Passive Treatment in Mine Remediation

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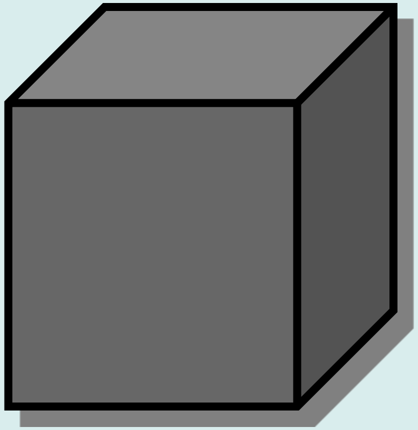
What Is Passive Treatment?

Passive treatment ≠



What Is Passive Treatment?

If it's not a Black Box, what is it ?

It's the:

- sequential
- ecological
- extraction

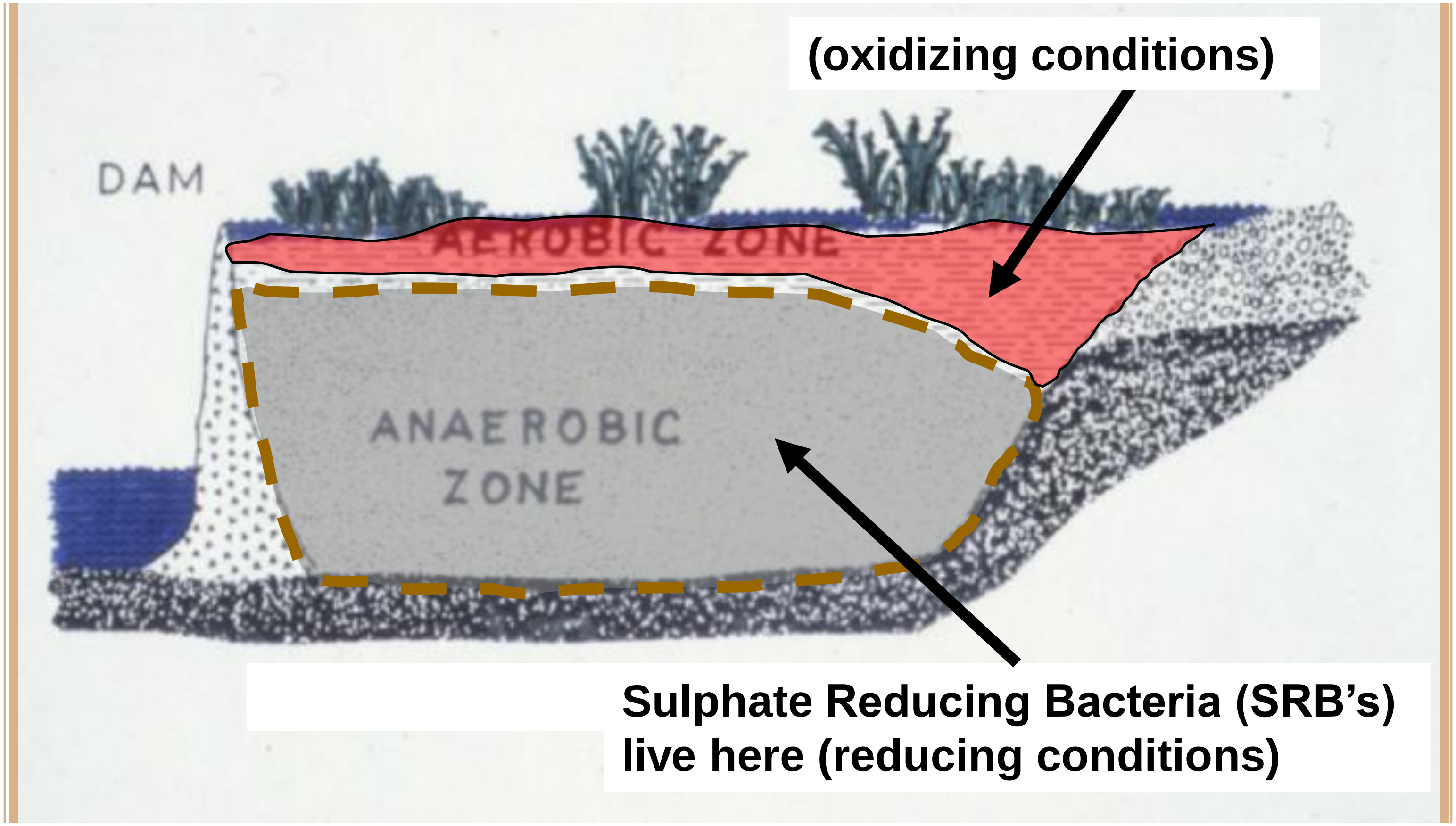
of metals in a man-made but naturalistic bio-system

Definition of Passive Treatment

Any water treatment process that:

- Utilizes common geochemical reactions typically assisted by microbes or plants,
- Does not require the addition of chemical reagents, power and/or short term exchange of process media, and
- Functions without human intervention for long periods.

