GEOHAZARDS IN TRANSPORTATION
IN THE APPALACHIAN REGION
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Passive Treatment of Metal-Bearing Runoff/Seepage 101: An Overview of the Technologies

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Presented by: Eric Blumenstein, Golder Associates

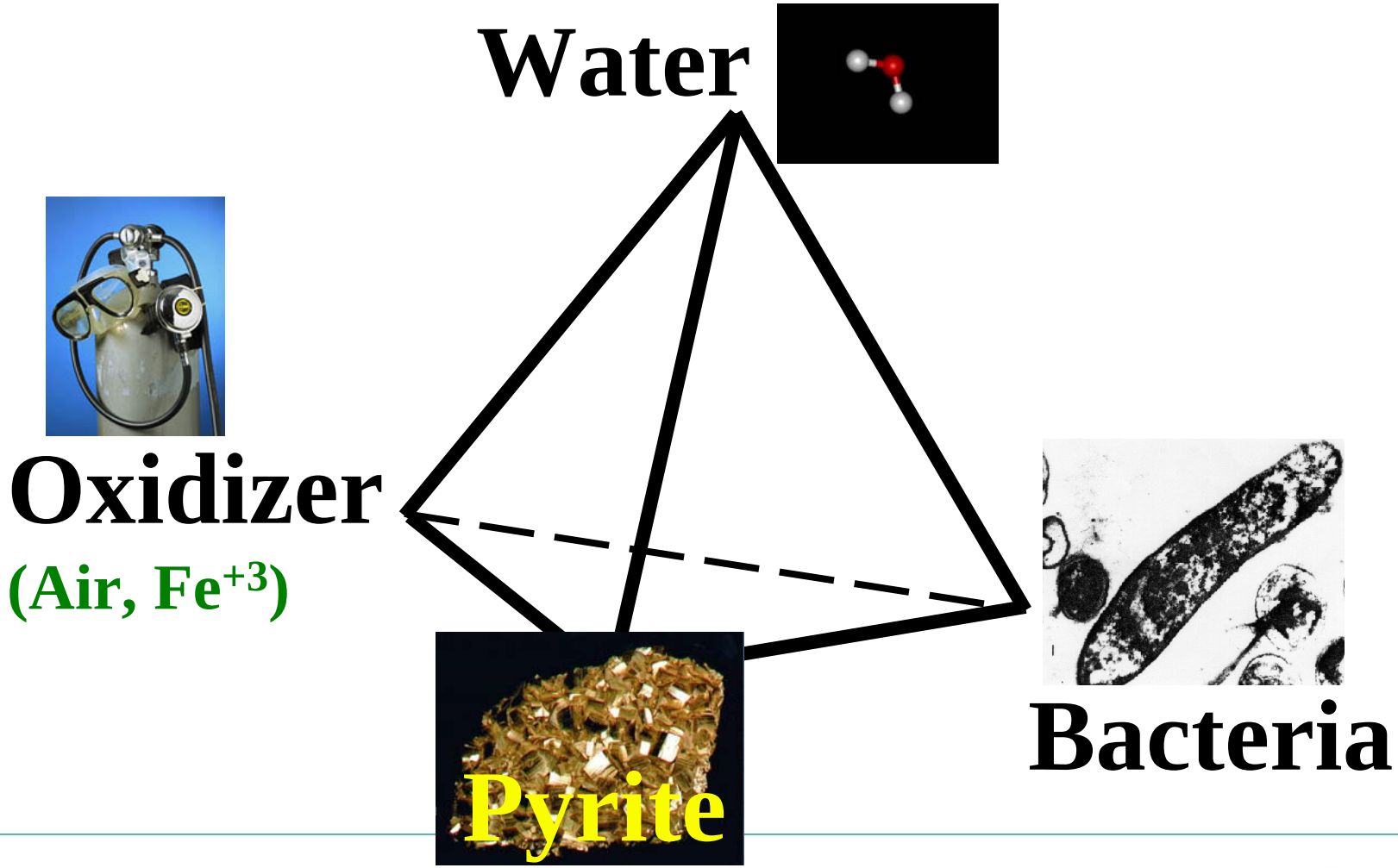
Terms

Acid
Mine
Drainage

Acid
Rock
Drainage

(aka
Mining
Influenced
Water –
[MIW])

Acid Rock Drainage Tetrahedron

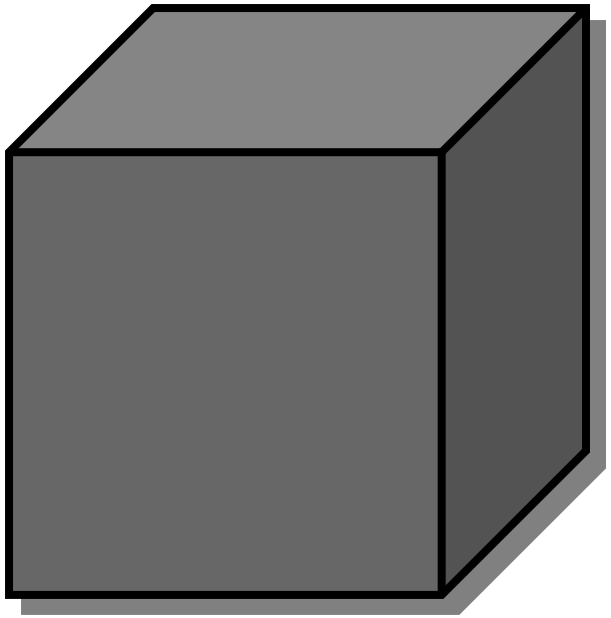


Mine Water Treatment Options

- Active treatment
- Passive treatment
- Combination active/passive (hybrids)

What Is Passive Treatment?

Passive treatment ≠



If It's Not a BLACK BOX, What Is Passive Treatment?

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.

P.T. Metal Removal Mechanisms

Major

- Sulfide and carbonate precipitation via sulfate reducing bacteria, et al.
- Hydroxide and oxide precipitation by *thiobacillus ferro-oxidans* bacteria, et al.
- Filtering of suspended materials and precips
- Carbonate dissolution/replacement

Minor

- Metal uptake into live roots, stems and leaves
- Adsorption and exchange with plant, soil and other biological materials

Passive Treatment Chemistry 101

REDUCING/ ANAEROBIC CONDITIONS

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

(Sulfate reduction and neutralization by bacteria)

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

(Sulfide precipitation)

OXIDIZING CONDITIONS

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

(Hydroxide precipitation)

ALL CONDITIONS

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

(Limestone dissolution)

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P.T. Chemistry 102 - Aluminum

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

(problematic due to sludge buildup)

Conditions within BCRs are favorable for aluminum hydroxysulfate precipitation:

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

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

Thomas, R.C. 2002. *Passive Treatment of Low pH, Ferric Iron-Dominated Acid Rock Drainage*. Doctoral Thesis. University of Georgia.

Rutkowski, T.R, Waples, J.S., Gusek, J.J. 2005. *Aluminum Removal in a Sulfate-Reducing Bioreactor.* Poster Presentation at the 2006 International Conference on Acid Rock Drainage (ICARD). St Louis, MO.

