Mine Waste Source Control; Successful Proof of Principle Testing

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Solutions for the World of Water

Outline

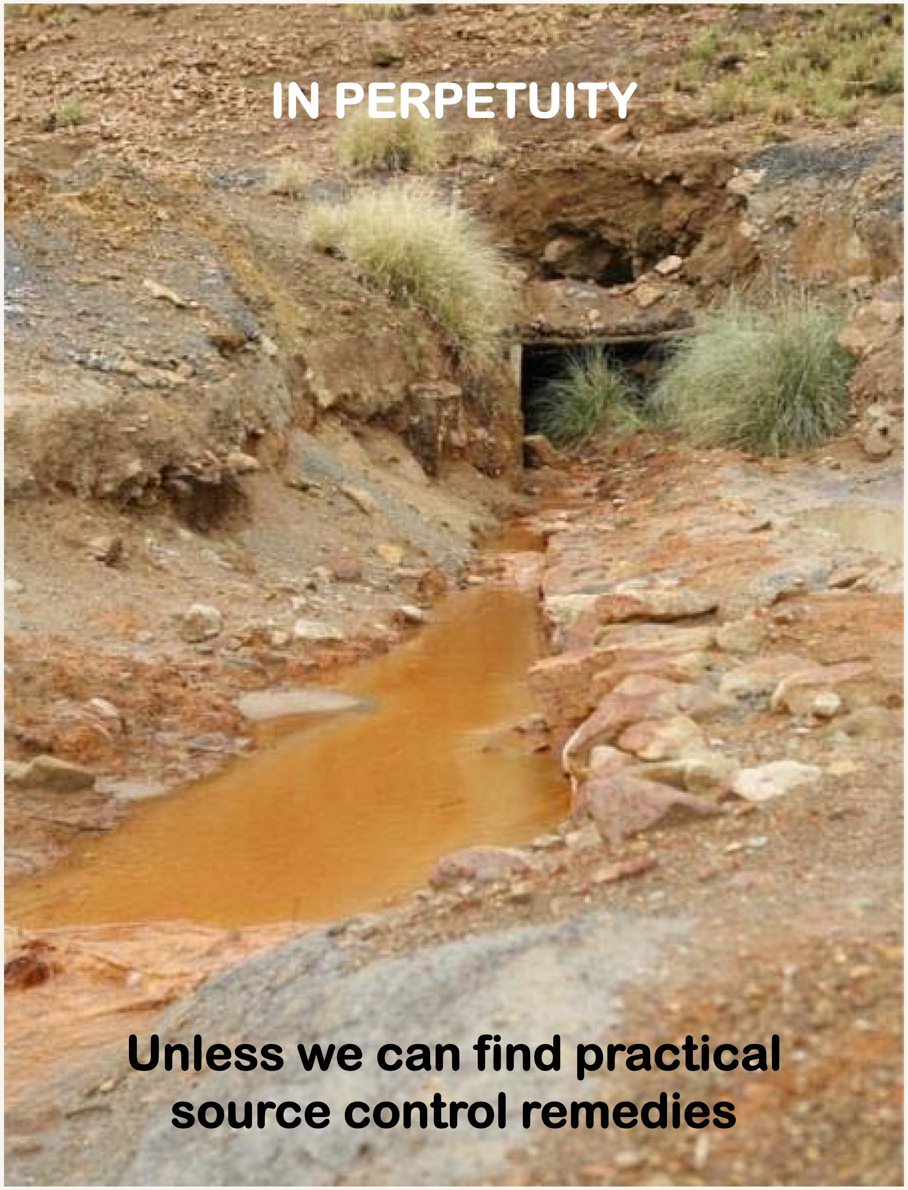
- What is source control?
- Why is it important?
- Why do we think it will work?
- Study Site
- Approach
- Results
- Conclusions
- Next steps

What is Source Control?

