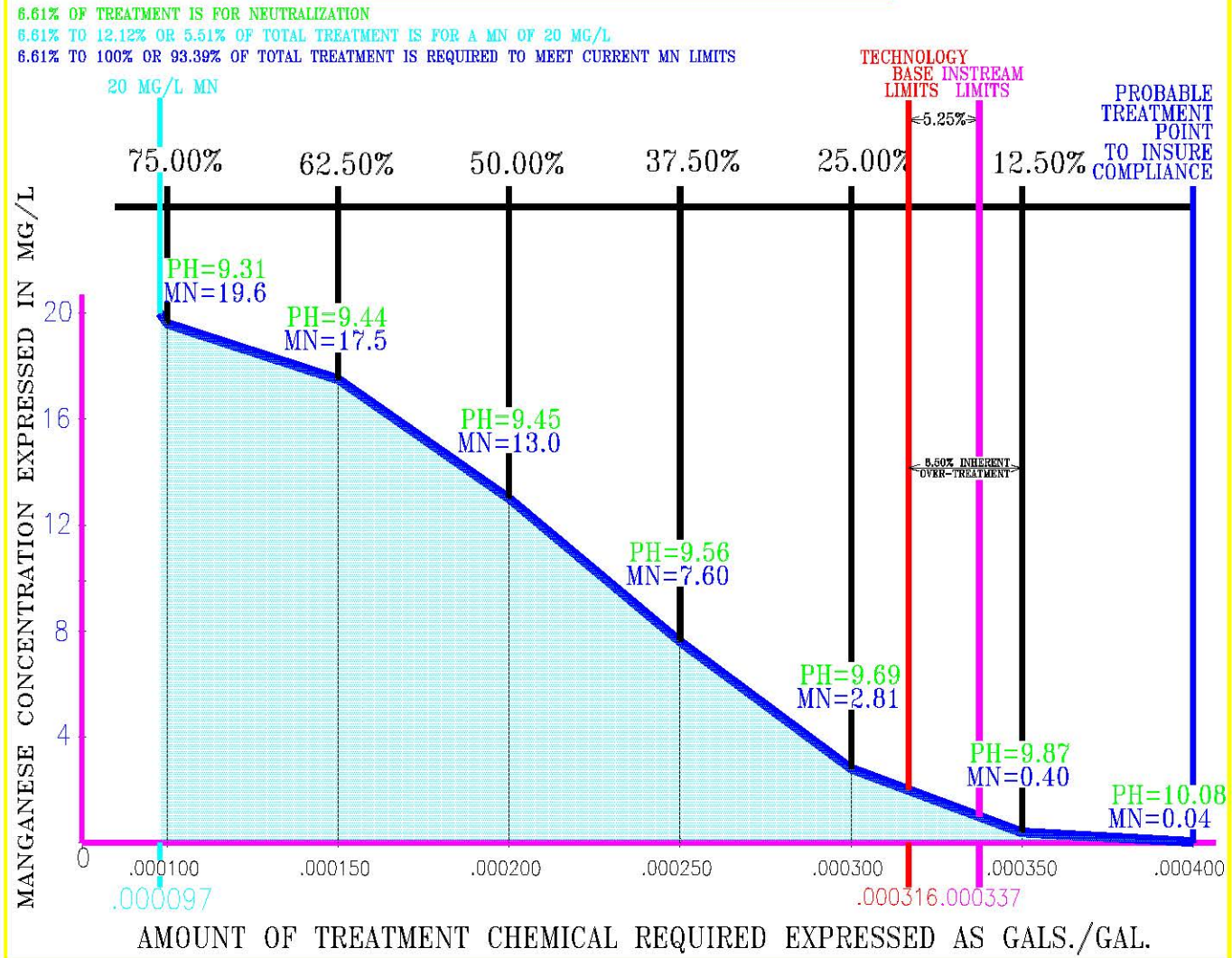
METAL	FERRIC IRON	FERROUS IRON	ALUMINUM	MANGANESE	FINAL PH=8.80
REMOVAL PH	N/A	N/A	9.56-9.69	9.87-10.08	FINAL MN=0.20
INFORMATION FOR CURVE PROVIDED BY: WOPEC TITRATION TEST					SLUDGE=40ML

THIS GRAPH REPRESENTS AN ACTUAL TITRATION TEST ON A SAMPLE OF ACID MINE DRAINAGE OBTAINED FROM ELK RUN, SITE NO.002. RESULTS WILL VARY WITH CHANGES IN WATER QUALITY DUE TO A CHANGE IN SURFACE AND GROUNDWATER FLOWS (QUANTITY AND QUALITY).