Typical Wetland Ecosystem



(oxidizing conditions)

Sulphate Reducing Bacteria (SRB's) live here (reducing conditions)

Oxidation
and
Reduction
Processes
in Competition

Natural Wetland

Balances All Possible Processes

Versus

Constructed Wetland

One Process is Emphasized in Each Cell

Passive Treatment Metal Removal Mechanisms

Major

- Hydroxide and oxide precipitation
- Sulphide and carbonate precipitation via Sulphate Reducing Bacteria (SRB)
- Carbonate dissolution/neutralization

Minor

- Filtering/settling of metal precipitates
- Metal uptake into plant tissues
- Adsorption onto organic & oxide materials

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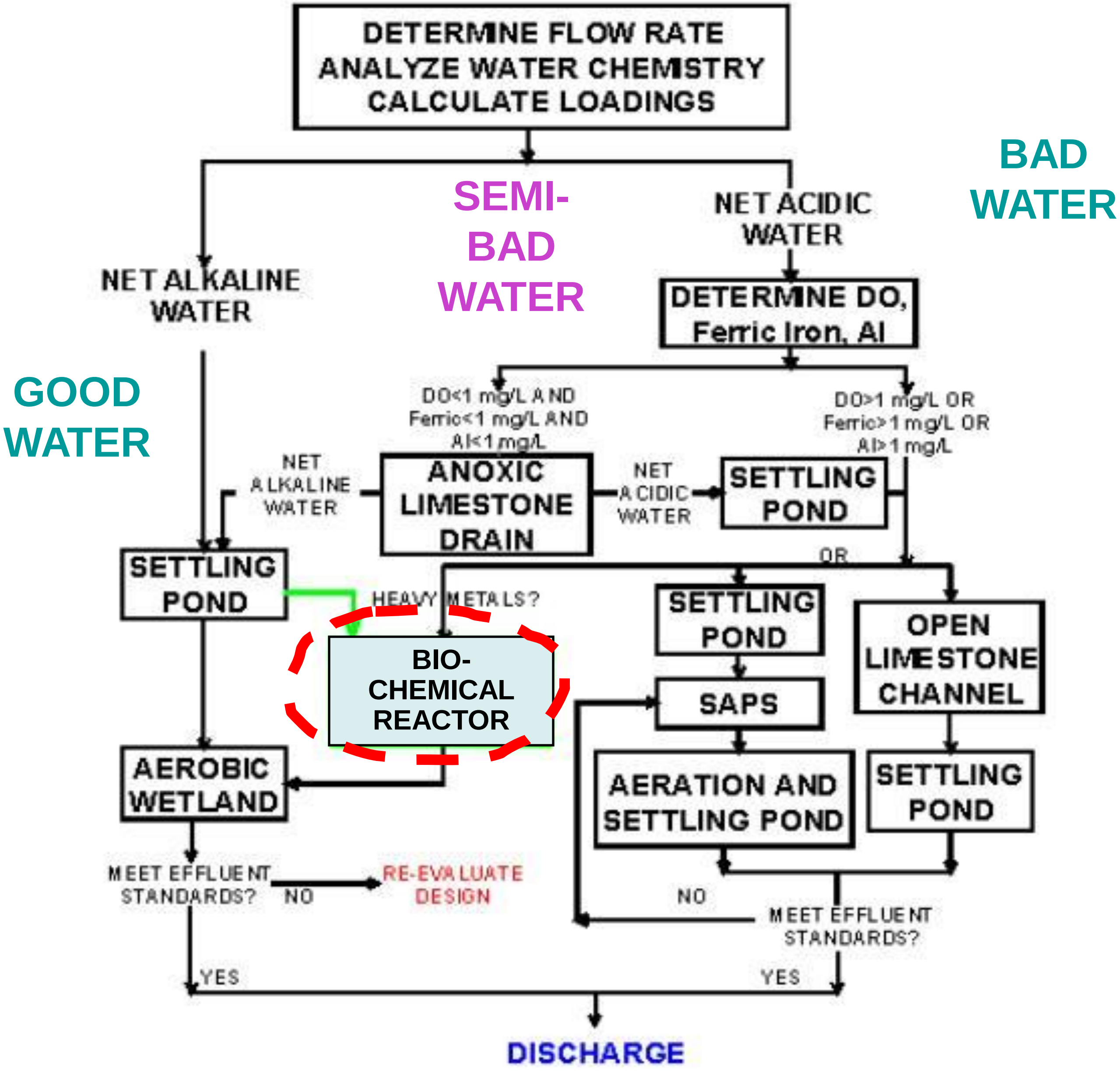


DETERMINE FLOW RATE
ANALYZE WATER CHEMISTRY
CALCULATE LOADINGS

BAD WATER

SEMI-BAD WATER

NET ACIDIC WATER

NET ALKALINE WATER

DETERMINE DO, Ferric Iron, Al

GOOD WATER

DO<1 mg/L AND Ferric<1 mg/L AND Al<1 mg/L

DO>1 mg/L OR Ferric>1 mg/L OR Al>1 mg/L

NET ALKALINE WATER

ANOXIC LIMESTONE DRAIN

NET ACIDIC WATER

SETTLING POND

SETTLING POND

OR

HEAVY METALS?

SETTLING POND

OPEN LIMESTONE CHANNEL

BIO-CHEMICAL REACTOR

SAPS

AEROBIC WETLAND

AERATION AND SETTLING POND

SETTLING POND

MEET EFFLUENT STANDARDS?

NO

RE-EVALUATE DESIGN

NO

MEET EFFLUENT STANDARDS?