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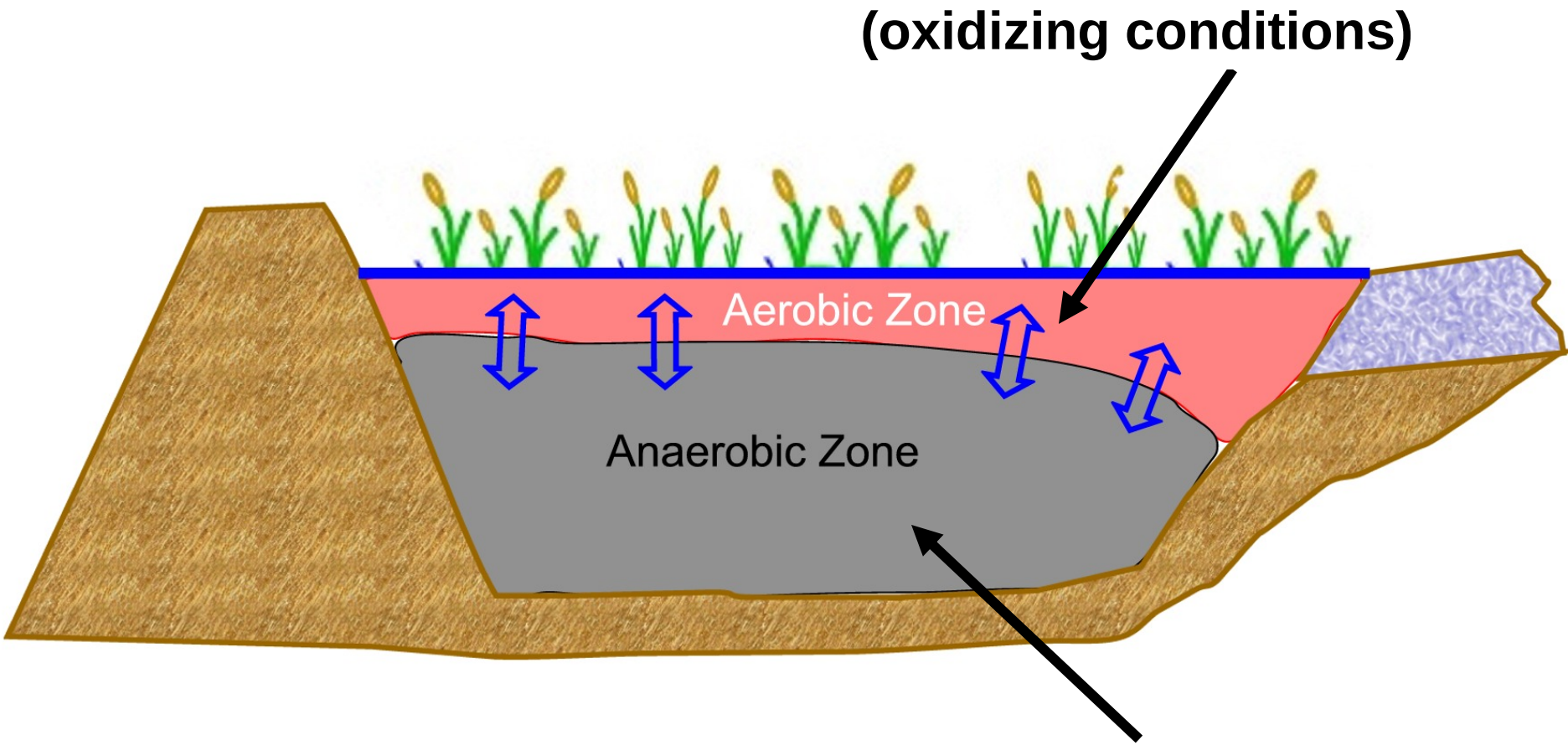
Typical Wetland Ecosystem



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Oxidation and Reduction
Processes in Competition

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

Thiobacillus - F. O. **live here (oxidizing conditions)**

Processes in Competition

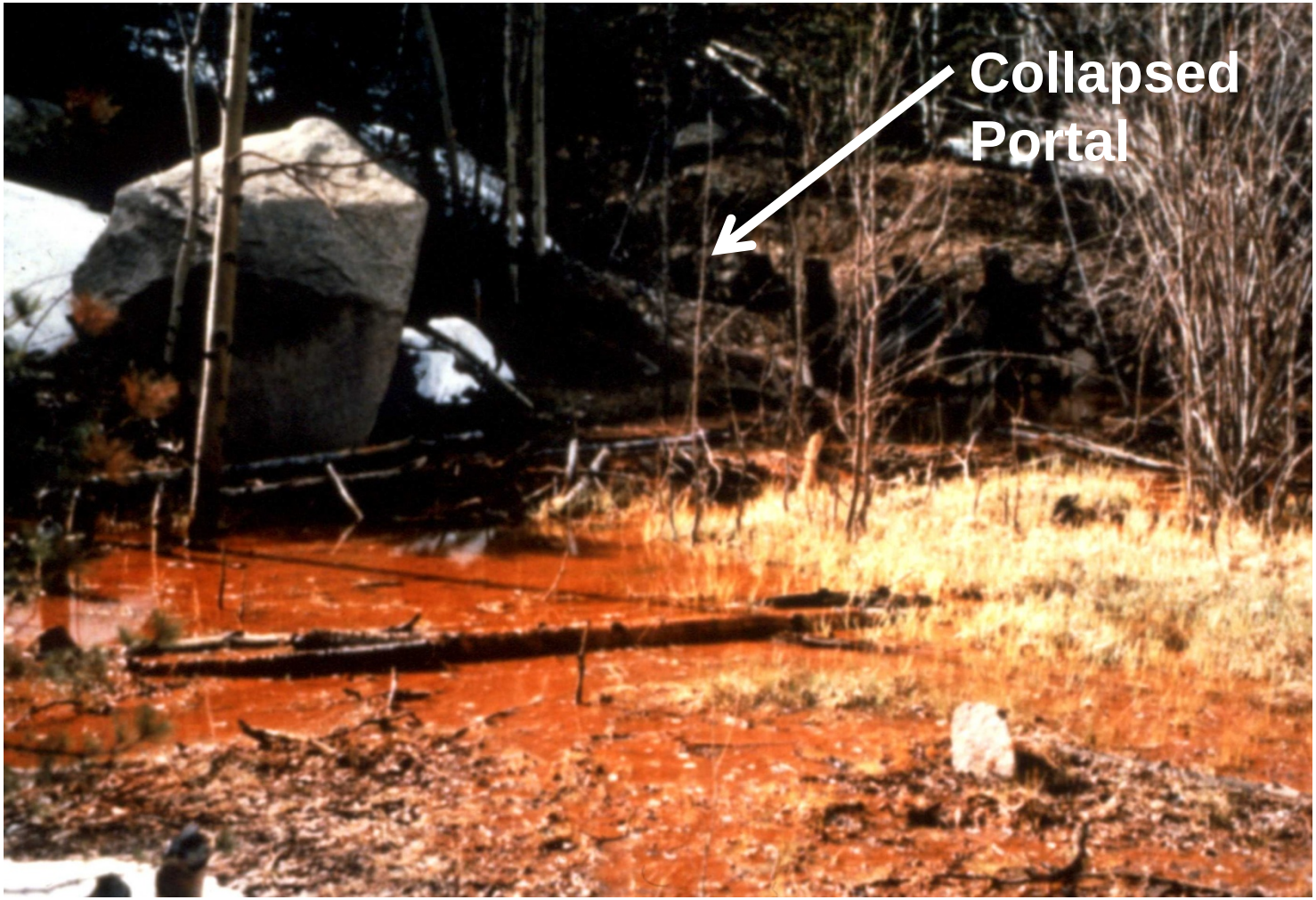
Natural Wetland Balances All Possible Processes

Versus

Passive Treatment System

One Process is Emphasized in Each Cell

Iron precipitation at abandoned metal mine in Colorado near drinking water reservoir