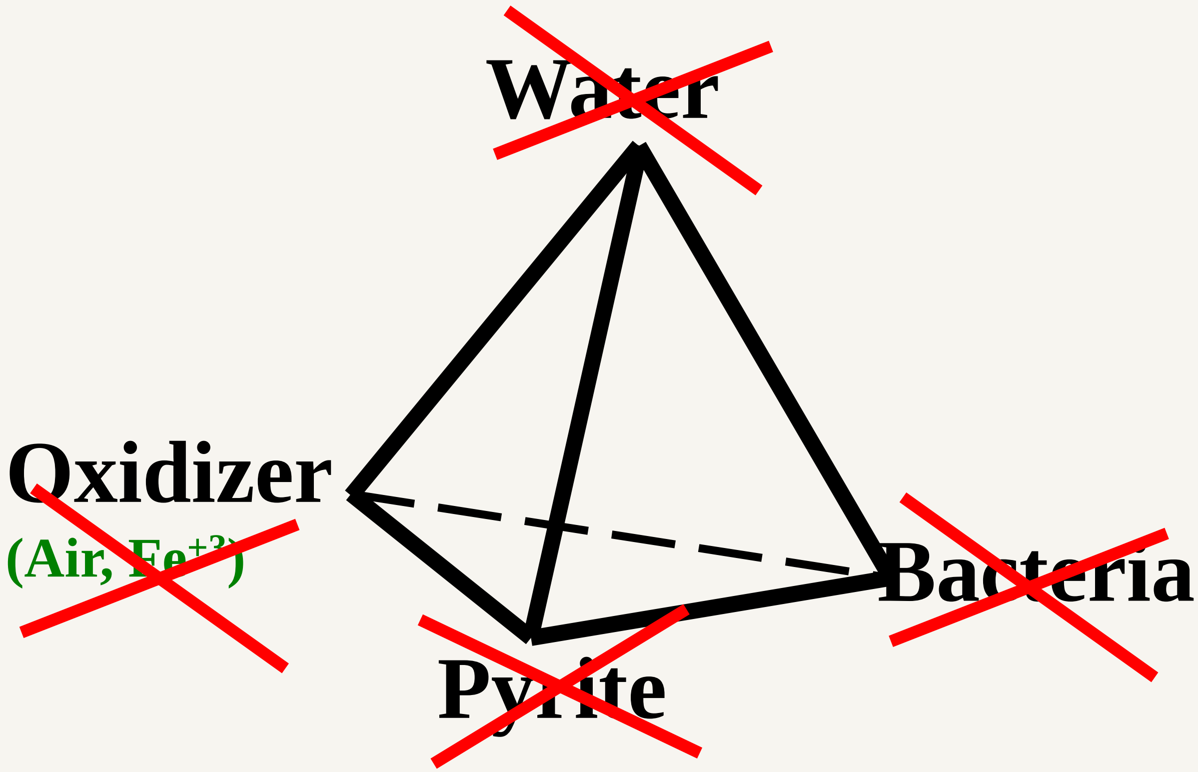
Guido Sarducci's
5 Minute University

Source Control 101

Why is it Important?



Acid Rock Drainage Tetrahedron



DO NOTHING = **PERPETUAL TREATMENT**

DO SOMETHING (anything) = **SUSTAINABLE REMEDIES**

Why do we think it will work?

Because it has!

Source Control – Is it too good to be true?
Montana Mine Design Operations and Closure Conference
May 2017

Source Control Options

- Pyrite
  - Avoidance
  - Processing
- Water
  - Covers
    - Impermeable
    - Evaporative
- Oxidizer
  - Subaqueous disposal
  - Organic covers
- Bacteria
  - Bactericides
  - Organic materials

Why Bacteria?

- They are everywhere!
- Shown to greatly accelerate rate of pyrite oxidation
  - Rate increases by orders of magnitude
- Been found in circumneutral mine drainage
- Major influence on the ultimate water quality

Acidithiobacillus Ferrooxidans

Changing the Microbial Community

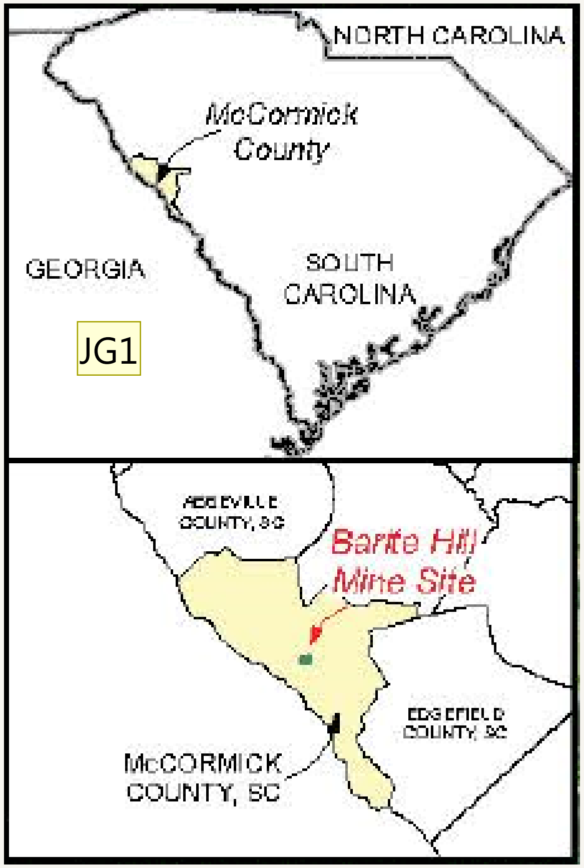
- ❑ Eliminate with bactericide
  - o Surfactants – Sodium Lauryl Sulfate
  - o US Bureau of Mines 1980's
  - o Create conditions for other bacteria

- ❑ Change environment and replace by competition
  - o Organics – milk
  - o Western Research Institute (2008)
  - o Create biofilms

THE SITE

Barite Hill Gold Mine

- McCormick, South Carolina
- Historic mining 1850's
- Open pit mining 1991-1994
- Reclamation from 1995 to 1999
- Bankruptcy July 1999
- Emergency action 2007
- Superfund designation 2009



