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Investigation of Experimental Anoxic Passive Treatment Systems

Westminster College

Environmental Science

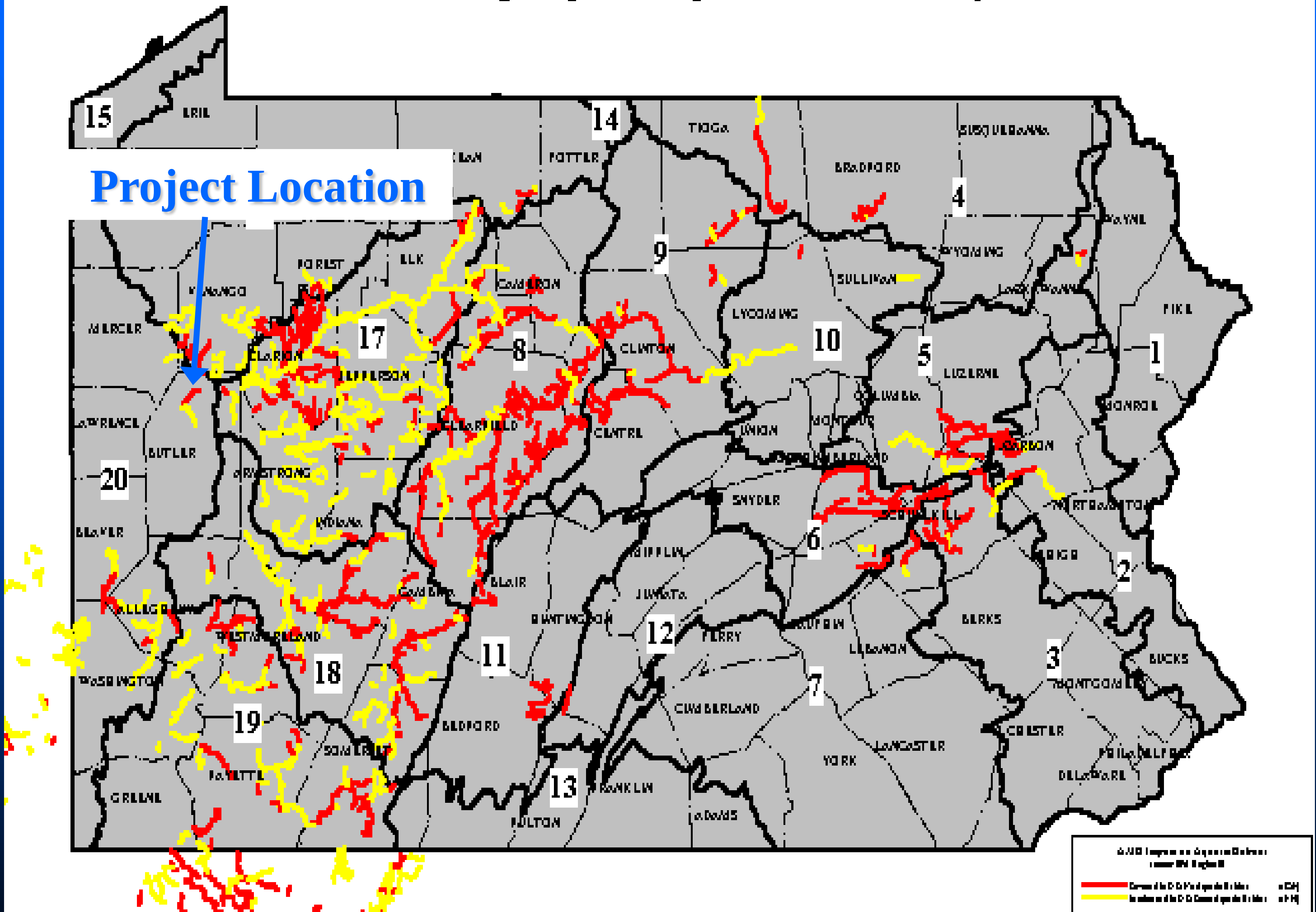
Senior Capstone Semester Research Project 2001


Acid Mine Drainage
What is it?
How is it formed?

Why Is It So Important?

- Overall
- Pennsylvania
  - 1/3 of waters
  - 4000 km of streams
  - Production of more coal

Acid Mine Drainage Impact on Aquatic Habitat in Pennsylvania



Legislation

- **The Clean Water Act**
  - 1972
  - Objective
  - Goals
- **The National Pollutant Discharge Elimination System (NPDES)**
- **Pennsylvania Clean Streams Law**

How Does AMD Happen?

- $2\ FeS_2 + 7\ O_2 + 2\ H_2O \rightarrow 2\ Fe^{2+} + 4\ SO_4^{2-} + 4\ H^+$

- $4\ Fe^{2+} + O_2 + 4\ H^+ \rightarrow 4\ Fe^{3+} + 2\ H_2O$
- $4\ Fe^{3+} + 12\ H_2O \rightarrow 4\ Fe(OH)_3 \downarrow + 12\ H^+$
- $FeS_2 + 14\ Fe^{3+} + 8\ H_2O \rightarrow 15\ Fe^{2+} + 2\ SO_4^{2-} + 16\ H^+$

Summary Reaction

- $4\ FeS_2 + 15\ O_2 + 14\ H_2O \rightarrow 4\ Fe(OH)_3 \downarrow + 8\ H_2SO_4$

AMD Remediation

- Important to the community
- Several Passive Treatment methods
  - Aerobic Wetlands
  - Compost (Anaerobic)
  - Limestone Channels
  - Anoxic Limestone Drain
  - Vertical Flow Pond (similar to our design)
  - Pyrosulite® Process
  - Diversion Wells

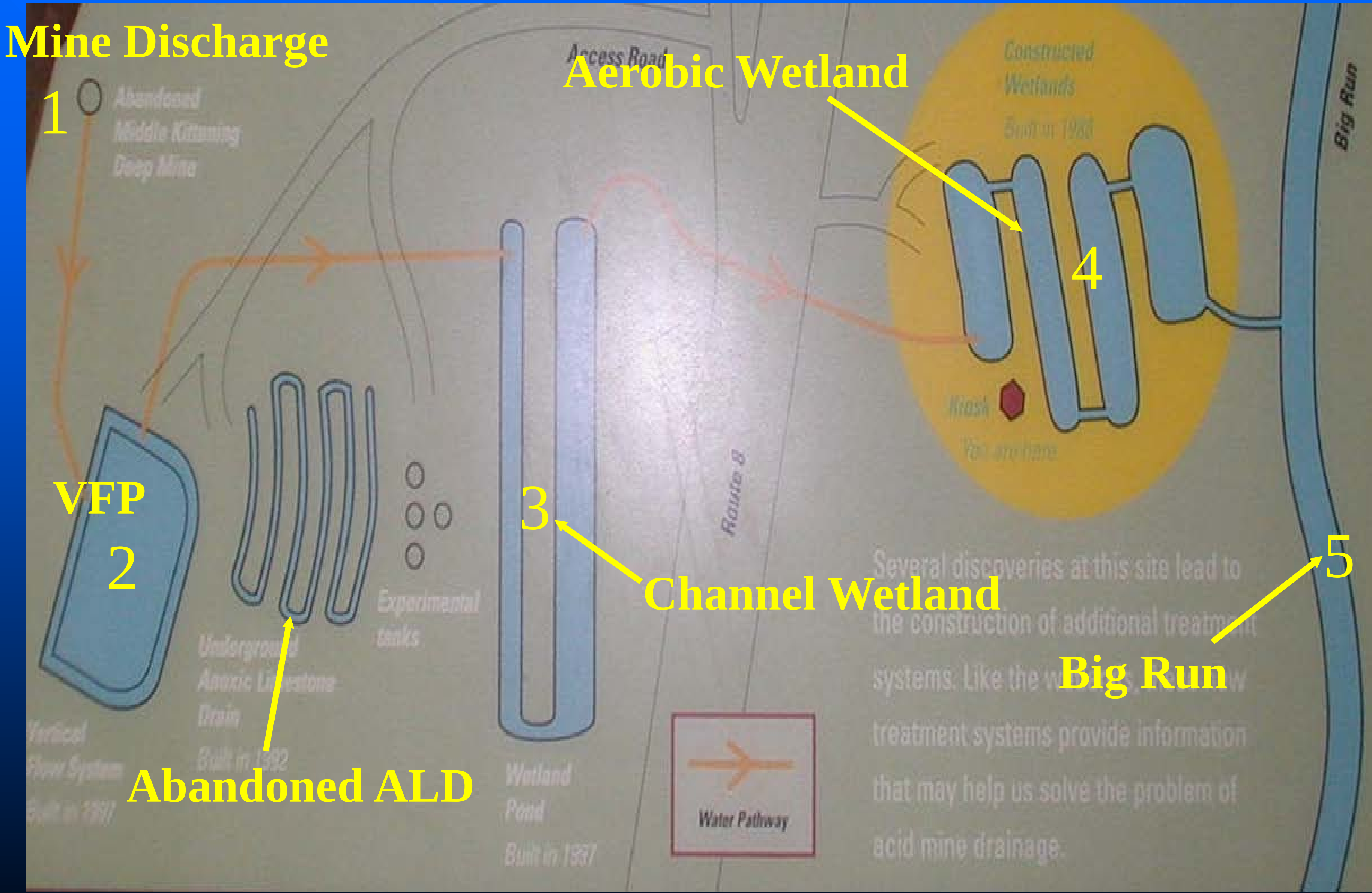
Jennings Environmental Education Center

- Site Location: Butler County, PA
- Slippery Rock Watershed: 725 km^2
  - Over 100 years of mining activity
  - Impact on headwaters

Jennings Environmental Education Center

- Site history: abandoned mine
  - Mine seal failure
  - Impact of contaminated mine water on Big Run
    - » Installation of mine seals
  - Mine seals failed
    - » Fish kill due to over loading of iron and aluminum

