SOVEREIGN CONSULTING INC.
AN ENVIRONMENTAL SERVICES FIRM

How Could the Gold King Mine Water be Passively Treated?

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GEOLOGICAL SOCIETY OF AMERICA
ANNUAL MEETING – DENVER, COLORADO
GOLD KING MINE SPECIAL SESSION

Outline

- Gold King Mine Thumbnail Sketch
- Passive Treatment Biogeochemistry
- Two Gold King Passive Treatment Design Concepts

The Gold King Site

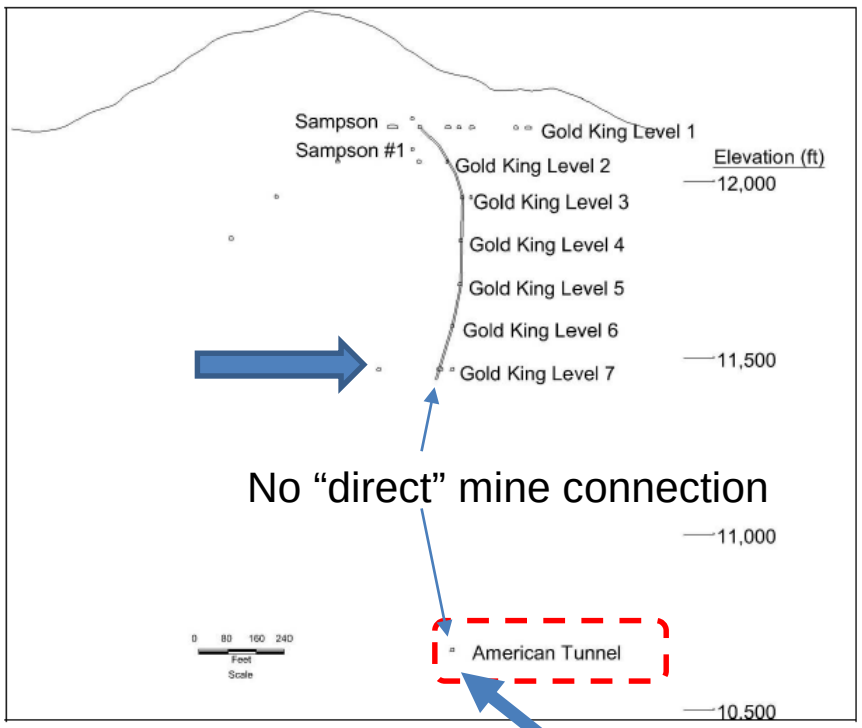
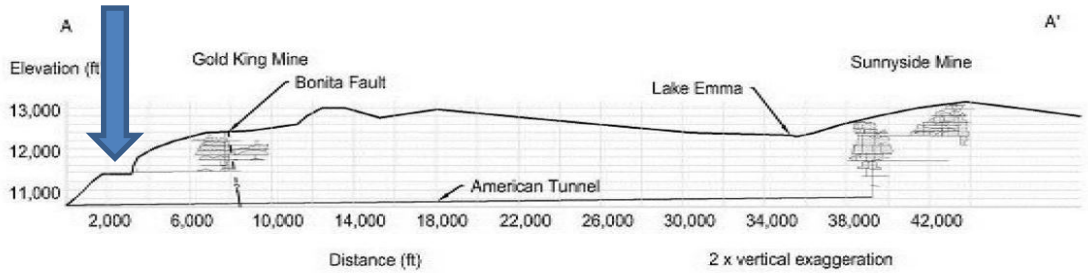


Figure 53.—Photograph showing the blowout at 10:56 a.m. on August 5, 2015 (photograph from EPA project files).

US Bureau of Reclamation, 2015



2 miles

American Tunnel Profile

"Natural" Attenuation

Mother Nature is pretty talented; to remediate heavy metals situations, ***She*** uses:

S*equential*

E*cological*

e***X****traction*

processes that have evolved over millennia (Thanks, *C. Darwin*)

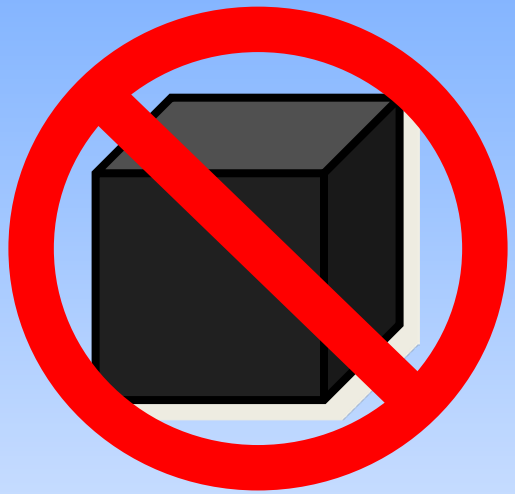
What Is the Passive Treatment Process?

Passive Treatment of MIW involves the:

S*equential*

E*cological*

*e****X****traction*



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

Iron Stromatolites & Fe/Mn Nodules

Shark Bay, Australia

Stromatolites built by cyanobacteria/algae, a process over 1 billion yrs. old

Fe/Mn Fossil Nodules

Courtesy of Nick Shearer, WV DEP

Ferricrete Deposits

Animas Basin, Colo.

