

Use of a Dispersed Alkaline Substrate and Limestone Beds to Treat Acid Mine Drainage at Soudan Mine, MN

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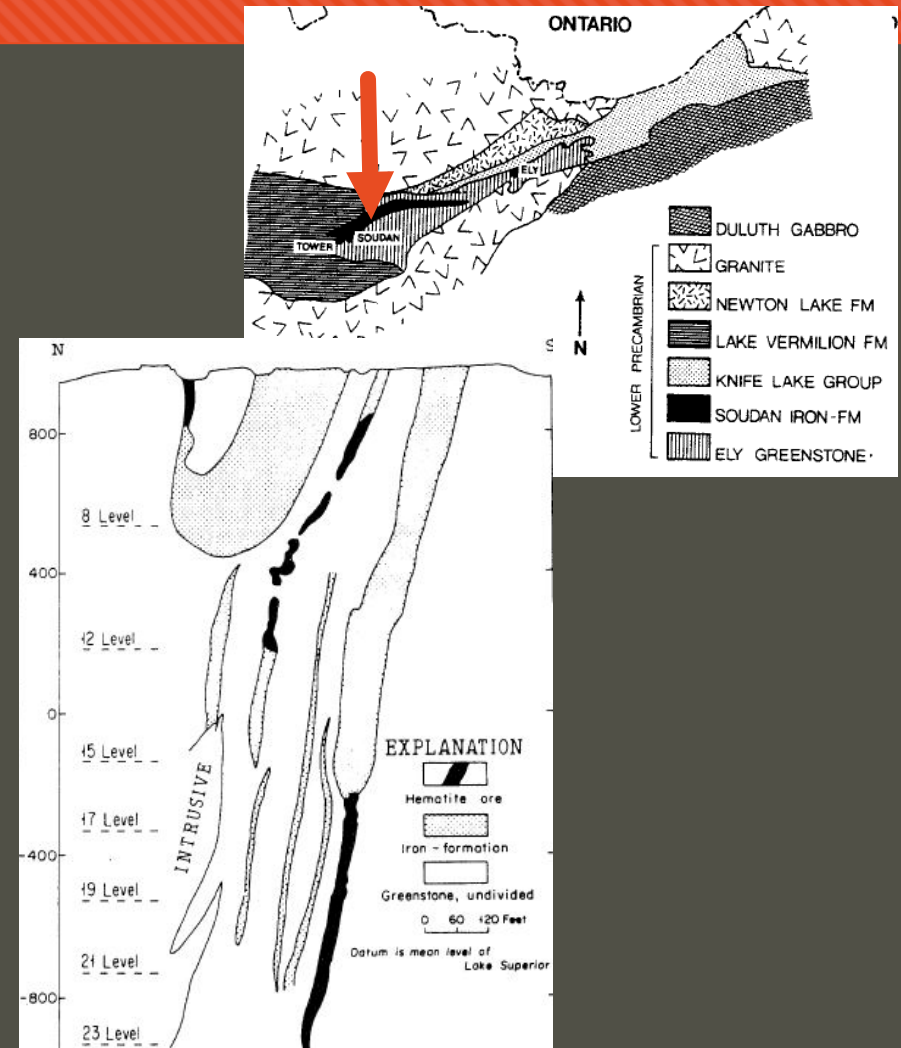
Soudan Mine

- MN's oldest & deepest iron mine
- Located 20 miles SW of Ely, MN



Soudan Mine: Geology

- Ely Greenstone
- Soudan Iron Formation
 - Massive, exceptionally hard, bluish-grey hematite
 - Over 60% iron
 - Steeply inclined folds and belts
- Quartz, chlorite, apatite, chalcopryite, pyrite, and other copper minerals