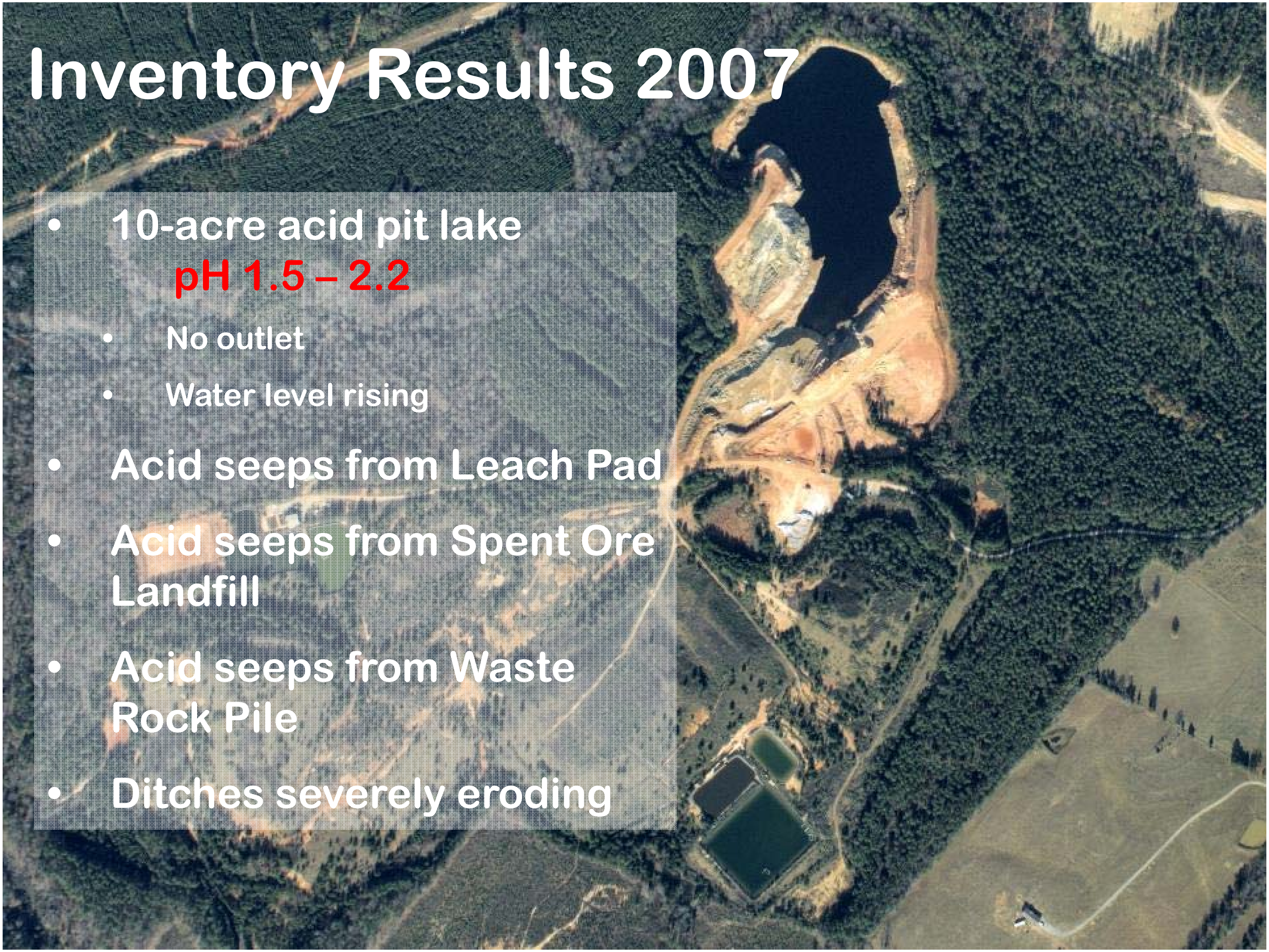
Slide 12

JG1 We need to try & find this with better resolution

Jim Gusek, 5/3/2019

Inventory Results 2007

- 10-acre acid pit lake
  pH 1.5 – 2.2
  - No outlet
  - Water level rising
- Acid seeps from Leach Pad
- Acid seeps from Spent Ore Landfill
- Acid seeps from Waste Rock Pile
- Ditches severely eroding



Remedial Action

Spillway Construction

Lake Neutralization and Carbon Addition


Stockpile
reclamation

2016

Problem

- Pit water continued to be acidic with high levels of trace metals
- Periodically retreated pit with sodium hydroxide
- Immediate pH increase but slow decline
- Continued input of acid from waste rock appears to be major source
- Need a more permanent and sustainable solution

Project Goal

Develop and test proof of principle tests to develop innovative remedial actions for the site

Project Objectives

- Collect and characterize representative samples from the site
- Conduct initial screening tests to refine proof of principle testing
  - No ASTM methods existed
  - Needed to develop tests
- Conduct proof of principle testing
- Evaluate remedial methods for various site components
  - Waste rock stockpiles
  - Pit water
  - Groundwater
  - Pit bottom

Proof of Principle

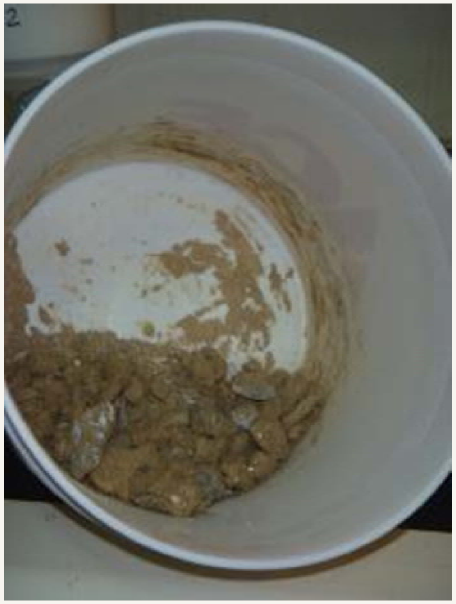
- Objective was to determine <u>only</u> if the technique could work
- Developed screening protocols to facilitate testing – eliminate dead ends early
- Based on standard testing techniques when possible
- Amendments added in excess

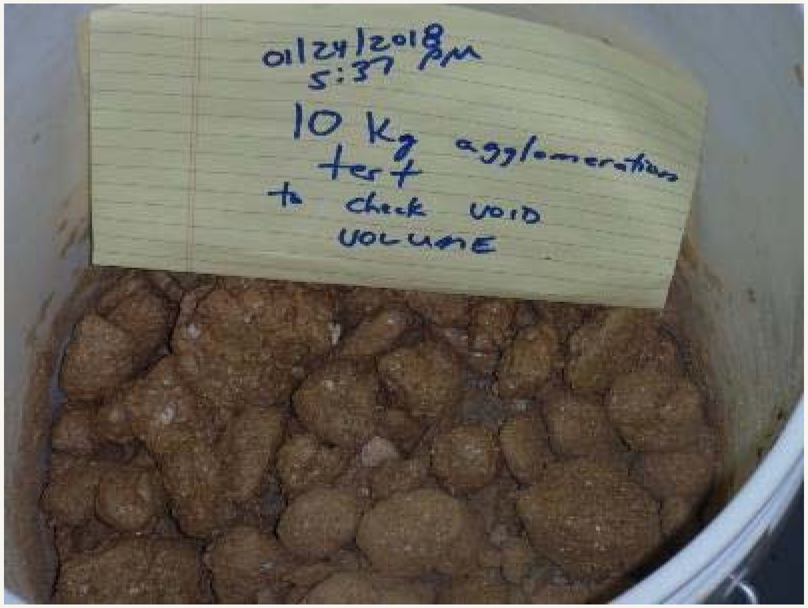
TO GO OR NOT TO GO;
THAT IS THE QUESTION