Deposit of iron-cemented stream gravel (ferricrete) with embedded wood fragments

Natural Iron-rich Acidic Spring Flowing into Cement Creek

Manganocrete Deposits

Animas Basin, CO & Patagonia, AZ

Alluvial manganocrete near the former Lake Emma in Eureka Gulch

MnO_2-cemented alluvium in Alum Creek

Natural Metal Removal Mechanisms

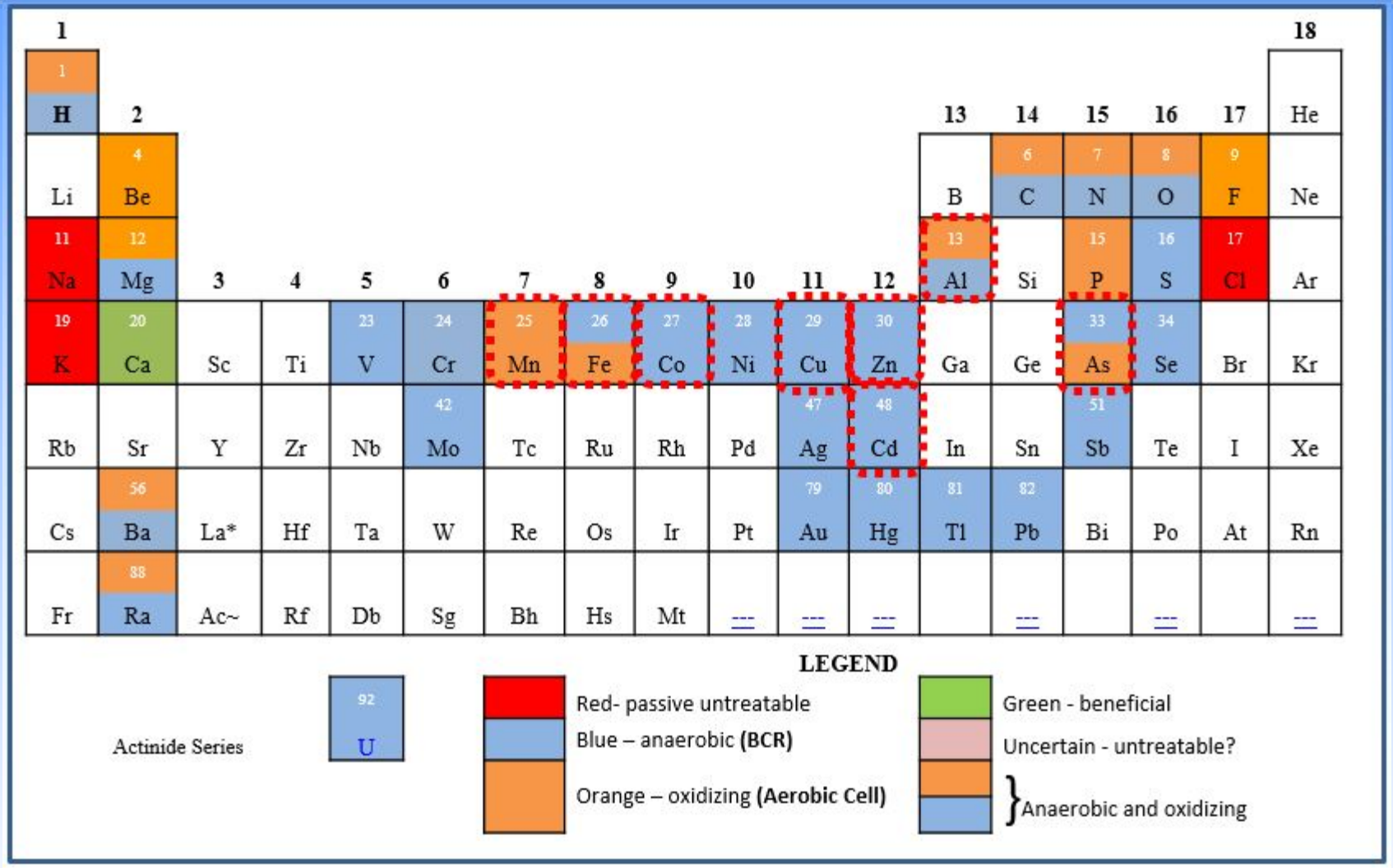
Major

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

Minor

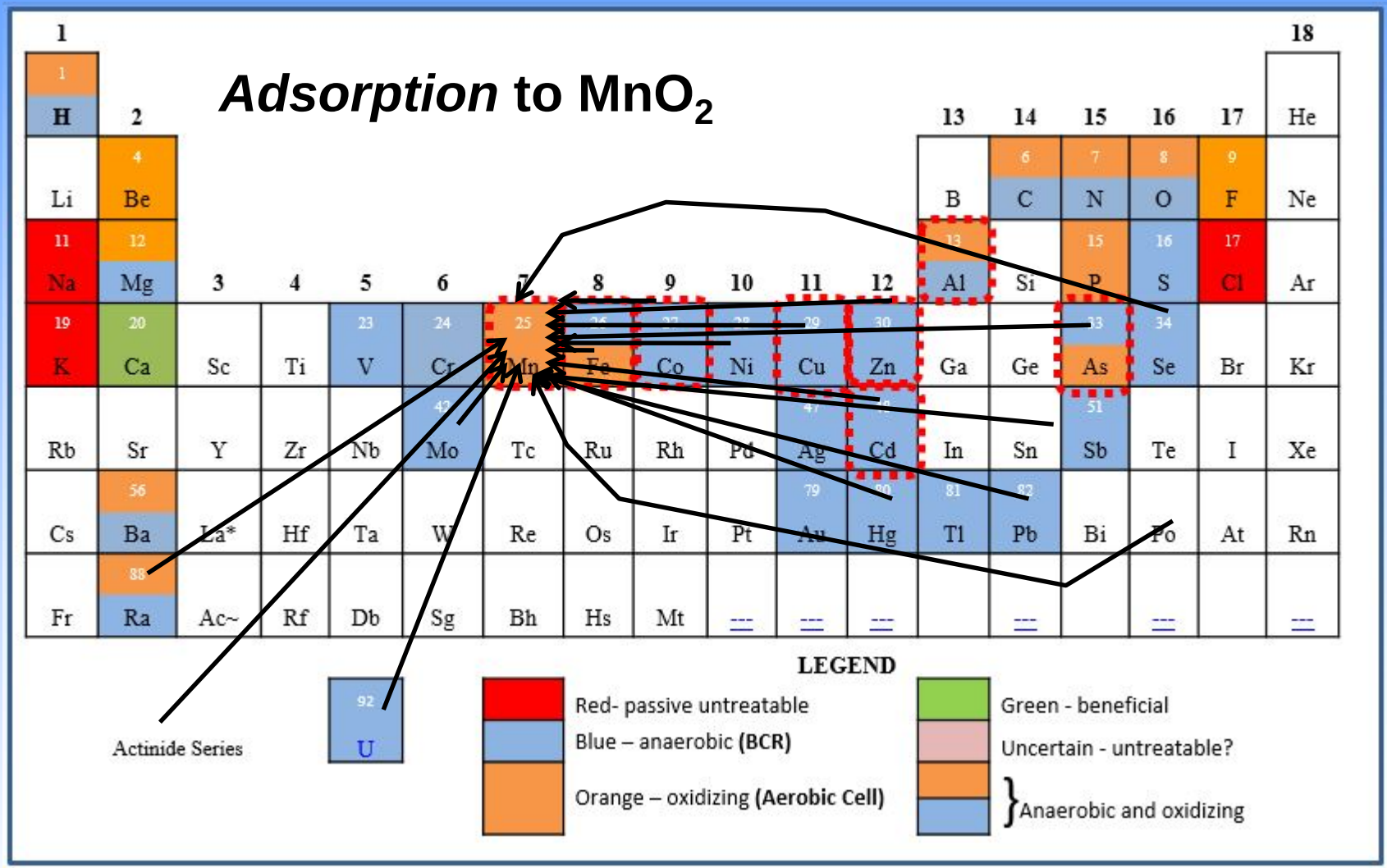
- Metal uptake into live roots, stems and leaves
- Adsorption and exchange with plant, soil and other biological materials