ELK RUN COAL CO. INCREMENTAL MANGANESE REDUCTION STUDY

ARTICLE III PERMIT S-5075-92 WVNPDES PERMIT WV1013441

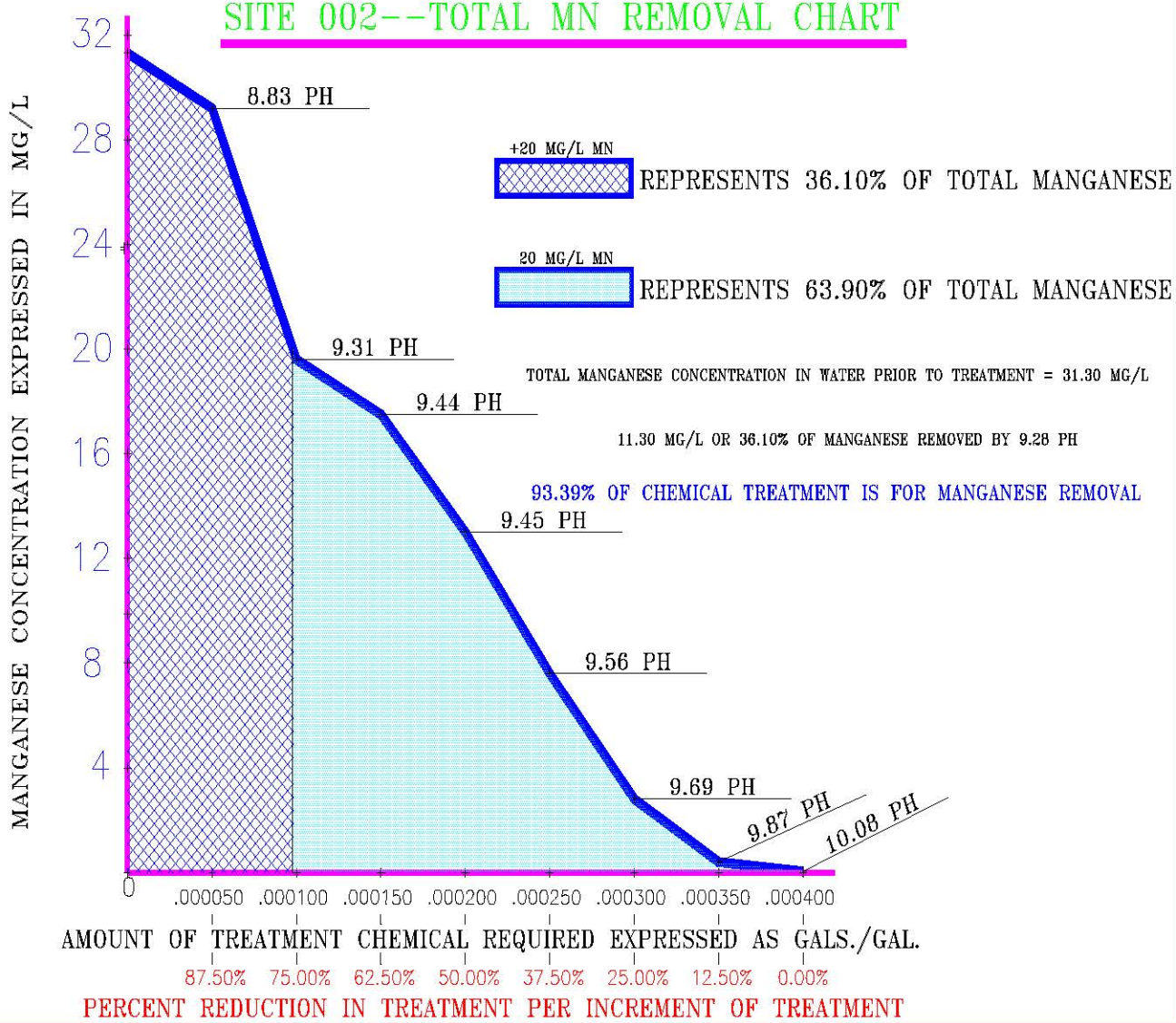
SITE 002--FINAL 20 MG/L MN



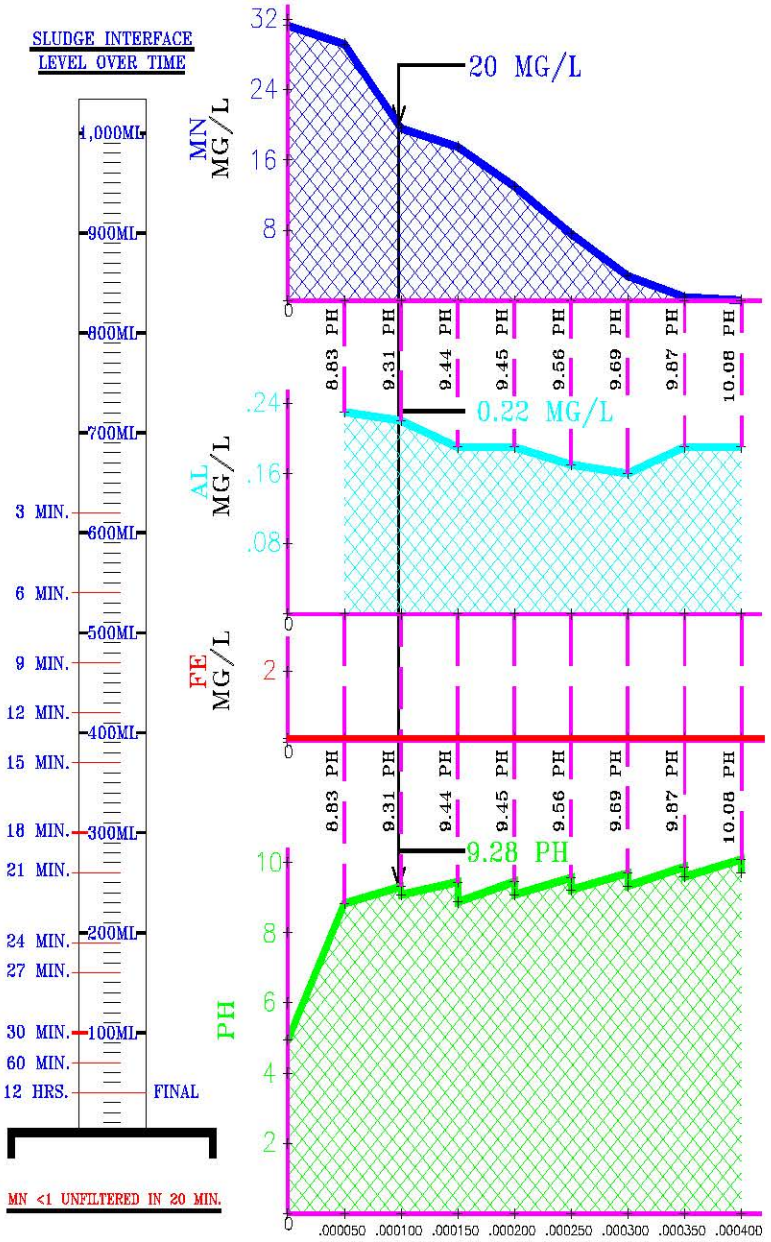
ELK RUN COAL CO. INCREMENTAL MANGANESE REDUCTION STUDY

ARTICLE III PERMIT S-5075-92 WVNPDES PERMIT WV1013441

SITE 002--TOTAL MN REMOVAL CHART



ELK RUN COAL CO. INCREMENTAL MANGANESE REDUCTION STUDY ARTICLE III PERMIT S-5075-92-SITE 002--TOTAL TITRATION



BATCH TITRATION RESULTS

TYPE OF TITRATION	CHEMICAL AMOUNT	PH	MANGANESE
INCREMENTAL	.000400 GAL/GAL	10.08	0.04 MG/L
BATCH	.000400 GAL/GAL	9.48	10.00 MG/L

CONCLUSION: AERATION DOES ASSIST IN THE TREATMENT OF THIS PARTICULAR WATER BY OXIDATION OF VARIOUS INTERMEDIATE METALS.

INDIVIDUAL PRECIPITATION POINTS

pH	Fe	Al	Mn
10.08	N/A	0.19	0.04
9.87	N/A	0.19	0.40
9.69	N/A	0.16	2.81
9.56	N/A	0.17	7.60
9.45	N/A	0.19	13.00
9.44	N/A	0.19	17.50
9.31	N/A	0.22	19.60
8.83	N/A	0.23	29.20
4.94	0.09	1.18	31.30

ELK RUN COAL COMPANY
MANGANESE LOADING INFORMATION
SITE 5075-002--SAMPLE POINT NO.49

MANGANESE (MG/L)		FLOW (GPM)
38.70		4.48
48.00		14.00
55.70		26.00
58.70		37.00
60.60		41.00
69.60		50.00
69.90		60.00
73.60		75.00
74.62		88.00
88.69		100.00
91.60		125.00
100.62		125.00

GENERAL INFORMATION

MEDIAN MANGANESE CONCENTRATION----------69.75 MG/L
MEDIAN FLOW----------55.00 GPM
TOXICITY TEST SAMPLE MN VALUE----------71.43 MG/L
MEDIAN MN LOAD PER GALLON OF RAW H2O----0.0005808 LBS.
ANNUAL MEDIAN MN LOAD/MEDIAN FLOW----------8.39 TONS

ANNUAL MN LOADING CHART BASED ON TOXICITY PH ADJUSTMENT

PH ADJ.	TOX. MN	% OF TOTAL	MEDIAN MN	MEDIAN FLOW	ANNUAL LOAD
NONE	71.43 MG/L	100.00 %	69.75 MG/L	55.00 GPM	8.39 TONS
6.00	49.00 MG/L	68.59 %	47.84 MG/L	55.00 GPM	5.76 TONS
7.50	49.50 MG/L	69.29 %	48.32 MG/L	55.00 GPM	5.82 TONS
9.00	37.30 MG/L	52.21 %	36.41 MG/L	55.00 GPM	4.38 TONS