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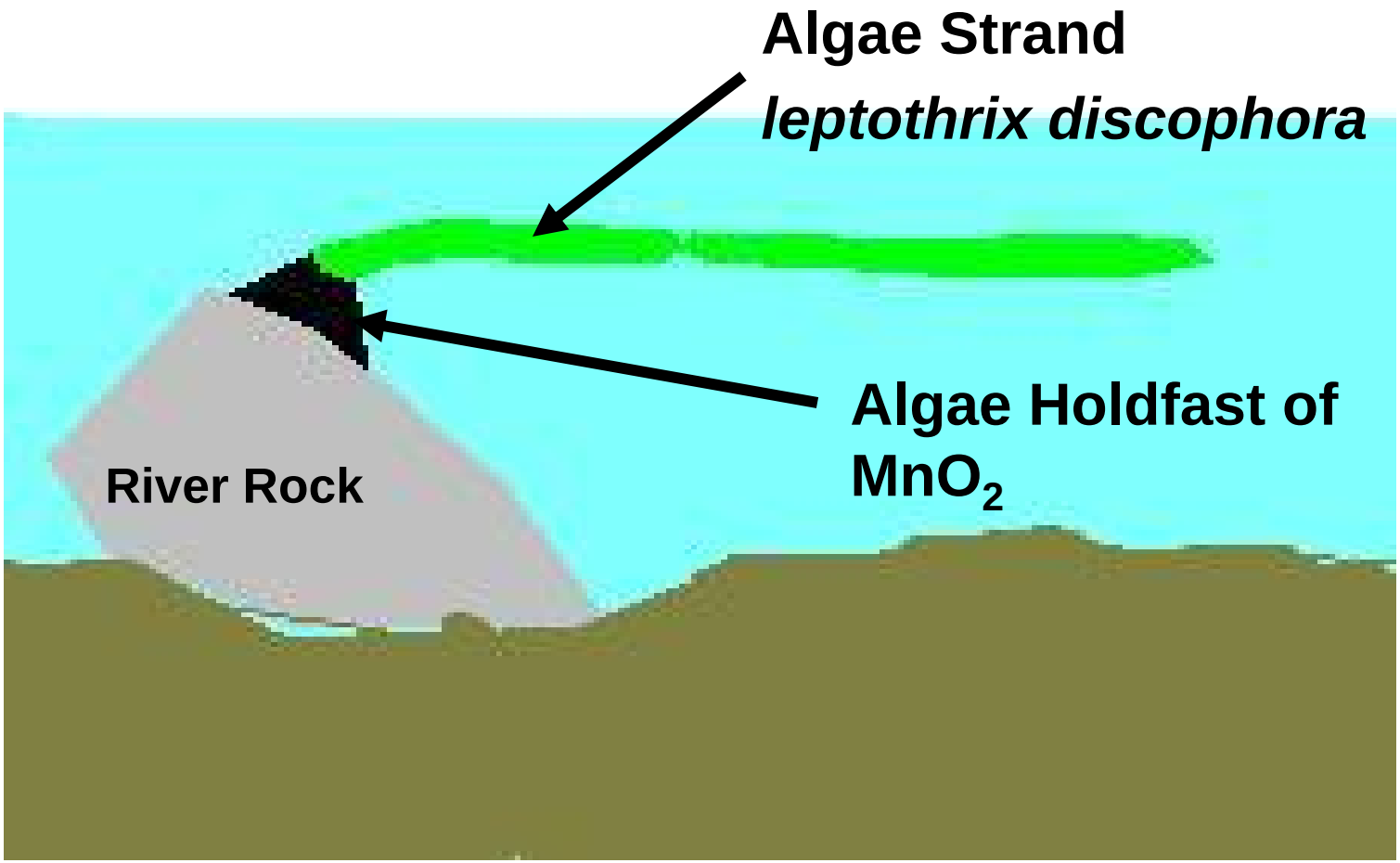
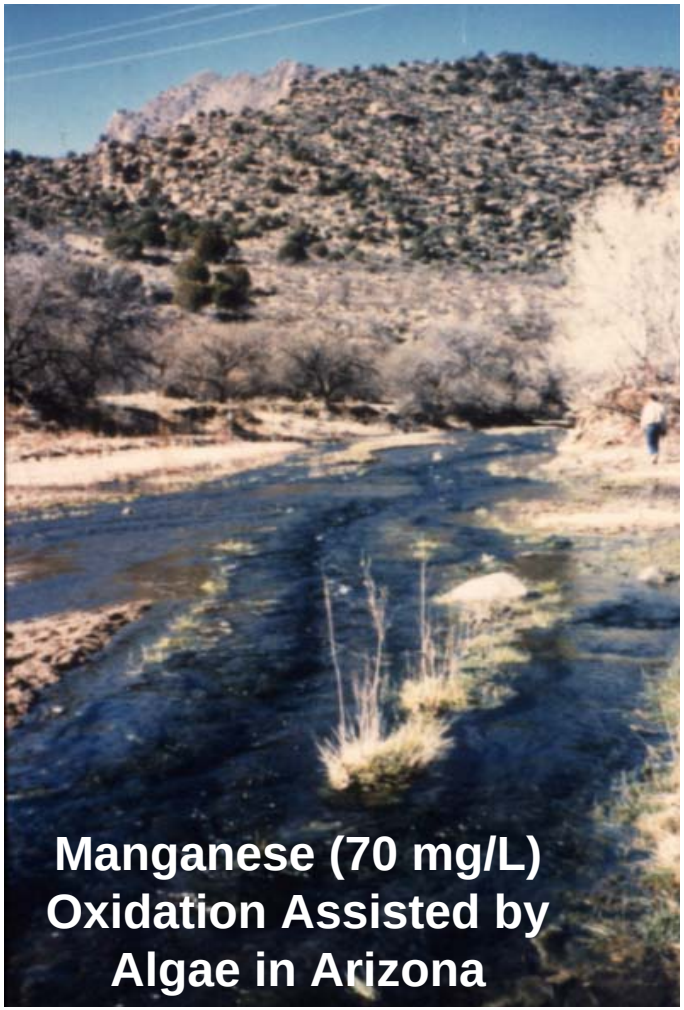
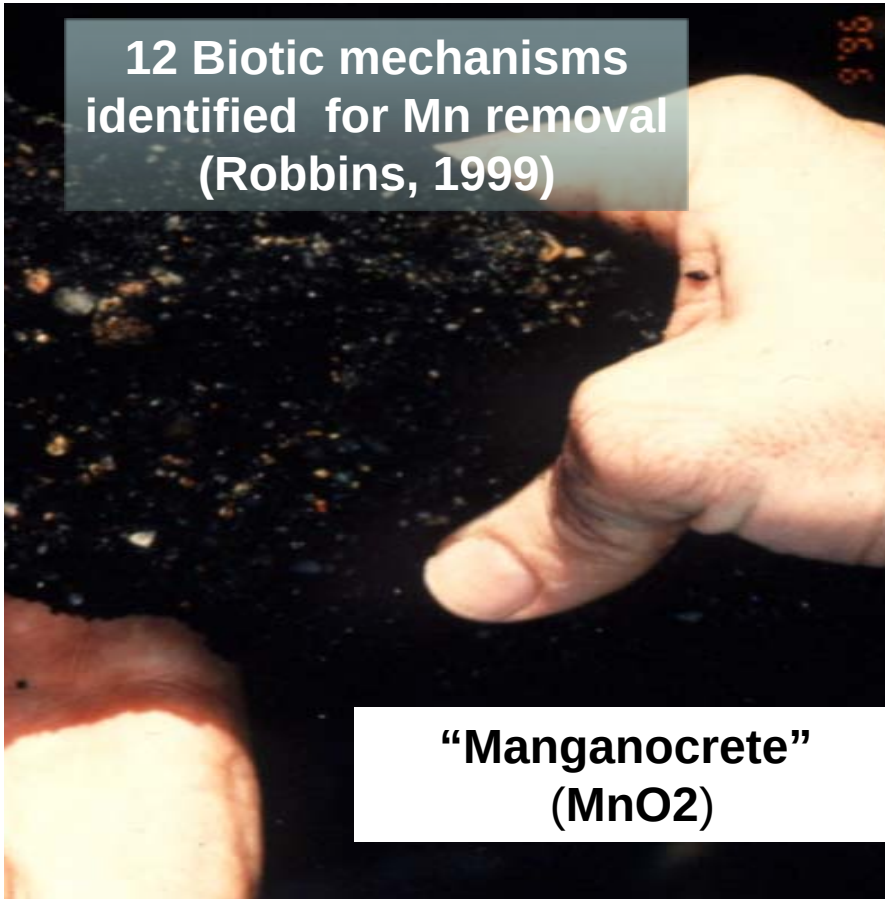
Another Aerobic Process – for Mn Removal