Periodic Table of Passive Treatment



Gusek, 2009

Periodic Table of Passive Treatment Re-Visited



Gusek, 2013

Anaerobic Biochemical Reactors (BCRs)

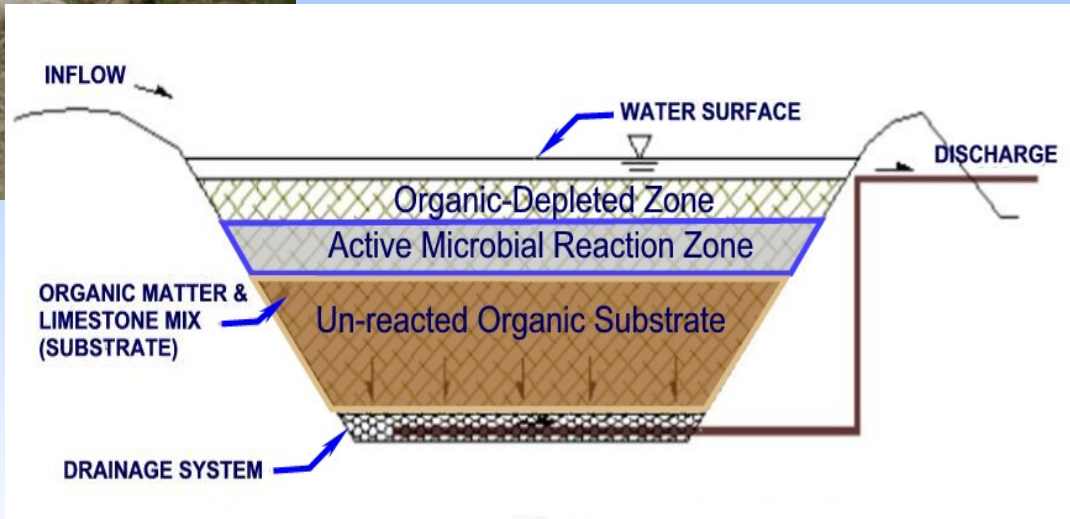
AKA

Vertical Flow Reactors

or

Sulfate Reducing Bioreactors (SRBRs)

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



Aerobic Cells

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

(plus adsorbed metals)

AKA Rock Filters

Iron Terraces – Aerobic Special Case

Modern Aerobic Wetlands & Ferricrete/Iron Terraces

Some ferricrete deposits in the Animas Basin are 9,000 yrs. old!

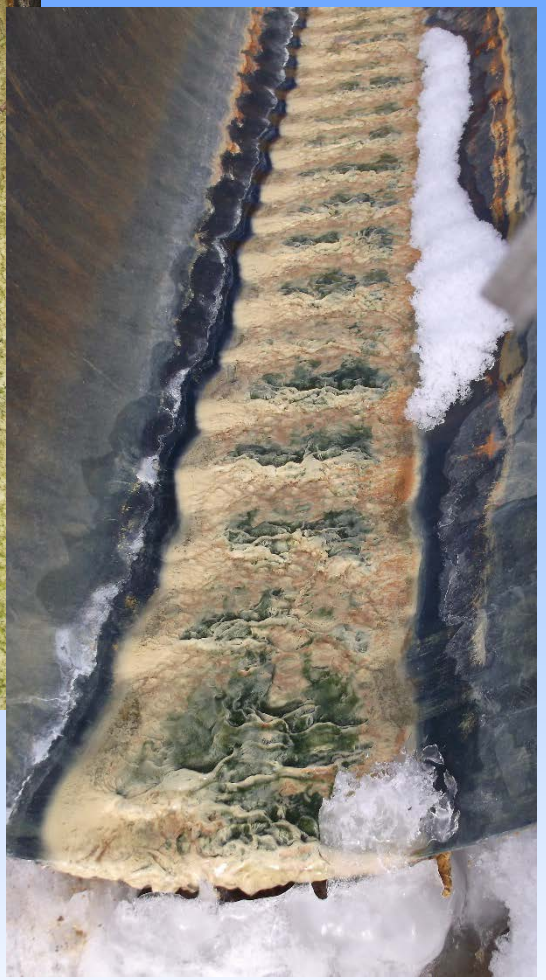
IRON TERRACE REACTIONS

$$6H^+ + (C_6H_{10}O_5)n + 3/2\ O_2 \Rightarrow 6C + 16\ H_2O + heat$$

(Cellulose Dehydration by Acidity)