ELK RUN MEDIAN VALUES FOR MN BY OUTLET

OUTLET	MN MEDIAN VALUE
011--SAMPLE 03	123.05 MG/L
011--SAMPLE 03C	170.45 MG/L
008--SAMPLE 08	10.87 MG/L
008--SAMPLE 09	29.81 MG/L
009--SAMPLE 23	29.71 MG/L
015--SAMPLE 31C	31.33 MG/L
004--SAMPLE 44E	50.96 MG/L
017--SAMPLE 45D	29.92 MG/L
003--SAMPLE 47	78.01 MG/L
002--SAMPLE 49	69.75 MG/L
001--SAMPLE 52	43.50 MG/L

ELK RUN 002 TOXICITY TEST RESULTS

SITE	PH	LC50	TUA	LO(0-48)	LO(0- 48)	DO 48	PH(0-48)	CON(0-48)
"FATHEAD MINNOWS"				100%	50%	100%	100%	100%
5075-001-52 RAW	3.60	N/A	N/A	N/A	N/A	N/A	N/A	N/A
5075-001-52 RAW	6.00	87.01	1.14	20 16 08	20 20 17	7.60	6.15 5.97 5.79	2320 2385 2405
5075-001-52 RAW	7.50	N/A	N/A	20 17 16	20 20 20	7.60	7.68 7.31 7.27	2320 2370 2385
5075-001-52 RAW	9.00	N/A	N/A	20 20 19	20 20 20	7.60	9.11 8.91 8.88	2360 2390 2405
5075-001-52 RAW	10.5	63.73	1.56	20 11 00	20 20 17	7.50	10.5 10.2 10.1	2365 2400 2410
001/9-30-98-DISC.	6.64	N/A	N/A	20 20 20	20 20 20	8.10	7.00 6.88 6.79	3410 3210 3200
001/10-28-98-DISC.	6.87	N/A	N/A	20 20 20	20 20 20	7.50	6.73 6.81 6.89	3000 3120 3295
001/11-18-98-DISC.	7.03	N/A	N/A	20 20 20	20 20 20	8.00	6.80 6.96 7.07	3440 3330 2985

SITE	PH	LC50	TUA	LO(0-48)	LO(0- 48)	DO 48	PH(0-48)	CON(0-48)
"DAPHNIA PULEX"				100%	50%	100%	100%	100%
5075-001-52 RAW	3.60	N/A	N/A	N/A	N/A	N/A	N/A	N/A
5075-001-52 RAW	6.00	72.36	1.38	20 13 03	20 20 18	7.70	6.15 5.92 5.73	2320 2375 2395
5075-001-52 RAW	7.50	N/A	N/A	20 15 13	20 20 19	7.70	7.68 7.37 7.31	2320 2385 2400
5075-001-52 RAW	9.00	N/A	N/A	20 19 17	20 20 20	7.70	9.11 8.89 8.79	2360 2395 2410
5075-001-52 RAW	10.5	59.46	1.68	20 09 00	20 20 15	7.60	10.5 10.2 10.1	2365 2385 2395
001/9-30-98-DISC.	6.64	N/A	N/A	20 20 18	20 20 18	8.10	7.00 6.93 6.84	3410 3215 3215
001/10-28-98-DISC.	6.87	N/A	N/A	20 20 20	20 20 20	7.50	6.73 6.83 6.89	3000 3125 3295
001/11-18-98-DISC.	7.03	N/A	N/A	20 20 20	20 20 20	8.00	6.80 7.00 7.07	3440 3430 3300

CONSEQUENCES OF MN TREATMENT FOR CURRENT NPDES LIMITS

1—PH LEVELS IN EXCESS OF 10

2—INCREASED CONDUCTIVITY

3—INCREASED DISSOLVED SOLIDS

4—ALUMINUM RESOLUBILIZATION

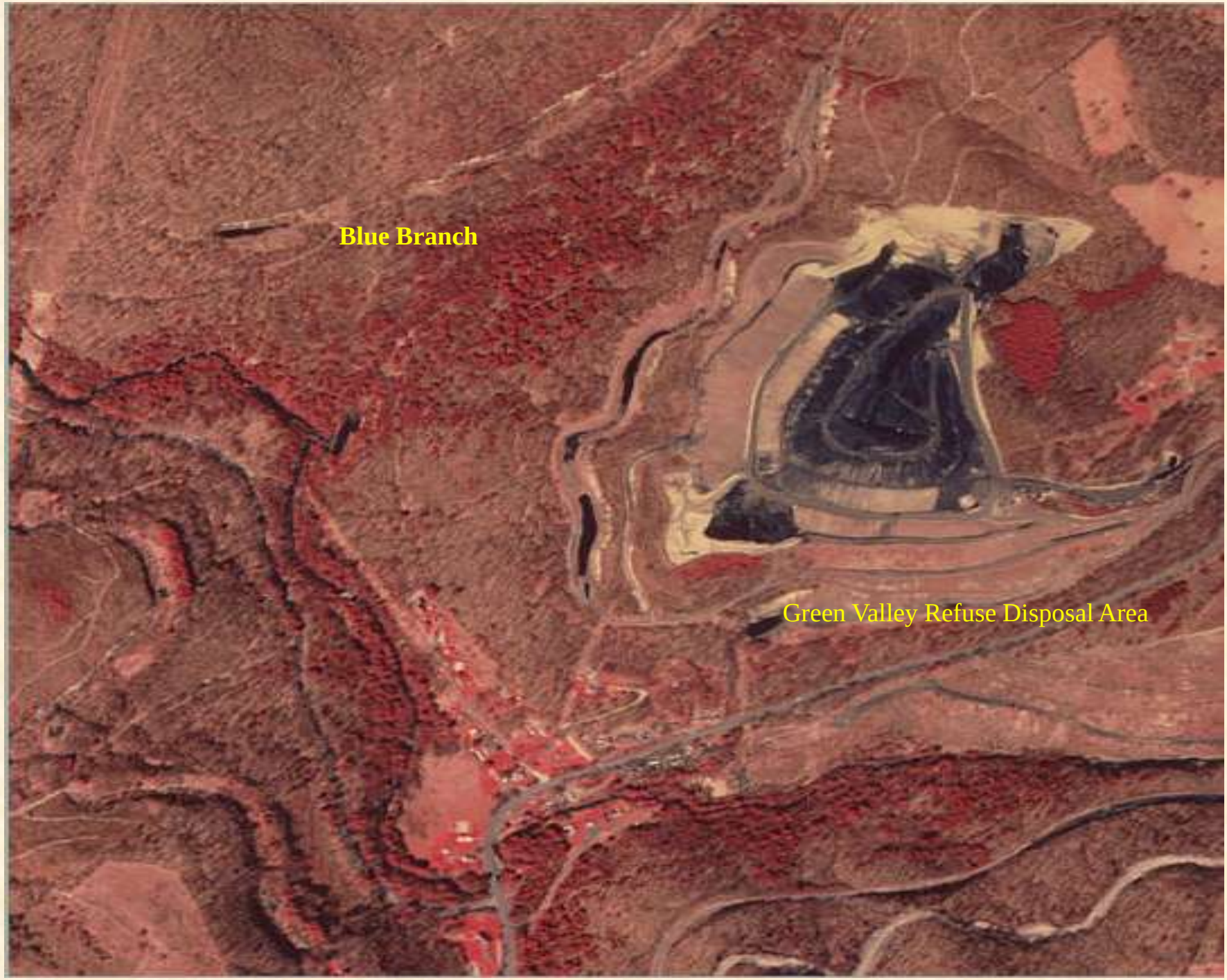
5—INCREASED TOXICITY FROM HARDNESS REDUCTION