Volunteer Manganese Mitigation



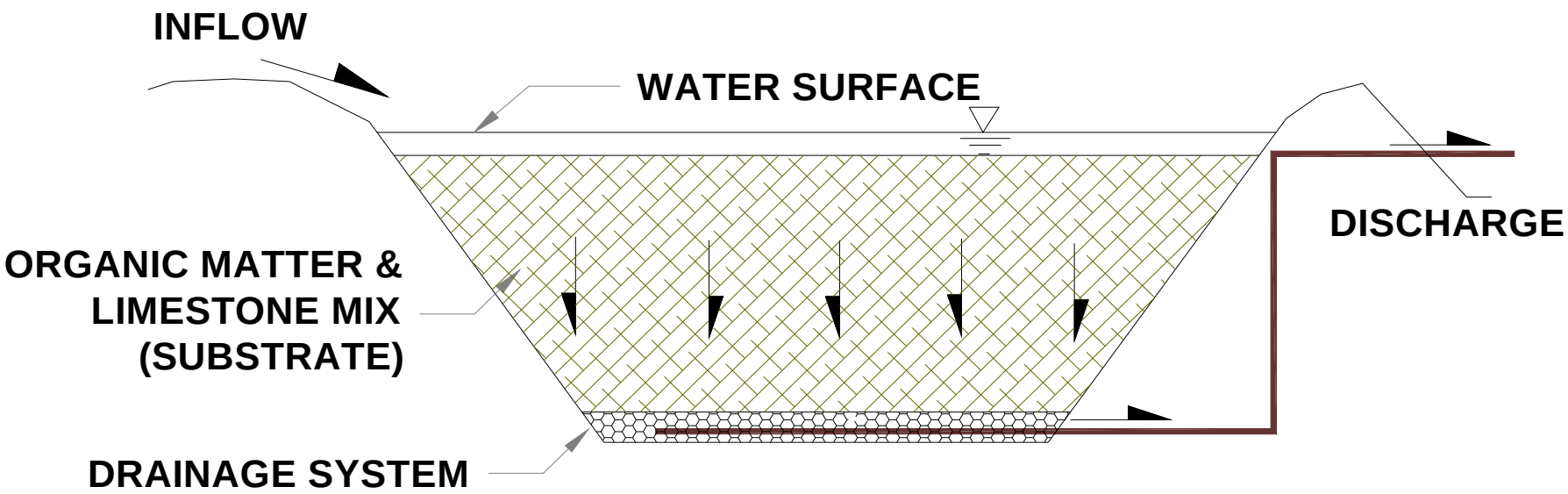
Manganese (70 mg/L) Oxidation Assisted by Algae in Arizona



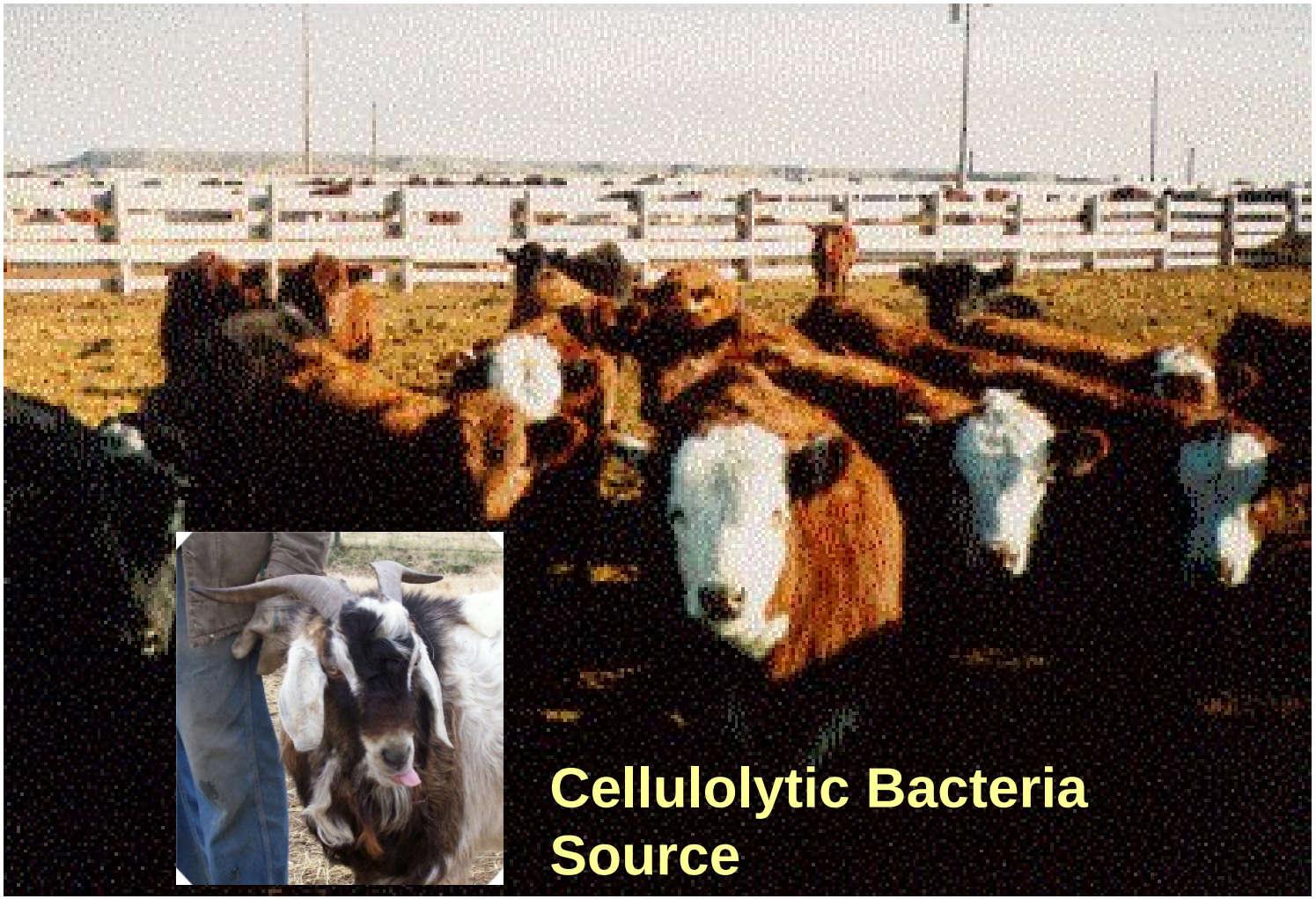
12 Biotic mechanisms identified for Mn removal (Robbins, 1999)

"Manganocrete" (MnO_2)

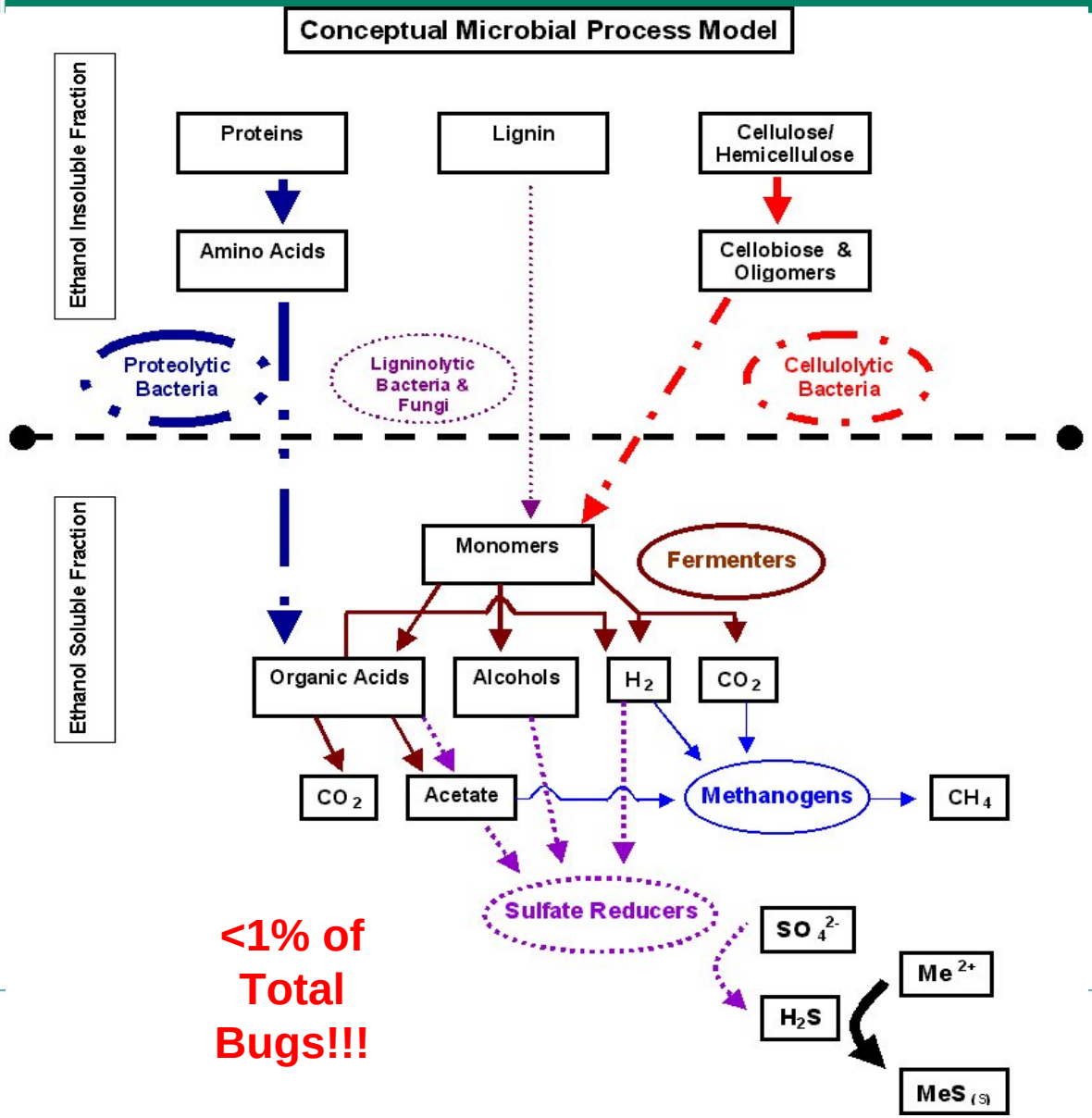
Biochemical Reactor (BCR) Schematic Cross Section



