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BUREAU OF LAND MANAGEMENT

Proof of Concept Bio-Terrace Aluminum Removal at an Abandoned Metal Mine, Idaho

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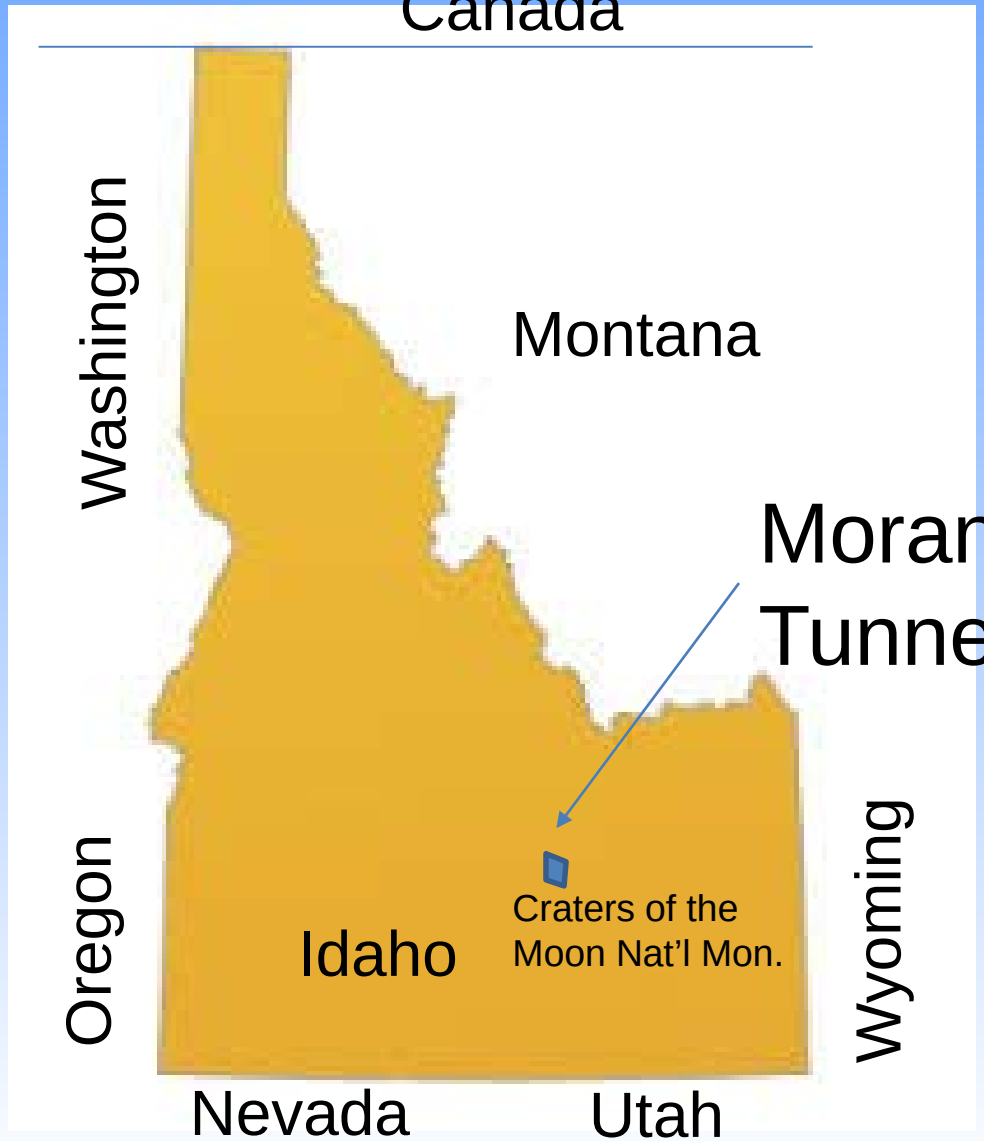
ECM Consulting Inc.
and
Joseph Larson, US Bureau of Land Management

Outline

- Moran Tunnel – Site Introduction
- Passive Treatment 101 – “It’s not a constructed wetland”
- Iron Terraces – Mother Nature @Work
- Aluminum Removal Mechanisms
- Proof of Concept Test Results
- Path Forward