6—INCREASE IN SLUDGE VOLUME FROM MG & CA

7—ELIMINATION OF PASSIVE ALTERNATIVES

JUST 35 YEARS AGO

Blue Branch—A Study in the Effects of Present Day Mn Limits Relative to Perpetual Treatment



BLUE BRANCH MN TREATMENT EVALUATION

PARAMETER	RESULT	UNIT	DATE	ANALYST	MDL	METHOD
Lab pH	6.40	S.U.	02/01/2005	KF	0.09	150.1
Total Alkalinity	18.31	mg/l	02/01/2005	JL	0.05	310.1
Total Acidity	<0.36	mg/l	02/01/2005	JL	0.36	305.1
Turbidity	18.00	NTU	02/01/2005	CRS	0.24	180.1
Specific Conductance	322.00	umhos @ 25 C	02/01/2005	KF	2.01	120.1
Total Sulfates	112.59	mg/l	02/01/2005	CRS	0.43	300.0
Chlorides	7.60	mg/l	02/01/2005	CRS	0.31	300.0
Total Iron	1.10	mg/l	02/02/2005	AY	0.007	200.7
Dissolved Iron	<0.007	mg/l	02/02/2005	AY	0.007	200.7
Total Manganese	0.50	mg/l	02/02/2005	AY	0.004	200.7
Dissolved Manganese	0.48	mg/l	02/02/2005	AY	0.004	200.7
Total Aluminum	1.24	mg/l	02/02/2005	AY	0.003	200.7
Dissolved Aluminum	<0.003	mg/l	02/02/2005	AY	0.003	200.7
Total Sodium	28.31	mg/l	02/02/2005	AY	0.010	200.7
Dissolved Sodium	25.87	mg/l	02/02/2005	AY	0.010	200.7
Total Magnesium	6.92	mg/l	02/02/2005	AY	0.004	200.7
Dissolved Magnesium	6.77	mg/l	02/02/2005	AY	0.004	200.7
Total Calcium	21.34	mg/l	02/02/2005	AY	0.010	200.7
Dissolved Calcium	20.81	mg/l	02/02/2005	AY	0.010	200.7
Total Hardness	81.78	mg/L Caco3/L Equiv.	02/02/2005	AY	-----	130.2
Dissolved Hardness	79.84	mg/L Caco3/L Equiv.	02/02/2005	AY	-----	130.2
Total Potassium	5.83	mg/l	02/02/2005	AY	0.008	200.7
Dissolved Potassium	5.55	mg/l	02/02/2005	AY	0.008	200.7
Total Sus. Solids	11.00	mg/l	02/01/2005	BJL	1.00	160.2
Total Dissolved Solids	185.00	mg/l	02/01/2005	BJL	1.00	160.1

20% Sodium Hydroxide Titration

pH	Iron	Manganese	Aluminum	Sodium	Magnesium	Calcium	Conductivity
6.40-Raw	<0.007	0.48	<0.003	25.87	6.77	20.81	322.00
7.50	<0.007	0.49	0.02	28.29	6.95	20.93	-----
8.00	<0.007	0.49	0.08	29.11	6.79	21.05	-----
8.50	<0.007	0.47	0.01	30.69	7.01	21.27	-----
9.00	<0.007	0.44	0.07	32.39	7.26	21.63	-----
9.50	<0.007	0.38	0.07	36.72	6.73	20.70	309.00
10.00	<0.007	0.22	<0.003	42.82	6.51	20.70	333.00
10.50	<0.007	<0.004	0.03	55.83	6.35	20.23	406.00
11.00	<0.007	<0.004	<0.003	91.17	4.67	19.09	789.00
11.50	<0.007	<0.004	<0.003	248.10	0.32	19.49	-----

Calcium Oxide Titration

pH	Iron	Manganese	Aluminum	Sodium	Magnesium	Calcium	Conductivity
6.40-Raw	<0.007	0.48	<0.003	25.87	6.77	20.81	322.00
7.50	<0.007	0.47	<0.003	27.56	6.76	22.44	-----
8.50	<0.007	0.45	0.15	26.94	6.76	22.99	-----
9.00	<0.007	0.46	0.56	27.12	6.91	25.46	-----
9.50	<0.007	0.36	0.08	27.41	6.81	27.35	328.00
10.00	<0.007	0.10	0.06	27.36	6.63	34.18	322.00
10.50	<0.007	0.09	0.27	25.51	6.44	45.53	374.00
11.00	<0.007	<0.004	<0.003	25.87	4.89	79.95	485.00
11.50	<0.007	0.06	0.31	25.39	2.59	170.30	-----

BLUE BRANCH POST TREATMENT—PH BUFFERING CHART—20% NAOH

Date	Time	Hours	pH		Date	Time	Hours	pH		Date	Time	Hours	pH		Date	Time	Hours	pH
2/2/2005	8:00 am	0.00	9.52		2/2/2005	8:00 AM	0.00	10.04		2/2/2005	8:00 AM	0.00	10.50		2/2/2005	8:00 AM	0.00	11.00
2/2/2005	10:00am	2.00	9.60		2/2/2005	10:00 AM	2.00	10.06		2/2/2005	10:00 AM	2.00	10.52		2/2/2005	10:00 AM	2.00	11.04
2/3/2005	2:00am	18.00	9.52		2/3/2005	2:00 AM	18.00	10.04		2/3/2005	2:00 AM	18.00	10.38		2/3/2005	2:00 AM	18.00	10.99
2/3/2005	1:00 pm	29.00	9.49		2/3/2005	1:00 PM	29.00	9.87		2/3/2005	1:00 PM	29.00	10.25		2/3/2005	1:00 PM	29.00	10.90
2/3/2005	11:00 pm	39.00	9.34		2/3/2005	11:00 PM	39.00	9.71		2/3/2005	11:00 PM	39.00	10.20		2/3/2005	11:00 PM	39.00	10.89
2/4/2005	6:00 AM	46.00	9.25		2/4/2005	6:00 AM	46.00	9.67		2/4/2005	6:00 AM	46.00	10.04		2/4/2005	6:00 AM	46.00	10.82
2/4/2005	8:00 PM	60.00	9.14		2/4/2005	8:00 PM	60.00	9.52		2/4/2005	8:00 PM	60.00	9.99		2/4/2005	8:00 PM	60.00	10.76
2/5/2005	8:00 AM	72.00	8.90		2/5/2005	8:00 AM	72.00	9.35		2/5/2005	8:00 AM	72.00	9.81		2/5/2005	8:00 AM	72.00	10.64
2/6/2005	8:00 AM	96.00	8.62		2/6/2005	8:00 AM	96.00	9.14		2/6/2005	8:00 AM	96.00	9.61		2/6/2005	8:00 AM	96.00	10.41
2/6/2005	4:00 PM	104.00	8.45		2/6/2005	4:00 PM	104.00	9.07		2/6/2005	4:00 PM	104.00	9.53		2/6/2005	4:00 PM	104.00	10.31
2/7/2005	1:00 AM	113.00	8.14		2/7/2005	1:00 AM	113.00	8.99		2/7/2005	1:00 AM	113.00	9.47		2/7/2005	1:00 AM	113.00	10.25
2/7/2005	7:00 AM	119.00	7.72		2/7/2005	7:00 AM	119.00	8.62		2/7/2005	7:00 AM	119.00	9.10		2/7/2005	7:00 AM	119.00	10.05
2/8/2005	6:00 AM	142.00	7.68		2/8/2005	6:00 AM	142.00	8.55		2/8/2005	6:00 AM	142.00	9.06		2/8/2005	6:00 AM	142.00	9.98
2/9/2005	4:00 AM	164.00	7.67		2/9/2005	4:00 AM	164.00	8.24		2/9/2005	4:00 AM	164.00	8.88		2/9/2005	4:00 AM	164.00	9.81
2/10/2005	4:00 AM	188.00	7.47		2/10/2005	4:00 AM	188.00	8.20		2/10/2005	4:00 AM	188.00	8.71		2/10/2005	4:00 AM	188.00	9.74