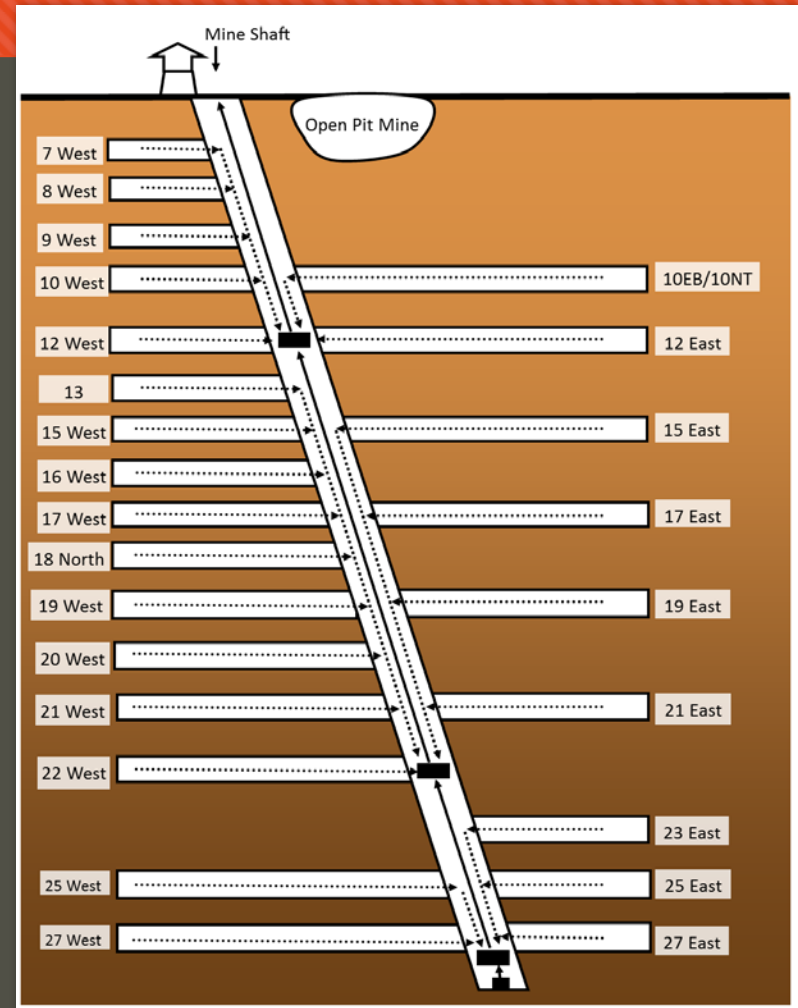
Soudan Mine: History

- Mining
 - Open pit 1884
 - Underground 1892
 - 27 levels
 - 2,341 ft deep
- Post-Mining
 - Donated to State of MN 1964
 - State Park
 - Historical landmark
 - Educational tours
 - Physics lab



Soudan Mine: Water

- Enters mine through open pits & fractures
- Pumped to surface
 - 60 gal/min
- Discharge
 - Permit
 - Copper 0.017 mg/L
 - Cobalt 0.004 mg/L
 - Soudan Annual Average
 - Copper 0.083-0.5 mg/L
 - Cobalt 0.006-0.026 mg/L
 - pH ~7.5





Soudan Mine: Water Treatment

- Siemens ion exchange system treats entire discharge
 - Cation resin
 - Suspended solids prematurely plug resin
 - Increases cost and maintenance



<http://www.waterworld.com/articles/iww/print/volume-10/issue-6/feature-editorial/historic-mine-uses-ion-exchange-for-copper-cobalt-removal.html>

Soudan Mine: Goal

- Treat individual levels in mine
- Meet discharge permit standards
- Eliminate surface treatment



Soudan Mine: Existing

- Level 10N discharge
 - pH 4-4.5
 - Copper ~ 10 mg/L
 - Major copper source
 - Cobalt ~ 0.2 mg/L
- Treatment system
 - Same resin and design as surface system