Moran Tunnel Site, Idaho



Moran Tunnel Site

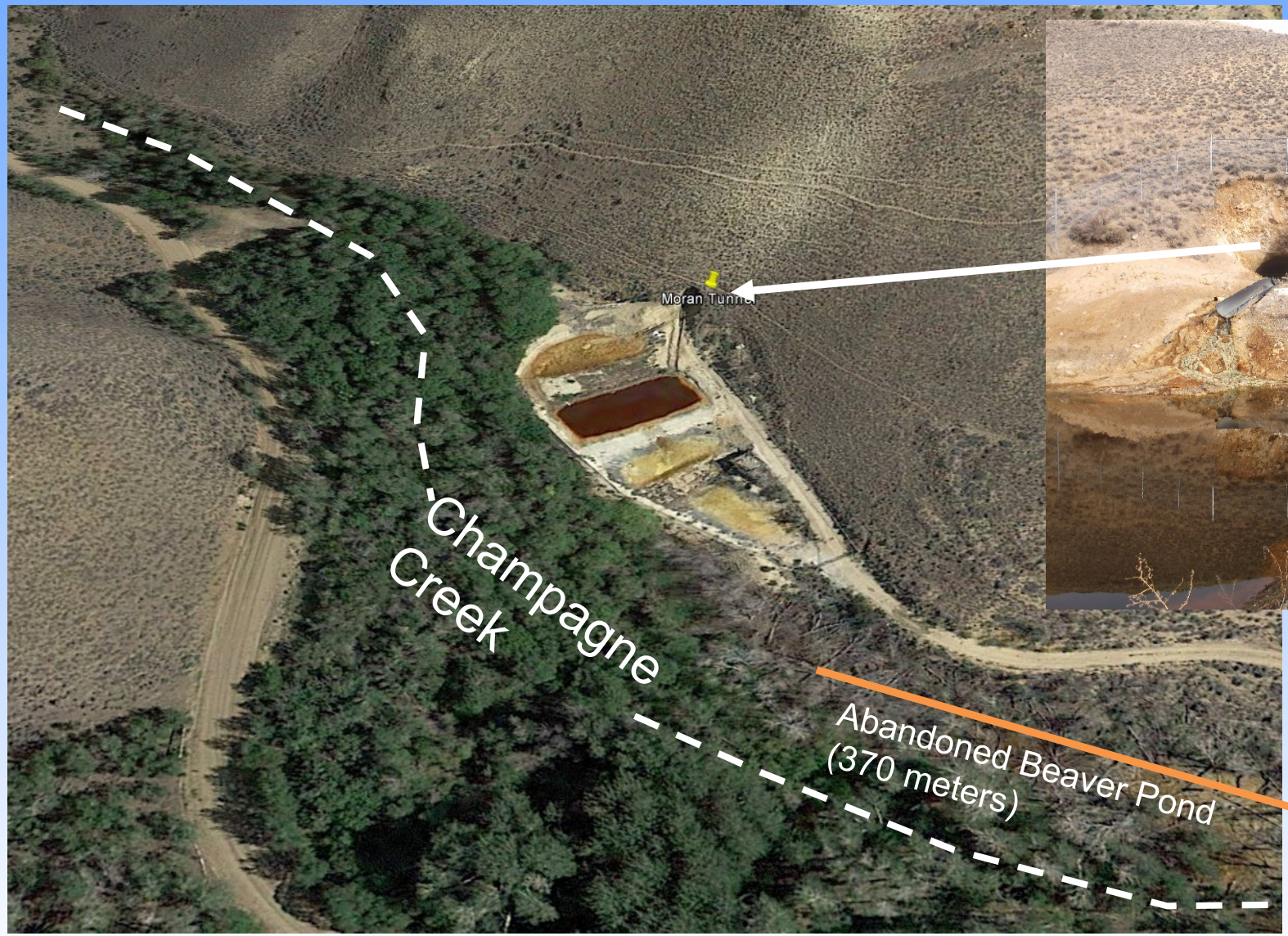
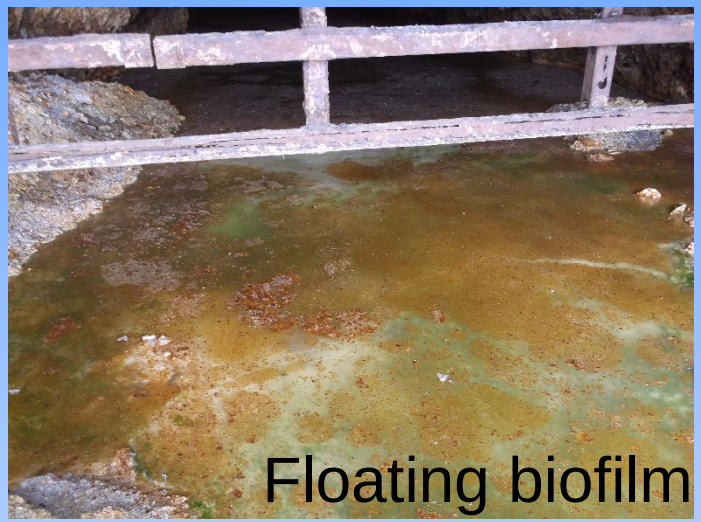
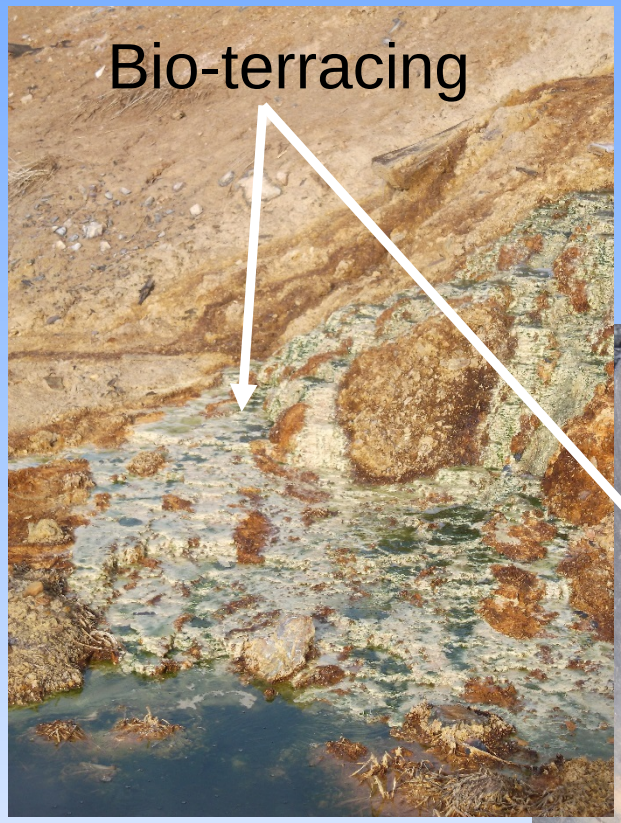


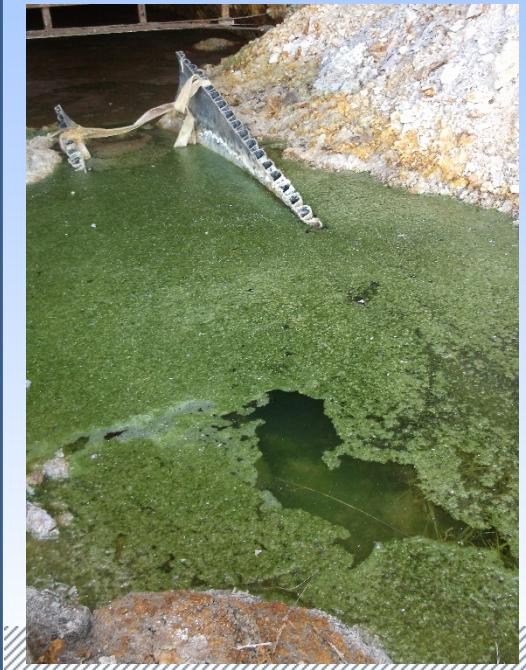
Image Courtesy Google Earth

Moran Tunnel Site - November 2013





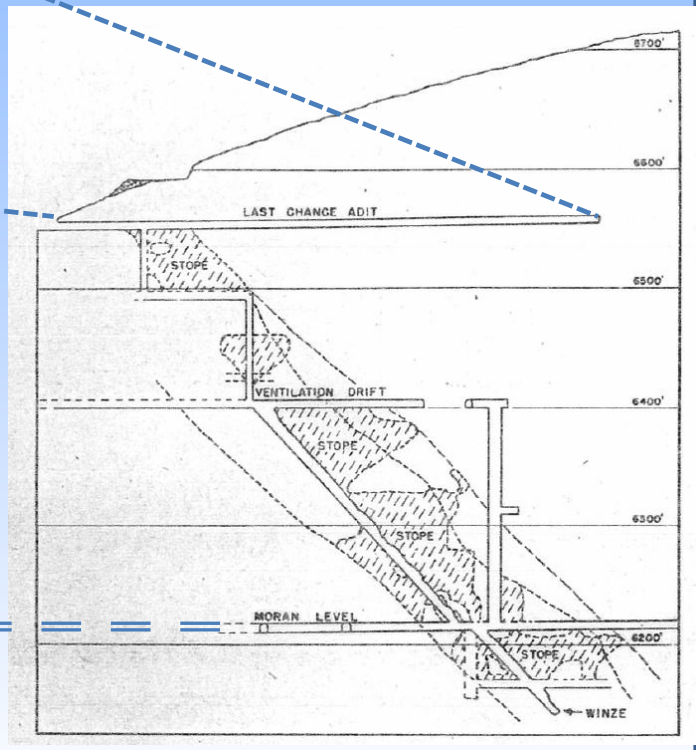
More than a century ago, Louis Pasteur said, "*Chance favors* only *the prepared mind*."



Cyanobacteria/Algae

Moran Tunnel & Last Chance Mine

Cu = 184 mg/L
Zn = 77 mg/L
As = 0.2 mg/L
Cd = 1.5 mg/L
Mn = 42 mg/L
SO_4 = 5,000 mg/L



ARD

pH - 3.15
Al - 800 mg/L
Fe – 1,700 mg/L
Flow ~ 12L/min.

Portal

Moran Tunnel

What Is the Passive Treatment Process?