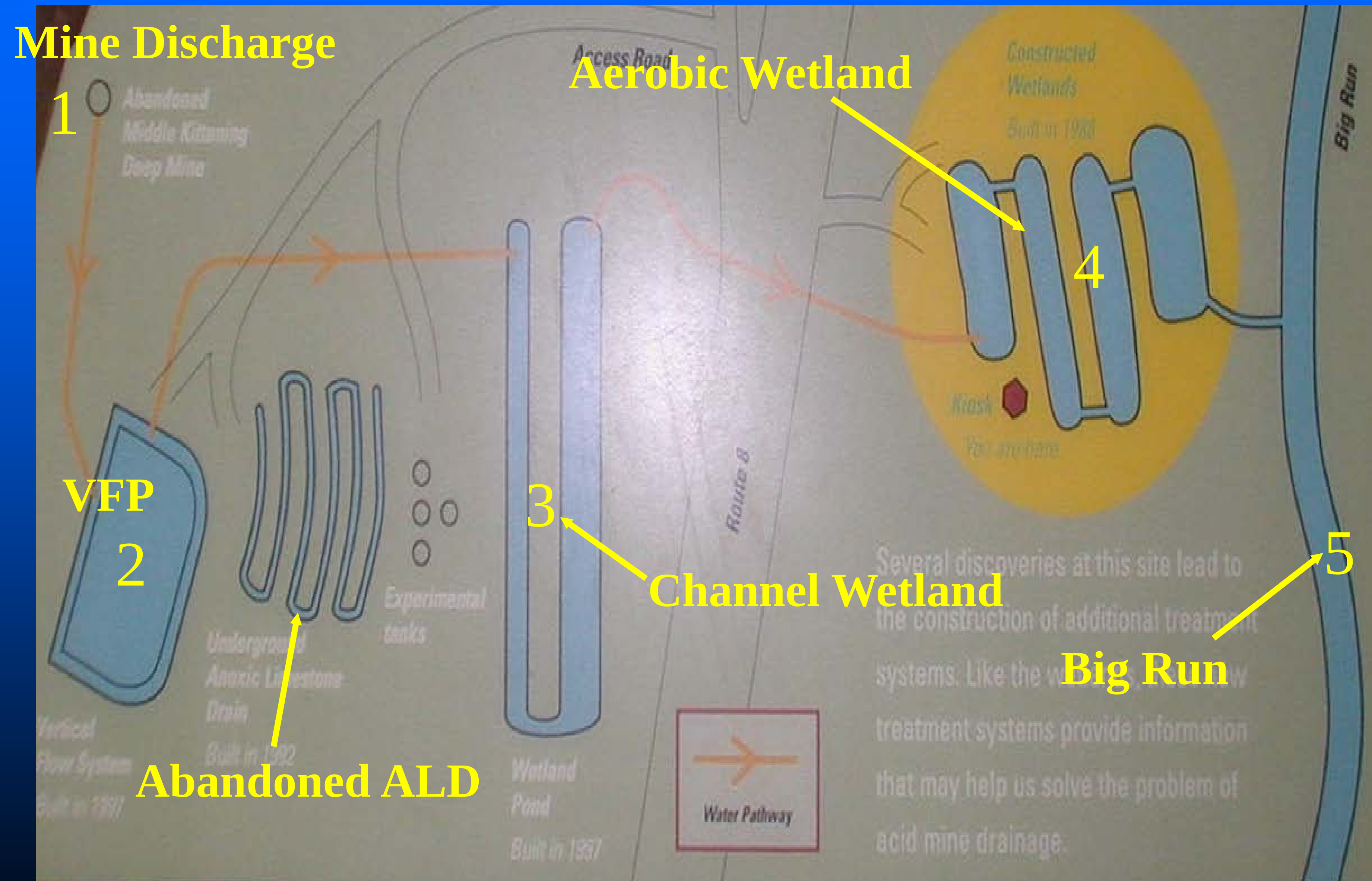
Jennings Site Overview



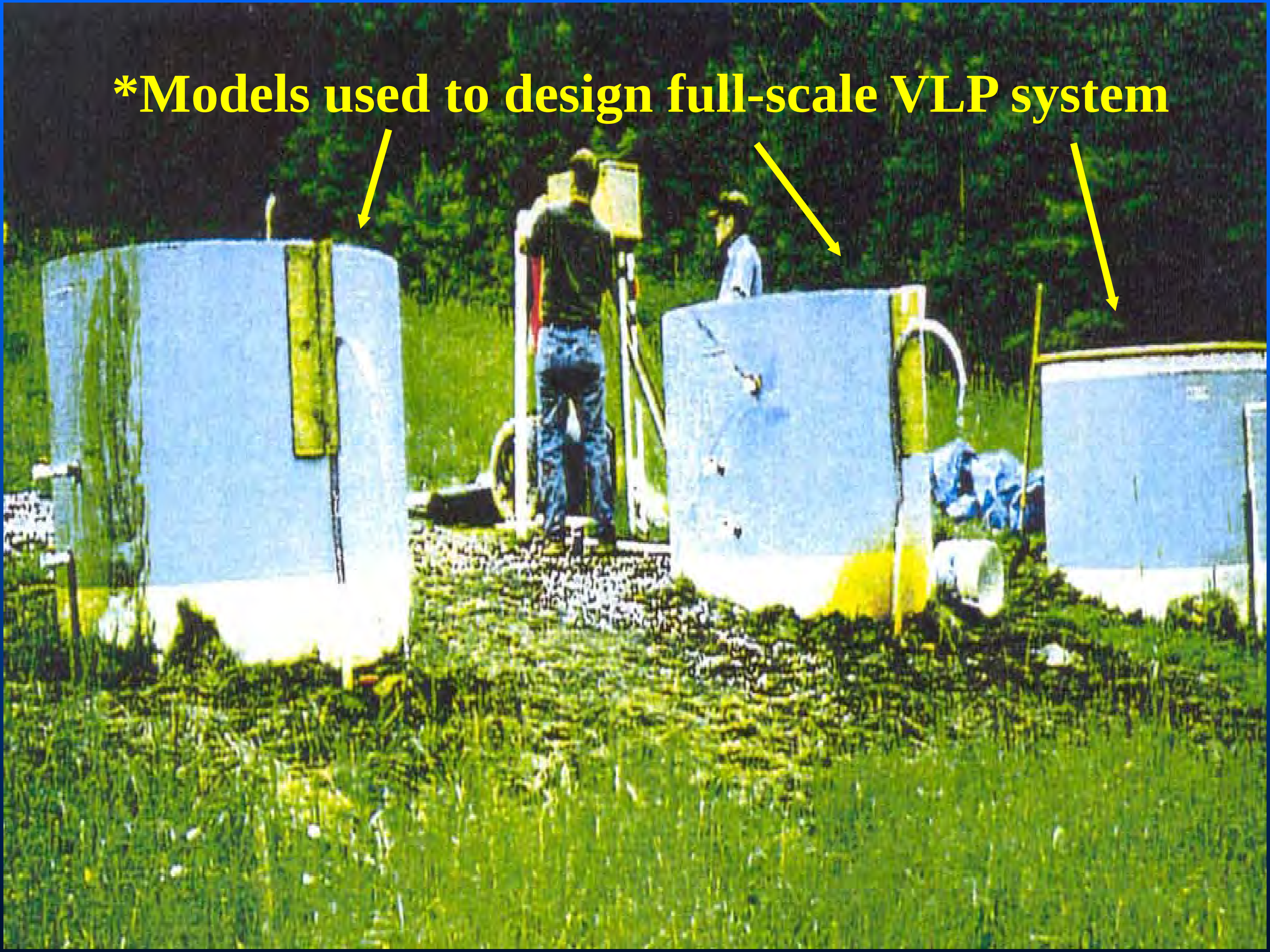
Acid Mine Discharge Source

Untreated AMD Surface Flow

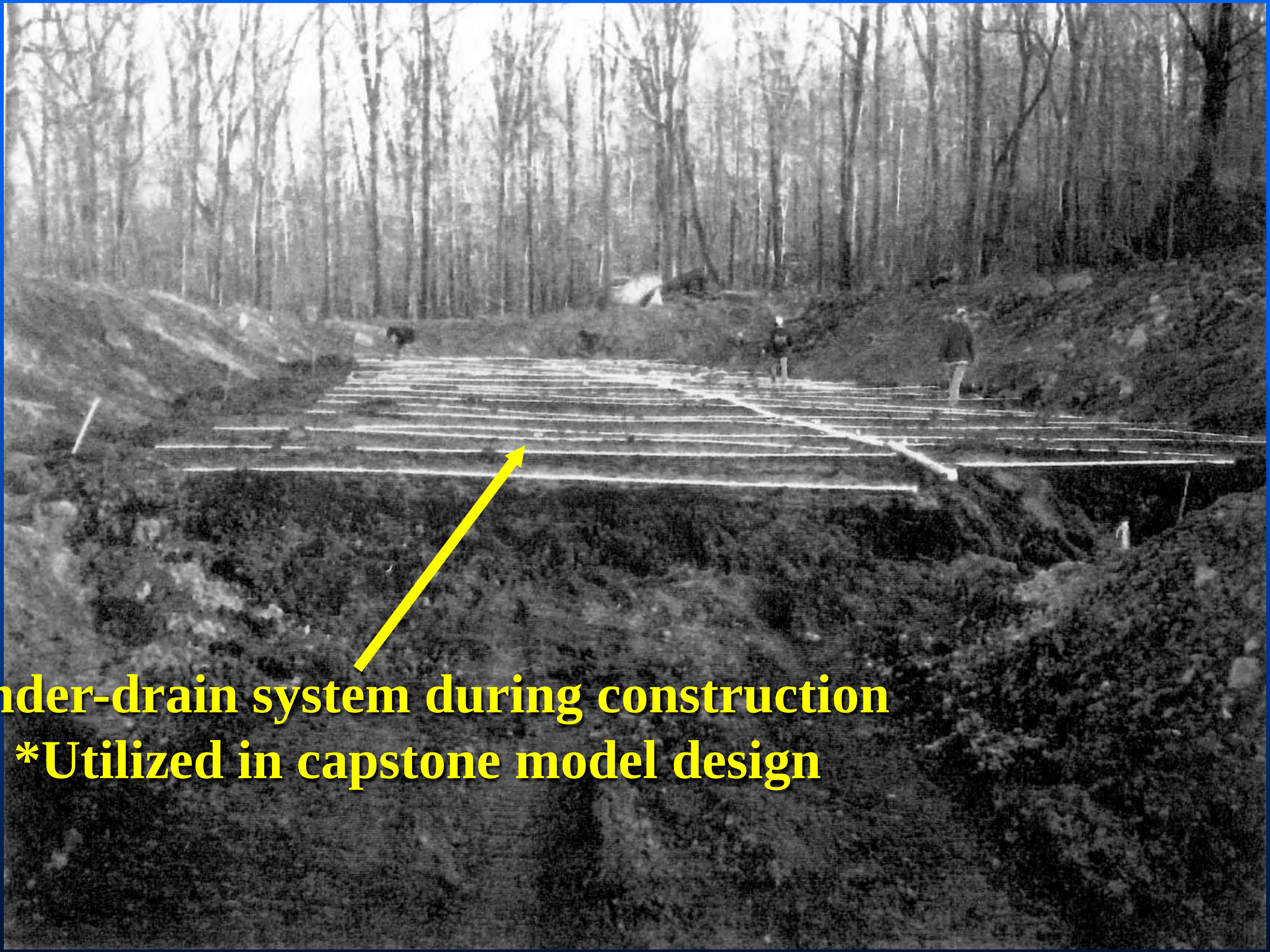
Jennings Site Overview



Pilot-scale Vertical Flow System



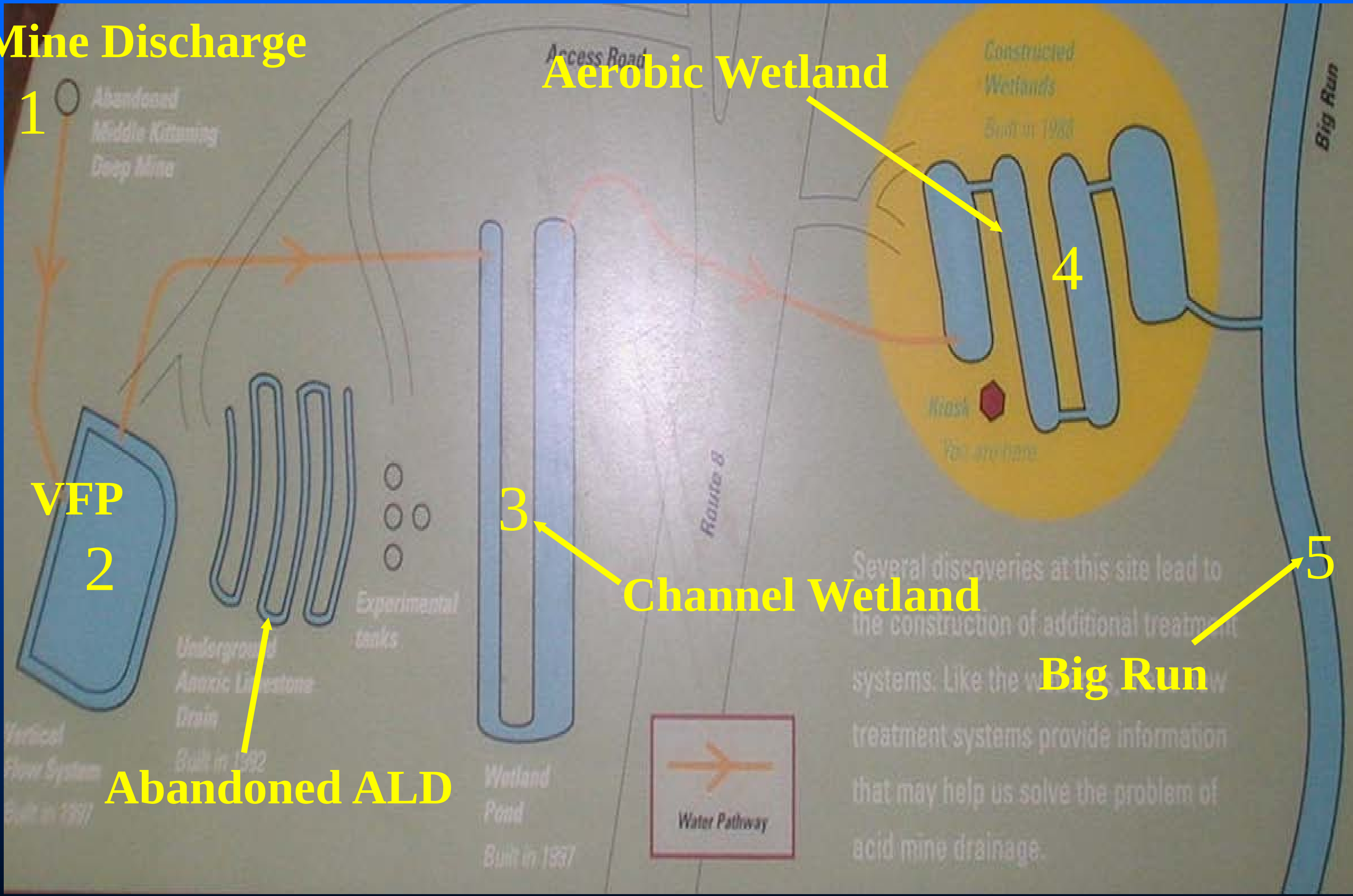
Under-drain System Cutaway: VLP



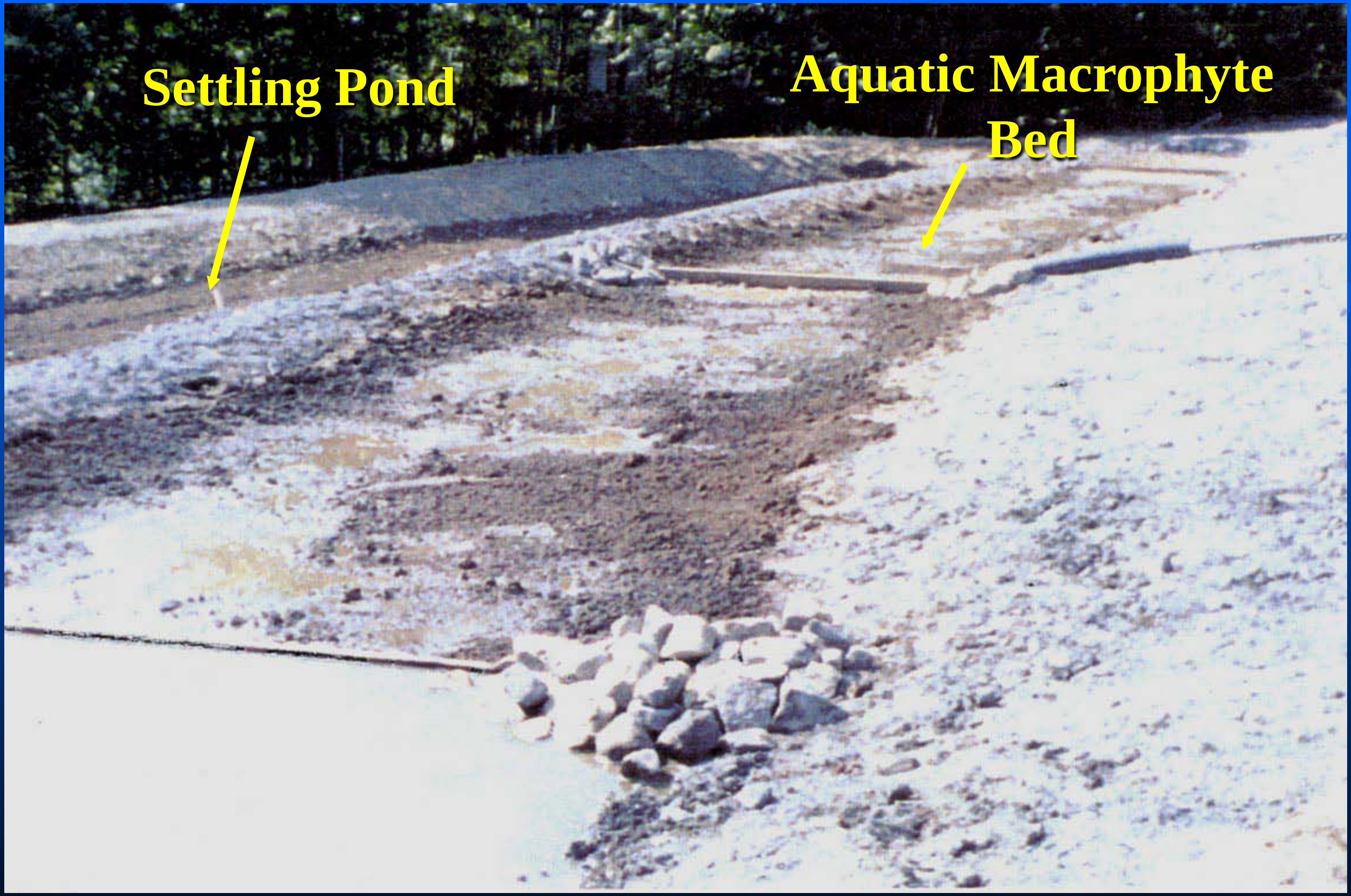
Under-drain system during construction
***Utilized in capstone model design**