Sample Collection

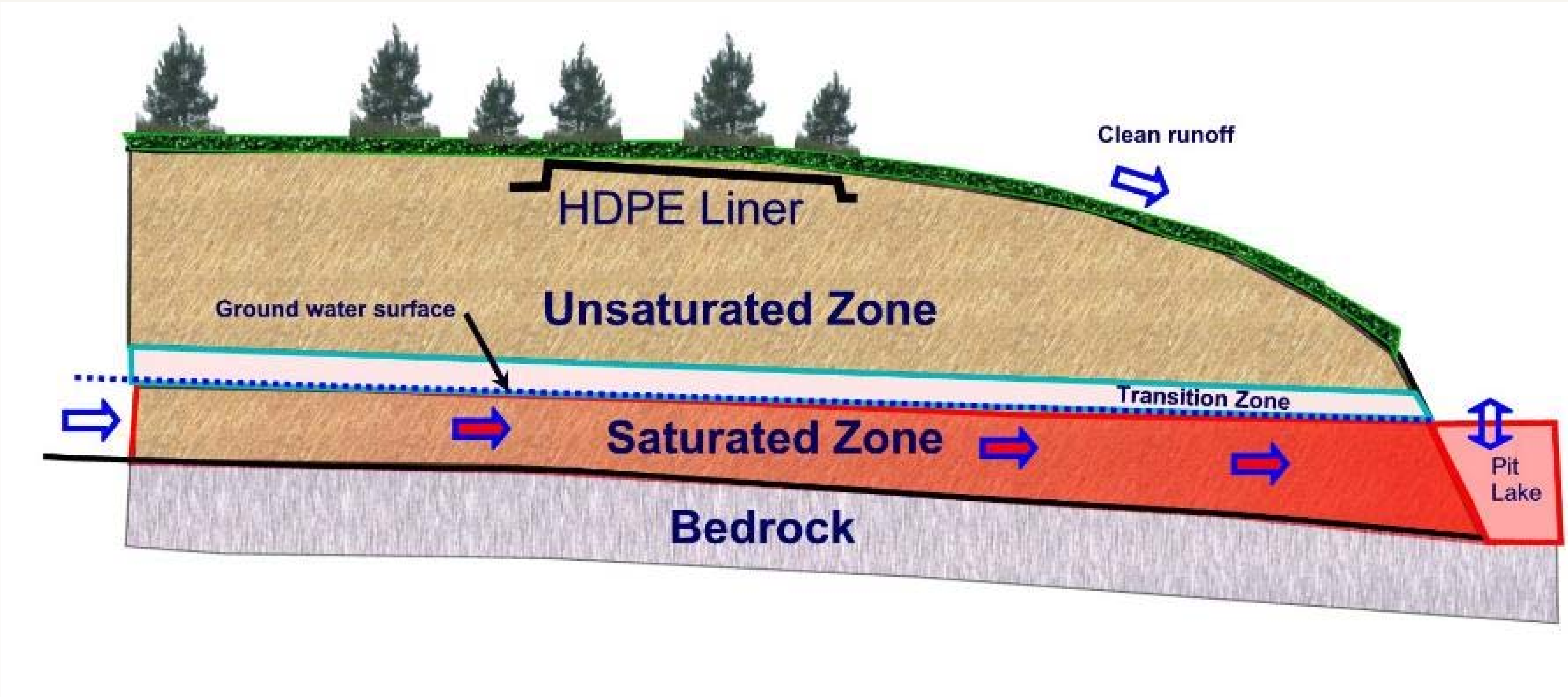
Sample Preparation

- **Sample contained large percentage of fines**
  - Poor flow properties
- **Agglomerated sample to improve hydraulic conductivity**
  - Agglomeration process only required distilled water
  - Use this sample in all reactors



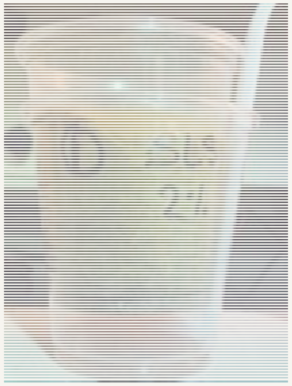


Stockpile conceptual model



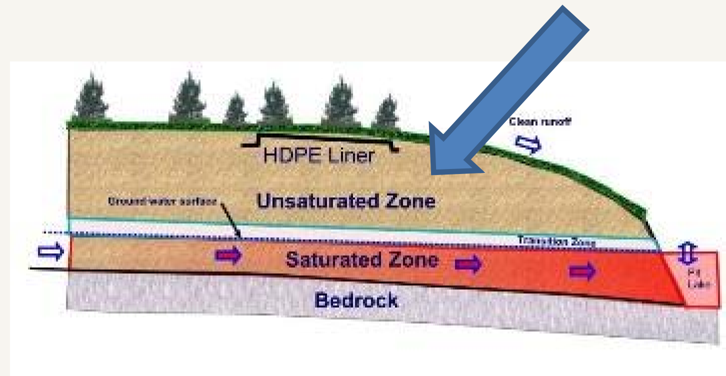
Approach

- Conduct screening protocols to eliminate test conditions that were doomed to fail or could be restrictive
  - Beaker Tests (milk & surfactants)
  - Modified US Bureau of Mines (surfactants)
- Develop specific test condition to simulate each zone in the stockpile
  - Unsaturated
  - Transition
  - Saturated