Passive Treatment of Mining Influenced Water (MIW) involves the:

S*equential*

E*cological*

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

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

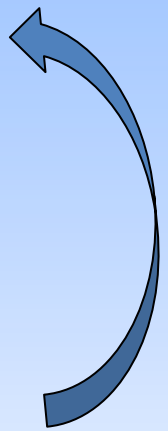
P.T. Metal Removal Mechanisms

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

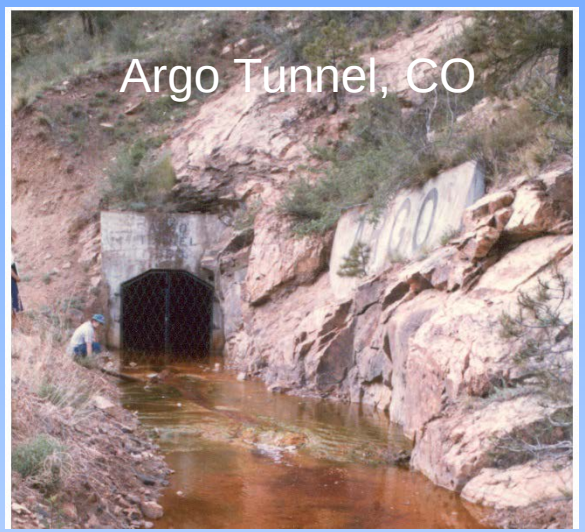
- Metal uptake into live roots, stems and leaves
- Adsorption and exchange with plant, soil and other biological materials

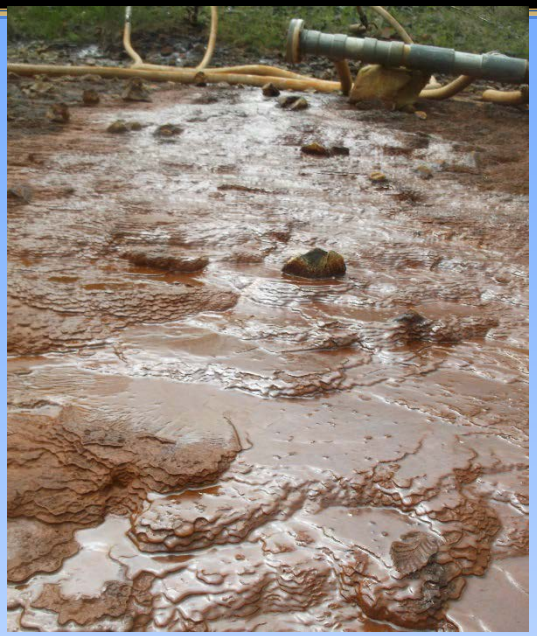


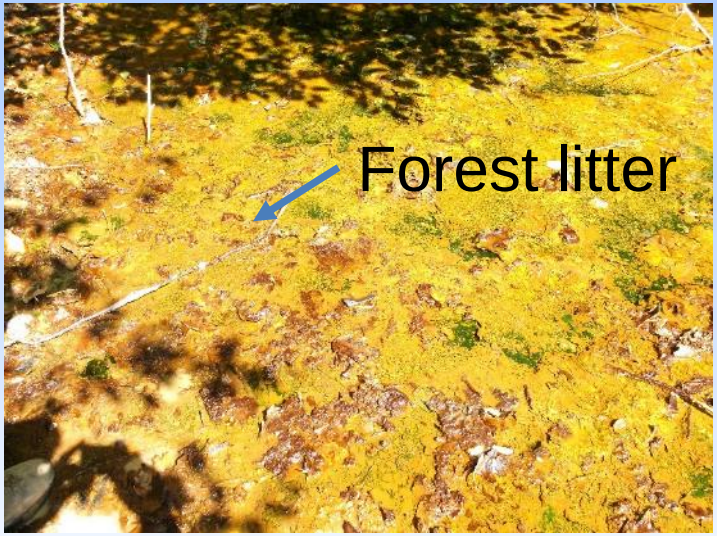
Iron Terraces – Coast to Coast (USA): Mother Nature at Work

Some ferricrete deposits in the Animas Basin, Colorado are 9,000 years old!