Full-scale Vertical Flow System

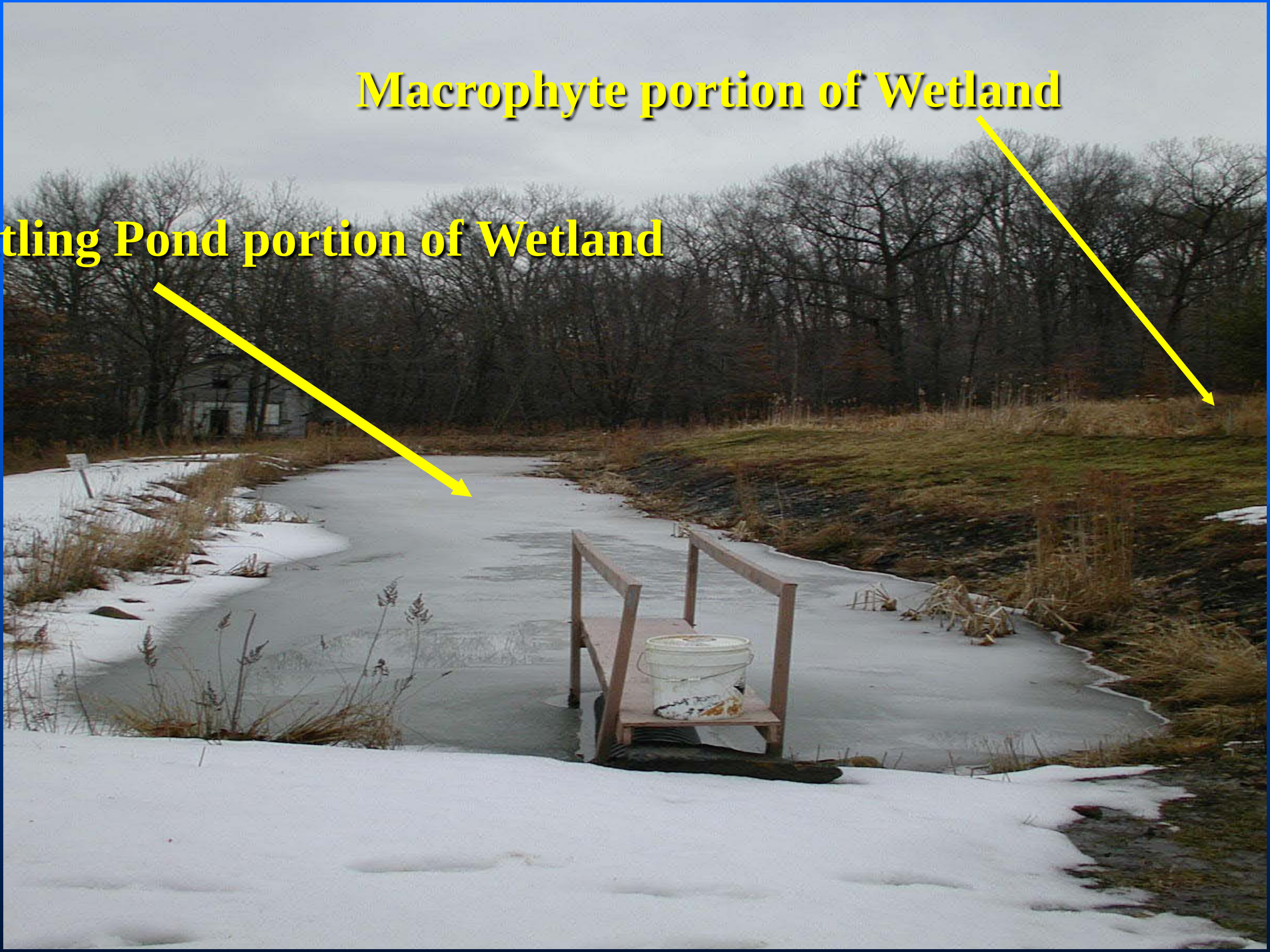
Jennings Site Overview



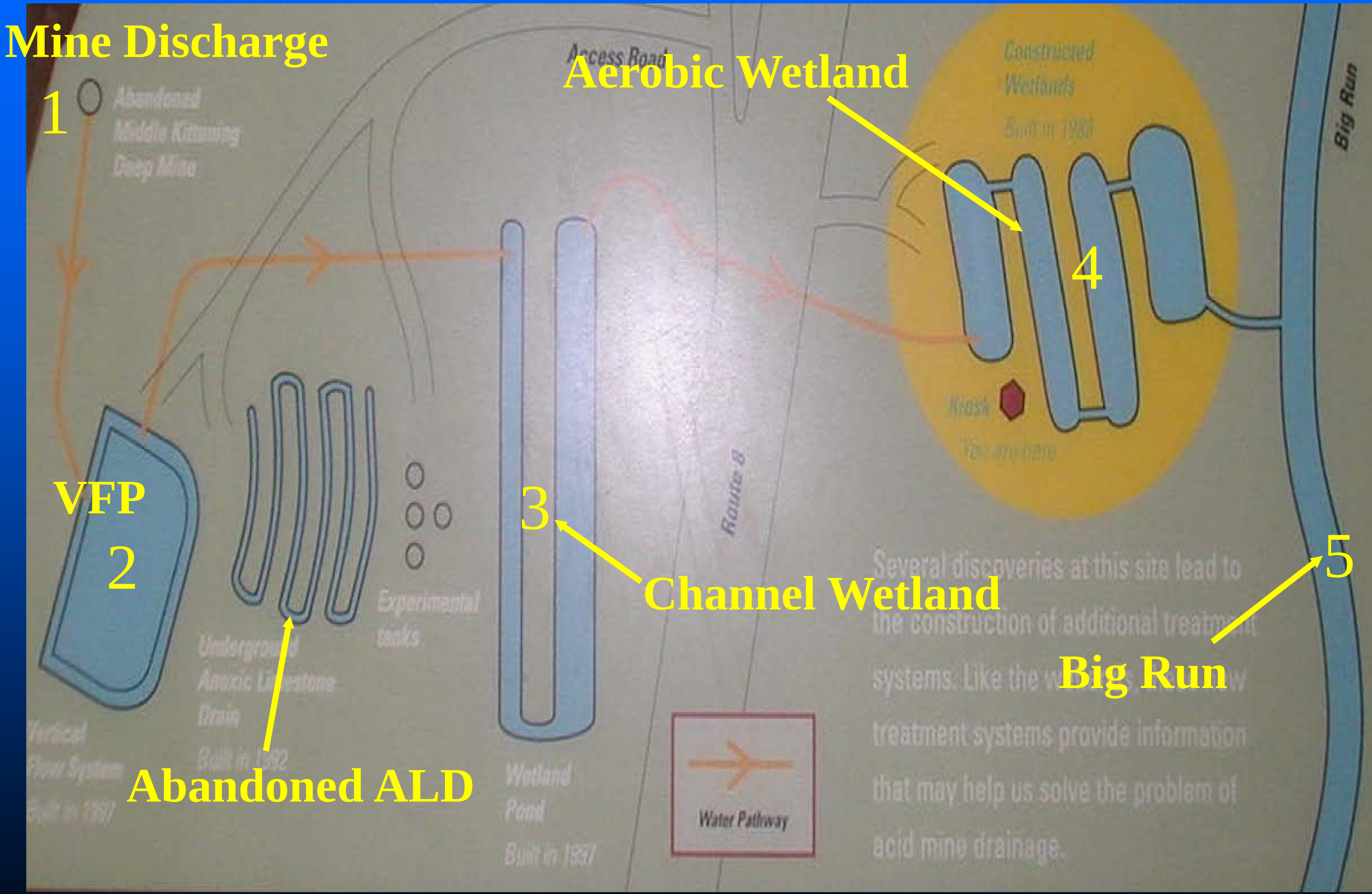
Construction of Channel Wetlands



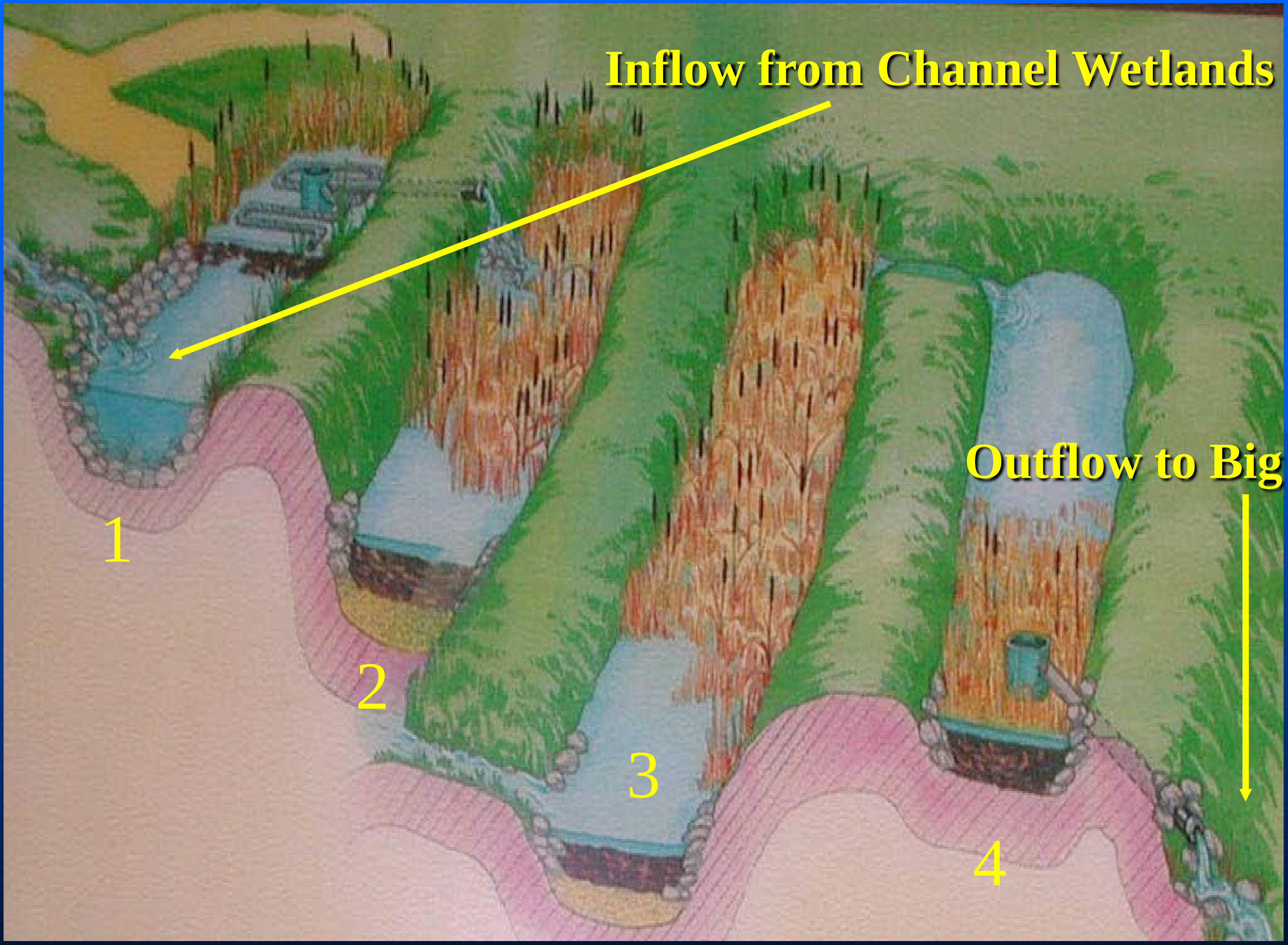
Channel Wetlands



Jennings Site Overview



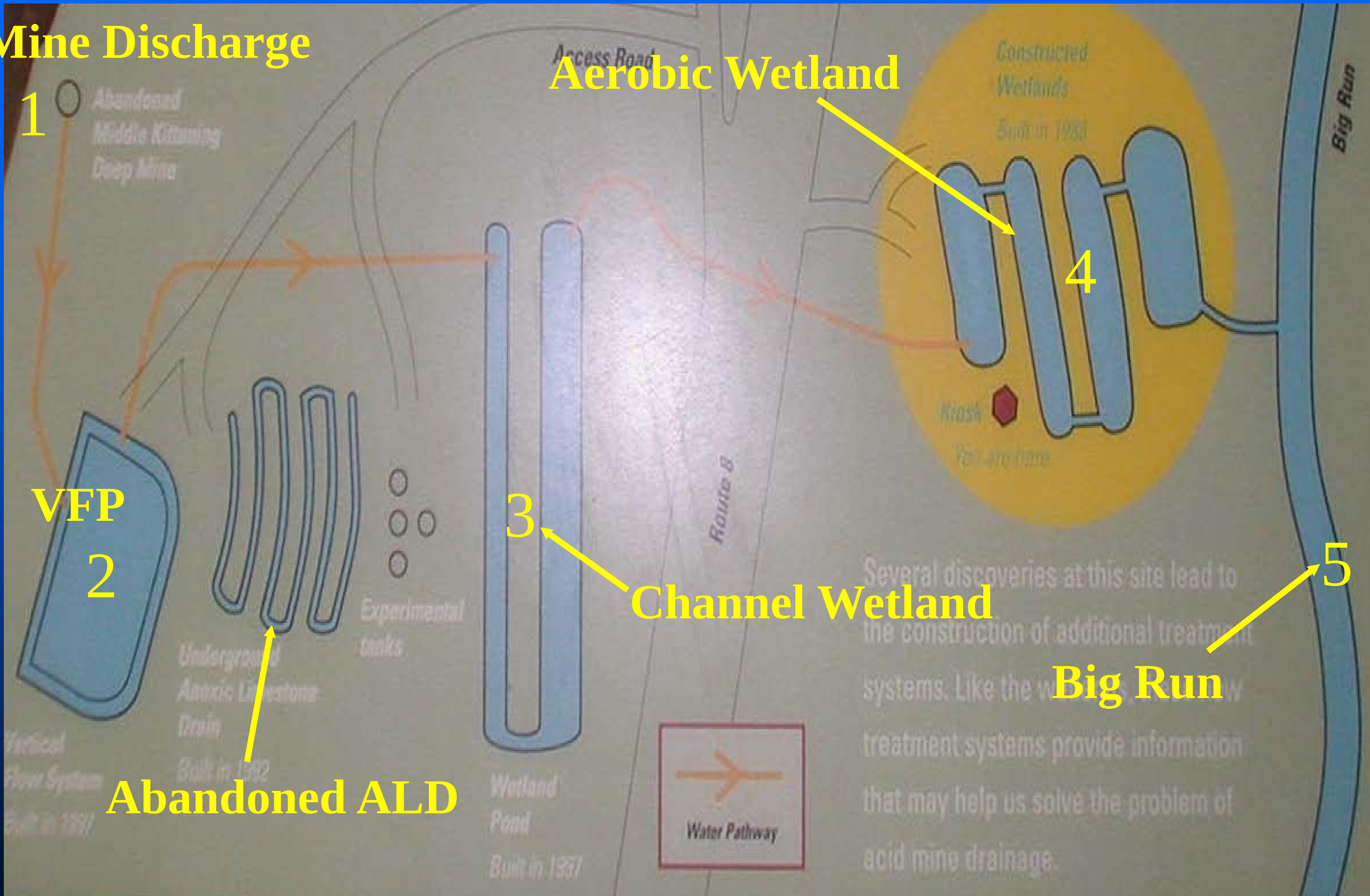
Aerobic Wetlands Model



Full-Scale Aerobic Wetlands

Treated Outflow to Big Run

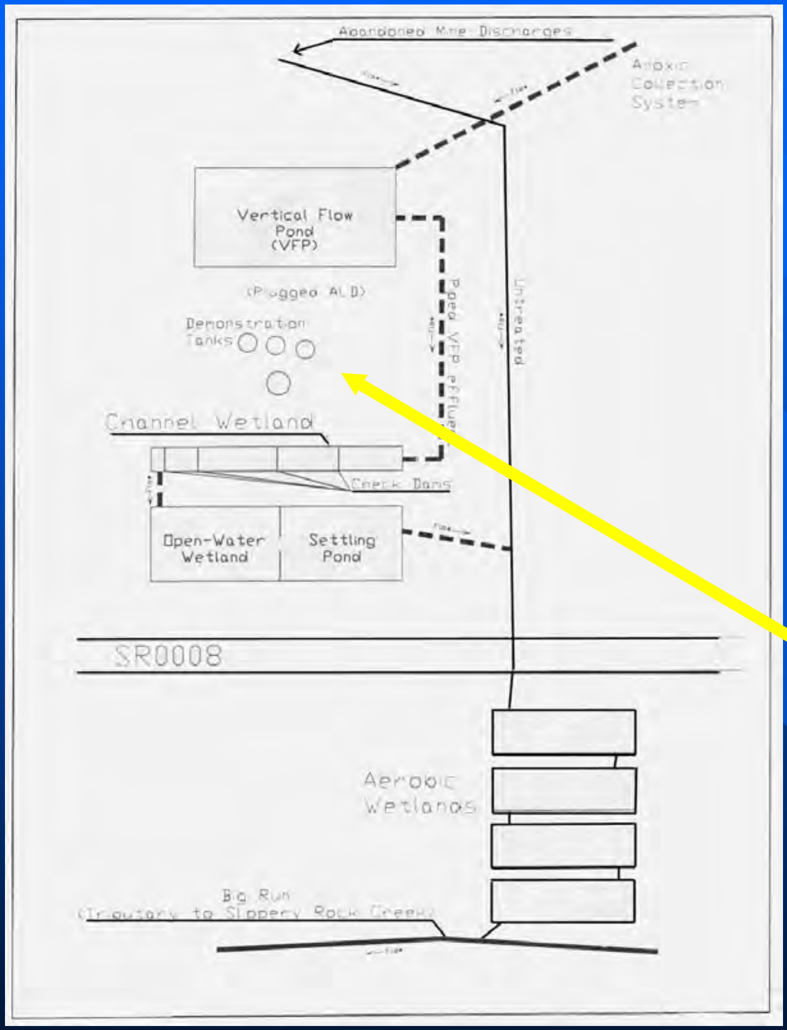
Jennings Site Overview



Project Goals

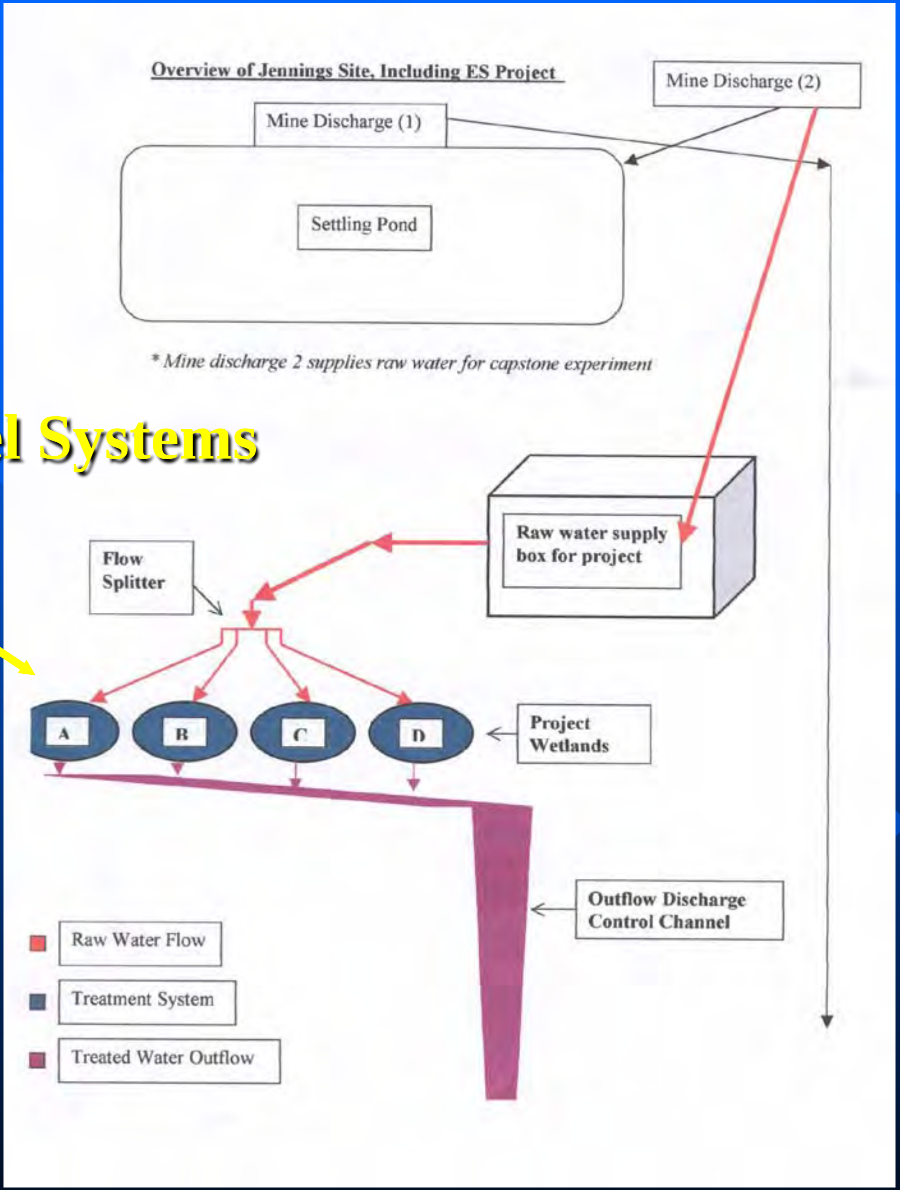
- Create two different model passive treatment systems
- Low cost system design
- Project Questions:
  - Original: Which system removes the greatest concentration of metals from the water(Fe, Al, Ni)?
  - Alternate: Which system retains the greatest concentration of metals in the water(Fe, Al, Ni)?