Unsaturated Zone

- Portion of the stockpile permanently above water
- Aerobic environment
- Reaction products moved by water infiltration
- Contains both residual and sulfide acidity

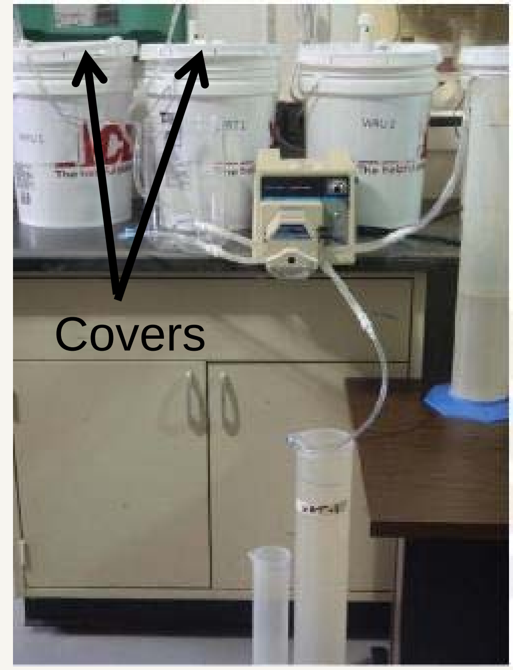


Residual stored acidity = reaction products that have not been rinsed out of stockpile

Sulfide potential acidity = unreacted sulfide minerals which can react in the future

Unsaturated Tests- Methods

- **Modified humidity cell test**
  - **20 kg sample**
  - **One week drying cycle**
    - **Similar to standard humidity cells**
  - **Peristaltic pump - flooded from bottom with distilled deionized water**
  - **Water pumped out**

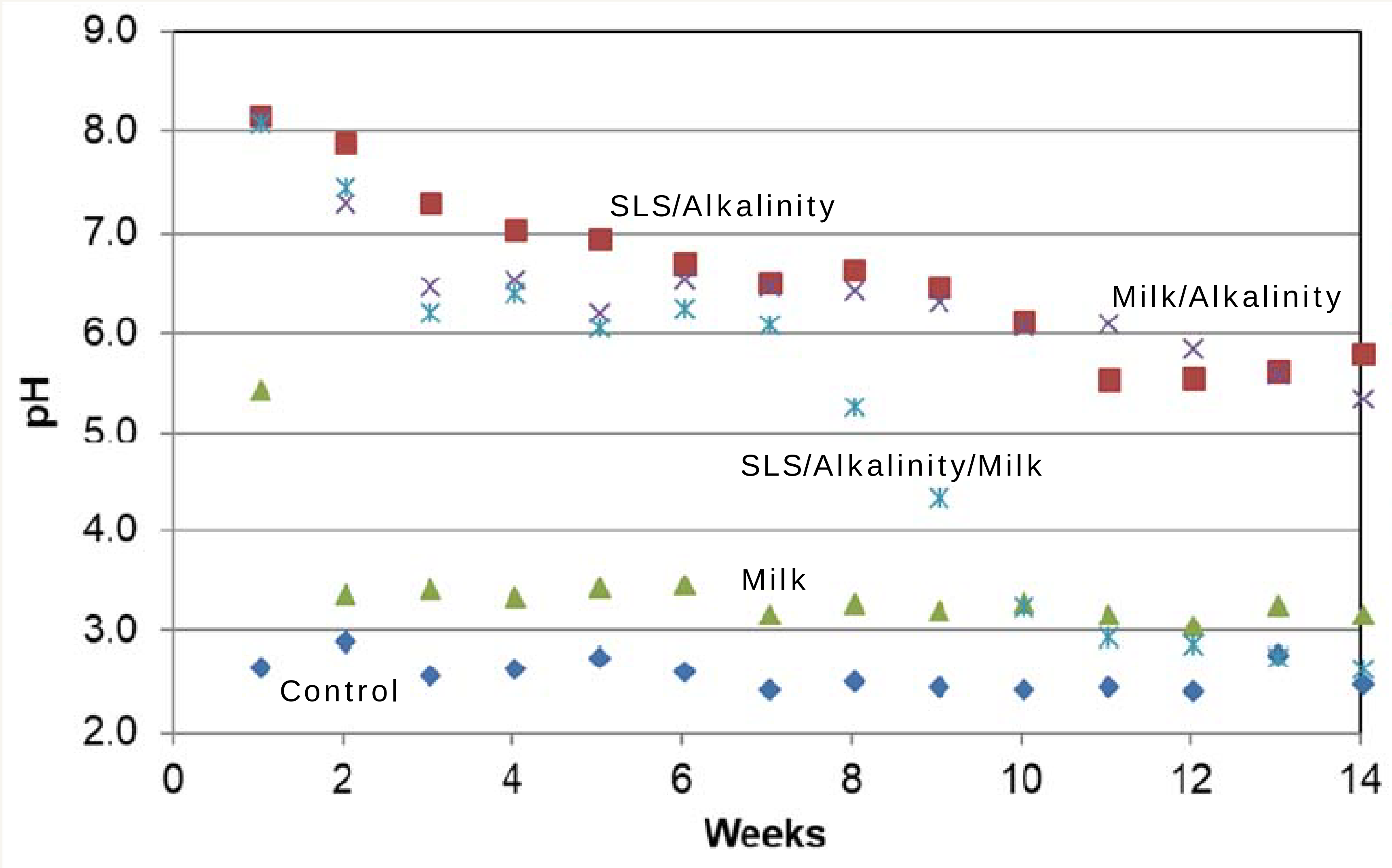


Unsaturated Tests- Treatments

- Control
- Sodium Lauryl Sulfate (SLS)/Alkalinity
- Sodium Lauryl Sulfate (SLS)/Alkalinity/Milk
  - Sequential application
- Milk
- Milk /Alkalinity