Sulfate Reducing Bacteria Sources



BCR Conceptual Microbial Process Model



Seyler, et al., 2003

<1% of Total Bugs!!!

BCR Cell Construction

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Passive Treatment System Components

Biological Components

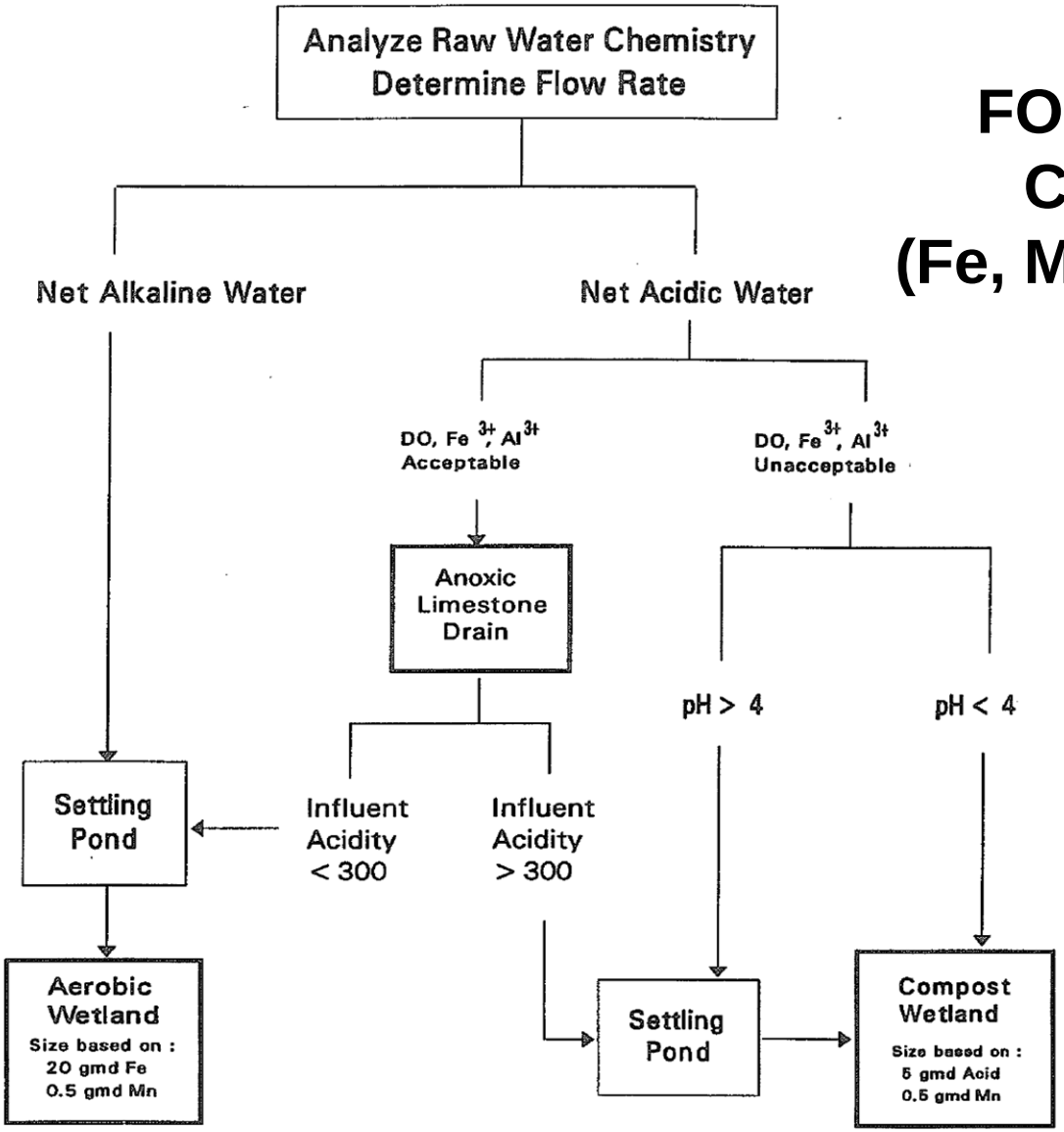
- Anaerobic Biochemical Reactors (BCRs)
- Aerobic Cells or Rock Filters
- Successive Alkalinity Producing Systems (SAPS)

Limestone Components

- Limestone Sand
- Anoxic Limestone Drains (ALD's)
- Alkaline Ponds
- Open Limestone Channels

Settling Ponds & Flow Equalization Ponds

Passive Treatment Decision Tree 1994



FOCUSED ON COAL MIW (Fe, Mn, Al, Acidity)