Project Design and Construction

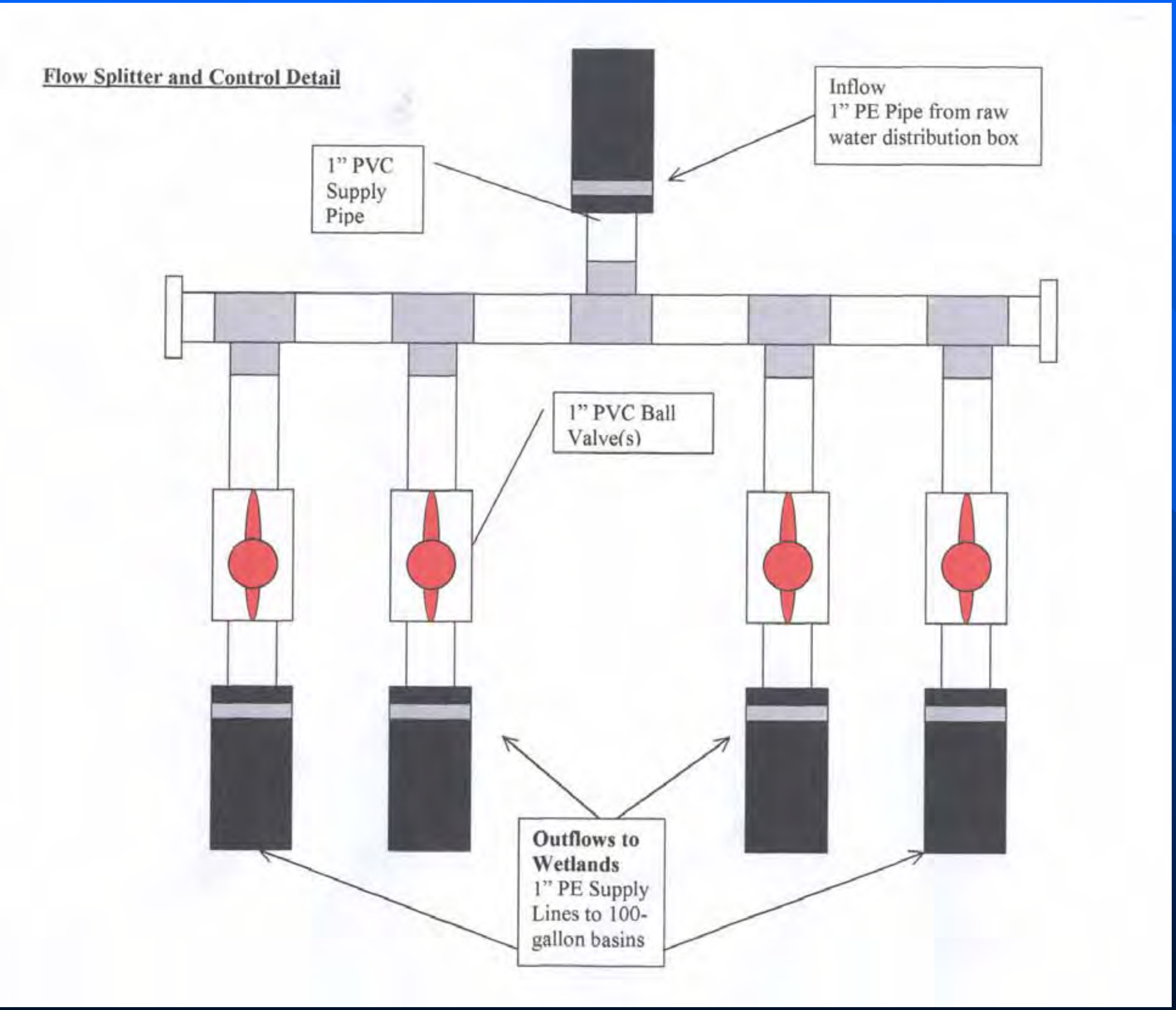


Conceptual View of Model Systems

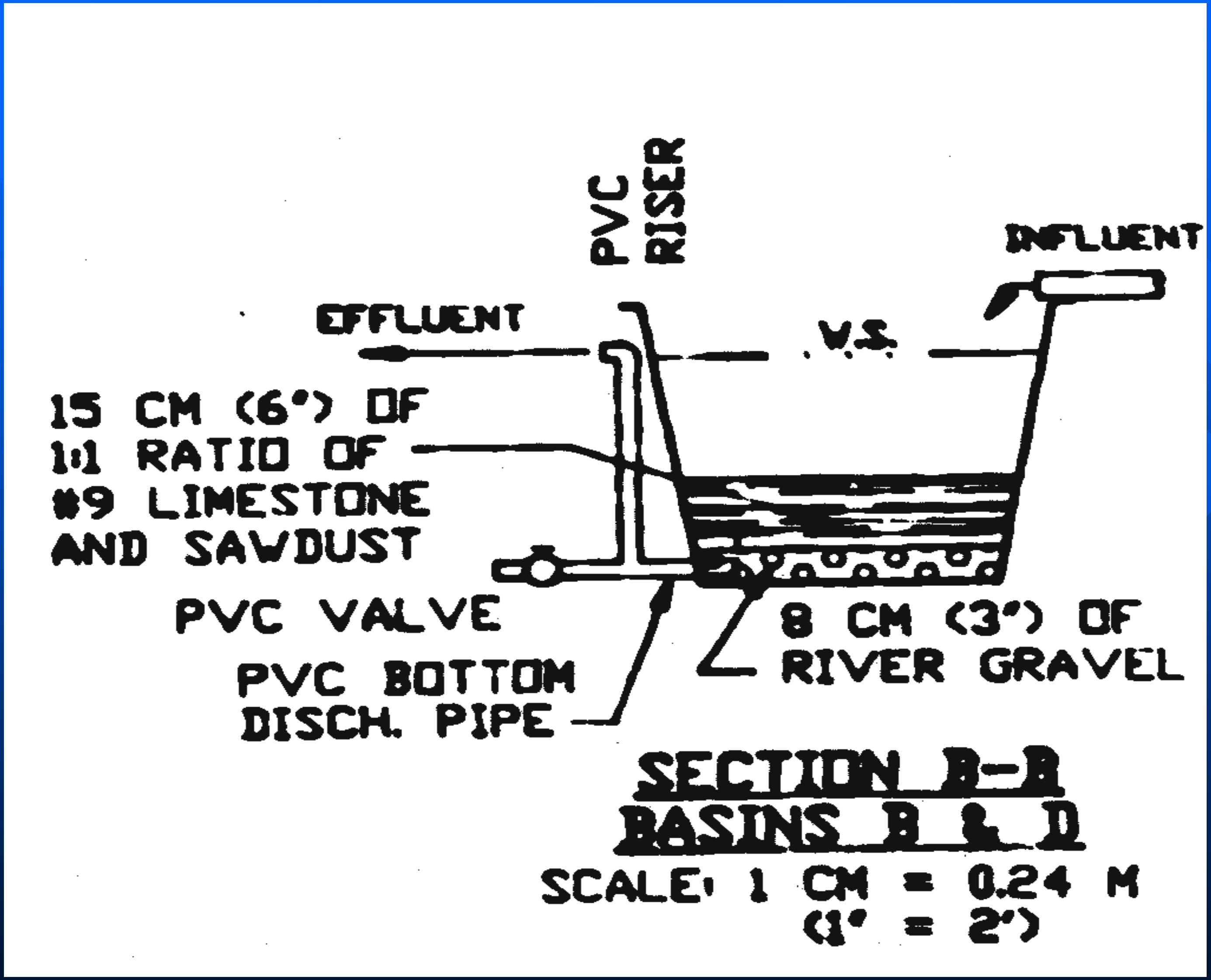
Capstone Model Systems



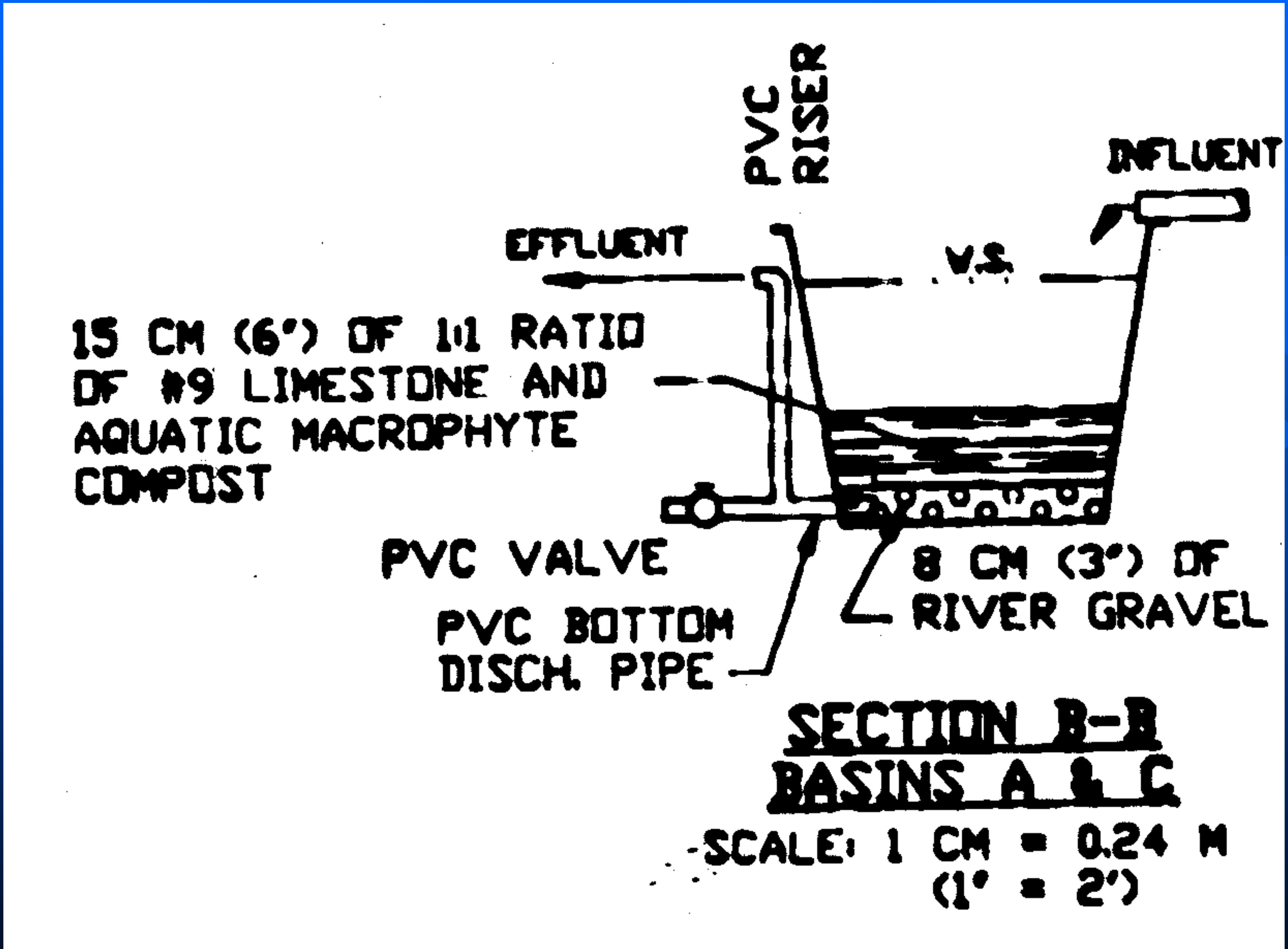
Flow Splitter Box



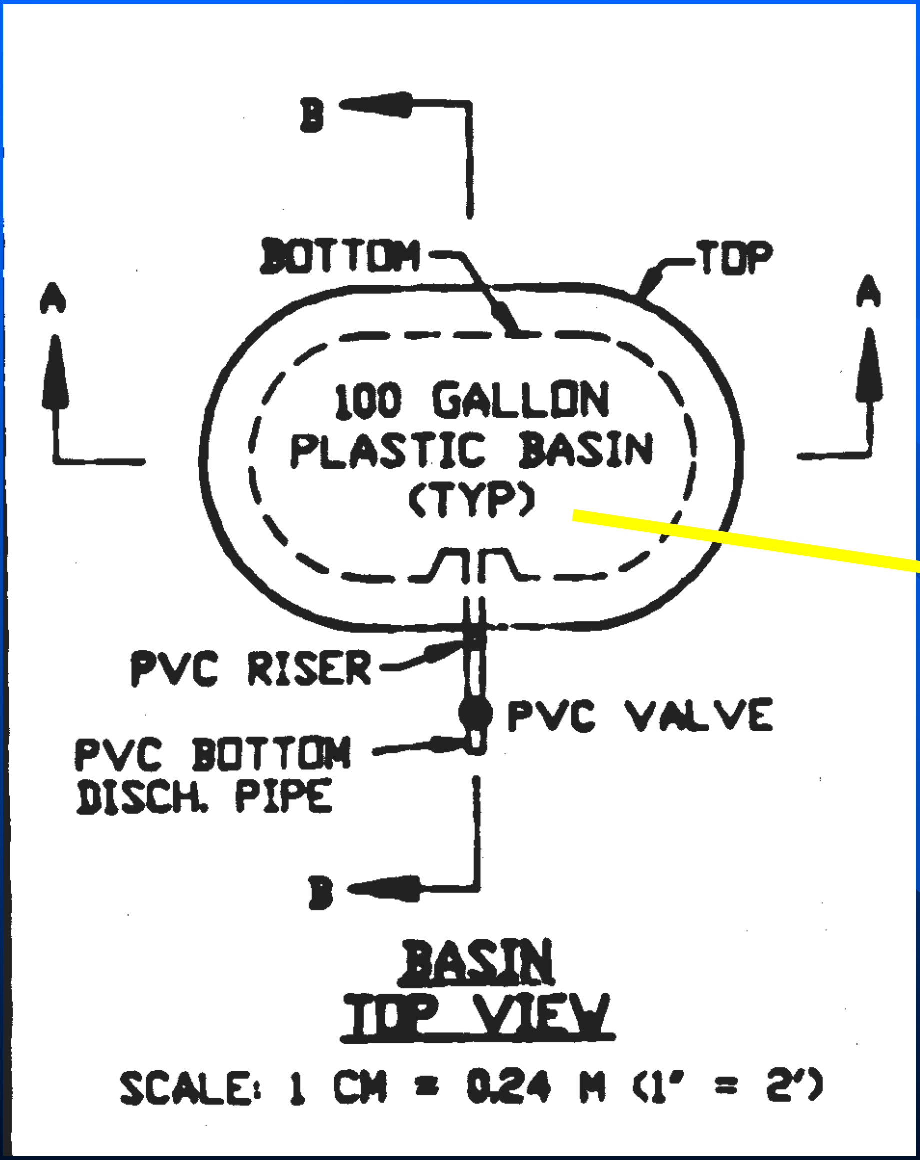
Cutaway of Sawdust Model System