YES

YES

DISCHARGE

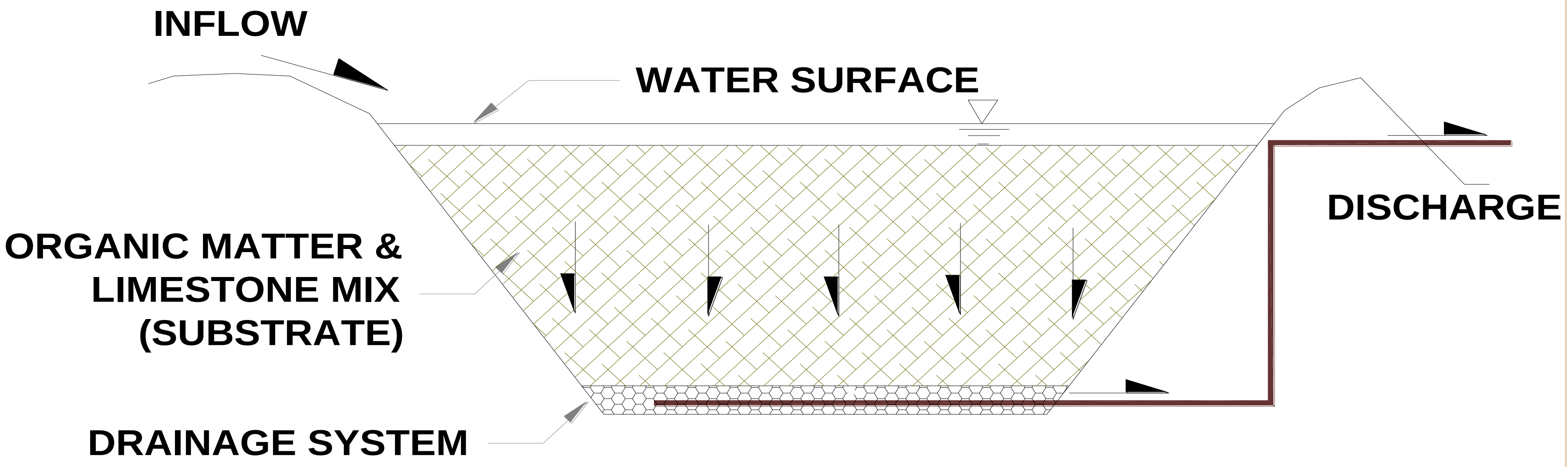
MODIFIED AFTER
HEDIN, ET AL., 1994

Anaerobic BCR’s

Also known as Vertical Flow Bioreactors and Sulphate Reducing Bioreactors

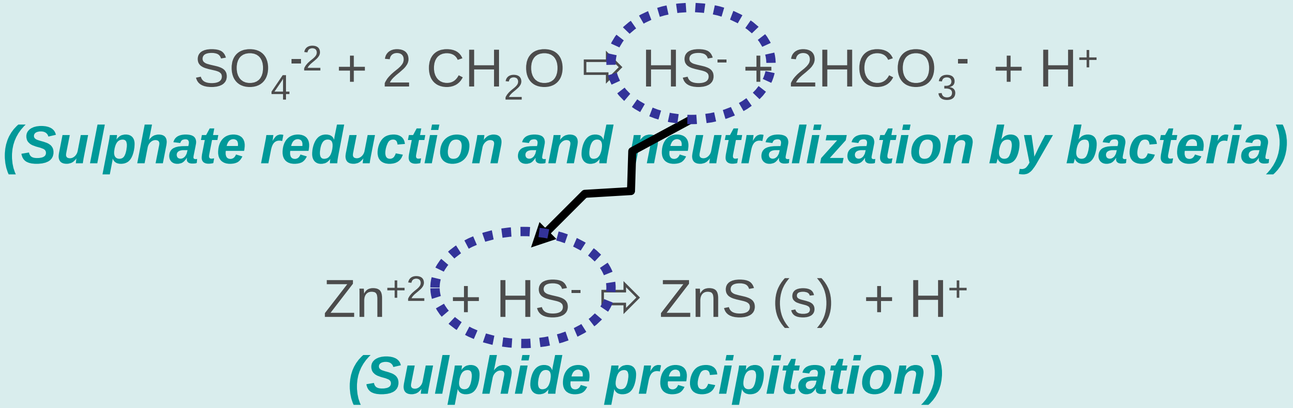
Aluminum and heavy metal removal, pH adjustment, alkalinity & hardness additions

Biochemical Reactor: Schematic Cross Section



BCR Cell Construction

BCR Treatment Chemistry Review



$$SO_4^{-2} + 2\,CH_2O \Rightarrow HS^- + 2HCO_3^- + H^+$$

(Sulphate reduction and neutralization by bacteria)

$$Zn^{+2} + HS^- \Rightarrow ZnS\,(s) + H^+$$

(Sulphide precipitation)

$$Fe^{+3} + 3\,H_2O \Rightarrow Fe(OH)_3\,(s) + 3\,H^+$$

(Hydroxide precipitation on the surface)

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

(Limestone dissolution)

BCR Treatment Chemistry: Aluminum Precipitation Reactions

$Al^{3+} + 3H_2O \Rightarrow Al(OH)_3$ (Gibbsite) $+ 3H^+$

(problematic due to sludge buildup)