BLUE BRANCH POST TREATMENT—PH BUFFERING CHART—CAO

Date	Time	Hours	pH		Date	Time	Hour	pH		Date	Time	Hour	pH		Date	Time	Hours	pH
2/3/2005	2:00 AM	0.00	9.64		2/3/2005	2:00 AM	0.00	10.0		2/3/2005	2:00 AM	0.00	10.50		2/3/2005	2:00 AM	0.00	11.00
2/3/2005	1:00 PM	11.00	9.51		2/3/2005	1:00 PM	11.00	9.92		2/3/2005	1:00 PM	11.00	10.38		2/3/2005	1:00 PM	11.00	10.73
2/3/2005	11:00 PM	21.00	9.30		2/3/2005	11:00 PM	21.00	9.59		2/3/2005	11:00 PM	21.00	10.15		2/3/2005	11:00 PM	21.00	10.49
2/4/2005	6:00 AM	28.00	9.19		2/4/2005	6:00 AM	28.00	9.46		2/4/2005	6:00 AM	28.00	10.04		2/4/2005	6:00 AM	28.00	10.36
2/4/2005	8:00 PM	42.00	9.11		2/4/2005	8:00 PM	42.00	9.34		2/4/2005	8:00 PM	42.00	9.96		2/4/2005	8:00 PM	42.00	10.24
2/5/2005	8:00 AM	54.00	8.97		2/5/2005	8:00 AM	54.00	9.14		2/5/2005	8:00 AM	54.00	9.68		2/5/2005	8:00 AM	54.00	9.97
2/6/2005	8:00 AM	78.00	8.68		2/6/2005	8:00 AM	78.00	8.90		2/6/2005	8:00 AM	78.00	9.37		2/6/2005	8:00 AM	78.00	9.57
2/6/2005	4:00 PM	86.00	8.62		2/6/2005	4:00 PM	86.00	8.73		2/6/2005	4:00 PM	86.00	9.24		2/6/2005	4:00 PM	86.00	9.32
2/7/2005	1:00 AM	95.00	8.53		2/7/2005	1:00 AM	95.00	8.62		2/7/2005	1:00 AM	95.00	9.14		2/7/2005	1:00 AM	95.00	9.23
2/7/2005	7:00 AM	101.00	8.41		2/7/2005	7:00 AM	101.00	8.30		2/7/2005	7:00 AM	101.0	8.86		2/7/2005	7:00 AM	101.00	8.95
2/8/2005	6:00 AM	124.00	8.35		2/8/2005	6:00 AM	124.00	8.30		2/8/2005	6:00 AM	124.0	8.80		2/8/2005	6:00 AM	124.00	8.87
2/9/2005	4:00 AM	146.00	8.29		2/9/2005	4:00 AM	146.00	8.20		2/9/2005	4:00 AM	146.0	8.66		2/9/2005	4:00 AM	146.00	8.66
2/10/2005	4:00 AM	170.00	8.23		2/10/2005	4:00 AM	170.00	7.95		2/10/2005	4:00 AM	170.0	8.58		2/10/2005	4:00 AM	170.00	8.55

BLUE BRANCH CHEMICAL CONSUMPTION PER TREATMENT PH

Gals./Gal.	pH		Gals./Gal.	pH		Gals./Gal.	pH		Gals./Gal.	pH
0.000000	6.55		0.000000	6.55		0.000000	6.55		0.000000	6.55
0.000025	8.61		0.000025	8.29		0.000025	8.43		0.000025	8.62
0.000050	9.13		0.000050	8.95		0.000050	9.01		0.000050	9.05
0.000075	9.52		0.000075	9.33		0.000075	9.36		0.000075	9.41
			0.000100	9.62		0.000100	9.62		0.000100	9.68
			0.000125	9.83		0.000125	9.81		0.000125	9.88
			0.000150	10.03		0.000150	9.97		0.000150	10.02
						0.000175	10.09		0.000175	10.14
						0.000200	10.25		0.000200	10.23
						0.000225	10.32		0.000225	10.32
						0.000250	10.39		0.000250	10.39
						0.000275	10.44		0.000275	10.44
						0.000300	10.50		0.000300	10.50
									0.000325	10.54
									0.000350	10.58
									0.000375	10.61
									0.000400	10.65
									0.000425	10.72
									0.000450	10.77
									0.000475	10.82
									0.000500	10.86
									0.000525	10.91
									0.000550	10.95
									0.000575	11.00

9.5

BLUE BRANCH ANNUAL COST FOR CHEMICALS/SLUDGE DISPOSAL

20% NAOH ANNUAL CHEMICAL AND SLUDGE DISPOSAL COSTS--9.50 pH

Avg. Flow	An. Chem.	An. Chem. $	An. Sldg. Vol.	An. Sldg. Dis. $	An. Chem./Sludge $
GPM'S	GALLONS	$0.50/GAL.	GALLONS		
25	985.50	$ 492.75	26,280	$ 1,314.00	$ 1,806.75
50	1,971.00	$ 985.50	52,560	$ 2,628.00	$ 3,613.50
100	3,942.00	$ 1,971.00	105,120	$ 5,256.00	$ 7,227.00
200	7,884.00	$ 3,942.00	210,240	$ 10,512.00	$ 14,454.00

20% NAOH ANNUAL CHEMICAL AND SLUDGE DISPOSAL COSTS--10.00 pH

Avg. Flow	An. Chem.	An. Chem. $	An. Sldg. Vol.	An. Sldg. Dis. $	An. Chem./Sludge $
25	1,971.00	$ 985.50	65,700	$ 3,285.00	$ 4,270.50
50	3,942.00	$ 1,971.00	131,400	$ 6,570.00	$ 8,541.00
100	7,884.00	$ 3,942.00	262,800	$ 13,140.00	$ 17,082.00
200	15,768.00	$ 7,884.00	525,600	$ 26,280.00	$ 34,164.00

20% NAOH ANNUAL CHEMICAL AND SLUDGE DISPOSAL COSTS--10.50 pH

Avg. Flow	An. Chem.	An. Chem. $	An. Sldg. Vol.	An. Sldg. Dis. $	An. Chem./Sludge $
25	3,942.00	$ 1,971.00	394,200	$ 19,710.00	$ 21,681.00
50	7,884.00	$ 3,942.00	788,400	$ 39,420.00	$ 43,362.00
100	15,768.00	$ 7,884.00	1,576,800	$ 78,840.00	$ 86,724.00
200	31,536.00	$ 15,768.00	3,153,600	$ 157,680.00	$ 173,448.00