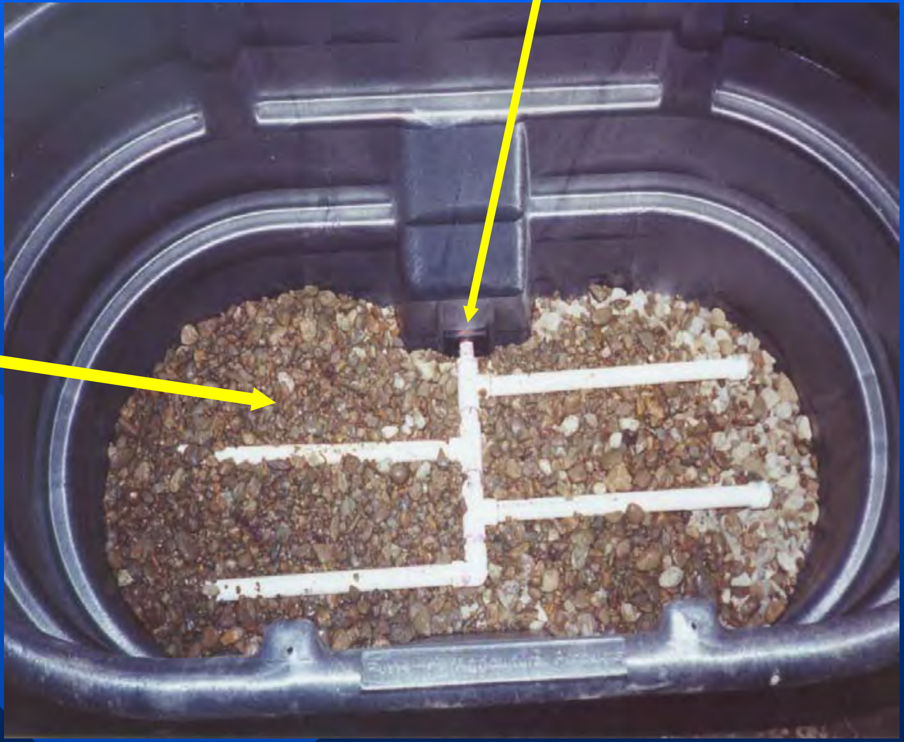
Cutaway of Macrophyte Model



Drain Detail



Outlet to PVC Riser



Installing Treatment Media

24-hour Sampling

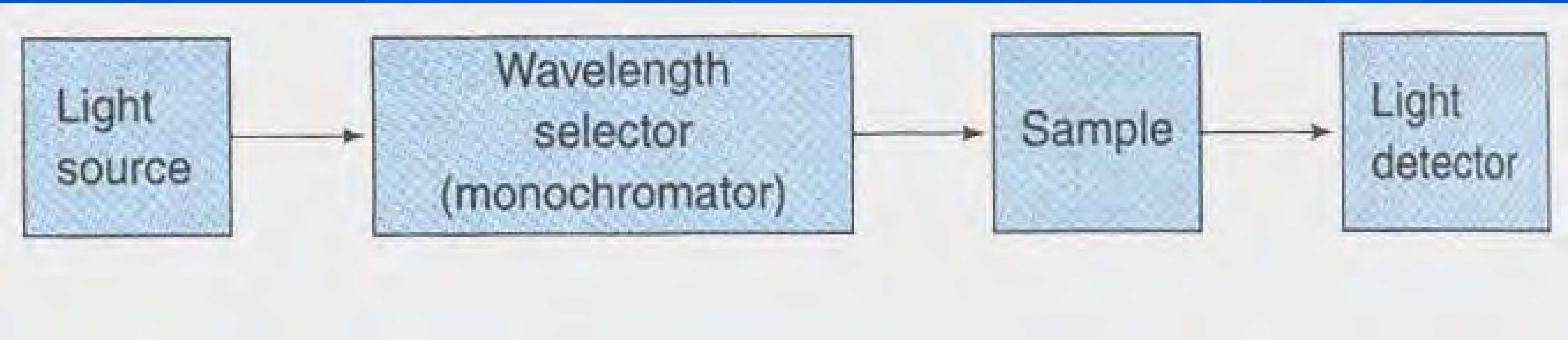
Weekly Sampling

Sample Preparation

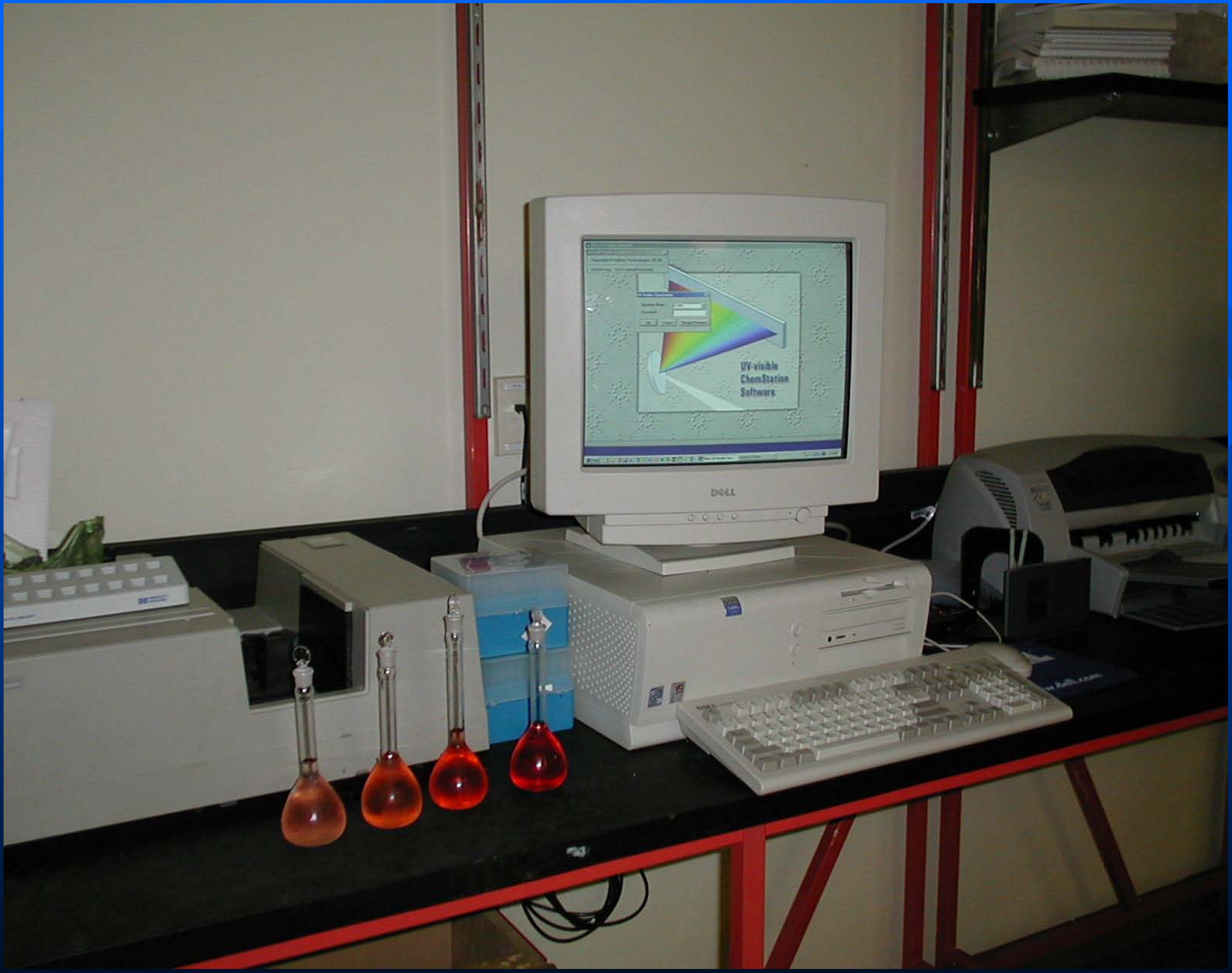
- Acidify each sample to pH<2
- Vacuum filter
- Randomize