Fe^{+2}, Forest Litter & Algae, the Common Denominators

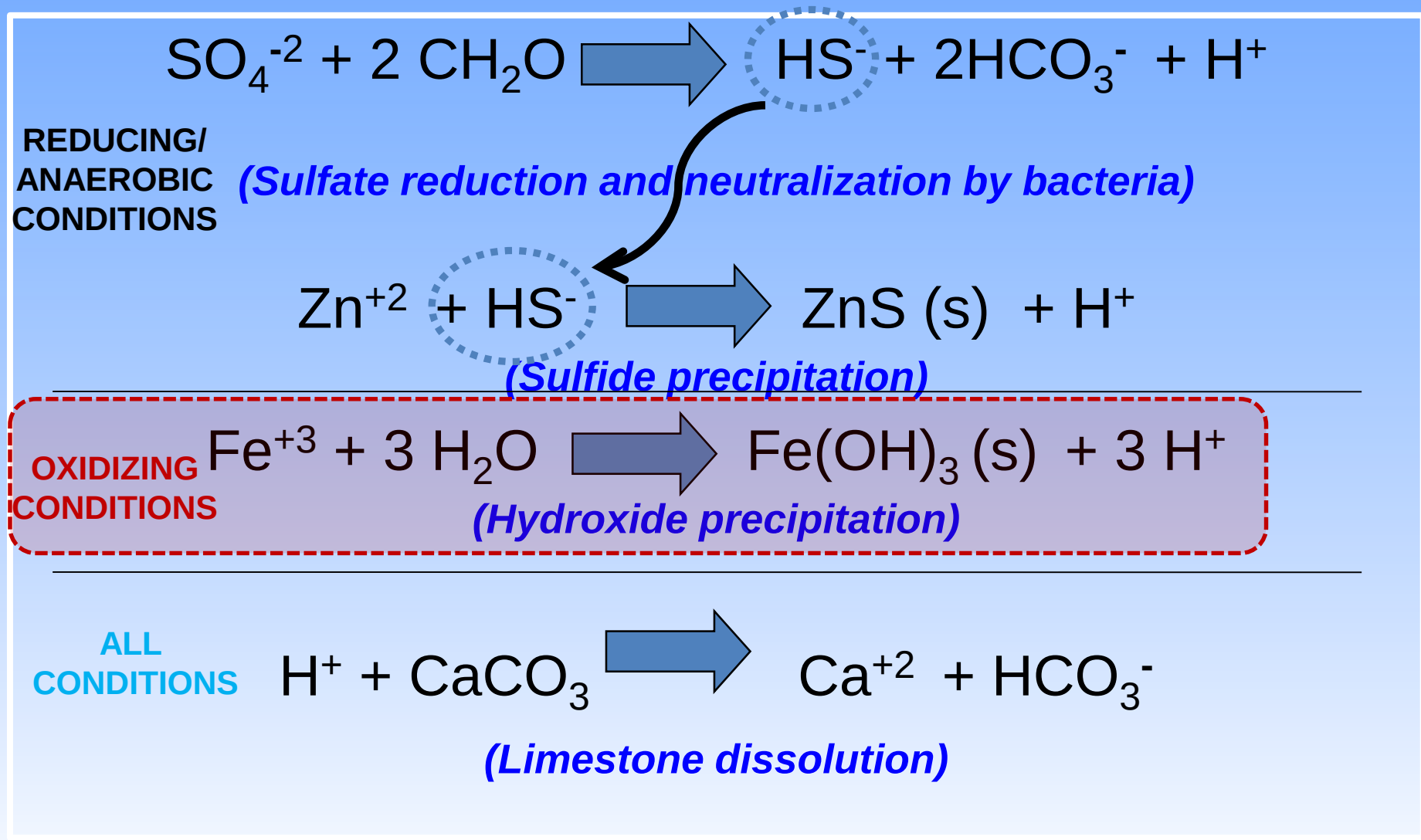




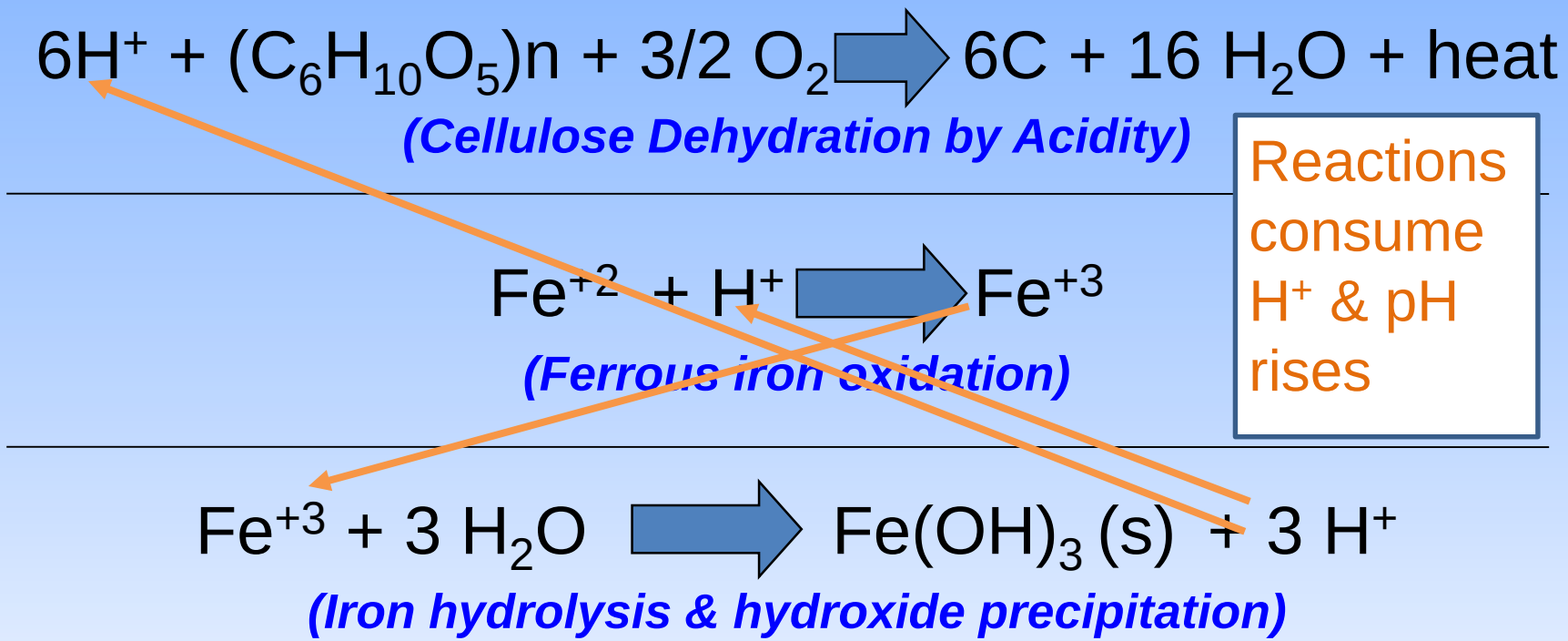


Aluminum? Deposition @ Red & Bonita Mine, CO

Passive Treatment Chemistry 101

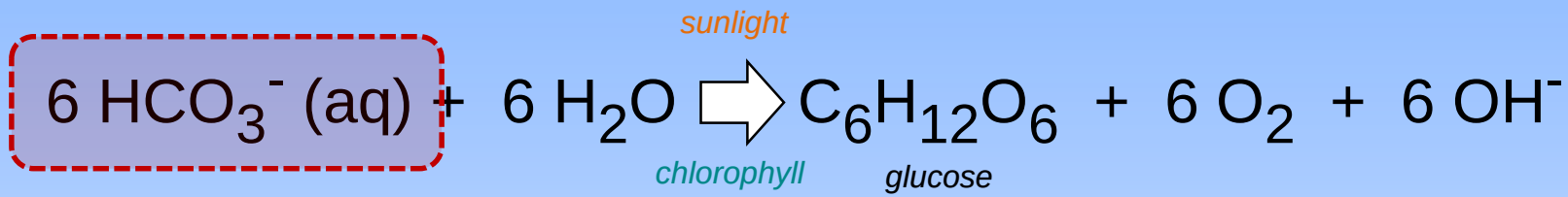


IRON TERRACE REACTIONS?