20% NAOH ANNUAL CHEMICAL AND SLUDGE DISPOSAL COSTS--11.00 pH

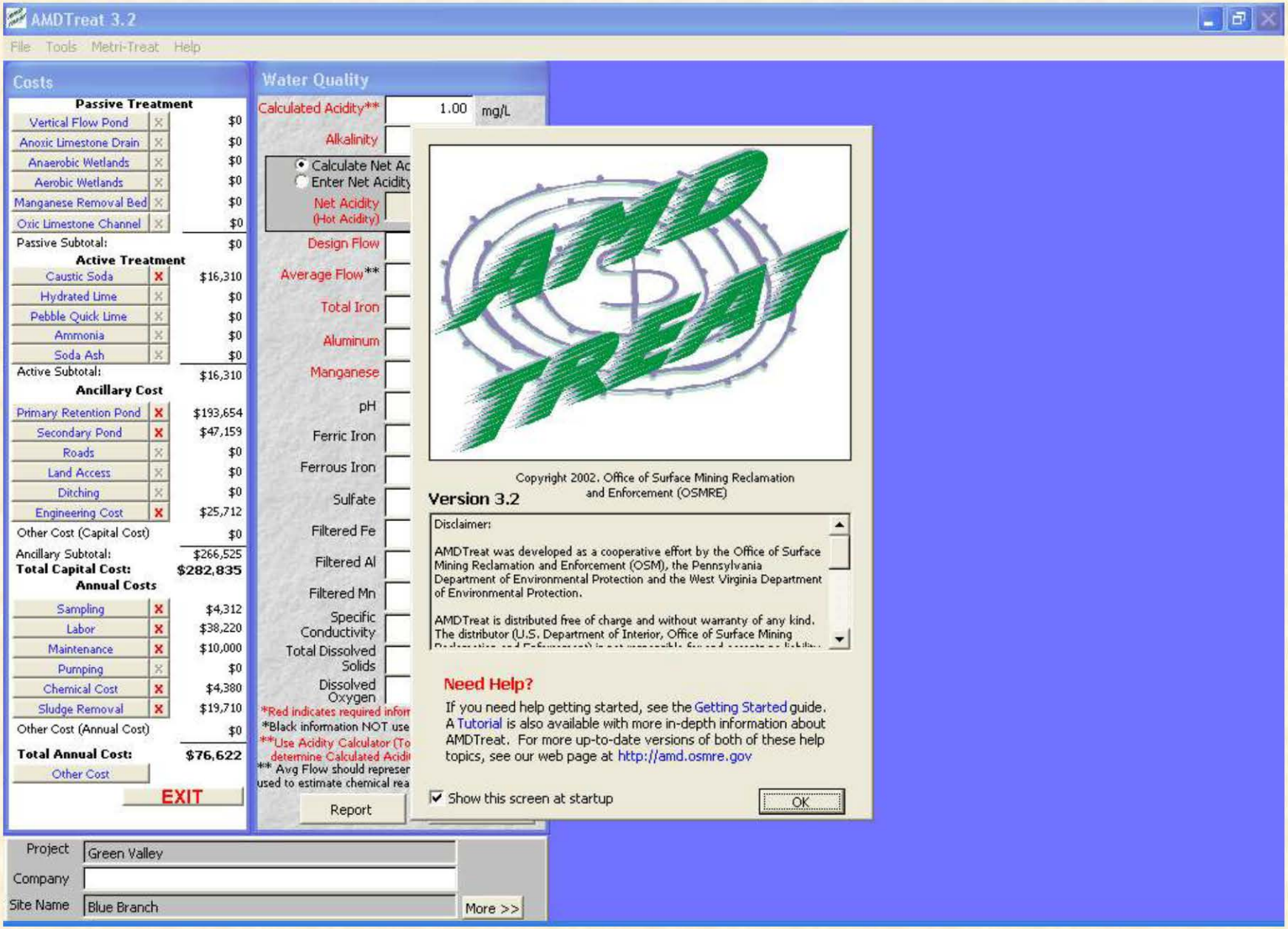
Avg. Flow	An. Chem.	An. Chem. $	An. Sldg. Vol.	An. Sldg. Dis. $	An. Chem./Sludge $
25	7,555.50	$ 3,777.75	525,600	$ 26,280.00	$ 30,057.75
50	15,111.00	$ 7,555.50	1,051,200	$ 52,560.00	$ 60,115.50
100	30,222.00	$ 15,111.00	2,102,400	$ 105,120.00	$ 120,231.00
200	60,444.00	$ 30,222.00	4,204,800	$ 210,240.00	$ 240,462.00

BLUE BRANCH "BASIC" ANNUAL COST FOR 9.5—10—10.5--& 11 PH VALUES

ANNUAL COSTS SUMMARY FOR 50 GALLONS PER MINUTE-20% NAOH

ANNUAL COSTS	9.5 PH	10 PH	10.50 PH	11.00 PH
CHEMICAL	$ 985.50	$ 1,971.00	$ 3,942.00	$ 7,555.50
SLUDGE DISPOSAL	$ 2,628.00	$ 6,570.00	$ 39,420.00	$ 52,560.00
SAMPLING	$ 4,312.00	$ 4,312.00	$ 4,312.00	$ 4,312.00
LABOR	$ 38,220.00	$ 38,220.00	$ 38,220.00	$ 38,220.00
MAINTENANCE	$ 10,000.00	$ 10,000.00	$ 10,000.00	$ 10,000.00
TOTALS	$ 56,145.50	$ 61,073.00	$ 95,894.00	$ 112,647.50

BLUE BRANCH AMDTREAT COST EVALUATION TO ACHIEVE 0.29 MG/L MN LIMIT



BLUE BRANCH AMDTREAT CAPITAL COST MODULE FOR CAUSTIC SODA

Caustic Soda $16310

1. Gallons of Caustic per Year	8,760.00	gal/yr
2. Gallons of Caustic per Month	730.00	gal/mo
3. Gallons of Caustic per Day	24.00	gal/day

☑ 4. Titration?

5. Caustic Titration Volume	.000300	gal caustic/gal water treated
6. Purity of Caustic Solution	99.00	purity of 20% caustic solution
7. Mixing Efficiency of Caustic Solution	90.00	%
8. Tank Cost	10000	$
9. Tank Volume	10000	gal
10. Delivery Frequency	12	times/yr
11. Valve Unit Cost	50.00	$
12. Number of Valves	3	nbr
13. Feeder Line Length	500	ft
14. Feeder Line Unit Cost	0.35	$/ft
15. Installation of System Unit Cost	35.00	$/hr
16. Installation Hours	16	hours

☑ 17. Automatic System?

18. PID pH Proportional Control	1875	$
19. pH Probe	550	$
20. Chemical Metering Pump	3000	$

☐ 21. Water Wheel Dispenser

22. Dispenser Cost	4000.00	$

Caustic Sub-Totals

23. Number of Tanks Required	1	nbr
24. Tank Cost	10,000	$
25. Automatic System or Wheel Dispenser Cost	5,425	$
26. Cost of Valves	150	$
27. Feeder Line Cost	175	$
28. Labor Cost	560	$
29. Total Capital Cost	**16,310**	$

Report Help

BLUE BRANCH AMDTREAT CAPITAL COST MODULE FOR PRIMARY RETENTION POND

Primary Retention Pond $193,654.00

1. Sludge Removal Frequency	1.000	times/year
2. Desired Retention Time	168.00	hours
☑ 3. Titration?		
4. Sludge Rate	.030000	gal sludge/gal H2O
5. Percent Solids	3.00	%
6. Sludge Density	8.35	lbs./gal.
7. Slope Ratio of Pond Sides (Run : Rise)	2.0 : 1	
8. Freeboard Depth	2.0	ft
9. Water Depth	6.0	ft
10. Excavation Unit Cost	4.50	$/yd3
11. Total Length of Effluent / Influent Pipe	150.00	ft
12. Unit Cost of Pipe	55.00	$/ft

Liner Cost

- ○ No Liner
- ◉ Clay Liner

13. Clay Liner Unit Cost	4.00	$/yd3
14. Thickness of Clay Liner	1.0	ft

- ○ Synthetic Liner

15. Synthetic Liner Unit Cost	2.60	$/yd2

☑ 16. Clearing and Grubbing?