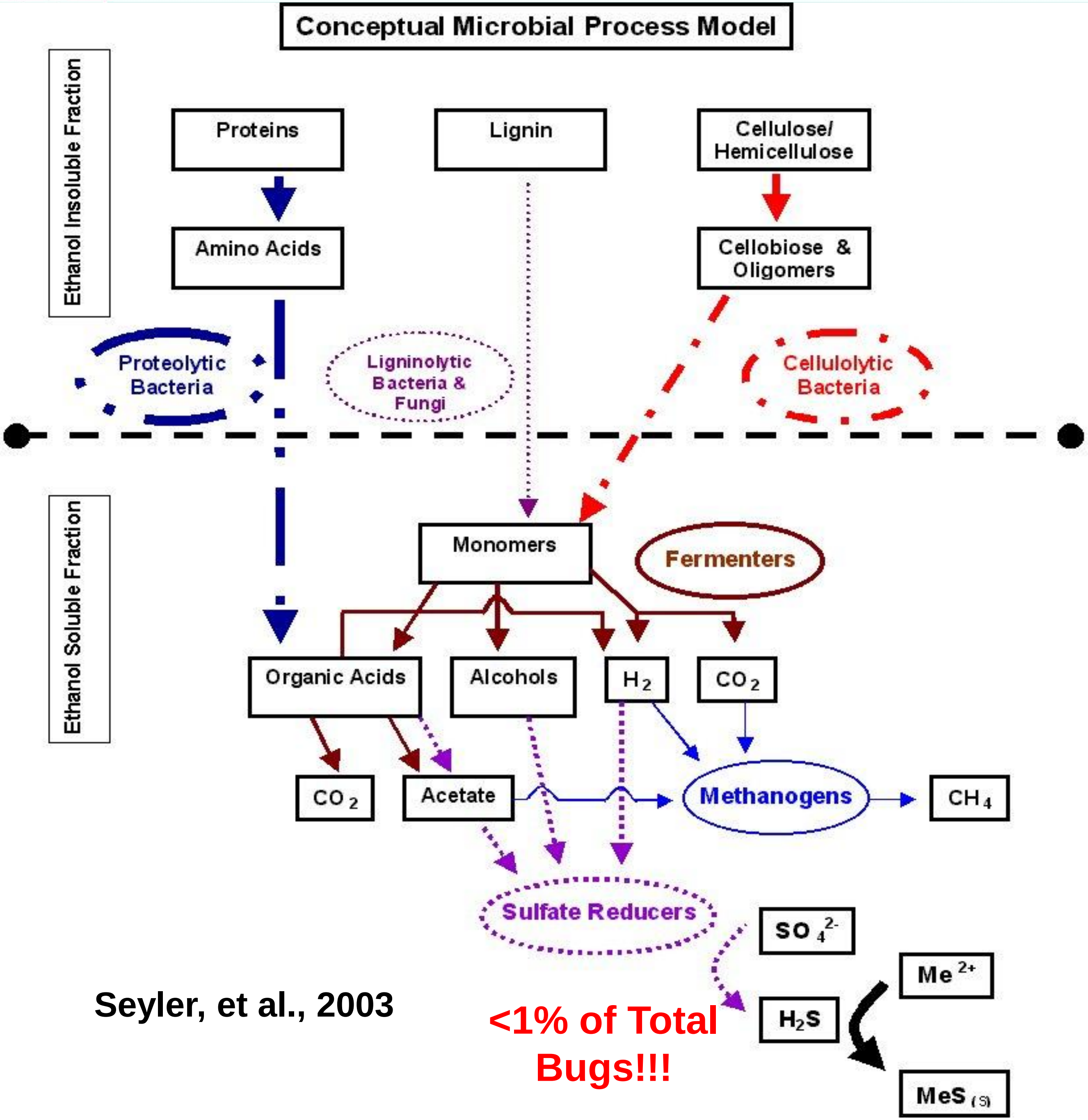
Conditions within BCRs are favorable for aluminum hydroxysulphate precipitation:

$$3Al^{3+} + K^+ + 6H_2O + 2SO_4^{2-} \Rightarrow KAl_3(OH)_6(SO_4)_2 + 6H^+$$

Alunite

$$6Ca^{2+} + 2Al^{3+} + 38H_2O + 3SO_4^{2-} \Rightarrow Ca_6Al_2(SO_4)_3(OH)_{12}{:}26H_2O + 12H^+$$