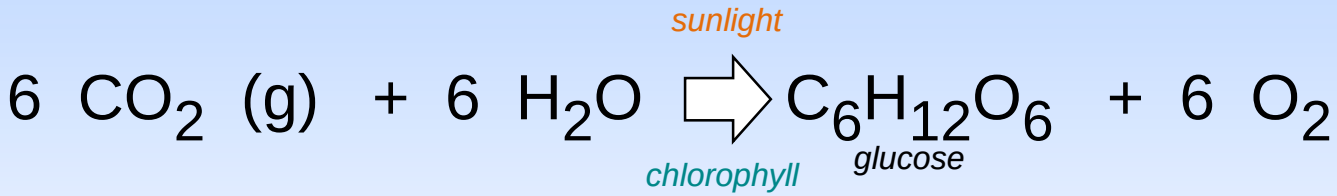
Cyanobacteria/Algae Can Raise pH

PHOTOSYNTHESIS IS AN IMPORTANT PROCESS FOR INCREASING pH



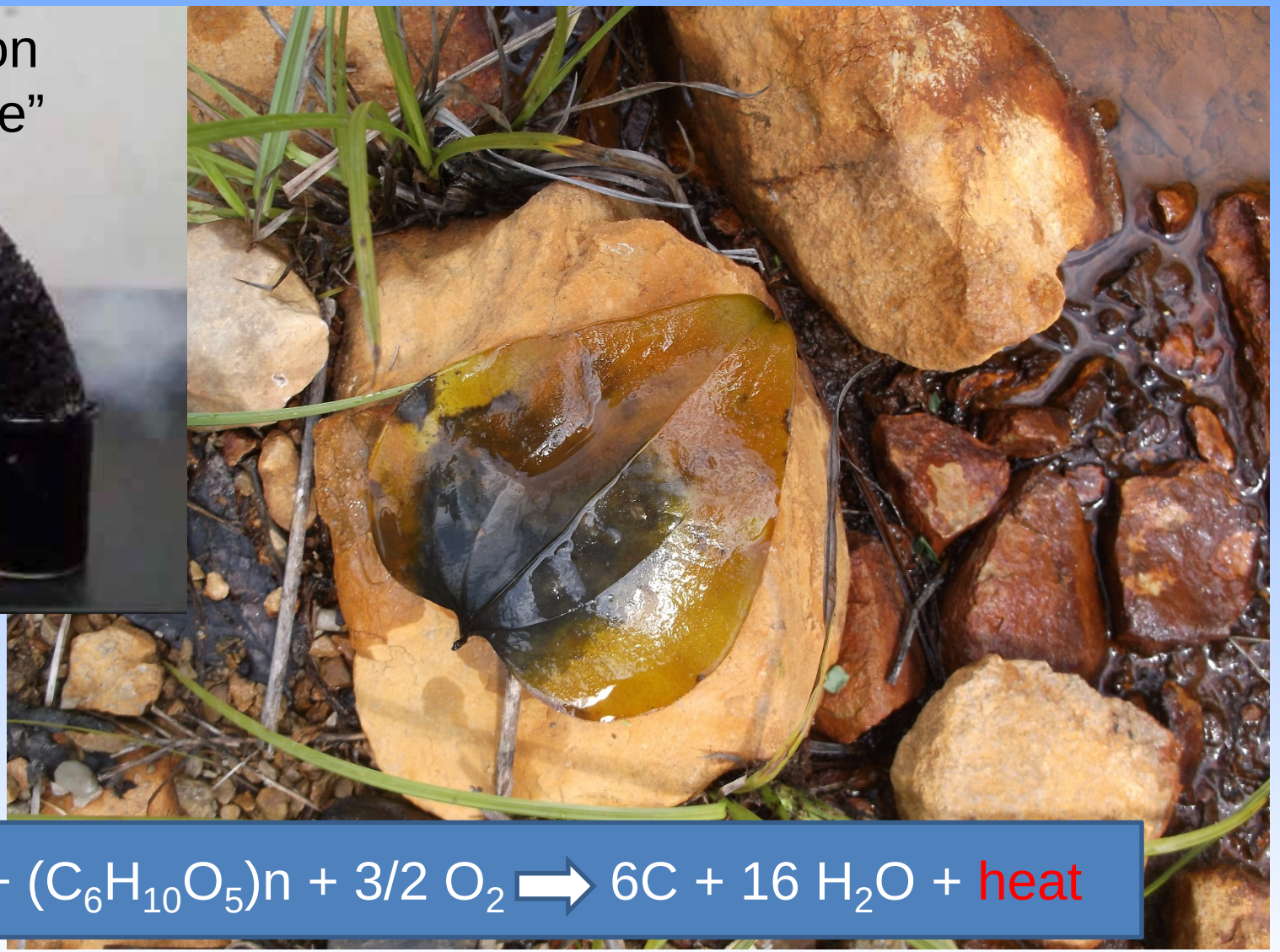
6 H_2CO_3 (aq) – carbonic acid

COMPARE WITH



Ref: T. Wildeman, 2005

Cellulose Dehydration by Acidity



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

Aluminum Behavior

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

(problematic due to sludge buildup)

Some conditions are favorable for aluminum hydroxysulfate precipitation (examples):

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

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

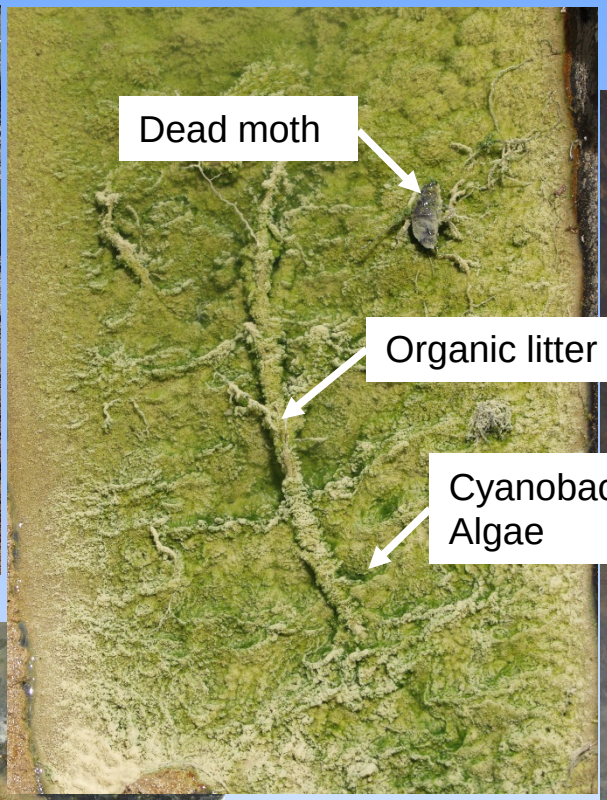
Thomas, R.C. 2002. *Passive Treatment of Low pH, Ferric Iron-Dominated Acid Rock Drainage*. Doctoral Thesis. University of Georgia.

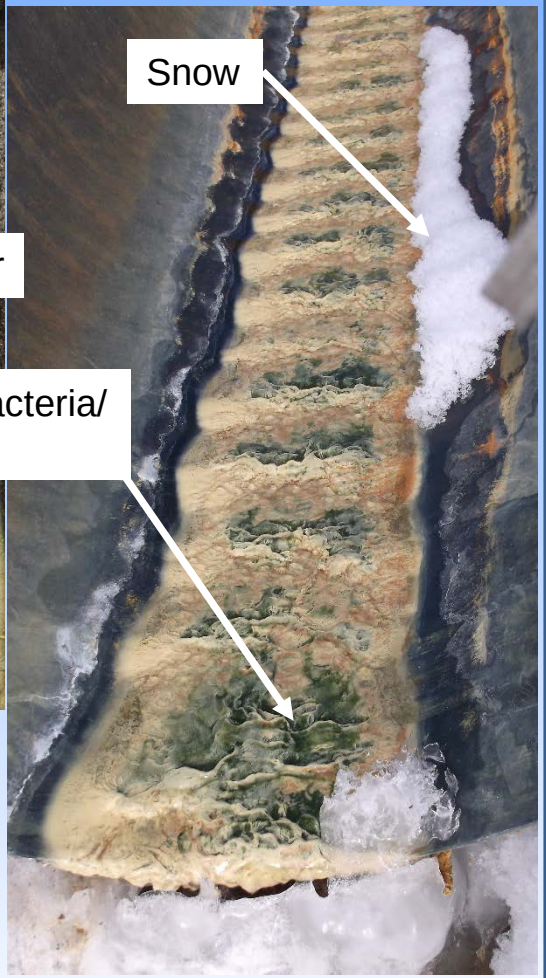
Other Aluminum Possibilities

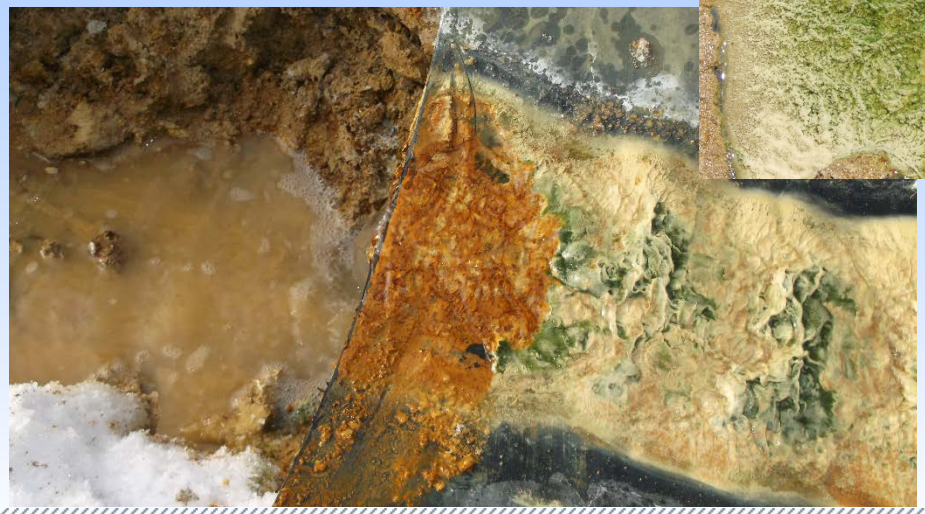
- Hydrobasaluminite $Al_4(SO_4)(OH)_{10}•12\text{-}36(H_2O)$
- Basaluminite $Al_4(SO_4)(OH)_{10}•5(H_2O)$
- Aluminite $Al_2(SO_4)(OH)_4•7(H_2O)$
- Kaolinite $Al_2Si_2O_5(OH)_4$
- Silvialite $(Ca,Na)_4Al_6Si_6O_{24}(SO_4,CO_3)$