Soudan Mine: New

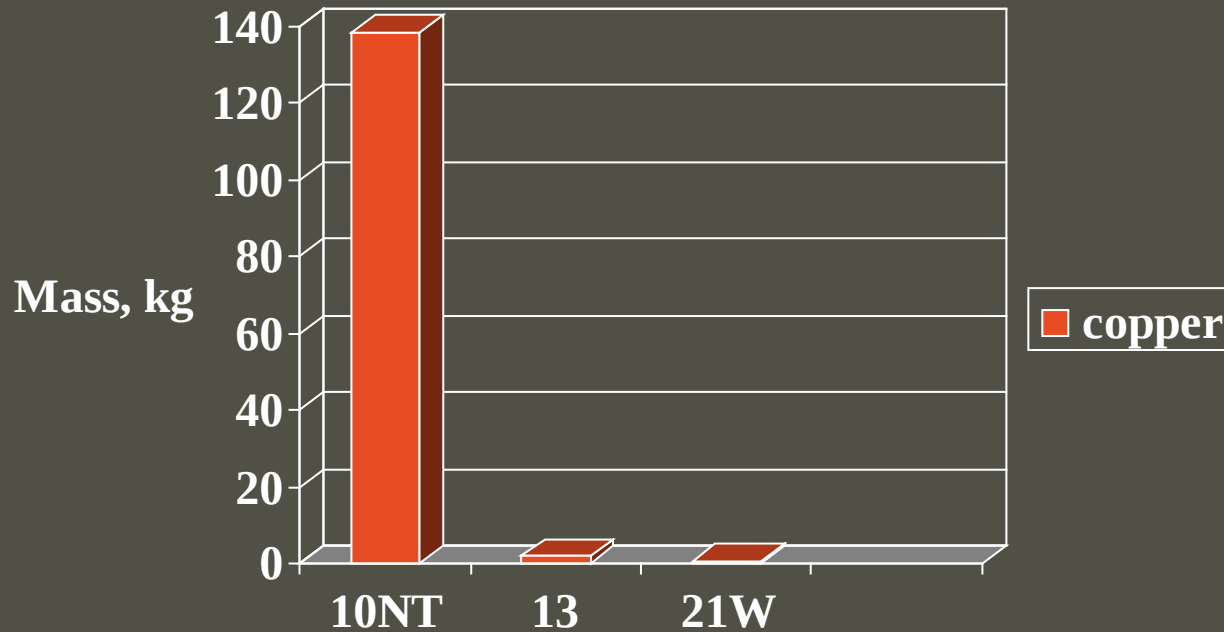
- Level 21W discharge
 - pH 2.5
 - Iron 50 mg/L
 - Manganese 0.8 mg/L
 - Copper 0.19 mg/L
 - Cobalt 0.18 mg/L
- Treatment system
 - Inexpensive
 - Easily maintained
 - Housed within the mine
 - No anaerobic conditions