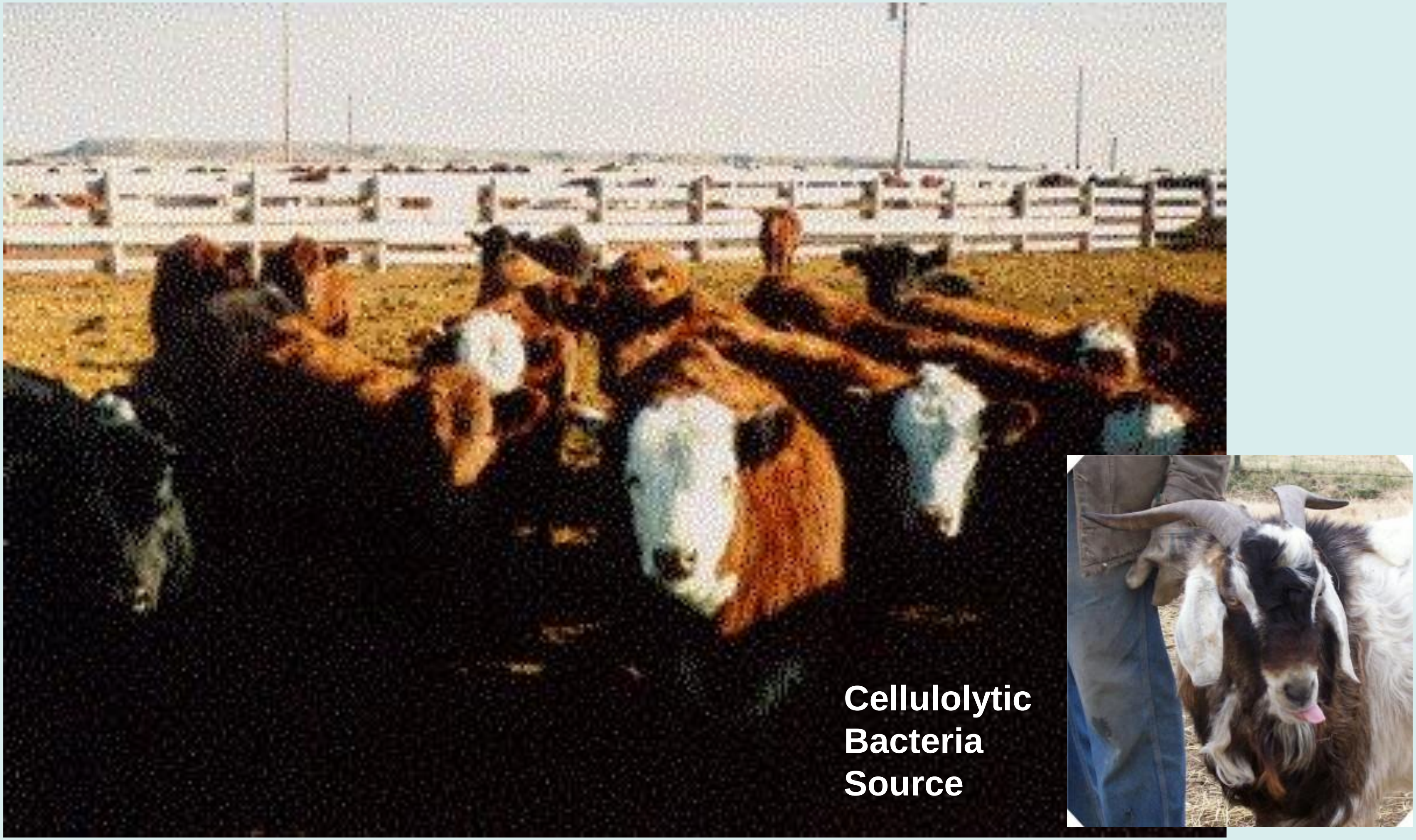
Ettringite



Seyler, et al., 2003

<1% of Total Bugs!!!

“Typical” Sulphate Reducing Bacteria Sources



Cellulolytic
Bacteria
Source

System Design Parameters

NO COOKBOOK (YET)

- MIW Geochemistry controls cell sequencing & cell type
- Dimensions governed by Metal & Acidity Loading

  i.e. concentration X flow rate

Passive Treatment: Staged Design Phases

- Lab (proof of principle) tests
- Bench tests
- Pilot tests
- Limited full scale (modules)
- Full scale implementation