Ratio of aluminum to sulfate varies from
6 Al to 1 SO_4 (Silvialite) to
0.67 Al to 1 SO_4 (Ettringite)

Aluminum Terrace Deposition @ Moran Tunnel, Idaho







pH 3.2
Al 800 mg/L
Fe 1,700 mg/L

Analysis of Existing Precipitates

Sampling Location		PORTAL		CREEK		BEAVER POND	
Parameter	Units	Value	Moles/ Kg	Value	Moles/ Kg	Value	Moles/ Kg
Sulfate	mg/kg	16,000	0.17	15,000	0.16	160,000	1.67
Phosphate as P	mg/kg	1.1		1.3		3.5	
Total Solids	*%*	*36.7*		*22.9*		*27.6*	
Aluminum	**mg/kg**	**5,400**	**0.20**	**2,400**	**0.09**	**4,300**	**0.16**
Calcium	mg/kg	790	0.02	1,500	0.04	58,000	1.45
Copper	mg/kg	300	0.00	280	0.00	1,300	0.02
Iron	**mg/kg**	**140,000**	**2.51**	**190,000**	**3.40**	**3,100**	**0.06**
Lead	mg/kg	3.3	0.000	5.2	0.000	2.9	0.000
Magnesium	mg/kg	440	0.02	610	0.03	13,000	0.53
Manganese	mg/kg	120	0.002	130	0.002	1,600	0.03
Silicon	mg/kg	2,000	0.07	660	0.02	4,300	0.15
Silver	mg/kg	<14.		<22.		<3.6	

Spec. Gravity Solids 1.7 to 2.3

Passive Treatment Staged Design Phases

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

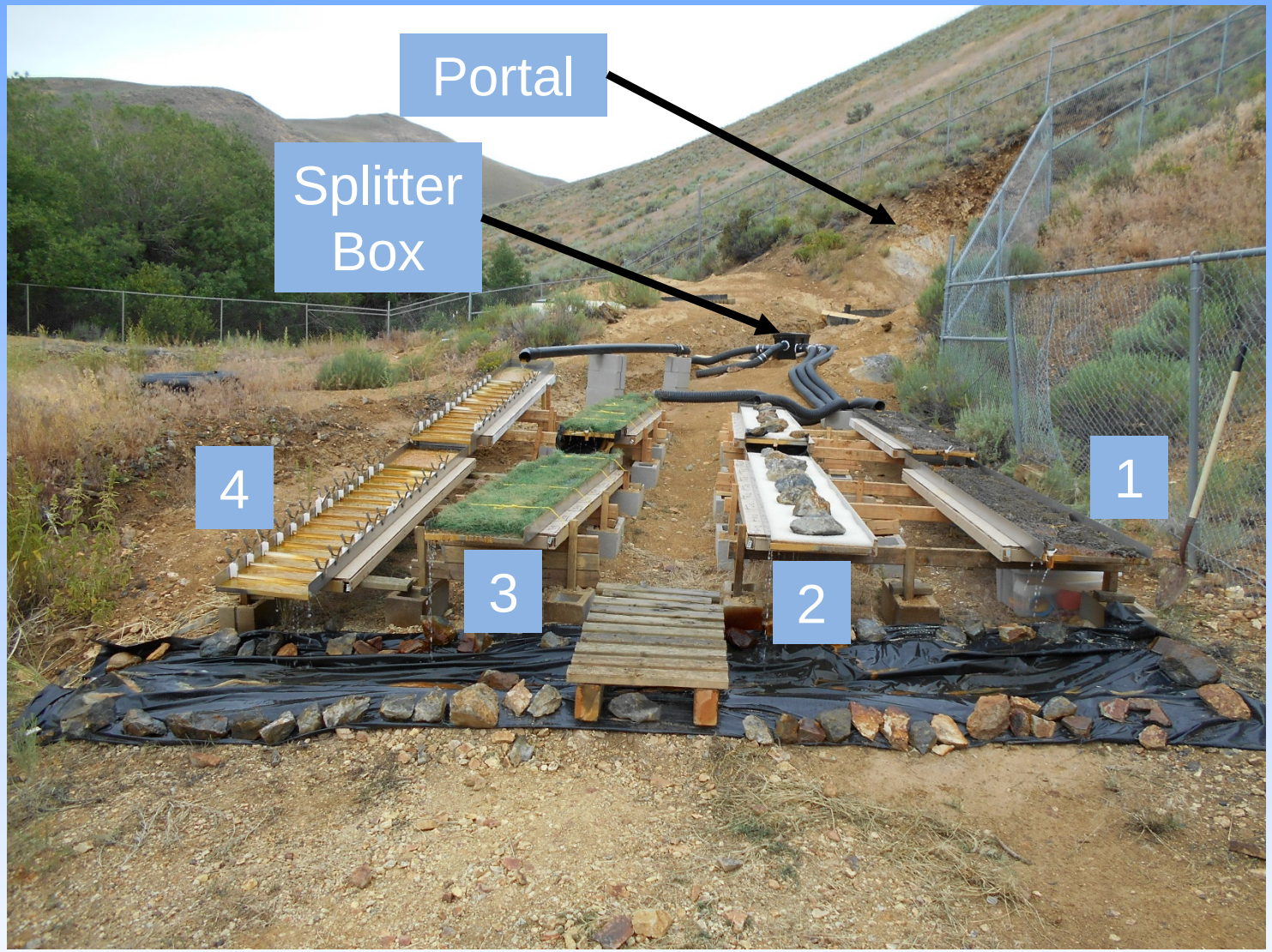
Aluminum Terrace POC – June to August 2016

Four troughs, 6.1 meters long, 46 cm wide (2.8 m^2), each receiving about 2.8 liters/min

- **Trough 1 High Organic** – Shredded willows, three layers of jute matting (erosion control mat); *slope: 0% to 2%*
- **Trough 2 Non-Organic** – Inert biomat filter media; *slope: 0% to 2%*
- **Trough 3 Anoxic** – Native soil & manure (50-50) covered with coconut coir erosion control mat; *slope: 0% to 1% (flat)*
- **Trough 4 Oxygenated** – Inert (glass) aquarium media with plastic ledges/terraces; *slope: 3% to 7%*