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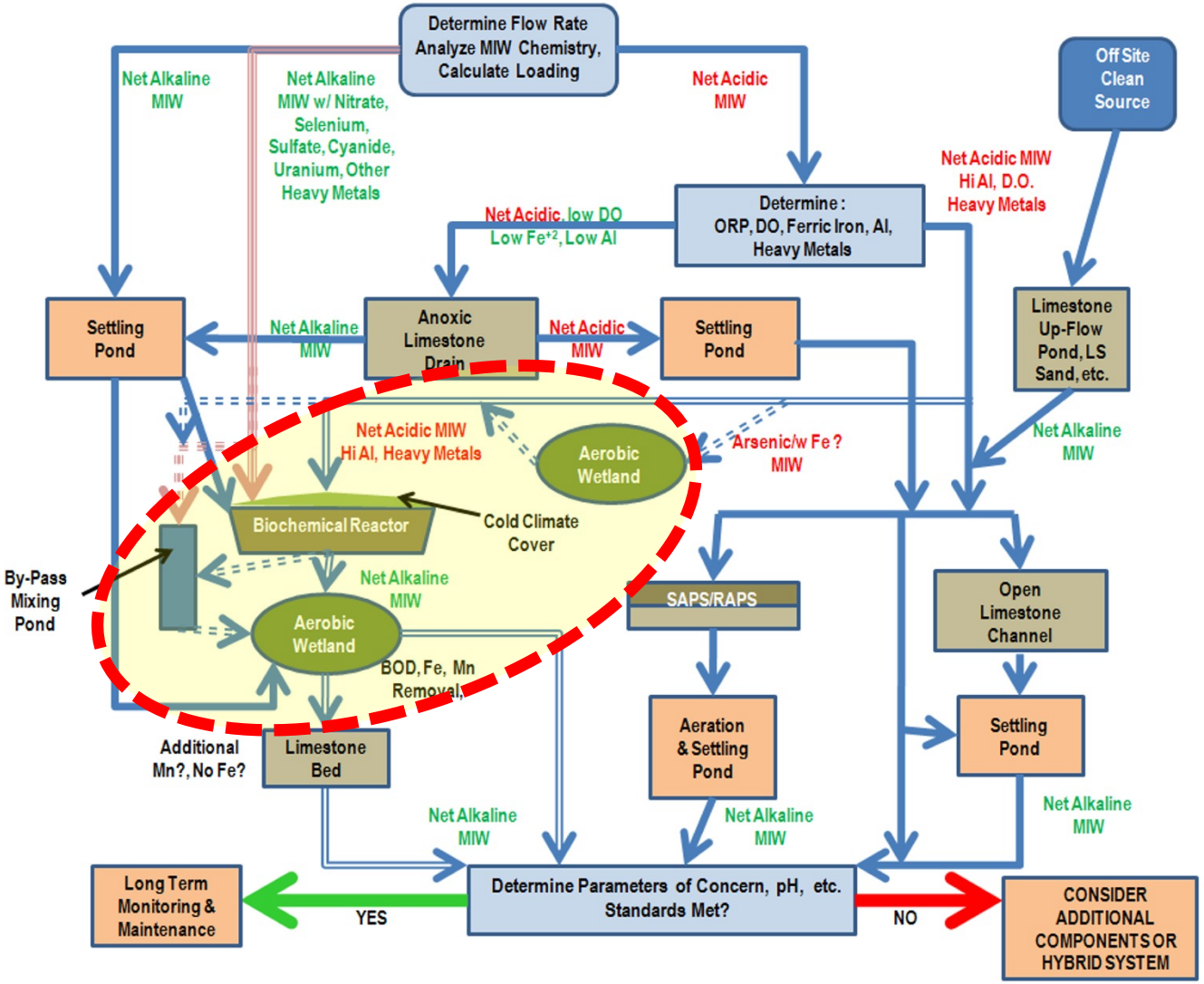
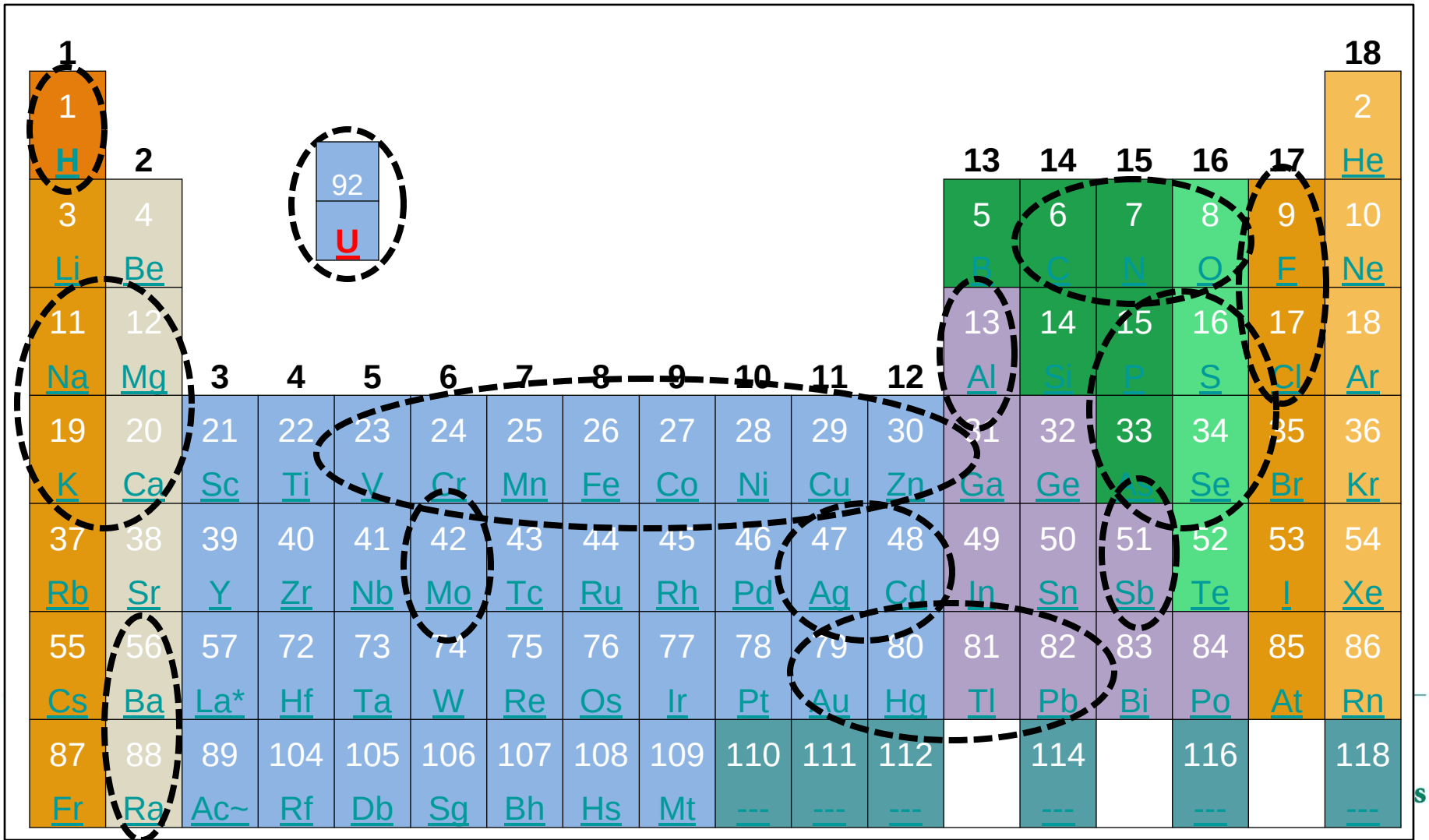
Passive Treatment Decision Tree 2009



Ref: Gusek, 2008

The Periodic Table of Elements with MIW Issues



Periodic Table of Passive Treatment

1												13	14	15	16	17	18
1 H	2																He
Li	Be											B	6 C	7 N	8 O	9 F	Ne
11 Na	12 Mg	3	4	5	6	7	8	9	10	11	12	13 Al	Si	15 P	16 S	17 Cl	Ar
19 K	20 Ca	Sc	Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	Ga	Ge	33 As	34 Se	Br	Kr
Rb	Sr	Y	Zr	Nb	42 Mo	Tc	Ru	Rh	Pd	47 Ag	48 Cd	In	Sn	51 Sb	Te	I	Xe
Cs	56 Ba	La*	Hf	Ta	W	Re	Os	Ir	Pt	79 Au	80 Hg	81 Tl	82 Pb	Bi	Po	At	Rn
Fr	88 Ra	Ac~	Rf	Db	Sg	Bh	Hs	Mt	---	---	---		---		---		---

Actinide Series: 92 U

LEGEND

- Red- passive untreatable
- Blue – anaerobic
- Orange - oxidizing
- Green - beneficial
- Uncertain - untreatable?
- } Anaerobic and oxidizing

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Passive Treatment Chemistry 101

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OXIDIZING CONDITIONS

ALL CONDITIONS

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(Limestone dissolution)

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Anaerobic Biochemical Reactors (BCRs)

AKA

Vertical Flow Reactors

or

Sulfate Reducing Bioreactors (SRBRs)

Aluminum and heavy metal removal, selenium removal, de-nitrification, pH adjustment, alkalinity & hardness addition

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Aerobic Cells

AKA Rock Filters

Fe, As, Biochemical Oxygen Demand (BOD), and Mn removal

Aerobic Cell Special Case:
Iron Terraces – Cure or Curse?

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Successive Alkalinity Producing Systems (SAPS)

Alkalinity addition to oxygenated Fe^{+3} - bearing acidic MIW

(no aluminum allowed)

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Limestone Sand

The limestone will be distributed downstream by periodic flooding.

The sand must be replenished approximately 1 or 2 times per year, depending on flooding frequency.

Limestone sand addition is most effective for streams that have low pH, but also relatively low dissolved metal concentrations.

Iron and/or aluminum hydroxides precipitate in the stream, but probably over a shorter stretch than without treatment.