Level 10NT

➤ 90% of copper

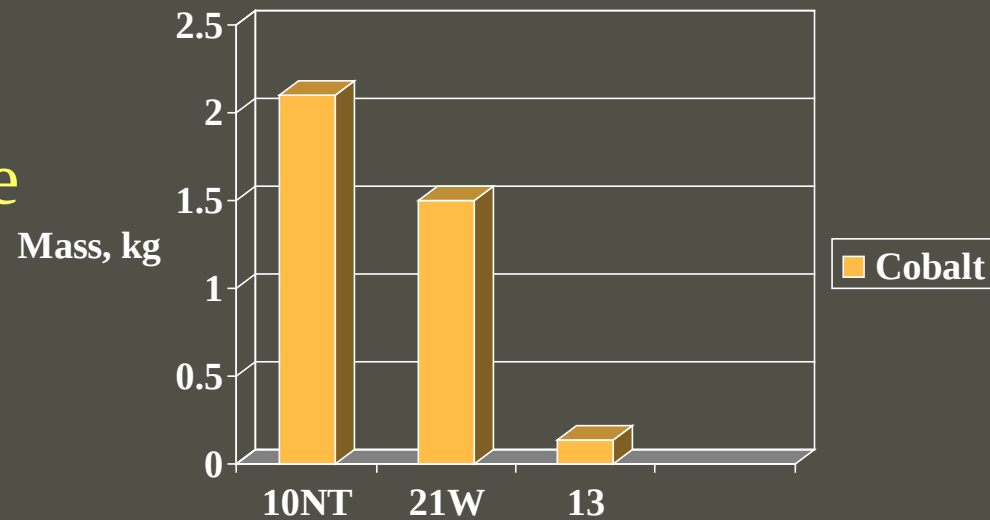
➤ ~ 50% of cobalt



Level 21W

➤ Second largest cobalt source

➤ ~ 40% of cobalt



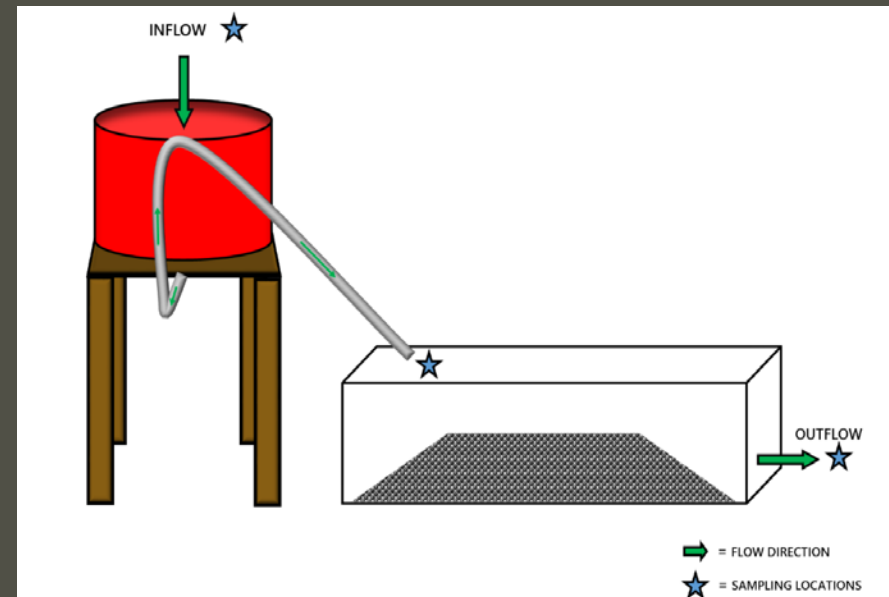
Soudan Mine: Approach

- Bench scale experiments
 - Dispersed Alkaline Substrate/Limestone Bed
 - Neutralize pH
 - Precipitate metals
 - Copper 0.017 mg/L
 - Cobalt 0.004 mg/L



Methods: Treatment System 1

- Column
 - Down flow
 - 8 inch diameter
 - Cedar wood chips coated with limestone sand
 - Flow rate allows for 24 hour residence time



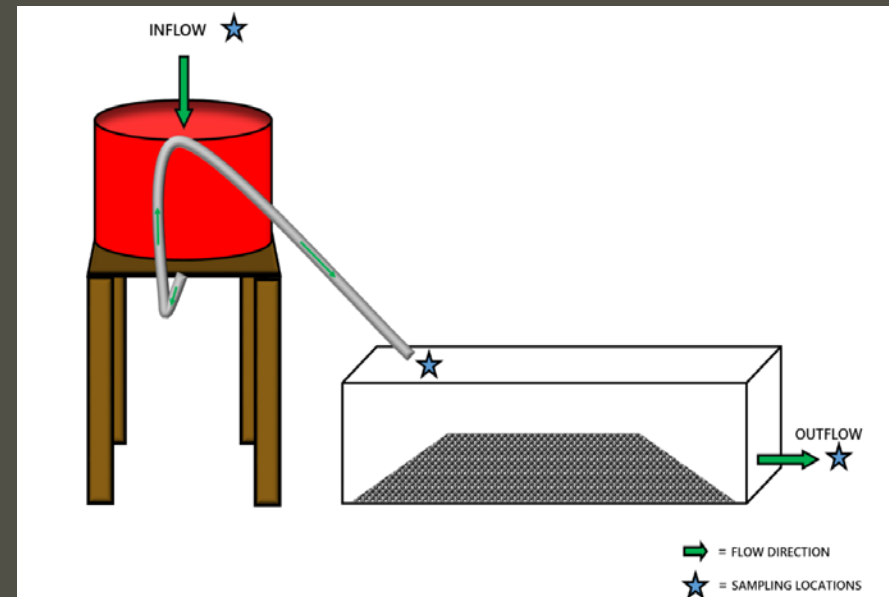
Methods: Treatment System 1

- Column
 - Raise pH to 4-5 or higher
 - Precipitate
 - Iron
 - Coprecipitate/adsorb
 - Copper