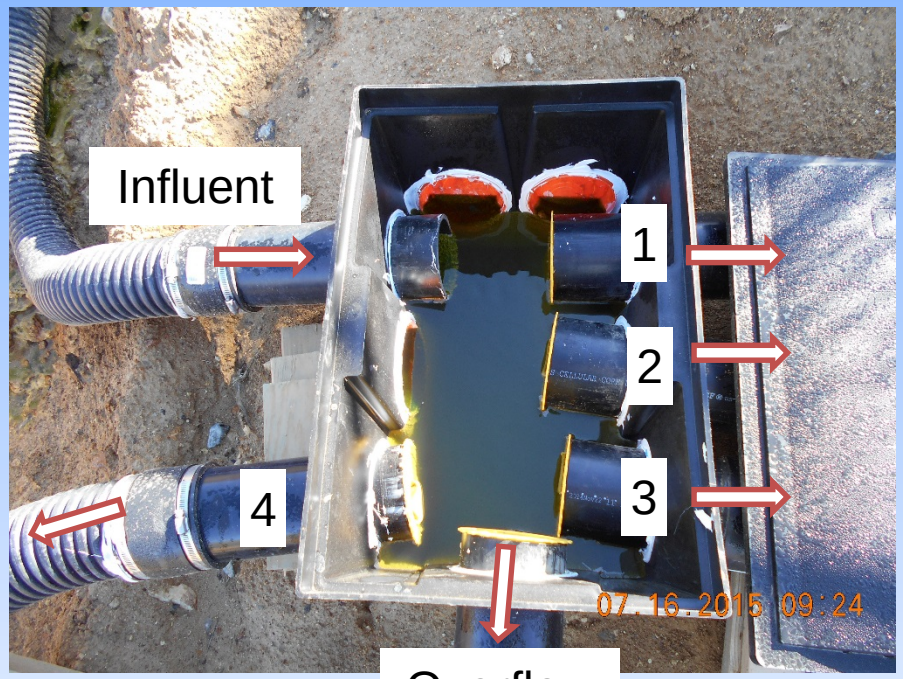
Test Duration: 56 days

Aluminum Terrace POC – June to August 2016

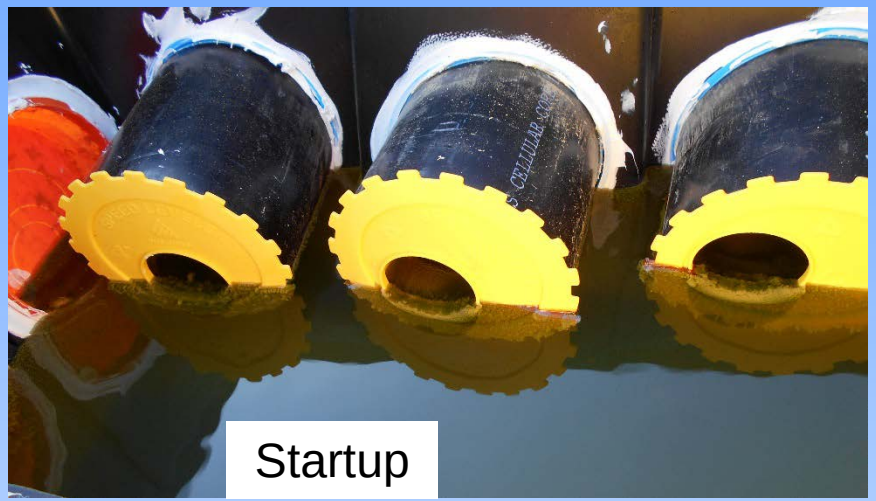


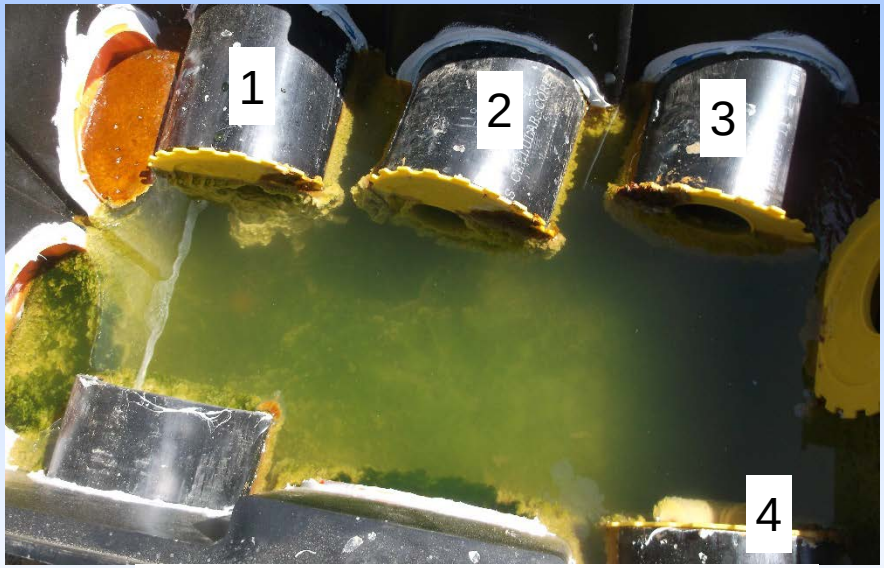
Aluminum Terrace POC – June to August 2016

Four troughs receiving about 4 liters/min. each



Adjustable flow splitter box for septic systems





Decommissioning – Day 56

Aluminum Terrace POC – June to August 2016

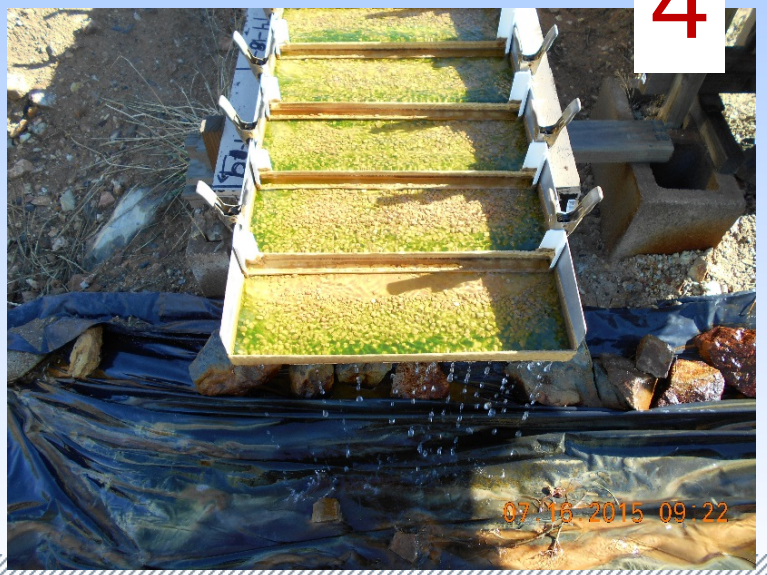
1

2

Aluminum Terrace POC – June to August 2016

3

4



Static Microcosm Tests

See Dave Jenkins paper,
ASMR Session 6A
Meeting Room 1
Wednesday, June 8
4:00 to 4:30p

POC Results – pH & Flow

Field pH						
Date	Week	Influent	Trough 1	Trough 2	Trough 3	Trough 4
6/24/2015	0	3.6				
6/27/2015	0	3.2	3.33	3.30	3.33	3.23
7/6/2015	1	3.47	3.45	3.51	3.5	3.44
7/16/2015	3	3.46	3.37	3.43	3.45	3.43
7/30/2015	5	3.76	3.14	3.18	3.15	3.22
8/6/2015	6	3.25	3.34	3.34	3.3	3.3
8/20/2015	8	3.38	3.36	2.95	2.85	3.34