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Anoxic Limestone Drain (ALD)

Alkalinity addition to oxygen-free Fe^{+2}-bearing, mildly net-acidic MIW

(no aluminum allowed)

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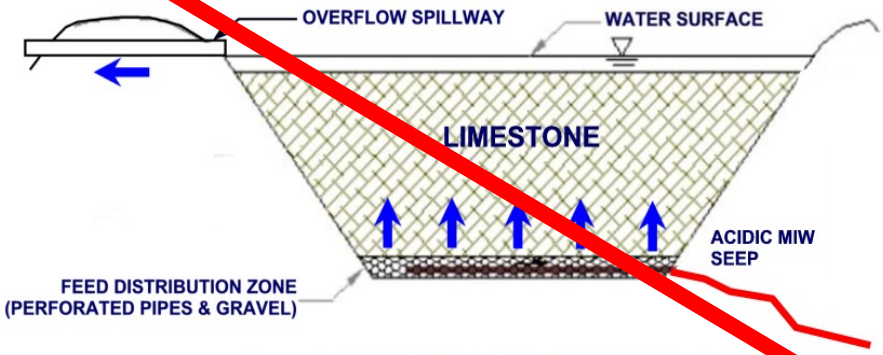
Open Limestone Channels

Open Limestone channels are made of cobble-sized limestone.

They are best used in steep terrain with oxygenated MIW.

The limestone gets coated by iron or aluminum hydroxides, but some limestone dissolution still occurs.

Alkaline/Limestone Ponds



- Limestone up-flow ponds are constructed on the upwelling of an MIW seep or underground water discharge point
- Limestone is placed in the bottom of the pond and the water flows upward through the limestone, adding alkalinity
- **Steel slag** has also been used to add alkalinity

(Faulkner and Skousen 1995).

Settling/Surge Ponds

Collection of suspended solids & clarifying,

flow equalization

Cell Design Parameters

NO COOKBOOK (YET)

- MIW Geochemistry (cell sequencing & cell type)
- Metal Loading = (concentration X flow rate)
- Surface Area is a function of loading
- Cell Depth can be a function of loading

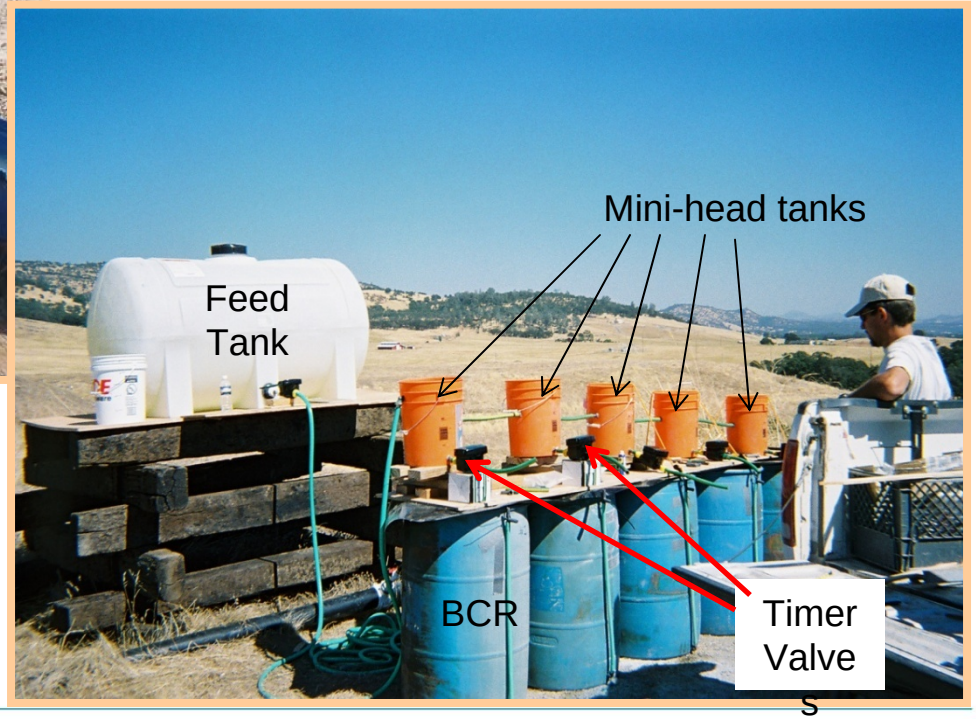
Passive Treatment Staged Design Phases

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

Lab - Proof of Principle Tests

Bench Scale Tests

Weekly sampling schedule is typical



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Pilot Scale Cells

BCR - Wyoming

BCR - Missouri

Aerobic - Missouri

Aerobic - Brazil

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Pilot BCR Golinsky Mine, CA (USFS)

Influent MIW

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

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

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Golinsky Site Access Challenges

“The Worst Surface Mine AMD/MIW in PA”

Local Residents

Fran Mine BCR Cell (Buried)
(Allegheny Mtn. Chapter Trout Unlimited)

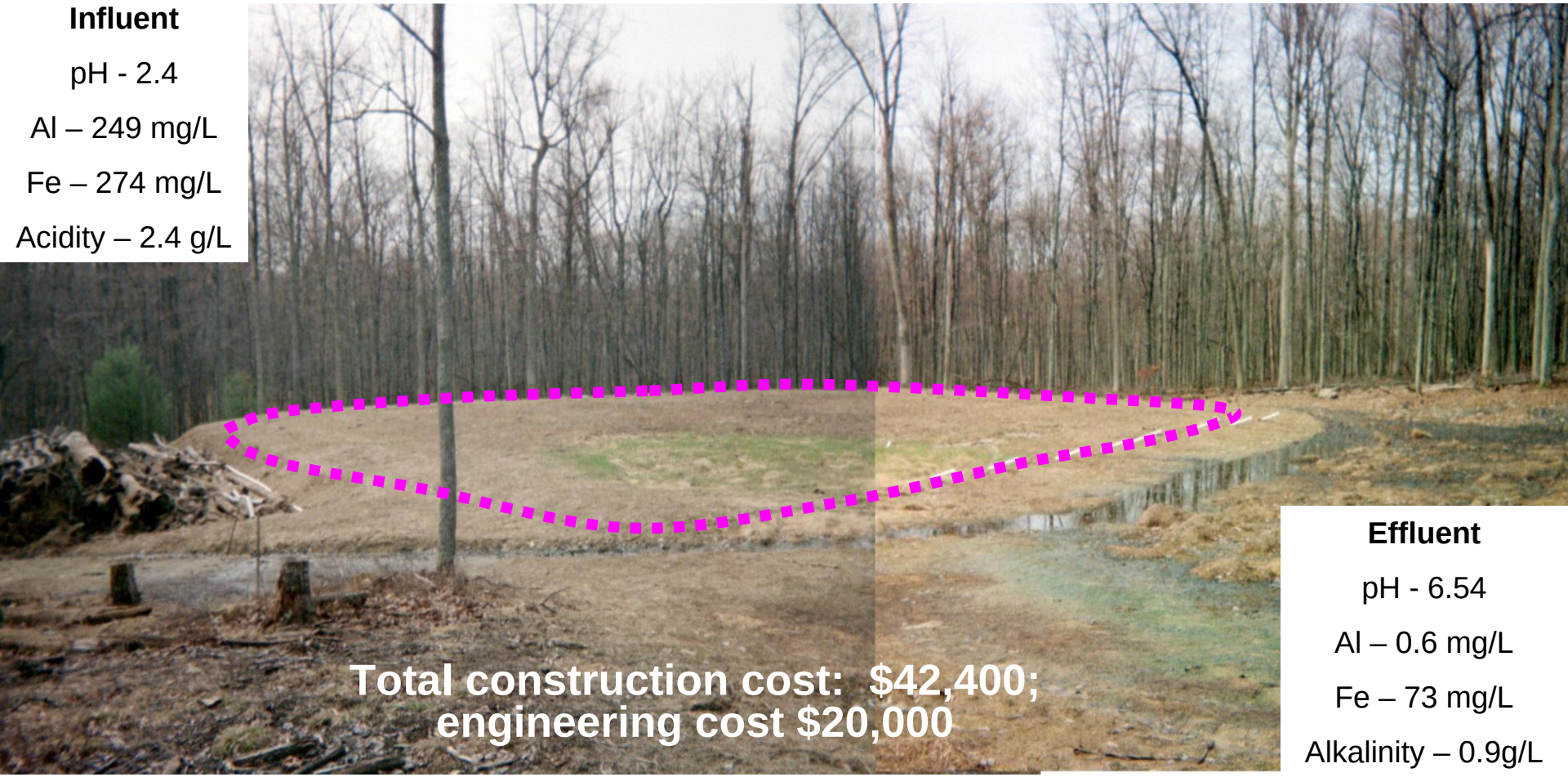
Influent

pH - 2.4

Al – 249 mg/L

Fe – 274 mg/L

Acidity – 2.4 g/L



Effluent

pH - 6.54

Al – 0.6 mg/L

Fe – 73 mg/L

Alkalinity – 0.9g/L

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Passive Treatment - Full Scale BCR System