Reaction consumes H^+ (acid) & pH rises and iron or aluminum can drop out

Volunteer Aluminum Terrace Deposition Idaho

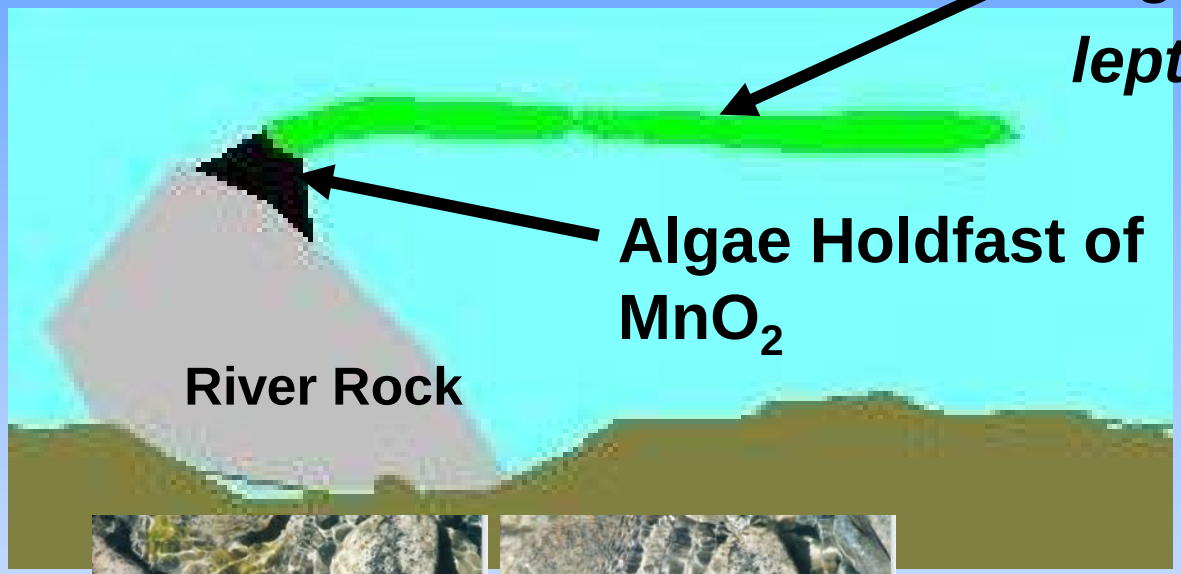


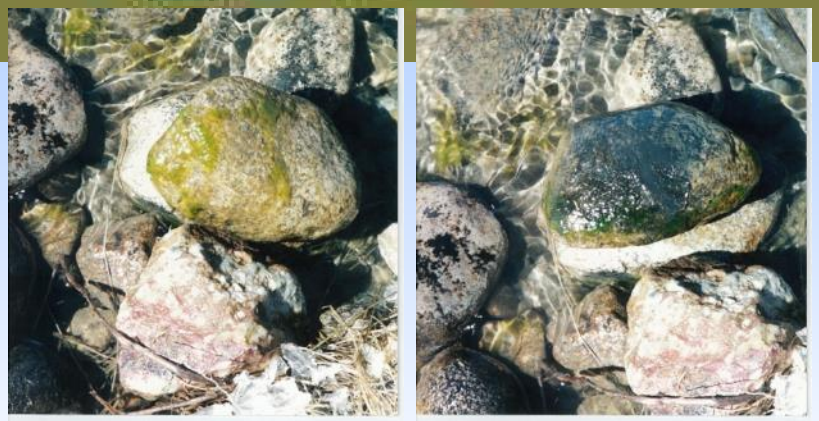
pH 2.5;
Al 800 mg/L
Fe 500 mg/L

Compare to Red and Bonita Mine Portal

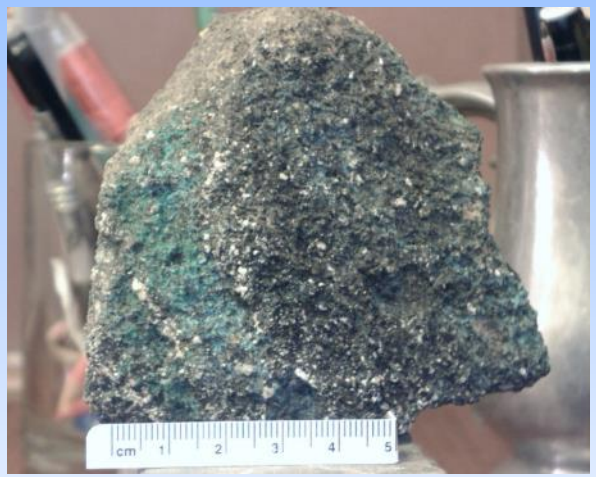
US Bureau of Reclamation, 2015

Manganese Oxidation at Neutral pH





Manganese/algae in outfall from Leadville Colorado (El. 10,000ft/3,050m) WTP in March



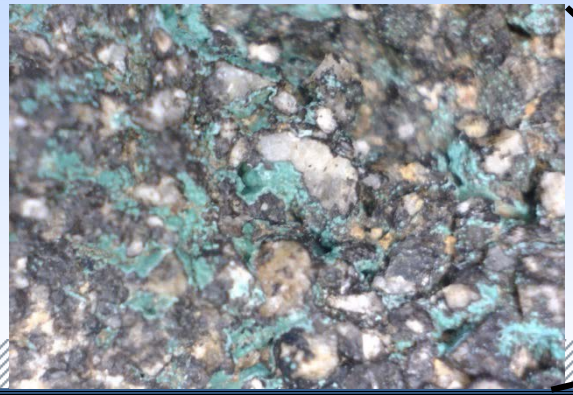
Manganocrete from paleo-channel near Prescott, AZ

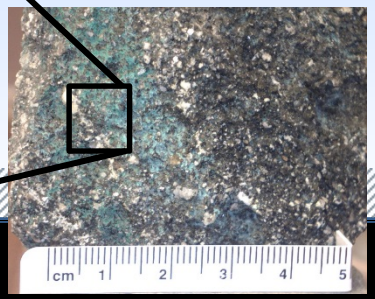
Why is *manganese* removal so important?