Bacterial inoculum added to milk reactors

Unsaturated Zone 20-kg Test pH Results

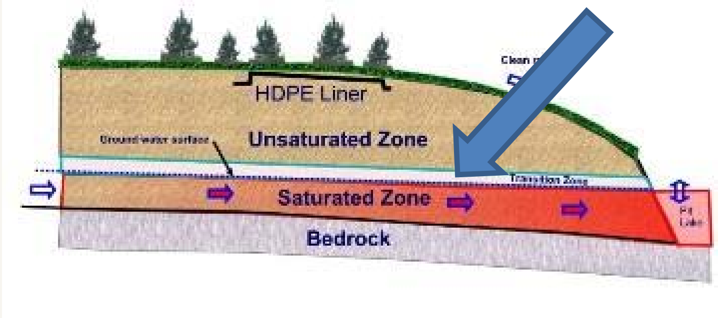


Unsaturated Zone 20-kg Test Microbial Suppression

Test Group	Type	Mesophilic and Acidophilic Fe-Oxidizers MPN (cells / mL)[1]	
		Week 3	Week 13
No Treatment	Aq	1.1×10^6	1.2×10^6
SLS + Alkalinity	Aq	9.0×10^0	9.3×10^2
Milk	Aq	4.3×10^4	9.3×10^4
Milk + Alkalinity	Aq	9.3×10^3	4.3×10^4
Sequential: SLS + Alkalinity (prior to Milk application)	Aq	2.4×10^5	$\geq 2.4 \times 10^6$

Transition Zone

- Portion of the stockpile between high and low water level
- Alternating wet and dry cycle
- Ideal conditions for oxidation and transport