Iron Analysis

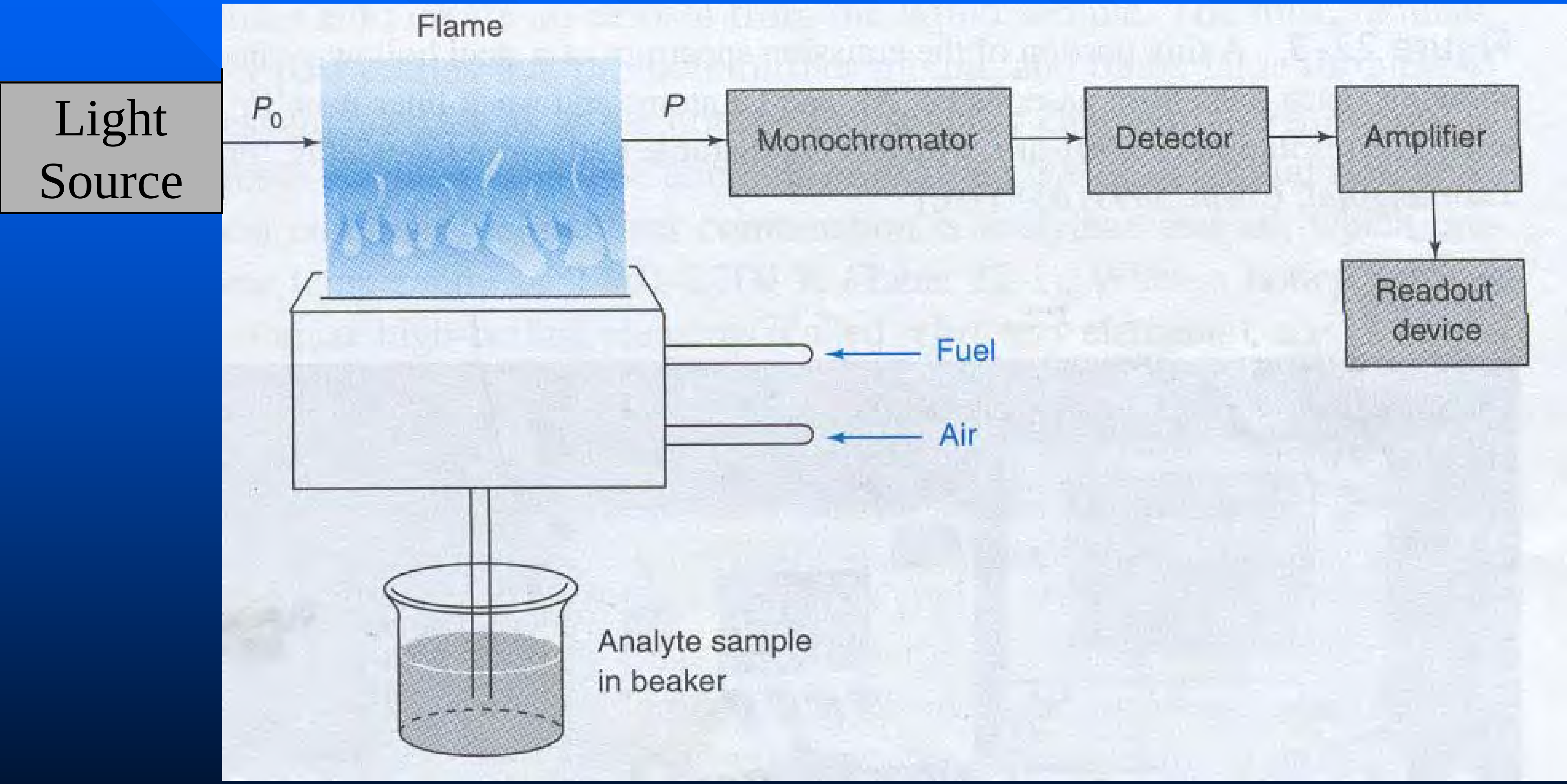
UV/Vis Spectroscopy



UV/Vis Spectrophotometer



Atomic Absorption



Nickel and Aluminum Analysis

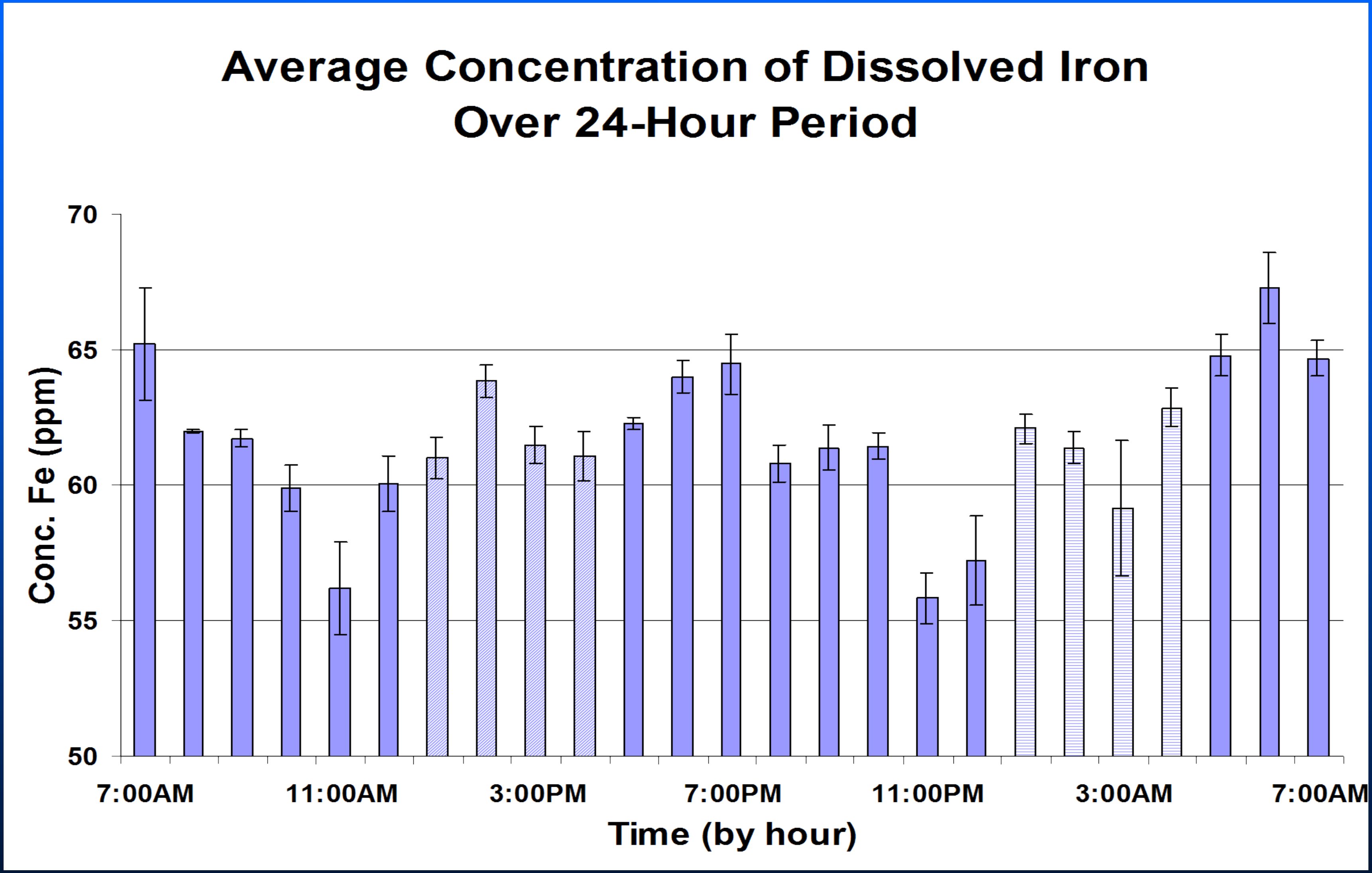
Quality Control

- Method Blanks
- Field Blanks
- Calibration Blanks
- Recalibrate Standard Curve

Results

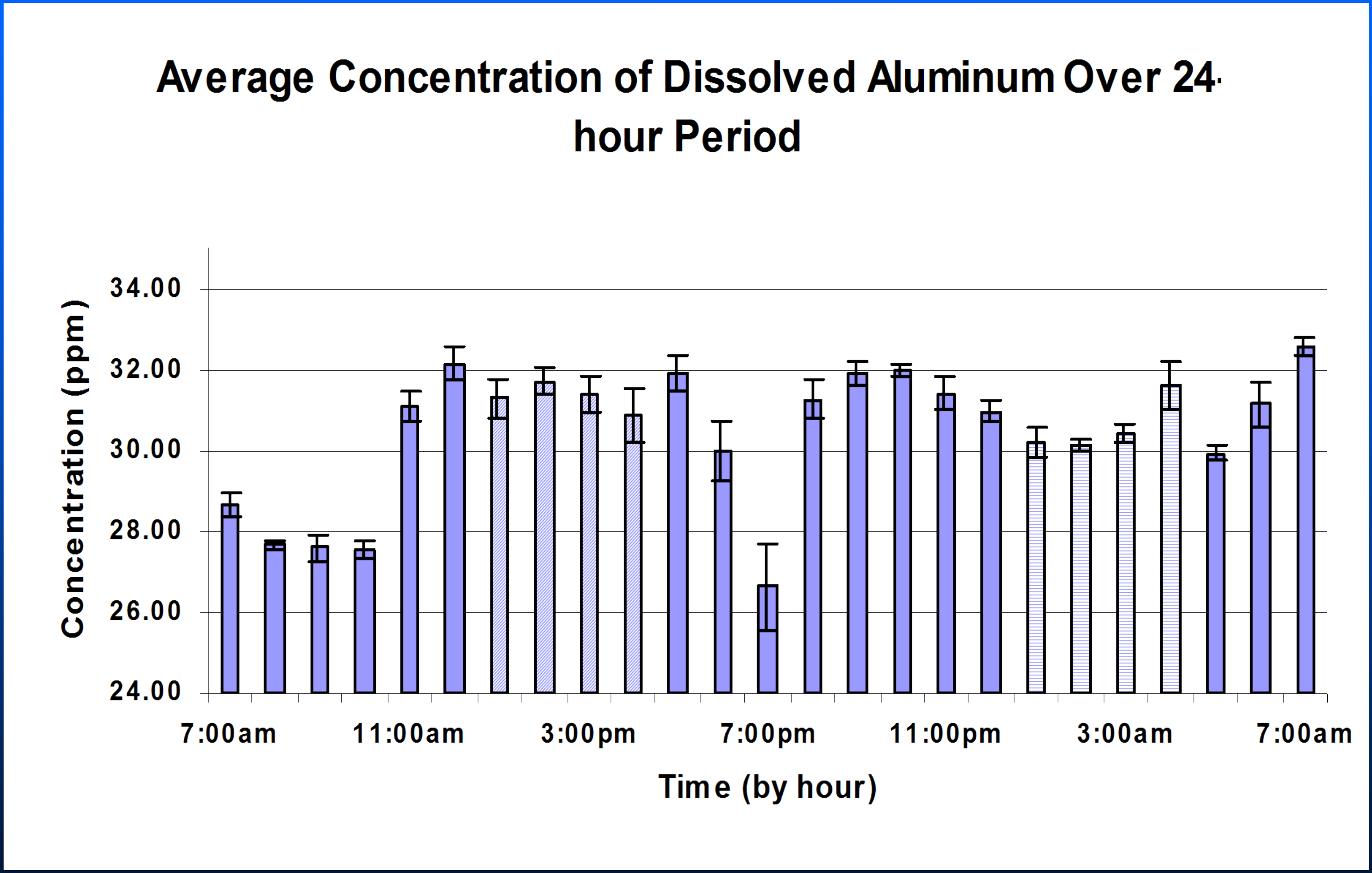
24-Hour Study

Iron

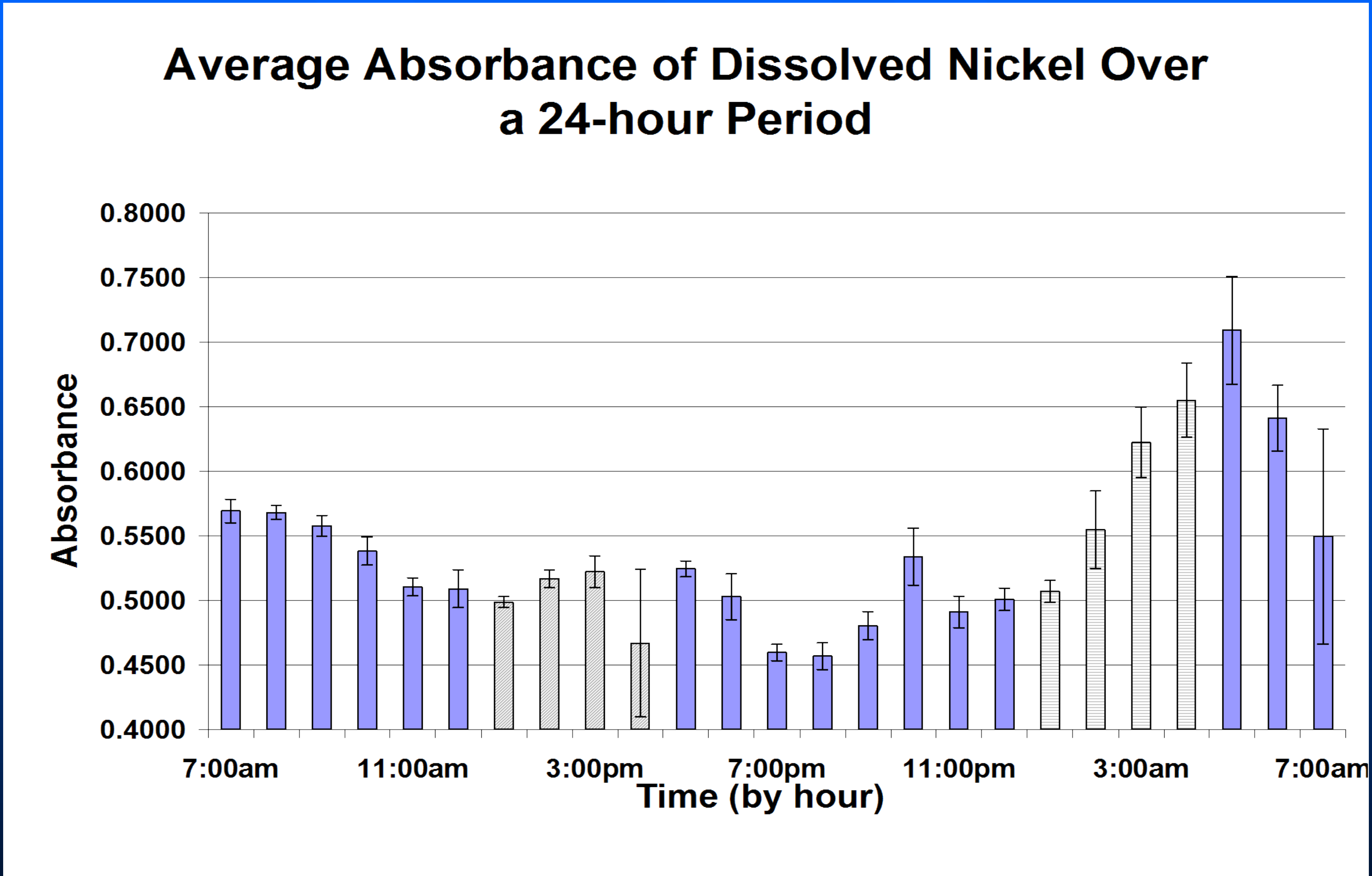


Average Concentration of Dissolved Iron
Over 24-Hour Period
70
65
60
55
50
Conc. Fe (ppm)
7:00AM
11:00AM
3:00PM
7:00PM
11:00PM
3:00AM
7:00AM
Time (by hour)

Aluminum


Average Concentration of Dissolved Aluminum Over 24-hour Period
Concentration (ppm)
34.00
32.00
30.00
28.00
26.00
24.00
7:00am
11:00am
3:00pm
7:00pm
11:00pm
3:00am
7:00am
Time (by hour)