Arsenic
Copper
Lead
Zinc
Cadmium
Mercury
Molybdenum

Manganese Oxide
(black stain on stream gravel)

Cobalt
Nickel
Selenium
Uranium
Radium
Silver
(***More*** Manganese)





The Gold King PTS Design Conditions

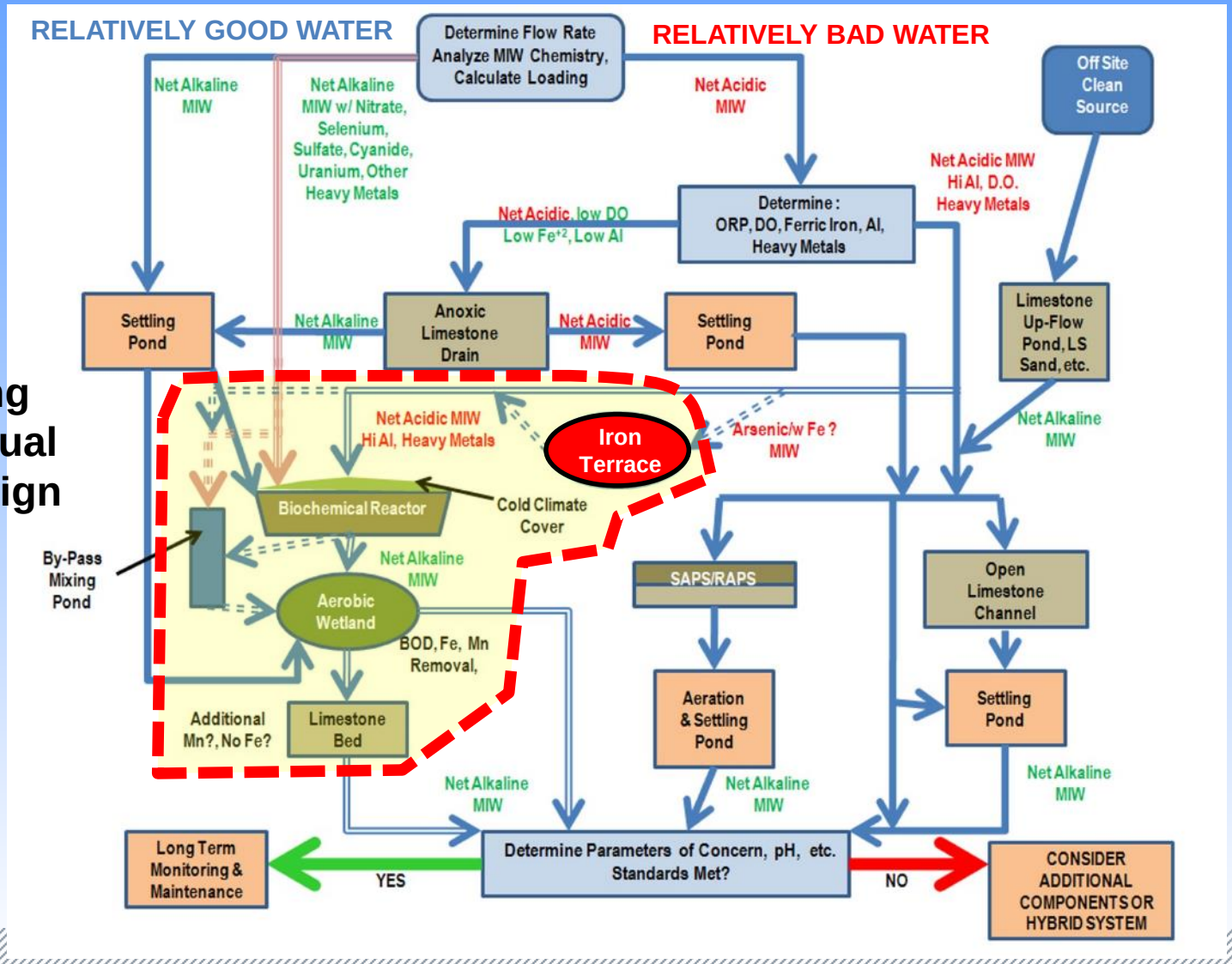
Parameter	Value	Units	Assumed Condition
Flow	300	gpm	Spring freshet
Flow	200	gpm	Steady state
pH	3.0	S.U.	Steady state
Aluminum	25	**mg/L**	Steady state
Arsenic	22	µg/L	Steady state
Iron	126	**mg/L**	Steady state
Cadmium	75	µg/L	Steady state
Copper	6.0	**mg/L**	Steady state
Cobalt	111	µg/L	Steady state
Manganese	35	mg/L	Steady state
Sulfate	1,760	**mg/L**	Steady state
Zinc	26	**mg/L**	Steady state