◉ 17a. Land Multiplier	1.50	ratio
○ 17b. Clear/Grub Acres	1.00	acre
18. Clear and Grub Unit Cost	1256.00	$/acre
19. Revegetation Cost	1500.00	$/acre
20. # of Ponds for this Design	1	Number

Calculated Pond Dimensions per Pond

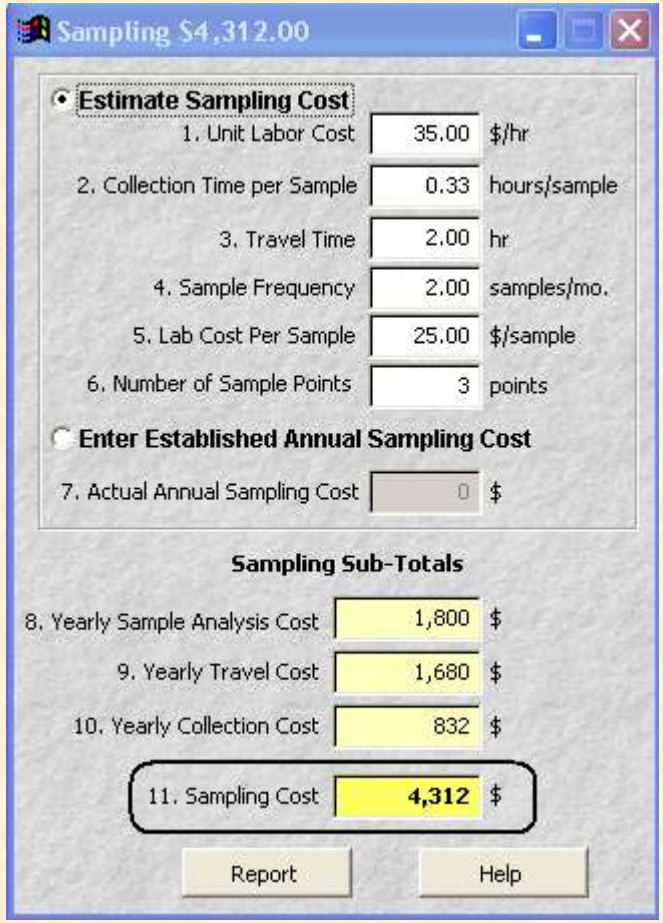
21. Length at Top of Freeboard	535	ft
22. Width at Top of Freeboard	271	ft
23. Estimated Annual Sludge	3,903	yd3/yr
24. Volume of Sludge per Removal	3,903	yd3/removal
25. Freeboard Volume	10,544	yd3
26. Water Volume	24,953	yd3
27. Excavation Volume	28,857	yd3
28. Excavation Volume	17.88	ac.- ft.
29. Clear and Grub Area	5.01	acres
30. Liner Area	17,223	yd2

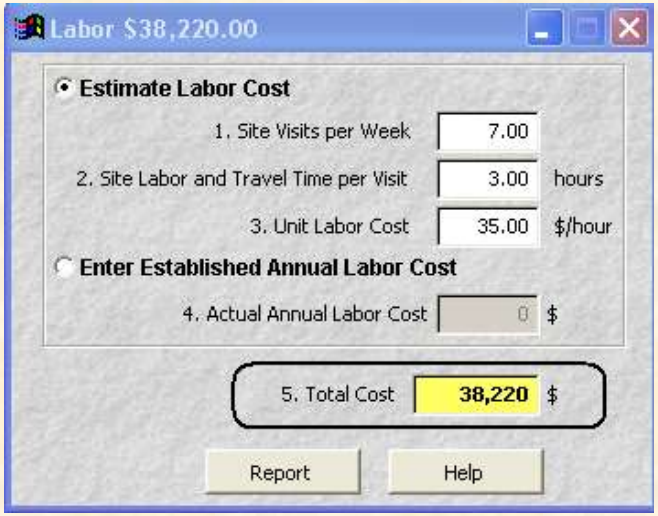
Primary Settling Ponds Sub-Totals

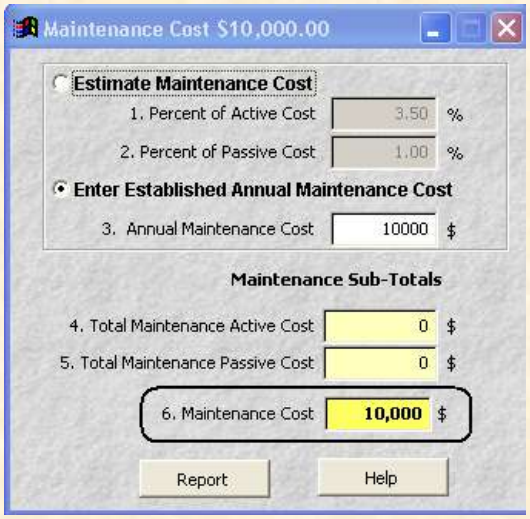
31. Excavation Cost	154,604	$
32. Pipe Cost	8,250	$
33. Liner Cost	21,997	$
34. Clearing and Grubbing Cost	6,295	$
35. Revegetation Cost	2,506	$
36. Estimated Cost	**193,654**	$

Report Help

BLUE BRANCH AMDTREAT--GENERAL--ANNUAL FIXED COST MODULES







BLUE BRANCH AMDTREAT CHEMICAL COSTS MODULE

Chemical Cost $4,380.00

A. Hydrated Lime ?

1.Titration?

2. Hydrated Lime Titration Amount	.000510	lbs of hydrated lime / gal of H2O
3. Hydrated Lime Purity	96.00	%
4. Mixing Efficiency of Hydrated Lime	90	%
5. Hydrated Lime Unit Cost	0.0500	$/lb

B. Pebble Quick Lime ?

6. Titration?

7. Pebble Lime Titration Amount	.000499	lbs of Pebble Lime / gal of H2O
8. Pebble Lime Purity	94.00	%
9. Mixing Efficiency of Pebble Lime	90.00	%

Delivered in Bags

10. Pebble Lime Bag Unit Cost	0.1000	$/lb

Bulk Delivery

11. Pebble Lime Bulk Unit Cost	0.0500	$/lb

C. Caustic Soda?

12. Titration?

13. Caustic Titration Amount	.000300	gal ofcaustic / gal H2O
14. Caustic Purity	99.00	purity of 20% caustic solution
15. Mixing Efficiency of Caustic	90.00	%

Non-Bulk Delivery

16. Caustic Non-Bulk Unit Cost	0.50	$/gal

Bulk Delivery

17. Caustic Bulk Unit Cost	0.40	$/gal

D. Limestone ?

18. Limestone Purity	90.00	%
19. Limestone Efficiency	60	%
20. Limestone Unit Cost	12.00	$/ton

E. Anhydrous Ammonia ?

21. Titration?

22. AmmoniaTitration Amount	.000467	lbs of ammonia / gal H2O
23. Ammonia Purity	99.00	%
24. Mixing Efficiency of Ammonia	90.00	%