Methods: Treatment System 1

- Limestone Bed
- Horizontal Flow
- Gravel sized
- Flow rate allows for 24 hour residence time



Methods: Treatment System 1

- Limestone Bed
 - Raise pH to 7-8
 - Precipitate
 - Manganese
 - Coprecipitate/adsorb
 - Cobalt



Methods: Treatment System



Results: Anticipated

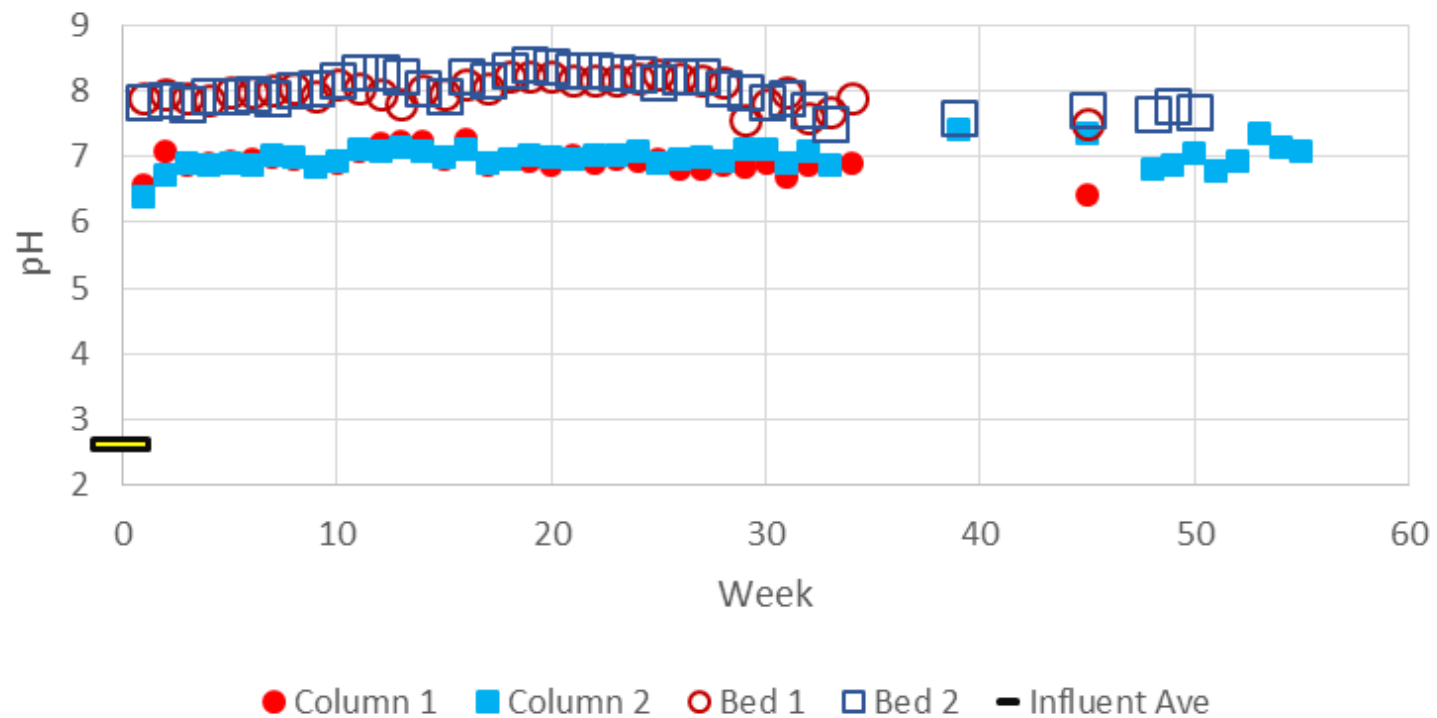
- Column
 - Raise pH 4-5 or higher
 - Precipitate
 - Iron
 - Coprecipitate/adsorb
 - Copper
- Limestone Bed
 - Raise pH 7-8
 - Precipitate
 - Manganese
 - Coprecipitate/adsorb
 - Cobalt