Passive Treatment: Lab - Proof of Principle Tests

Buckeye Landfill, OH
POP Test Bottles

Brewer Gold Mine, SC
POP Test Bottles

Passive Treatment: Bench Scale Tests

Weekly sampling schedule is typical

Bench BCR Biopsy

Pilot Scale Cells

BCR - Wyoming

BCR - Missouri

Aerobic - Missouri

Aerobic - Brazil

Selected Case Studies

Applications of Biochemical Reactors and Aerobic Systems

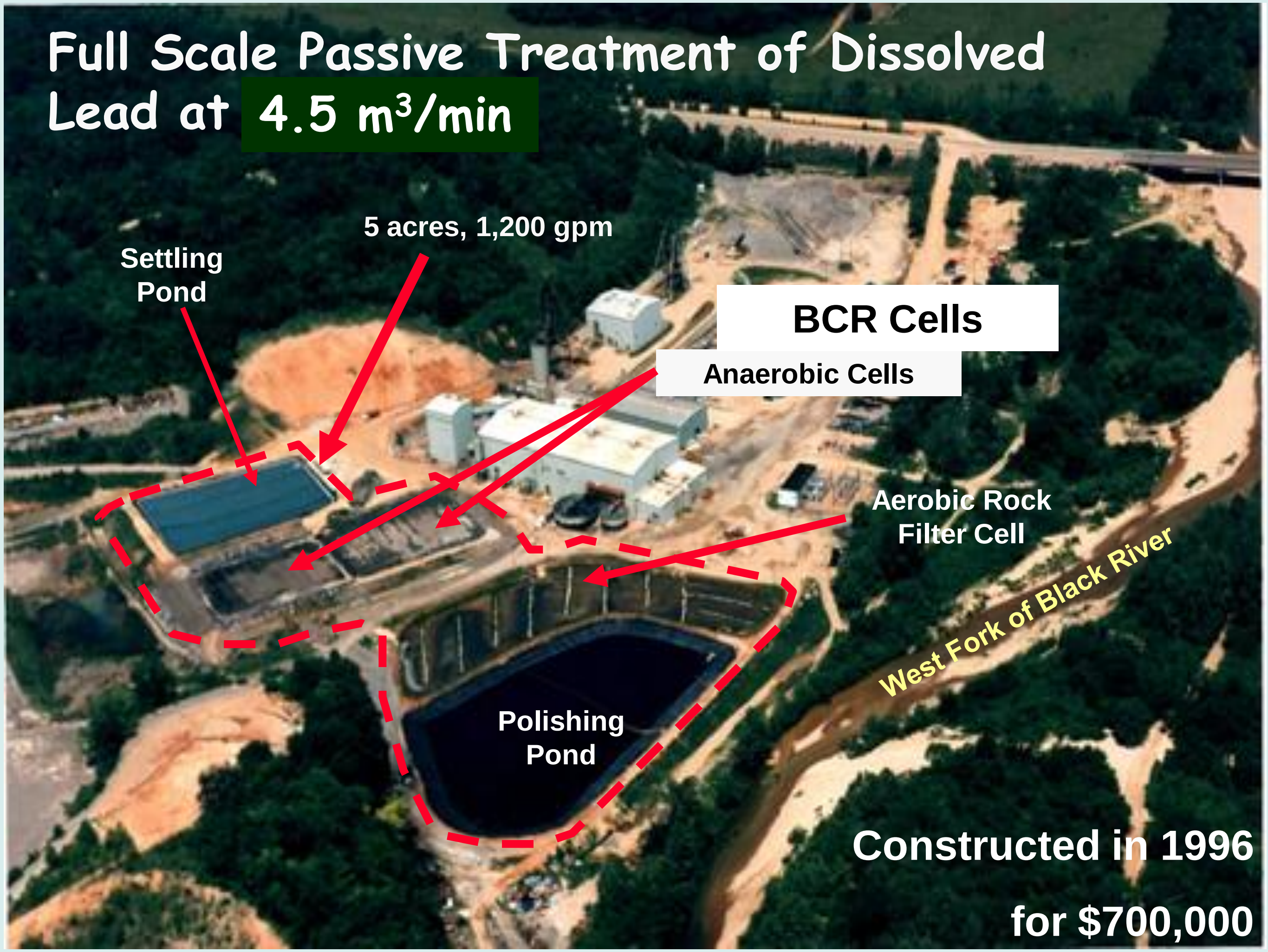
in the Passive Treatment of

Mining Influenced Water

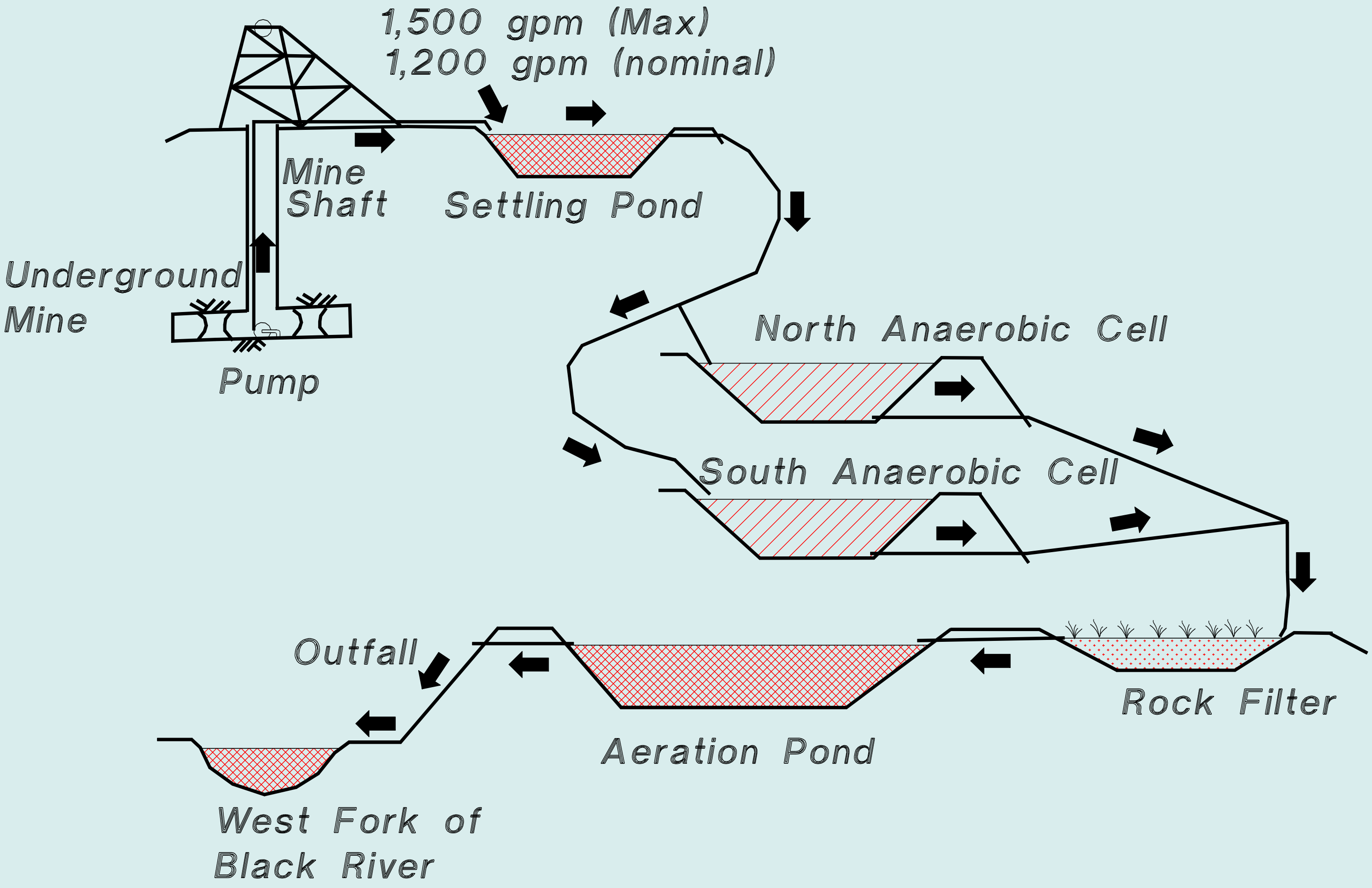
Large Scale, Demonstration, and Pilot Scale Systems

- West Fork, Missouri, USA (Large)
- Judy 14, Pennsylvania USA (Demo)
- Fran Mine, Pennsylvania USA (Pilot)
- Golinsky Mine, California USA (Pilot)

West Fork, Missouri



West Fork System Layout



West Fork System
Key Components / Dimensions

- Settling Pond 3,000m^2
- 2 Anaerobic (BCR) Cells 2,000m^2 each,
- 2m deep, 40mm HDPE liner - substrate:
  - 67% sawdust, 19% limestone (low Mn),
  - 12% manure, 2% hay
- Aerobic Rock Filter – 6,000m^2
- HDPE-lined Aeration Pond – 8,000m^2
- Total cost (1996) with engineering: $US 700,000

West Fork System Results

Influent Water

pH – 7.8 s.u.