West Fork Lead Mine, Missouri
Constructed in 1996 for Asarco

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Full Scale Passive Treatment of Dissolved Lead at 1,200 gpm

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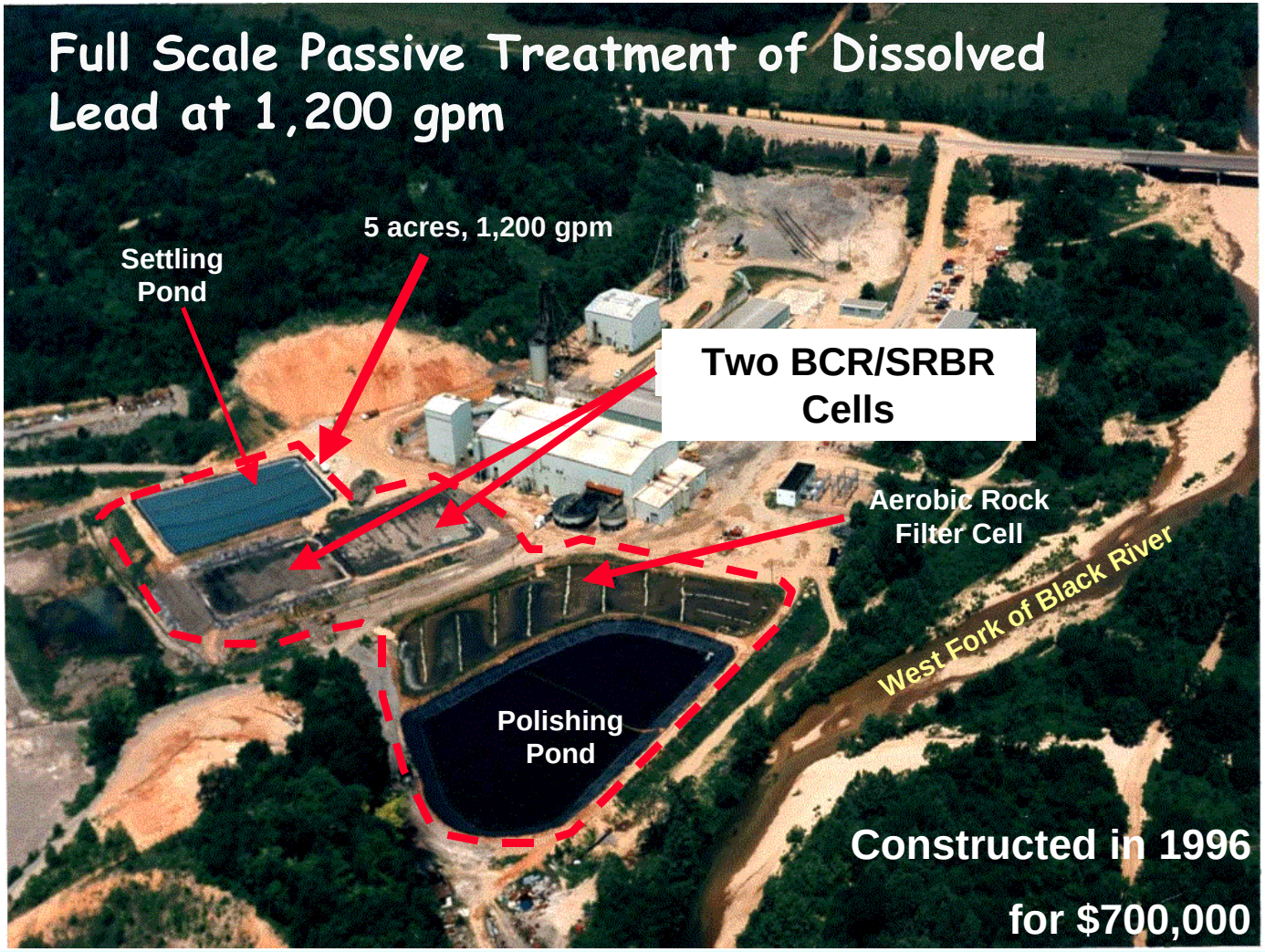
Full Scale Passive Treatment System Example



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Key Treatment Issues

- Land surface available?
- System longevity/maintenance
- Disposal of residuals (hazardous waste?)
- Performance criteria/odors
- Cost (design, capital, operating, NPV)
- Why don’t they always work as designed?

P.T. Advancements 1985 to 2009

- Established design protocol
  - Lab, bench, pilot studies
  - Physical and geochemical design parameters
  - Better understanding of microbiology
- Wide range of operating conditions
  - pH 2.5 to 8.5
  - Metals (Fe, Cu, Pb, Zn, Cd, Cr, Mn, Hg, Mo, Al, Se, As, U, Co, Tl)
  - Non-metals (CN, SO_4, NO_3, NH_3, BOD_5, P)
  - Temperatures (0 to 30 deg C)
  - Flows up to 1,200 gpm

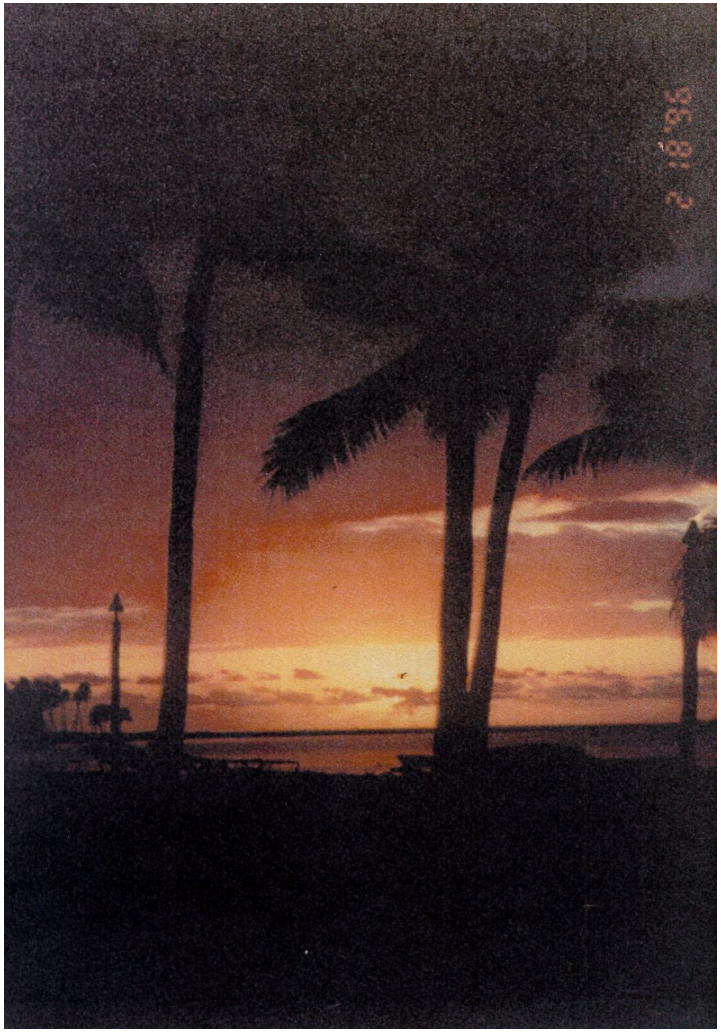
Advantages of Passive Treatment

- Low NPV cost (*50% of active treatment*)
- No moving parts
- Simple to operate
- Resilient to quantity variations
- Wildlife habitat?
- Long term (<u>but not walk-away</u>) solution
- Mimics Mother Nature
- Blends into landscape
- Politically correct
- Non-hazardous residuals (*depends on MIW*)
- Regulatory acceptance
- Resource recovery in future

Summary

- Any mine water can be treated… for a price; passive is **HALF** the cost of active treatment for identical chemistry.
- Passive treatment systems can handle a wide variety of flows, water, chemistry and site conditions (low to high: pH, metal concentration, flow and temperature).
- P.T. system longevity is on the order of decades.
- Design process is established; passive treatment is a proven methodology for treating MIW.

Thank You



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

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