Chemistry from Aug-Sept 2015

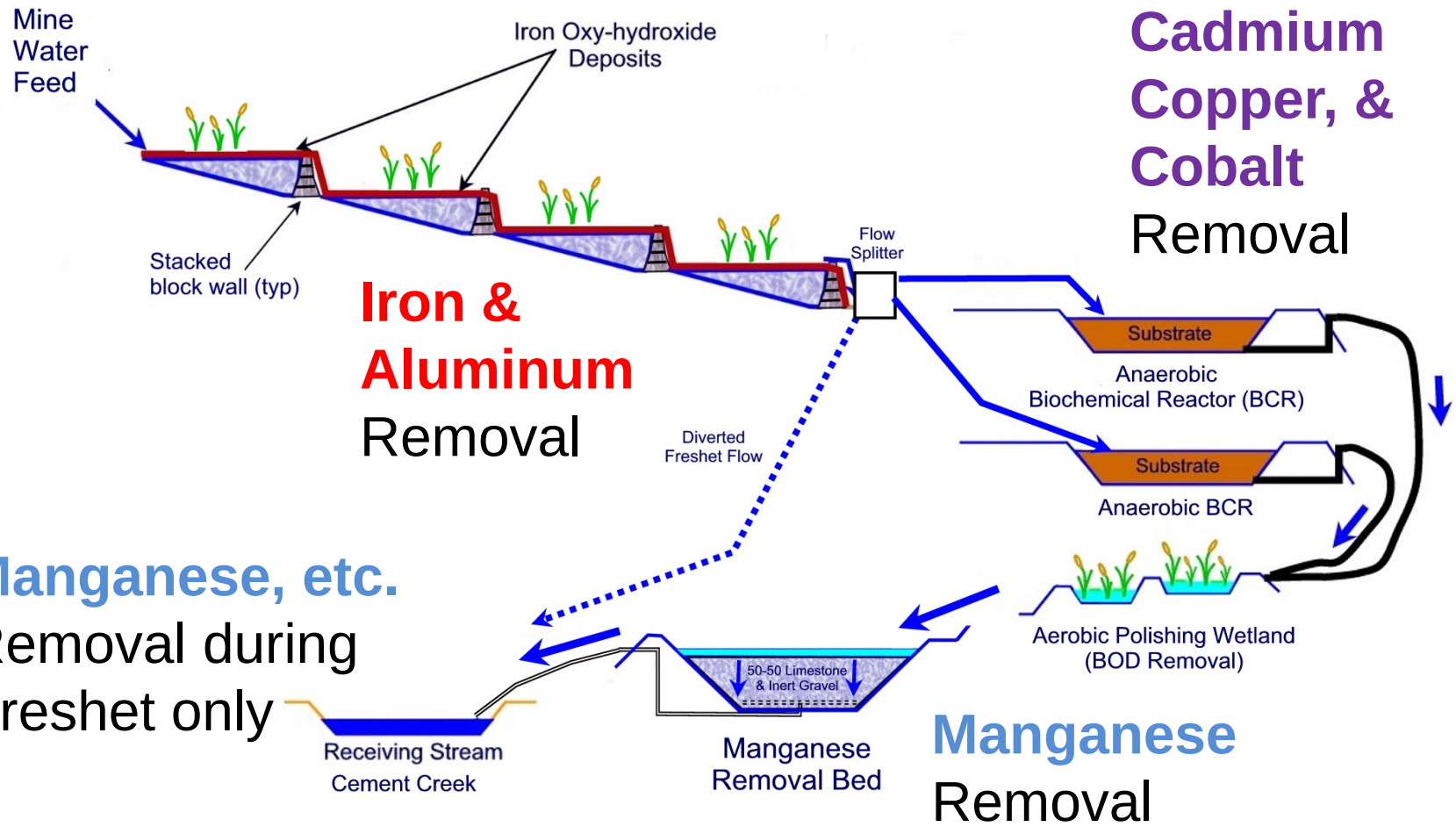
US EPA, 2016

Passive Treatment Decision Tree 2016

Gold King Conceptual PTS Design #1



Conceptual Gold King PTS #1



Zinc, Cadmium Copper, & Cobalt Removal

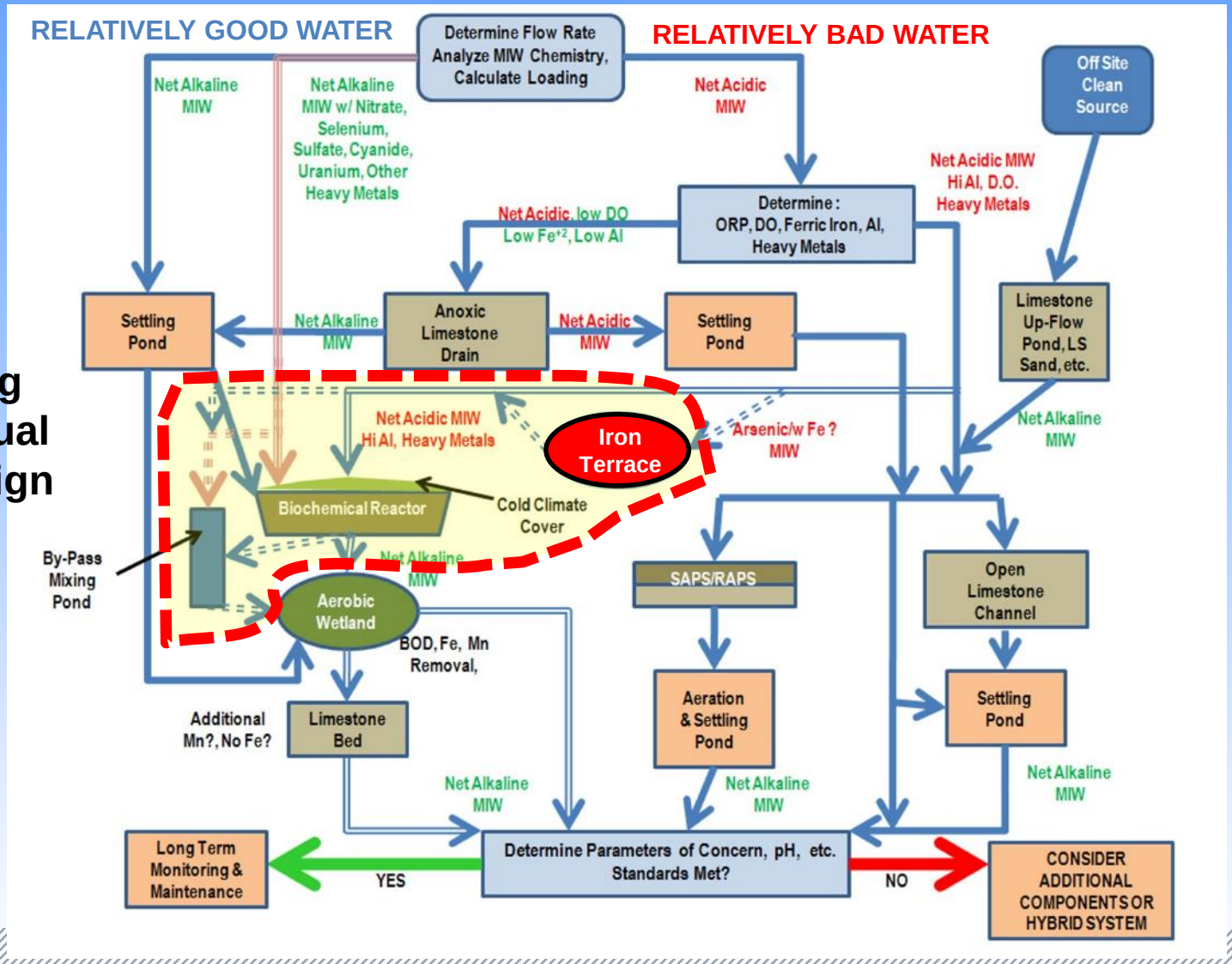
Iron & Aluminum Removal

Manganese, etc. Removal during Freshet only

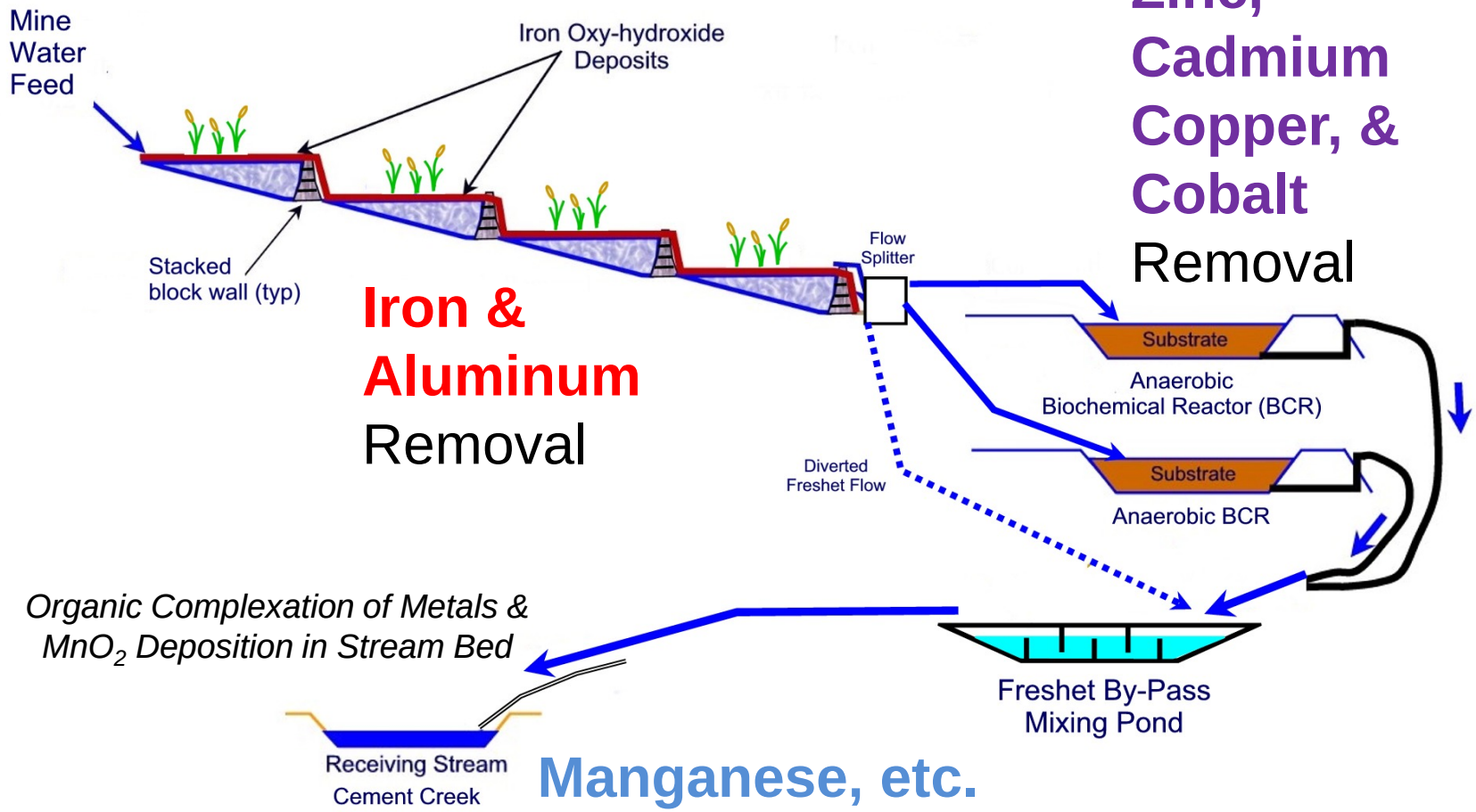
Manganese Removal

Passive Treatment Decision Tree 2016

Gold King Conceptual PTS Design #2



Conceptual Gold King PTS #2

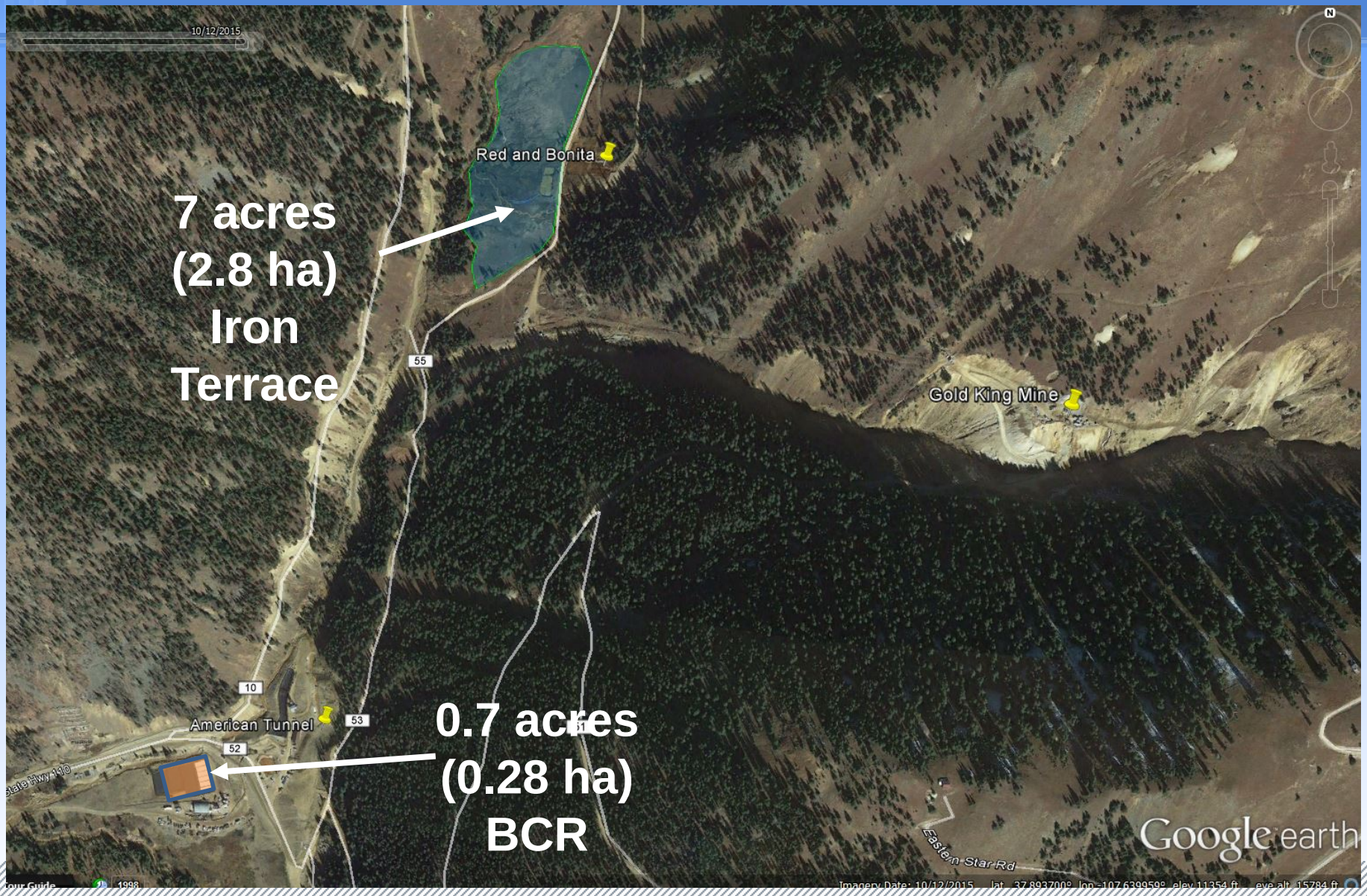