Pb – 0.6 mg/L as aqueous lead carbonate complex

Zn – 0.08 mg/L

Sulphate ~180 mg/L

SRBR Effluent Water

pH - 7.8 s.u. (no change)

Pb - 0.027 to 0.05 mg/L (meets NPDES standard)

Zn – <0.05 mg/L

Sulphate – <140 mg/L

4.5m^3/min, 24 hours/day, 7 days/week;
Constructed in 1996

Demo Scale BCR
Judy 14 Pennsylvania Coal Mine

Constructed with Pennsylvania Growing Greener Funds by the Blacklick Creek Watershed Association

Judy 14 Project Background

- Seepage from Abandoned *Judy 14* underground coal mine (mined in 1950's)
- SAPS units were not working
- ***Elevated aluminum caused plugging problems***
- Experience from a pilot system @ 9.5 L/min on a similar water was good

Judy 14 Bioreactor
Key Components / Dimensions

- Valved diversion pipe
- One SRBR Cell 0.75m deep, 1,300 m^2 bottom area, 300mm compacted clay liner, substrate:
  - 50% wood chips, 30% limestone;
  - 10% manure, 10% hay
- Aerobic Rock Filter – designed, but built undersized
- Total cost with engineering: $US158,000

Judy 14 BCR Demo Results

Influent Water	**BCR Effluent Water**
pH – 3.0	pH – 6.6
Fe – 45 mg/L	Fe – 0.5 mg/L
Al – 33 mg/L	Al – 0.07 mg/L
Mn – 2.6 mg/L	*Mn – 2.3 mg/L*
Zn – 0.86 mg/L	Zn – 0.06 mg/L
Cu – 0.10 mg/L	Cu – BDL @.0009
Ni – 0.32 mg/L	Ni – 0.002 mg/L

Flow: 38 Liters/min

Constructed in late 2002

Pilot Scale Anaerobic BCR
Fran Mine Site - Pennsylvania Surface Coal Mine

The “worst acid drainage in Pennsylvania” – work sponsored by Allegheny Mtn Chapter of Trout Unlimited

Fran Mine Project Background

- Abandoned surface coal mine seepage
- Mined in 1970’s, pit was backfilled
- Injection of fly ash grout helped control MIW but it was not enough
- Total flow of 160L/m @ full scale impacts 8 km of trout fishery
- Bench scale BCR tests successful – *no plugging problems from aluminum precipitates*
- Pilot system design and construction funded by private donations & government grants

Fran Mine Bioreactor
Key Components / Dimensions

- Valved diversion pipe (problematic)
- One BCR Cell 1m deep (buried), 404m^2 bottom area; 40mm PVC liner, substrate:
  - 50% wood chips, 30% limestone;
  - 10% manure, 10% hay
- Aerobic Rock Filter – designed, but not built; mini version added later.
- Total construction cost: $US42,400; engineering cost $US20,000

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Pilot Scale Anaerobic BCR
Fran Mine Site

Soil Cover

Fran Mine Pilot BCR Results

Influent Water

pH – 2.4

Fe – 298 mg/L

Al – 257 mg/L

Mn – 25 mg/L

Cu – 0.56 mg/L

Zn – 2.0 mg/L

Acidity – 2,734 mg/L

Sulphate – 3,215 mg/L

Effluent Water

pH – 6.4

Fe – 64 mg/L (Fe^{+2}=46)