Nickel

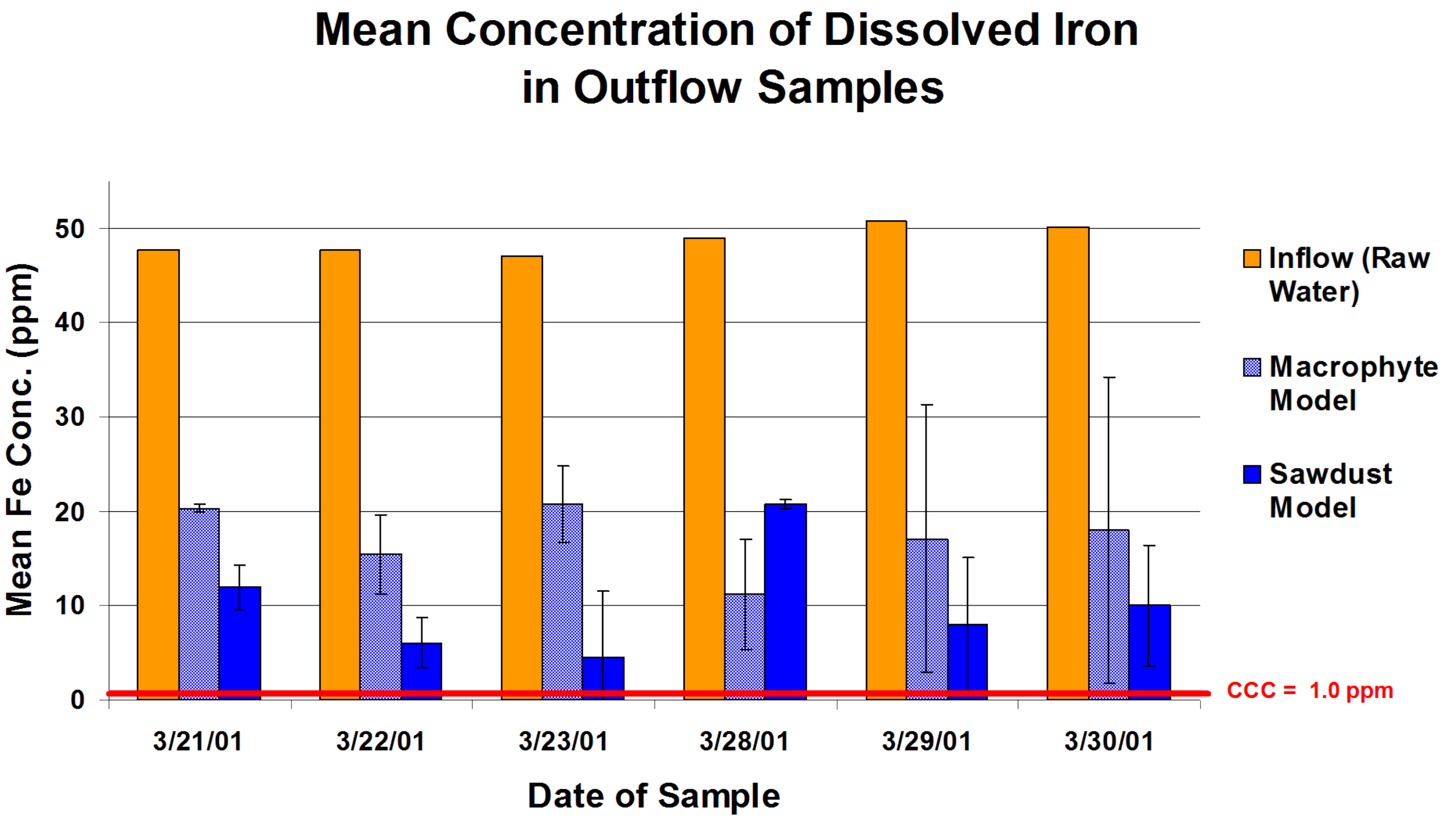


Average Absorbance of Dissolved Nickel Over a 24-hour Period
0.8000
0.7500
0.7000
0.6500
0.6000
0.5500
0.5000
0.4500
0.4000
Absorbance
7:00am
11:00am
3:00pm
7:00pm
11:00pm
3:00am
7:00am
Time (by hour)

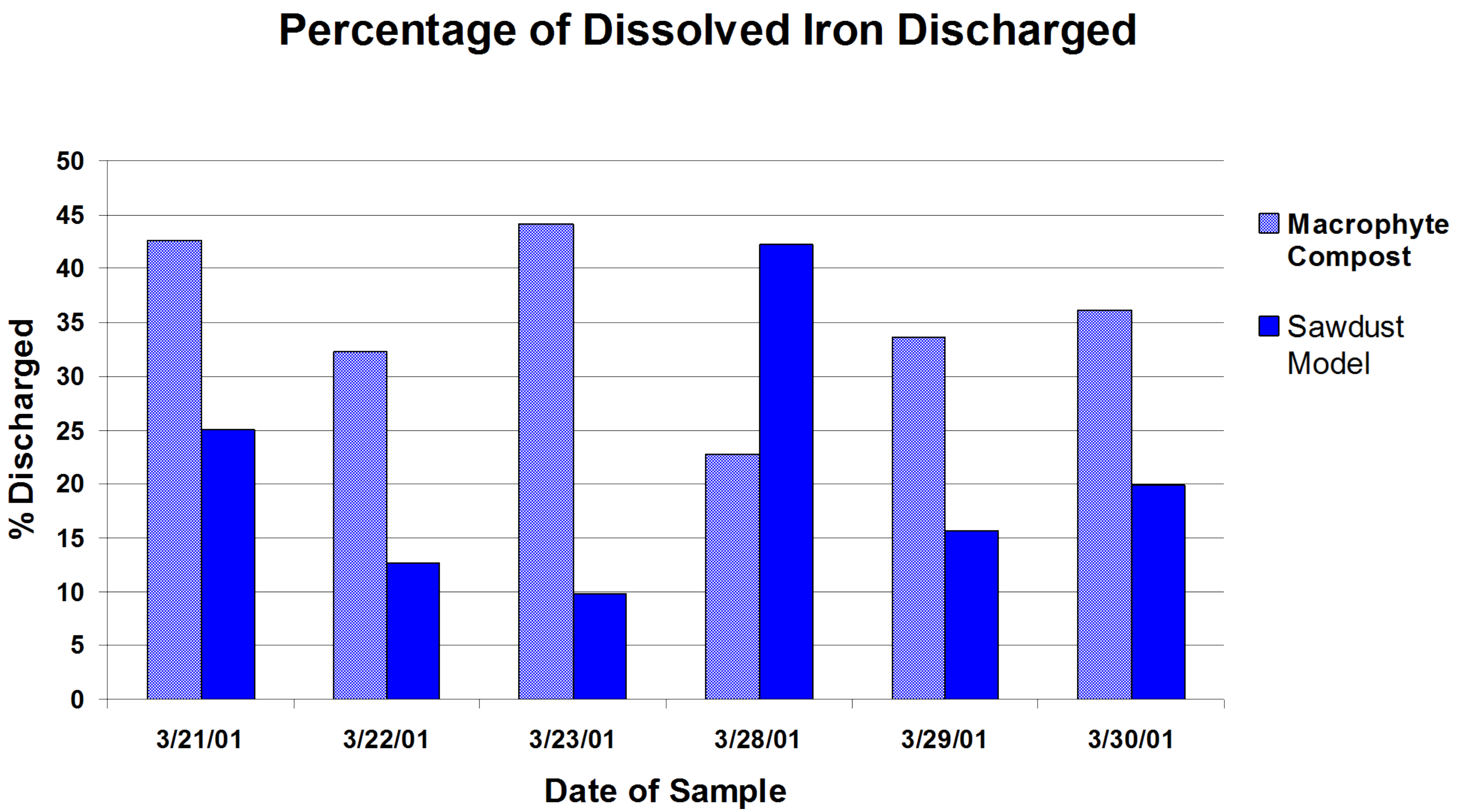
Results

2-Week Study

Iron

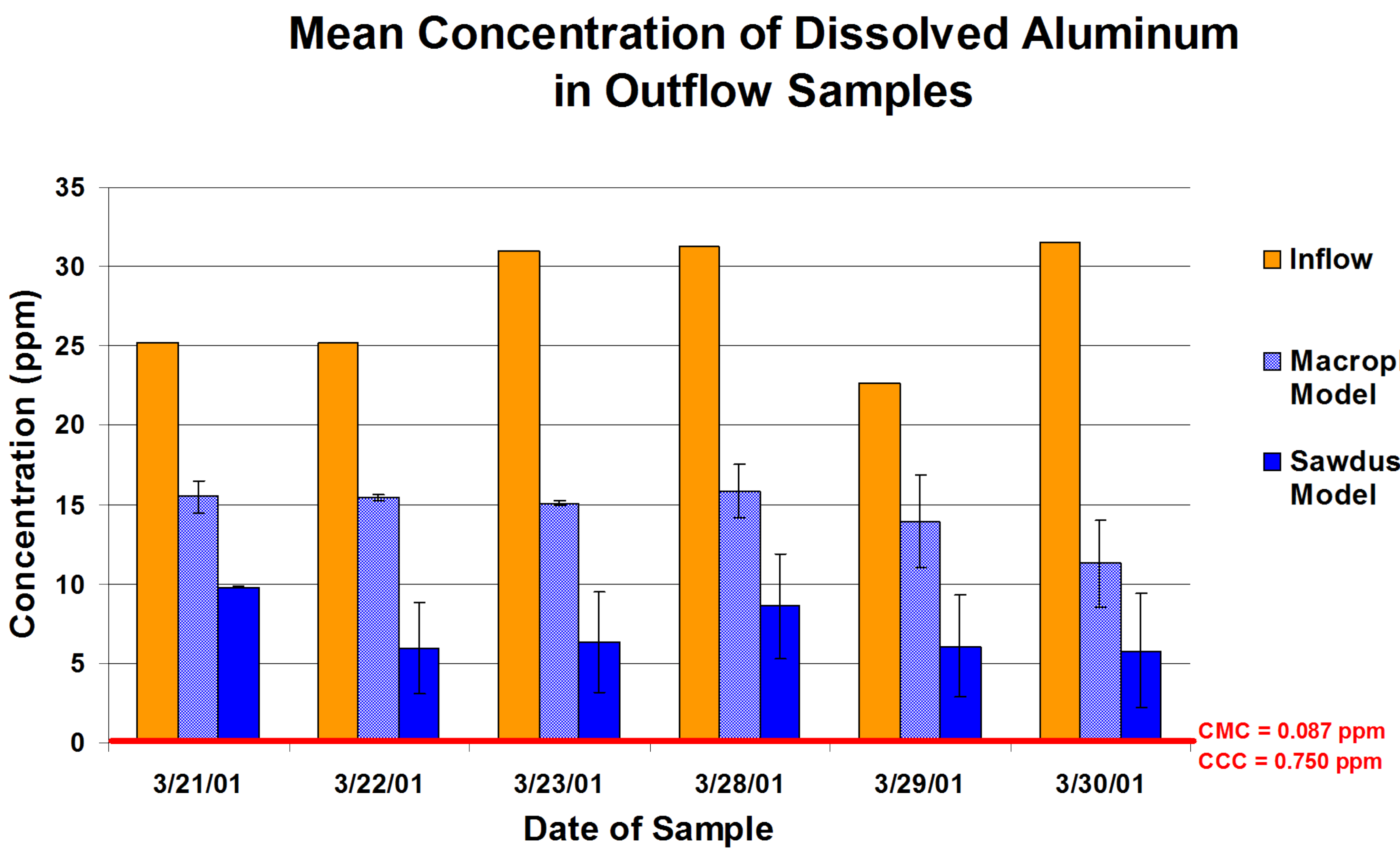

Mean Concentration of Dissolved Iron
in Outflow Samples
Mean Fe Conc. (ppm)
0
10
20
30
40
50
3/21/01
3/22/01
3/23/01
3/28/01
3/29/01
3/30/01
Date of Sample
Inflow (Raw Water)
Macrophyte Model
Sawdust Model
CCC = 1.0 ppm

Iron



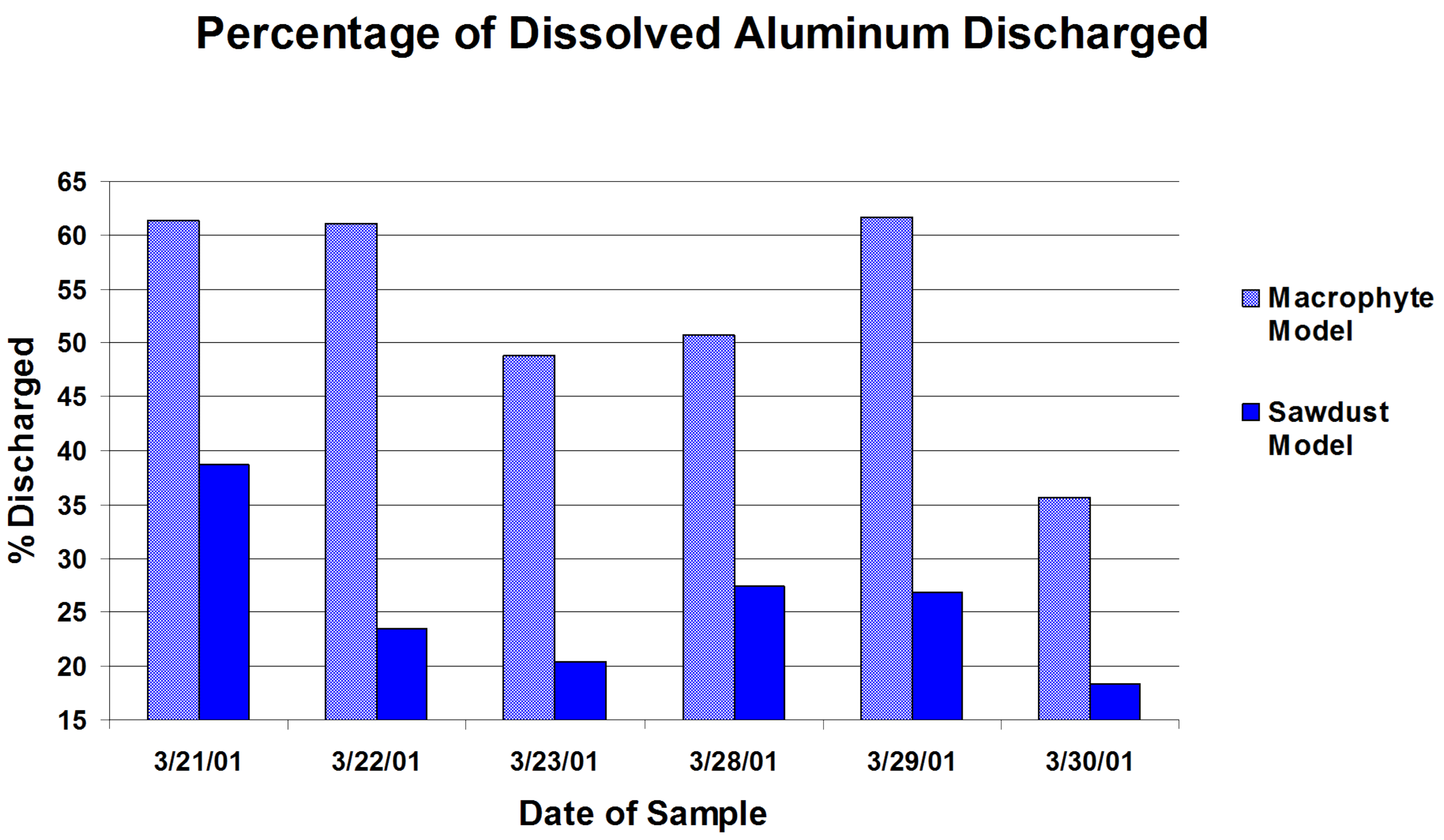
Percentage of Dissolved Iron Discharged
50
45
40
35
30
25
20
15
10
5
0
% Discharged
3/21/01
3/22/01
3/23/01
3/28/01
3/29/01
3/30/01
Date of Sample
Macrophyte Compost
Sawdust Model