Zinc, Cadmium Copper, & Cobalt Removal

Iron & Aluminum Removal

Manganese, etc. Removal

Gold King PTS Sites?



Tailings and Mine Waste Conference, Keystone Colorado Oct. 3-5, 2016

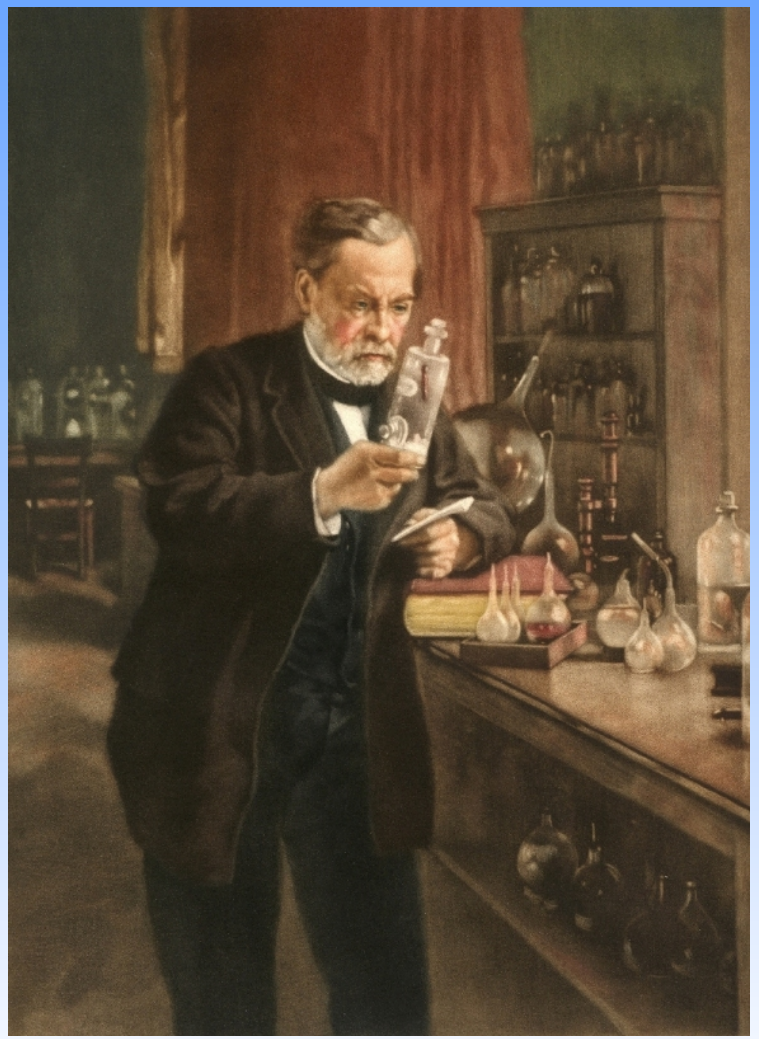
A Pathway to Walk-Away? – 30 Year Old Technology to Suppress Acid Rock Drainage Revisited

- Use of bactericides to suppress ARD
- Seven case history successes
- Merging old and new technologies

REVIEW – Pathway to Walk-Away

1. ***Primary Source Control*** to minimize flow, metals concentrations, and loading
2. ***Reclamation/Remediation*** to sustain primary source control measures for the long term
3. ***Passively Treat*** residual 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)
   - Major processes are:
     - Chemical precipitation (usually facilitated by bugs) in aerobic and anaerobic conditions
     - Adsorption to MnO_2, etc. (facilitated by algae)

Thank You



“In the fields of observation, *chance favors* only *the prepared mind*.”

L. Pasteur

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