Al – <0.02 mg/L

Mn – 26.4 mg/L

Cu – BDL @0.0009 mg/L

Zn – 0.127 mg/L

Alkalinity – 1,038 mg/L

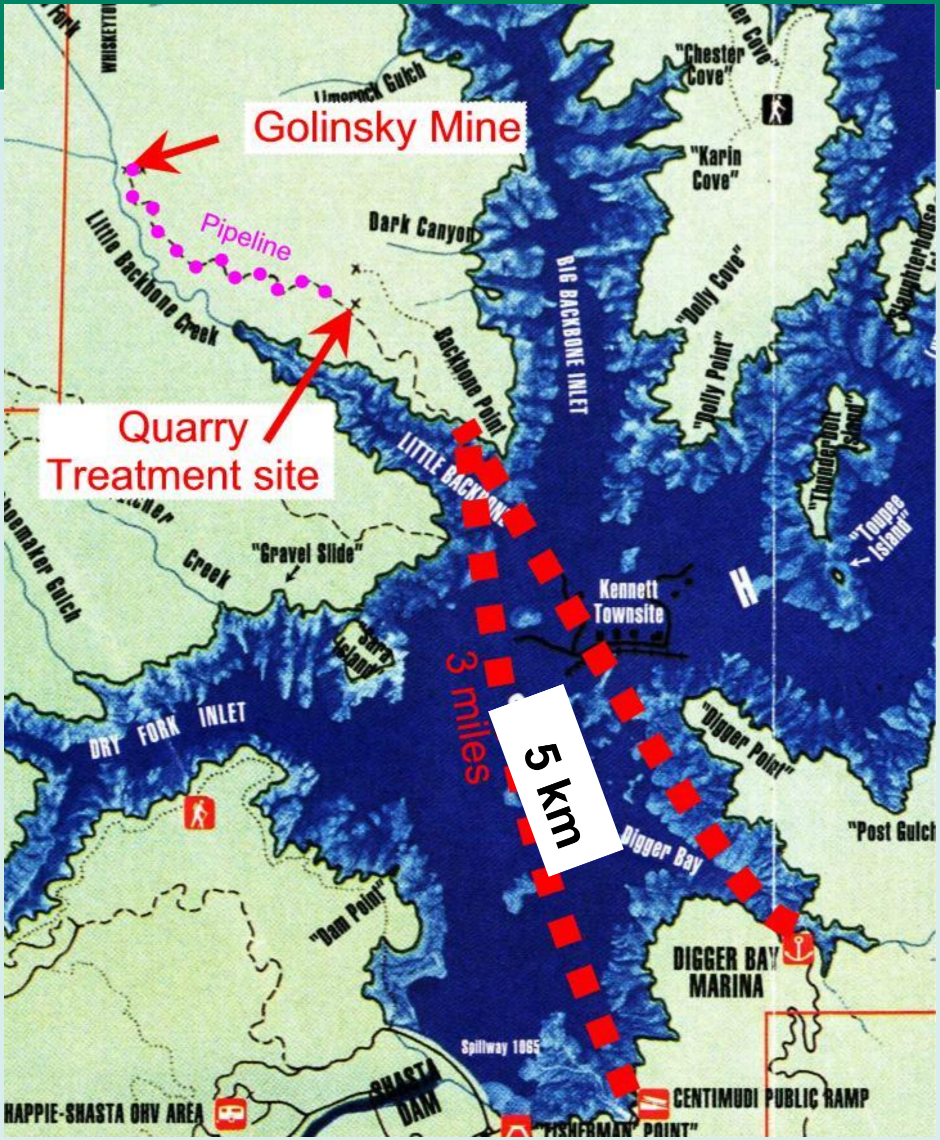
Sulphate – 752 mg/L

Flow: 3.8 to 7.6 L/m Constructed in late 2002

Design Complete; full scale on hold as of 2008

Golinsky Mine, California

Remote Location



Project Phases

- Bench Test *(Jan ‘04 to May ‘04)*
- Pilot Scale Test *(July ’04 to Sept ‘06)* *decommissioning data suggested about 20 yrs of longevity remained*
- Full Scale Pipeline *(Fall, ’04)*
- Full Scale Design S*RBR - module #1 (2008)*
- Module 1 Construction - 2009

Golinsky Mine Pilot BCR
Key Components / Dimensions

- Valved diversion (off 150mm pipeline)
- One BCR Cell 0.75m deep, 95m^2 bottom area, 18mm HDPE Permalon$^{\text{TM}}$ liner, substrate:
  - 40% co-gen fuel, 29% limestone, 1% ash,
  - 10% rice hulls, 10% manure, 10% hay
- Aerobic Rock Filter – not designed, but natural channel functioning as one.
- Total cost with engineering: ~$US 350,000

Golinsky Mine, CA (USFS)

Influent

pH – 3.0

Fe – 104 mg/L

Al – 24.5 mg/L

Mn – 1.3 mg/L

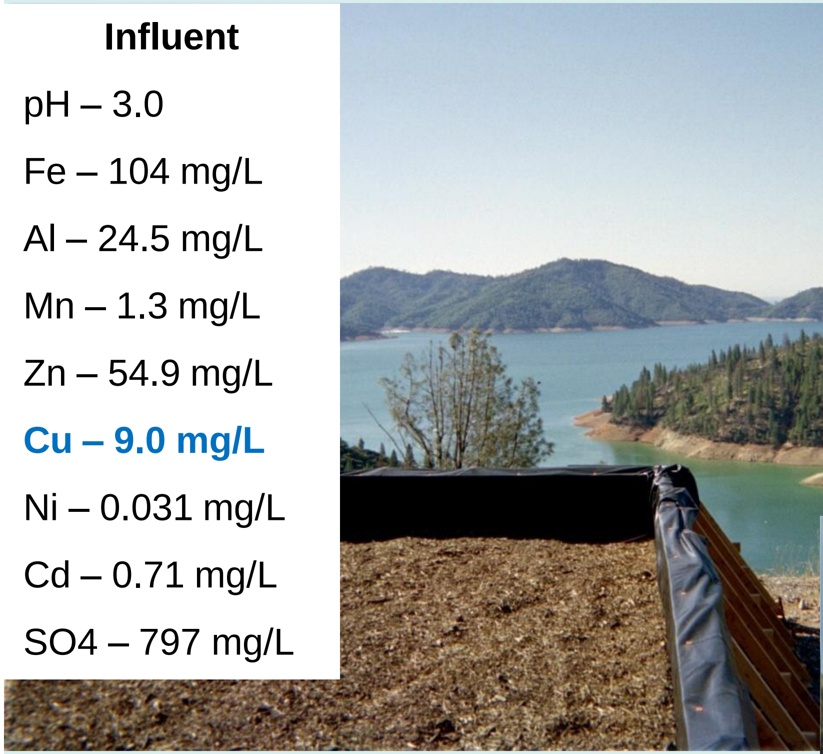
Zn – 54.9 mg/L

Cu – 9.0 mg/L

Ni – 0.031 mg/L

Cd – 0.71 mg/L

SO4 – 797 mg/L



Total cost with engineering: ~$350,000

Pilot BCR

45, 420 cubic meters treated over 27 months

Effluent

pH – 7.2

Fe – 0.8 mg/L

Al – 0.06 mg/L

Mn – 2.5 mg/L

Zn – 0.1 mg/L

Cu – <0.003 mg/L

Ni – 0.007mg/L

Cd – 0.006 mg/L

SO4 – 488 mg/L

Golinsky Pilot BCR

Why Don’t Passive Systems Always Work As Designed?

- No design “Just build a swamp here, fill that pond over there with manure and call it good.”
- Poor design **Undersized for load**, applying wrong geochemical approach, phased design lacking, complex geochemistry, startup and operational procedures.
- Not enough maintenance (low maintenance does not mean **“NO”** maintenance).
- Last minute changes to construction specs can affect system performance - experience helps.

Advantages of Passive BCR Treatment

- No aluminum plugging
- Uses waste organic materials
- Easy to test conceptual designs
- Simple to operate
- Resilient to loading variations
- Consumes sulphate or selenate
- Bury to minimize vandalism
- Can easily handle net acidic water or net alkaline water
- Generates more net alkalinity in effluent
- Might be able to place in underground mines
- Opportunities for community involvement in organic procurement

In Water Treatment, If You’re Not Part of the Solution, You’re Part of the Precipitate.

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