Non-Bulk Delivery

25. Ammonia Non-Bulk Unit Cost	0.40	$/lb

Bulk Delivery

26. Ammonia Bulk Unit Cost	0.15	$/lb

F. Soda Ash ?

27. Titration?

28. Soda Ash Titration Amount	.001200	lbs of soda ash / gal H2O
29. Soda Ash Purity	99.00	%
30. Mixing Efficiency of Soda Ash	60	%
31. Soda Ash Unit Cost	0.1400	$/lb

	Chemical Cost Sub-Totals		Annual Amount of Chemicals Consumed	
32. Total Hydrated Lime Cost	745	$	14,892	lbs
33. Total Pebble Lime Cost	729	$	14,570	lbs
34. Total Caustic Soda Cost	4,380	$	8,760	gals
35. Total Limestone Cost	0	$	0	tons
36. Total Anhydrous Ammonia Cost	5,455	$	13,636	lbs
37. Total Soda Ash Cost	0	$	0	lbs

38. Selected Chemical: CAUSTIC SODA

Annual Chemical Cost 4,380 $

Help

Report

BLUE BRANCH AMDTREAT COSTS/INORMATION SUMMARY

Printed on 05/14/2005

Company Name

Project Green Valley

Site Name Blue Branch

AMD TREAT

AMD TREAT MAIN FORM

Costs	
Passive Treatment	
Vertical Flow Pond	0
Anoxic Limestone Drain	0
Anaerobic Wetlands	0
Aerobic Wetlands	0
Manganese Removal Bed	0
Oxic Limestone Channel	0
Passive Subtotal:	0
Active Treatment	
Caustic Soda	16,310
Hydrated Lime	0
Pebble Quick Lime	0
Ammonia	0
Soda Ash	0
Active Subtotal:	16,310
Ancillary Cost	
Primary Retention Pond	193,664
Secondary Pond	47,169
Roads	0
Land Access	0
Ditching	0
Engineering Cost	25,712
Other Cost (Capital Cost)	0
Ancillary Subtotal:	266,525
Total Capital Cost:	282,835
Annual Costs	
Sampling	4,312
Labor	36,220
Maintenance	10,000
Pumping	0
Chemical Cost	4,380
Sludge Removal	18,710
Other Cost (Annual Cost)	0
Total Annual Cost:	78,622

Water Quality

Calculated Acidity	1.00	mg/L
Alkalinity	0.00	mg/L

◉ Calculate Net Acidity (Acid-Alkalinity)
○ Enter Net Acidity manually

Net Acidity (-Hot Acidity)	1.00	mg/L
Design Flow	500.00	gpm
Average Flow	50.00	gpm
Total Iron	1.10	mg/L
Aluminum	1.20	mg/L
Manganese	0.60	mg/L
pH	6.40	su
Ferric Iron	0.00	mg/L
Ferrous Iron	0.00	mg/L
Sulfate	0.00	mg/L
Filtered Fe	0.00	mg/L
Filtered Al	0.00	mg/L
Filtered Mn	0.00	mg/L
Specific Conductivity	0.00	uS/cm
Total Dissolved Solids	0.00	mg/L
Dissolved Oxygen	0.00	mg/L

BLUE BRANCH AMDTREAT 75 YEARS NET PRESENT COST COMPARISON

Pay Back Years 0.0

1. Inflation Rate 3.000 %
2. Rate of Return 3.000 %
3. Design Life of Treatment System 75.0 years

	Treatment System 1				Treatment System 2				
4. Capital Cost	282,835 $				397,687 $				
5. Annual Cost	95,894 $				72,971 $				
ITEM 1	Description of Item				Description of Item				
6. Replacement Cost Item 1 (in today's $)	5,425 $				85,000 $				
7. Replacement Years for Item 1	10 yr	20 yr	30 yr	40 yr	20 yr	40 yr	60 yr	0 yr	
8. Item 1 Replacement Cost for selected years	5,425	5,425	5,425	5,425 $	85,000	85,000	85,000	0 $	
9. Total Net Present Replacement Cost Item 1	21,700 $				255,000 $				
ITEM 2	Description of Item				Description of Item				
10. Replacement Cost Item 2 (in today's $)	5,425 $				0 $				
11. Replacement Years for Item 2	50 yr	60 yr	0 yr	0 yr	0 yr	0 yr	0 yr	0 yr	
12. Item 2 Replacement Cost for selected years	5,425	5,425	0	0 $	0	0	0	0 $	
13. Total Net Present Replacement Cost for Item 2	10,850 $				0 $				
							Difference		
14. Total Net Present Capital Cost (Capital + Replacement)	315,385 $				652,687 $		337,302 $		
15. Present Value Annual Cost	7,192,050 $				5,472,825 $		1,719,225 $		
16. Net Present Cost	**7,507,435** $				**6,125,512** $				

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BLUE BRANCH MN TREATMENT EVALUATION

PARAMETER	RESULT	UNIT	DATE	ANALYST	MDL	METHOD
Lab pH	6.40	S.U.	02/01/2005	KF	0.09	150.1
Total Alkalinity	18.31	mg/l	02/01/2005	JL	0.05	310.1
Total Acidity	<0.36	mg/l	02/01/2005	JL	0.36	305.1
Turbidity	18.00	NTU	02/01/2005	CRS	0.24	180.1
Specific Conductance	322.00	umhos @ 25 C	02/01/2005	KF	2.01	120.1
Total Sulfates	112.59	mg/l	02/01/2005	CRS	0.43	300.0
Chlorides	7.60	mg/l	02/01/2005	CRS	0.31	300.0
Total Iron	1.10	mg/l	02/02/2005	AY	0.007	200.7
Dissolved Iron	<0.007	mg/l	02/02/2005	AY	0.007	200.7
Total Manganese	0.50	mg/l	02/02/2005	AY	0.004	200.7
Dissolved Manganese	0.48	mg/l	02/02/2005	AY	0.004	200.7
Total Aluminum	1.24	mg/l	02/02/2005	AY	0.003	200.7
Dissolved Aluminum	<0.003	mg/l	02/02/2005	AY	0.003	200.7
Total Sodium	28.31	mg/l	02/02/2005	AY	0.010	200.7
Dissolved Sodium	25.87	mg/l	02/02/2005	AY	0.010	200.7
Total Magnesium	6.92	mg/l	02/02/2005	AY	0.004	200.7
Dissolved Magnesium	6.77	mg/l	02/02/2005	AY	0.004	200.7
Total Calcium	21.34	mg/l	02/02/2005	AY	0.010	200.7
Dissolved Calcium	20.81	mg/l	02/02/2005	AY	0.010	200.7
Total Hardness	81.78	mg/L Caco3/L Equiv.	02/02/2005	AY		130.2
Dissolved Hardness	79.84	mg/L Caco3/L Equiv.	02/02/2005	AY		130.2
Total Potassium	5.83	mg/l	02/02/2005	AY	0.008	200.7
Dissolved Potassium	5.55	mg/l	02/02/2005	AY	0.008	200.7
Total Sus. Solids	11.00	mg/l	02/01/2005	BJL	1.00	160.2
Total Dissolved Solids	185.00	mg/l	02/01/2005	BJL	1.00	160.1