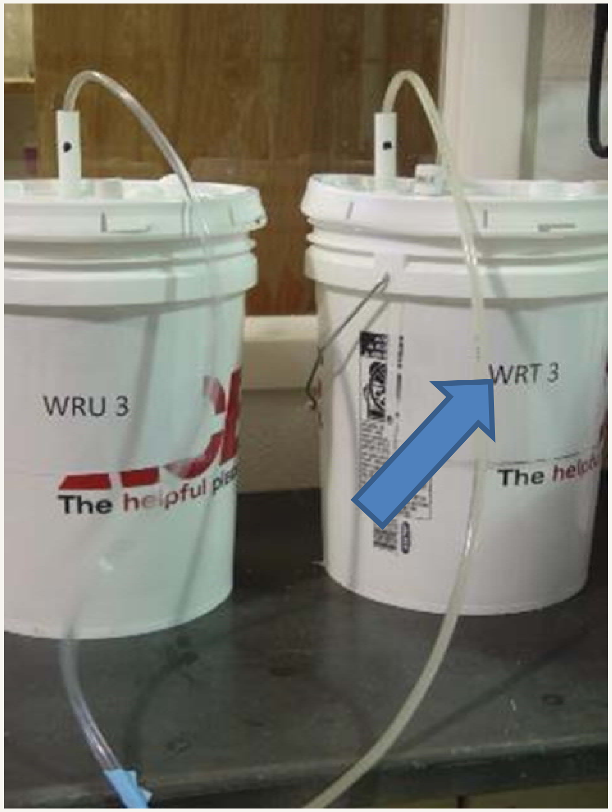


Transition Zone Tests-Treatments

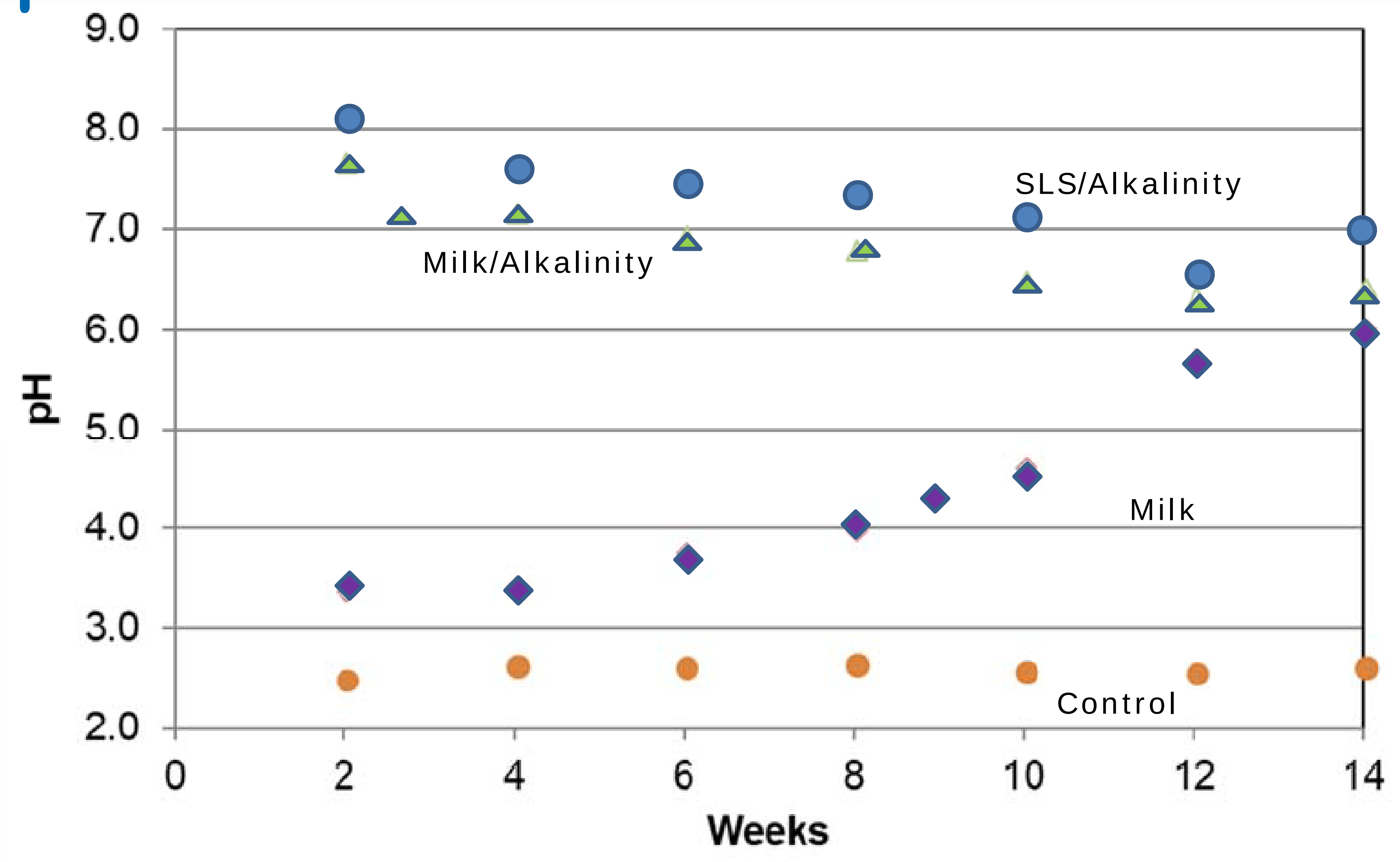
- Control
- Sodium Lauryl Sulfate (SLS)/Alkalinity
- Milk
- Milk /Alkalinity

Transition Tests- Methods

- 20 kg sample
- Alternate one week cycles / flood and dry
- Reactors flooded from bottom with peristaltic pump
- Simulated natural groundwater was used as rinse
- Water pumped out



Transition Zone 20-kg Test pH Results



Transition Zone – Microbial Results

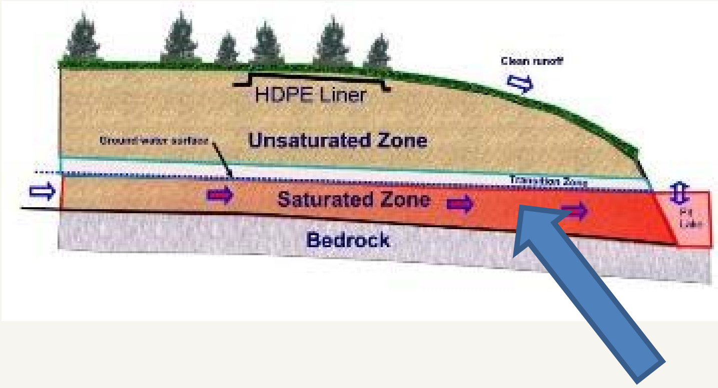
Test Group	Type	Mesophilic and Acidophilic Fe-Oxidizers MPN (cells / mL)[1]	
		Week 3	Week 13
No Treatment	Aq	4.6×10^5	4.6×10^6
SLS + Alkalinity	Aq	$< 3.0 \times 10^0$	$< 3.0 \times 10^0$
Milk	Aq	9.3×10^4	9.3×10^4
Milk + Alkalinity	Aq	2.3×10^2	2.3×10^3

Transition Zone – Microbial Results

Test Group	Sample Type	Anaerobic SO4- Reducers MPN (cells / mL)[a, b]	
		Week 9	Week11
No Treatment	Aq	< 1×10^0	< 1×10^0
SLS + Alkalinity	Aq	7.5×10^1	< 1×10^0
Milk	Aq	< 1×10^0	< 1×10^0
Milk + Alkalinity	Aq	5.0×10^5	1.4×10^3

Saturated Zone

- Portion of the stockpile below low water level
- Permanently flooded
- Low pH
- High ferric iron
- Sulfide oxidation occurs due to ferric iron