Flow Rate Liters/min						
Date	Week	Influent	Trough 1	Trough 2	Trough 3	Trough 4
6/24/2015	0	9.5				
6/27/2015	0		1.4	2.8	2.8	2.4
7/6/2015	1		1.3	2.7	2.6	2.7
7/16/2015	3	9.5	1.3	2.8	2.3	3.3
7/30/2015	5	10.0	3.4	1.2	2.2	1.7
8/6/2015	6	10.0	2.6	2.3	1.6	2.3
8/20/2015	8	9.9	3.4	0.1	0.03	4.2

Results - Iron

Dissolved Fe (mg/L)						
Date	Week	Influent	Trough 1	Trough 2	Trough 3	Trough 4
6/26/2015	0	1730	Organic	Non-Organic	Anoxic	Oxygenated
7/2/2015	1					
7/16/2015	3		1510	1380	1360	1430
7/30/2015	5	1770	1730	1760	1830	1750
8/6/2015	6	1700	1880	1880	1760	1770
8/20/2015	8	1650	1770	1590	1170	1750
8/20/2015 Dup			1500			
Average		1712.5	1678.0	1652.5	1530.0	1675.0

Total Fe (mg/L)						
Date	Week	Influent	Trough 1	Trough 2	Trough 3	Trough 4
6/26/2015	0	1700				
7/2/2015	1					
7/16/2015	3		1810	1760	1760	1790
7/30/2015	5	1750	1800	1690	1770	1770
8/6/2015	6	1780	1680	1670	1700	1760
8/20/2015	8	1700	1660	1620	1190	1690
8/20/2015 Dup			1600			
Average		1732.5	1710.0	1685.0	1605.0	1752.5

Results – Aluminum

Dissolved Al (mg/L)						
Date	Week	Influent	Trough 1	Trough 2	Trough 3	Trough 4
6/26/2015	0	873	Organic	Non-Organic	Anoxic	Oxygenated
7/2/2015	1					
7/16/2015	3		926	843	841	843
7/30/2015	5	878	864	879	955	878
8/6/2015	6	795	887	887	846	832
8/20/2015	8	763	759	787	954	734
8/20/2015 Dup			750			
Average		827	837	849	899	822

Total Al (mg/L)						
Date	Week	Influent	Trough 1	Trough 2	Trough 3	Trough 4
6/26/2015	0	817				
7/2/2015	1					
7/16/2015	3		869	835	832	837
7/30/2015	5	804	829	793	844	821
8/6/2015	6	812	775	773	793	812
8/20/2015	8	760	747	755	935	740
8/20/2015 Dup			790			
Average		798.3	802.0	789.0	851.0	802.5

Organic Non-Organic Anoxic Oxygenated

Removal Rates Evaporation - Corrected

Metal	Trough 1	Trough 2	Trough 3	Trough 4
Fe	0.96%	4.47%	10.26%	1.89%
Al	1.40%	2.94%	0.00%	3.75%
Mn	3.84%	5.28%	0.18%	6.45%
Average	2.07%	4.23%	3.48%	4.03%

Organic

Non-Organic

Anoxic

Oxygenated

Grams/Day/m^2 Removal Rates

Constituent	T1	T2	T4
	Solids analytical results		
Sulfate (mg/Kg)	30,000	48,000	49,000
Iron (mg/Kg)	77,000	100,000	100,000
Aluminum (mg/Kg)	6,100	2,500	3,800
Mass of solids recovered (Kg)	5.9	12.7	2.8
Area of media (m^2)	2.8		
Days of testing	56		
	Grams removed per sq meter per day		
Sulfate	1.13	3.89	0.88
Iron	2.90	8.10	1.79
Aluminum	0.23	0.20	0.07
	Organic	Non-Organic	Oxygenated

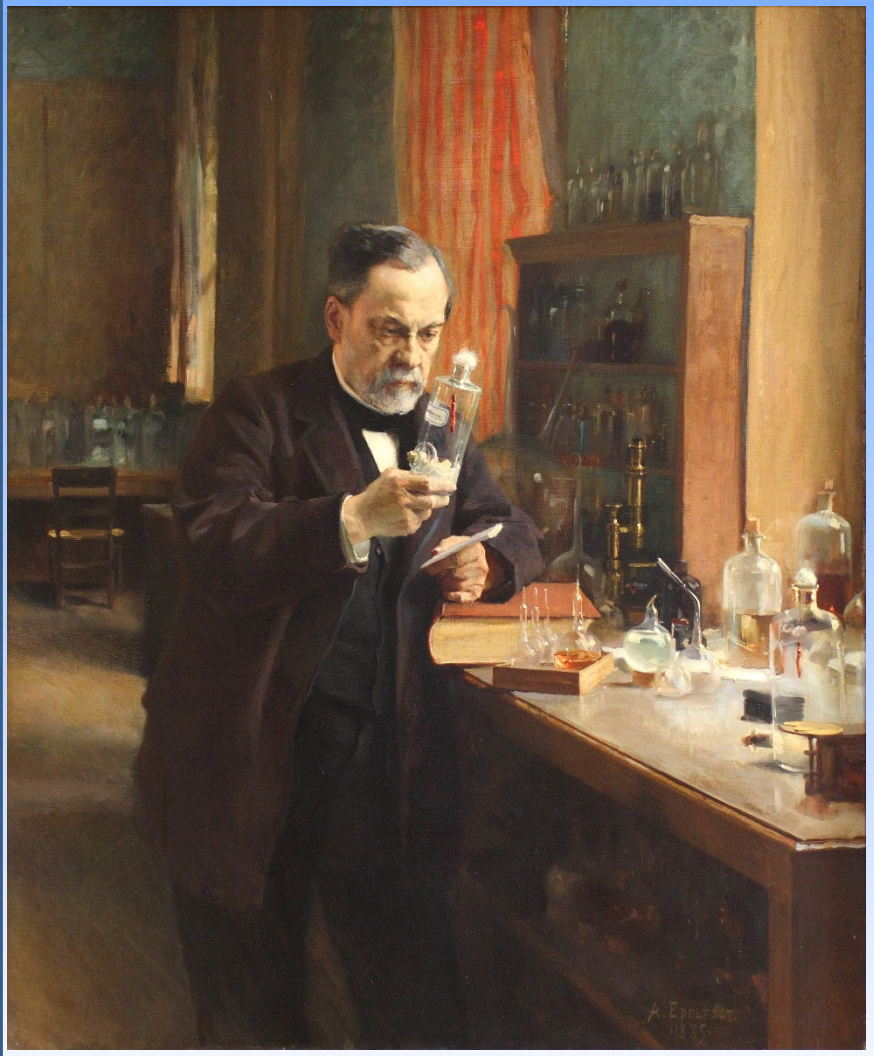
Summary

- Trough 2 performed the best overall during the test interval – *what happens when voids are filled?*;
- Trough 4 performed the best for aluminum and manganese, *but poorly by comparison for iron*;
- Trough 3 performed the best for iron, *but poorly by comparison for aluminum and manganese*; and
- The troughs without organic matter (Troughs 2 and 4) performed considerably better in reducing aluminum and manganese than the troughs with organic matter (Troughs 1 and 3). *(Too much of a good thing?)*

Path Forward

- Construct a pilot system (Fall 2015 - completed);
- Pilot test suspended due to winter onset;
- Design a full scale Iron/Aluminum Terrace to fit within the available space at the portal using the **Trough 2 Design** (completed);
- Build full scale IAT in summer of 2016 (in progress);
- Monitor “Portal IAT” and either expand AIT on land closer to “beaver dam” or construct a biochemical reactor, etc. to remove remaining metal loading (2018).

Thank You



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

Louis Pasteur

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