Aluminum



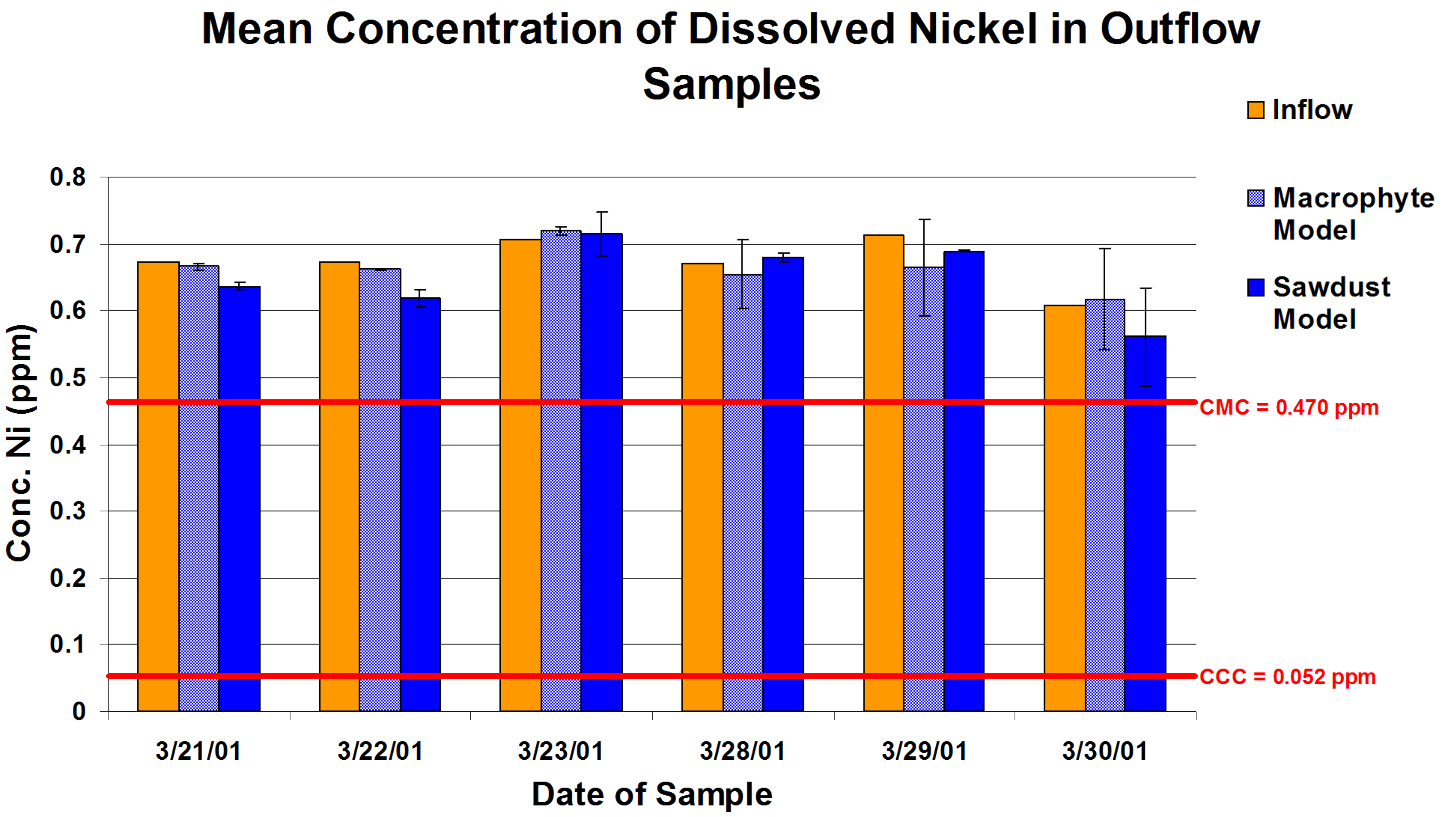
Mean Concentration of Dissolved Aluminum
in Outflow Samples
35
30
25
20
15
10
5
0
Concentration (ppm)
3/21/01
3/22/01
3/23/01
3/28/01
3/29/01
3/30/01
Date of Sample
Inflow
Macrophyte Model
Sawdust Model
CMC = 0.087 ppm
CCC = 0.750 ppm

Aluminum



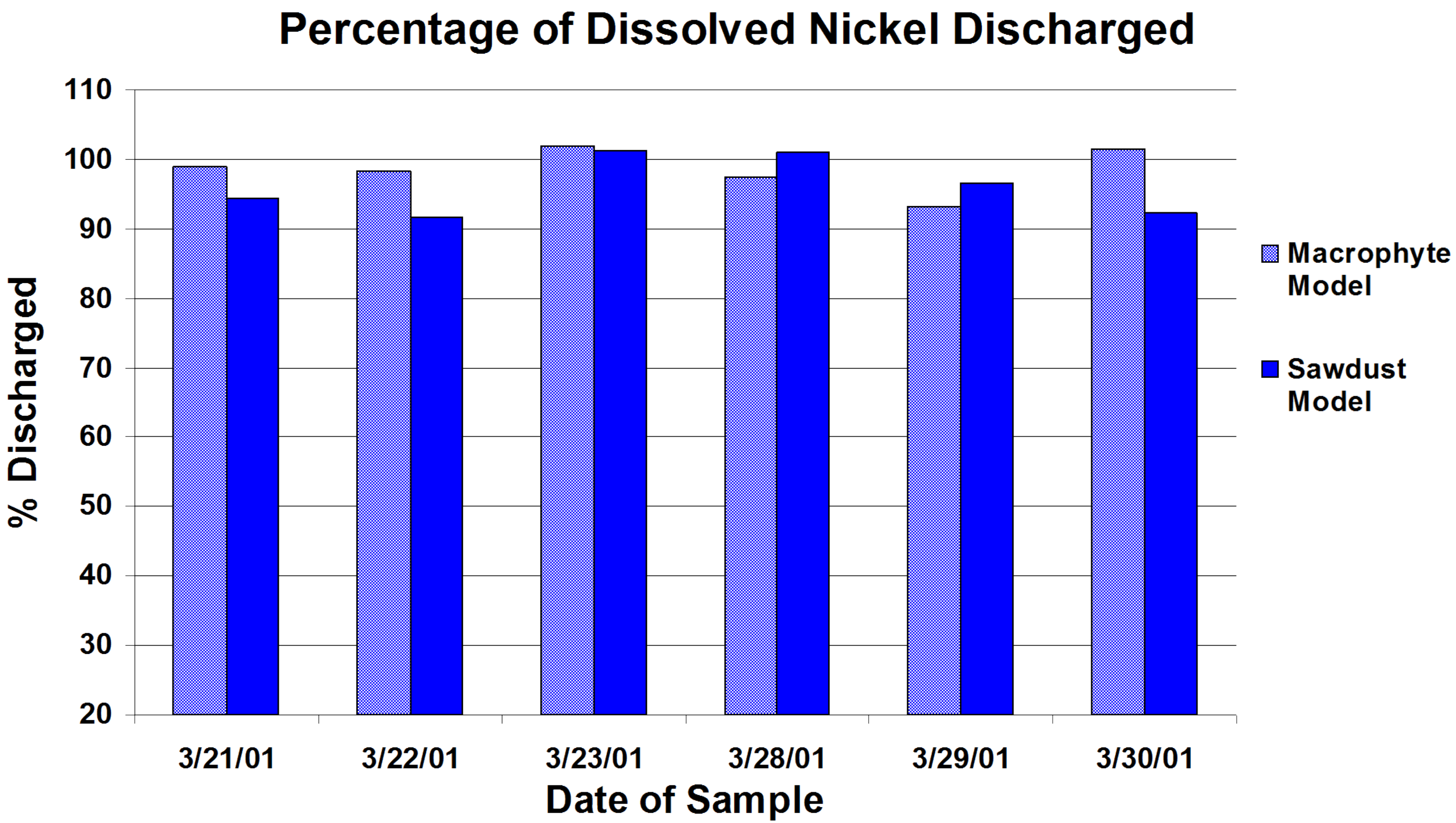
Percentage of Dissolved Aluminum Discharged
65
60
55
50
45
40
35
30
25
20
15
% Discharged
3/21/01
3/22/01
3/23/01
3/28/01
3/29/01
3/30/01
Date of Sample
Macrophyte Model
Sawdust Model

Nickel



Mean Concentration of Dissolved Nickel in Outflow Samples
Inflow
Macrophyte Model
Sawdust Model
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Conc. Ni (ppm)
CMC = 0.470 ppm
CCC = 0.052 ppm
3/21/01
3/22/01
3/23/01
3/28/01
3/29/01
3/30/01
Date of Sample

Nickel


Percentage of Dissolved Nickel Discharged
% Discharged
110
100
90
80
70
60
50
40
30
20
3/21/01
3/22/01
3/23/01
3/28/01
3/29/01
3/30/01
Date of Sample
Macrophyte Model
Sawdust Model

Discussion

Reflection on Project Goals

- Revising our project question and goals:
  - » New Information
  - » Alternate Question: Which system retains the greatest concentration of metals in the water(Fe, Al, Ni)?

- Who benefits?
  - » Community importance & cost
  - » Relevance beyond AMD
  - » Basis for future research

Comparison of Models

- Macrophyte Model:
  - Discharges high metal concentrations
  - Lower maintenance
- Sawdust Model:
  - Discharges low metal concentrations
    - » System expected to fail rapidly
    - » Higher maintenance

Conclusion

- Relative Performance:
  - Overall macrophyte model prevails
  - Why this outcome?
    - » Porosity characteristics of macrophyte media
      - Contact with media
    - » Macrophyte media and microbes
      - Anoxia
      - Encouraging metals reduction

Are the Systems Really Different?

- Ocular Analysis
  - Differences arise
  - Macrophyte system prevails

- Statistical Analysis
  - Statistically indistinguishable
  - Function of sample size
  - Additional Replication
    - » Statistical Power

Future Research

- Changes to future project design
  - Replication of model systems
  - Duration of outflow sampling
  - Additional 24-hour inflow sampling
  - Monitor alkalinity
  - Improved flow control

Thank You

Jennings Environmental Education Center

Slippery Rock Watershed Coalition

Stream Water Restorations Inc.

CDS Associates

Our Advisors: Dr. Balczon and Dr. Wooster

ES Committee

Full-Scale Vertical Flow Pond

Description

A full-scale Vertical Flow Pond (aka Vertical Flow System) was placed on-line in September 1997. This facility was funded through a US EPA FY96 Section 319 grant as Project 18 and through extensive in-kind contributions provided by a public-private partnership effort. This innovative facility was installed as a demonstration system for passive treatment technology which was included in public outreach and "hands-on" environmental education programs.

As identified in the Project 18 final report submitted in 1999, this demonstration facility has been extremely successful not only in treating the dissolved aluminum-bearing abandoned mine drainage, previously considered untreatable by passive methods, but also in expanding both public and private participation in the continuing development of passive technology and watershed restoration activities.

One of the "outgrowth" projects was installing pilot-scale systems to further develop passive treatment technology at this outdoor demonstration site. The pilot-scale systems developed under the current EPA 319 grant was an expansion of these "outgrowth" projects.

"As-Builts", a detailed narrative, and water monitoring through 4/1999 by the PA DEP, Knox District Mining Office and US Department of Energy are provided in the Final Report for the full-scale system. (See attached list of reports.) The "Vertical Flow Pond Fact Sheet" and a sketch "As-built" for the Vertical Flow Pond are attached.

Average values listed below include the analyses used in the 1999 Final Report and additional influent and effluent analyses attached to this report.

Point	Flow (gpm)	pH	alkalinity (mg/l)	acidity (mg/l)	T. Fe (mg/l)	T. Mn (mg/l)	T. Al (mg/l)
VFP influent	--------	3.2	0	287	48	15	17
VFP effluent	22	6.6	183	-164	9	14	<1

Influent: $n_{(pH, alkalinity, acidity)} = 64$; $n_{(Fe, Mn)} = 70$; $n_{(Al)} = 69$; Effluent: $n_{(flow)} = 78$; $n_{(chemical\ parameters)} = 59$ (average pH not determined from H^+ concentration)

Also included in the 1999 Final Report are analyses of selected heavy metals. The average values are listed below.

Point	Zn (*u*g/l)	Ni (*u*g/l)	Co (*u*g/l)
VFP influent	870	610	310
VFP effluent	40	40	50

n = 7 (09/97 thru 04/99)

Findings

The analyses for the standard mining parameters represent four years of operation from September 1997 through September 2001. The most recent analyses demonstrate that the VFP continues to successfully treat the abandoned mine drainage. The net alkaline effluent currently has a 6.6 pH, about 100 mg/l alkalinity, 12 mg/l total iron, 14 mg/l total manganese, and essentially no aluminum.

Zinc, nickel, and cobalt concentrations were also observed to be consistently and substantially decreased by the full-scale Vertical Flow Pond. The mechanism for removal is unknown.

As an “outgrowth” project of the previous and current grants, the forms and quantities of metals retained in the treatment media of the VFP are being determined by Slippery Rock University. Permeability has been decreasing and the retention of metal solids is thought to be responsible, at least in part, for this observation.

JENNINGS WATER QUALITY IMPROVEMENT COALITION

c/o Stream Restoration, Inc. e-mail at sri@salsgiver.com

VERTICAL FLOW POND FACT SHEET

Jennings Environmental Education Center, PA DCNR, Bureau of State Parks
Brady Township, Butler County, PA

"A Public-Private Partnership Effort"

FUNDING SOURCE:

US Environmental Protection Agency Fiscal Year 1996 Section 319 grant through the PA Department of Environmental Protection Bureau of Land and Water Conservation and through the generous contributions by private industry and volunteers.

PROJECT PARTICIPANTS:

Hedin Environmental
CDS Associates, Inc.
Girl Scouts
Jesteadt Excavating
Slippery Rock University
Quality Aggregates Inc.
Stream Restoration Inc.
Jennings Environmental Ed. Center
Grove City College
Homeschool Students
PA Bureau of District Mining Ops.(Knox)
Shaliston Trucking
Amerikohl Mining, Inc.
U. S. Department of Energy

COMPLETION DATE:

Major construction completed September 1997
Water Monitoring: PA DEP Knox DMO (9/97 thru 4/99), CDS Associates, Inc. (on-going)

MATERIALS USED FOR TREATMENT:

300 Tons of Spent Mushroom Compost mixed with 380 Tons of AASHTO# 9 Special, 90%CCE, limestone aggregate (2½-foot layer).

WATER COLLECTION AND DISTRIBUTION:

Overdrain: 2" PVC header pipe with 3/4" perforated laterals (20' in length) every 6 feet fed by three 2" inlet pipes from flow splitter box. The overdrain is on top of the media below a 1½-foot " water cap". Flow splitter box plumbed into anoxic collection system.

Underdrain: Three sections of 2" PVC fed by 3/4" perforated laterals (15' in length) every 6 feet bedded in river gravel (8-inch layer).

Outlet: 4" flexible plastic pipe with clear insert for observation, adjustable to control water level.

SYSTEM DIMENSIONS (FEET):

	Length	Width	Depth
Vertical Flow System	150	50	6
Channel Wetland	175	8	<½
Wetland	100	20	½
Settling Pond	100	20	3

WATER QUALITY (representative):

Sample Point	Flow (gpm)	pH	alkalinity (mg/l)	acidity (mg/l)	Fe (mg/l)	Mn (mg/l)	Al (mg/l)
raw	30	2.9	0	260	50	8	20
treated	30	7.0	200	0	1	6	<1