Saturated Zone Tests- Treatments

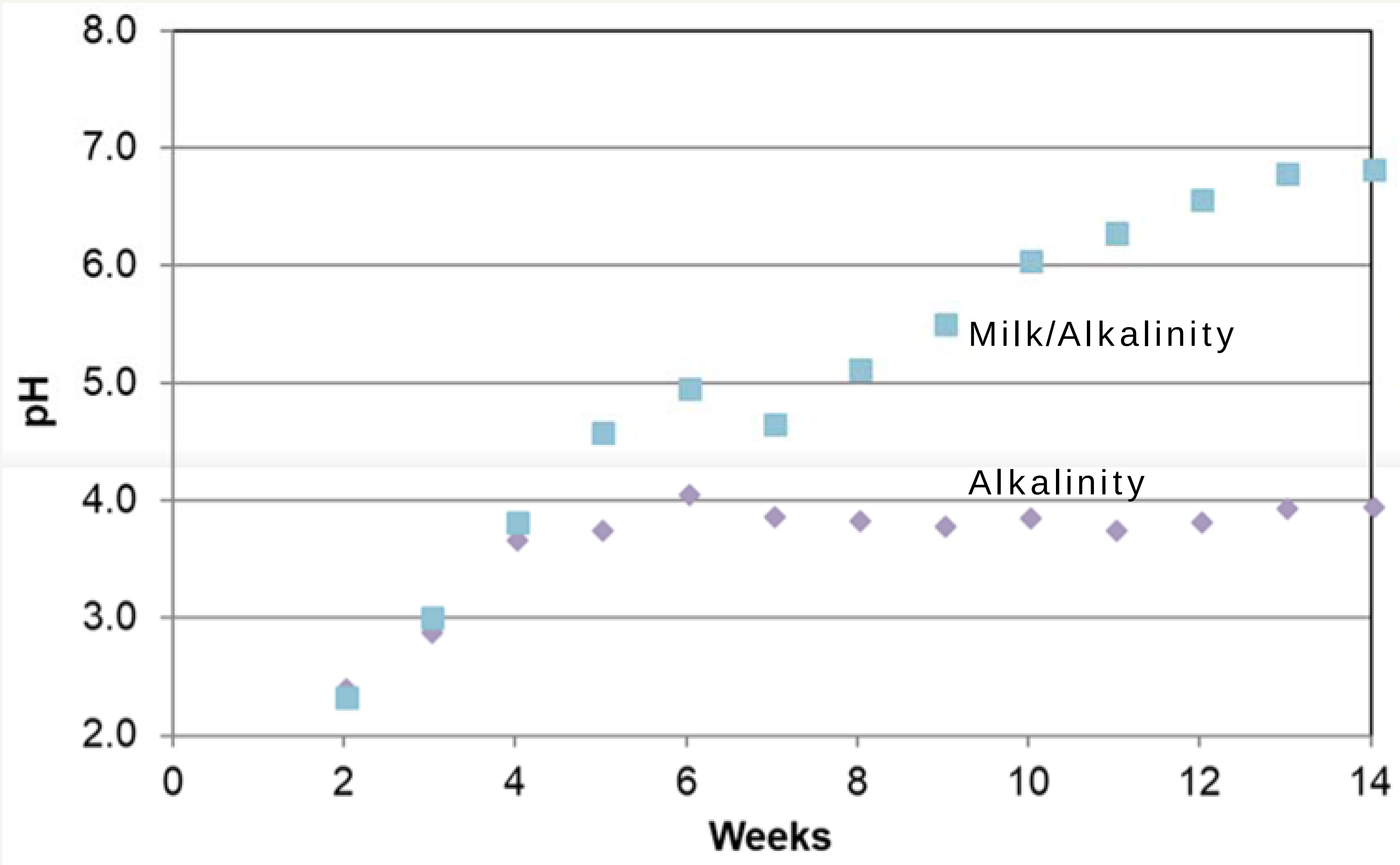
- ❑ **Alkalinity**
- ❑ **Milk /Alkalinity**

Since primary oxidation is by ferric iron
SLS would not be expected to be effective

Saturated Zone Tests - Methods

- 20 kg sample
- Permanently flooded
- Sample volume withdrawn weekly
- Water replaced
- Amendments added over time
  - Initial portion of study
  - Simulate groundwater flow

Saturated Zone-pH results



Saturated Zone-Microbial results

Test Group	Sample Type	Anaerobic SO4-Reducers MPN (cells / mL)[a, b]	
		Week 9	Week 11
Alkalinity	Aq	$< 1 \times 10^{0}$	$< 1 \times 10^{0}$
Milk/Alkalinity	Aq	1.2×10^{5}	2.7×10^{4}

Conclusions

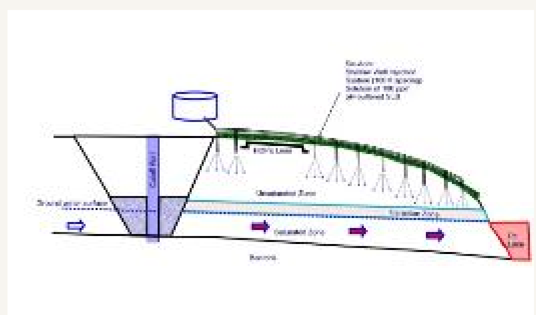
Source Control Works!

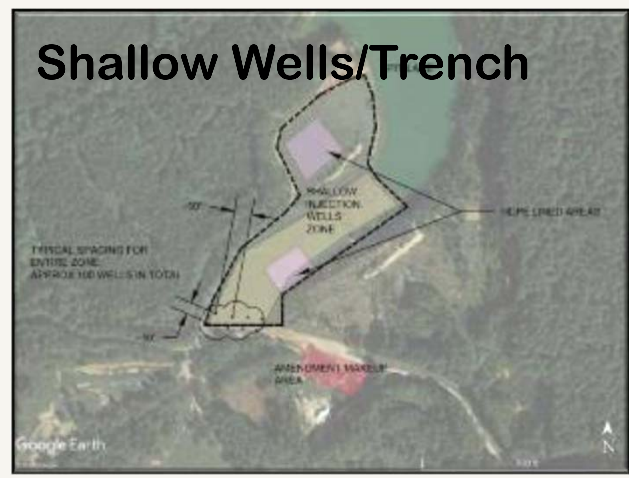
Conclusions

- Microbial community successfully modified
- SLS/ Alkalinity effective at suppressing acidophilic bacteria in the *unsaturated* and *transition* zone
- Milk/Alkalinity
  - Effective in *transition* and *saturated* zone
  - Neutralized acidity
  - Replaced acidophiles with sulfate reducers

Next Steps

- ❑ Phase 2
  - ❑ Refine site model
    - ❑ Mass release estimates
  - ❑ Determine optimum addition rates
  - ❑ Application methods
    - ❑ Drip irrigation
    - ❑ Wells
    - ❑ Trenches
- ❑ Field Testing





Acknowledgements

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The Choice

Questions?