pH 6.5-8.5

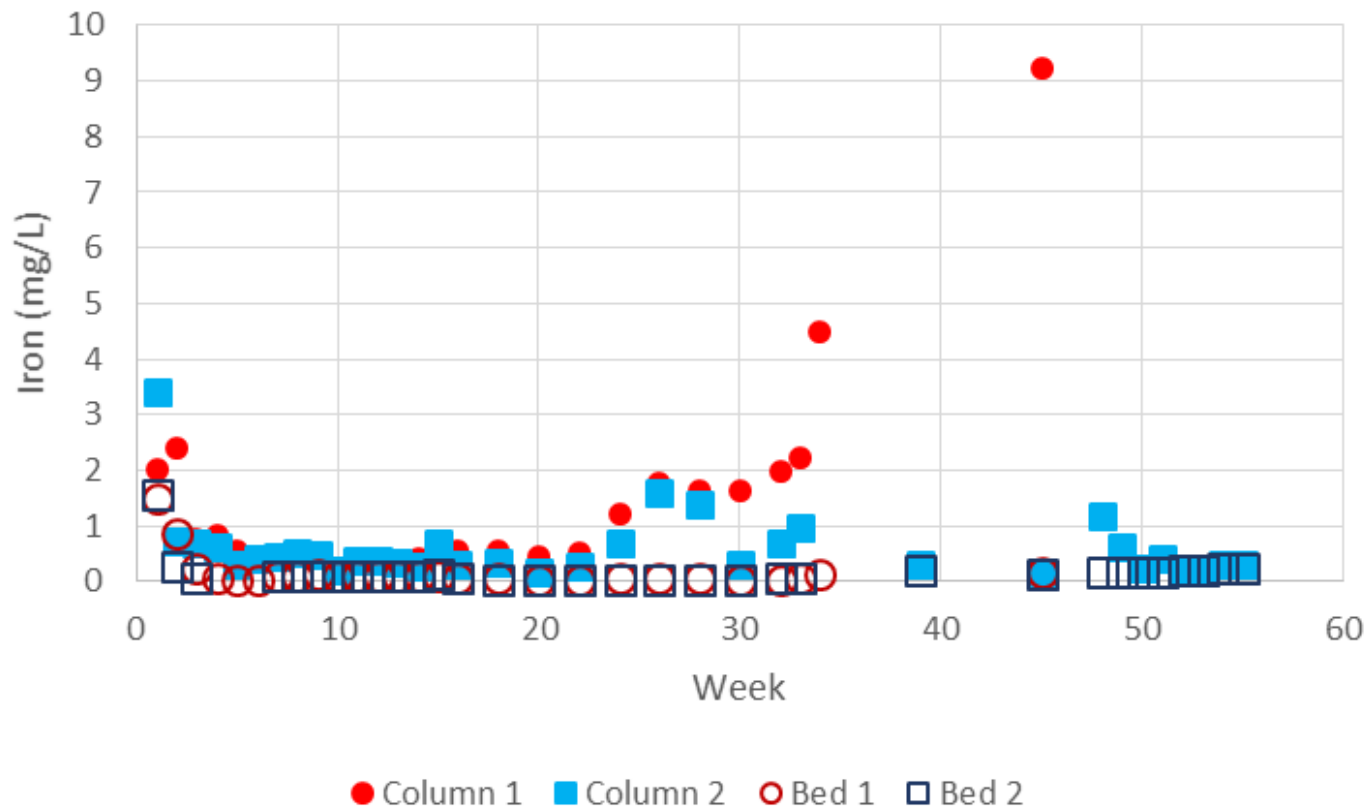
Cu 0.017 mg/L

Co 0.004 mg/L

Results: pH

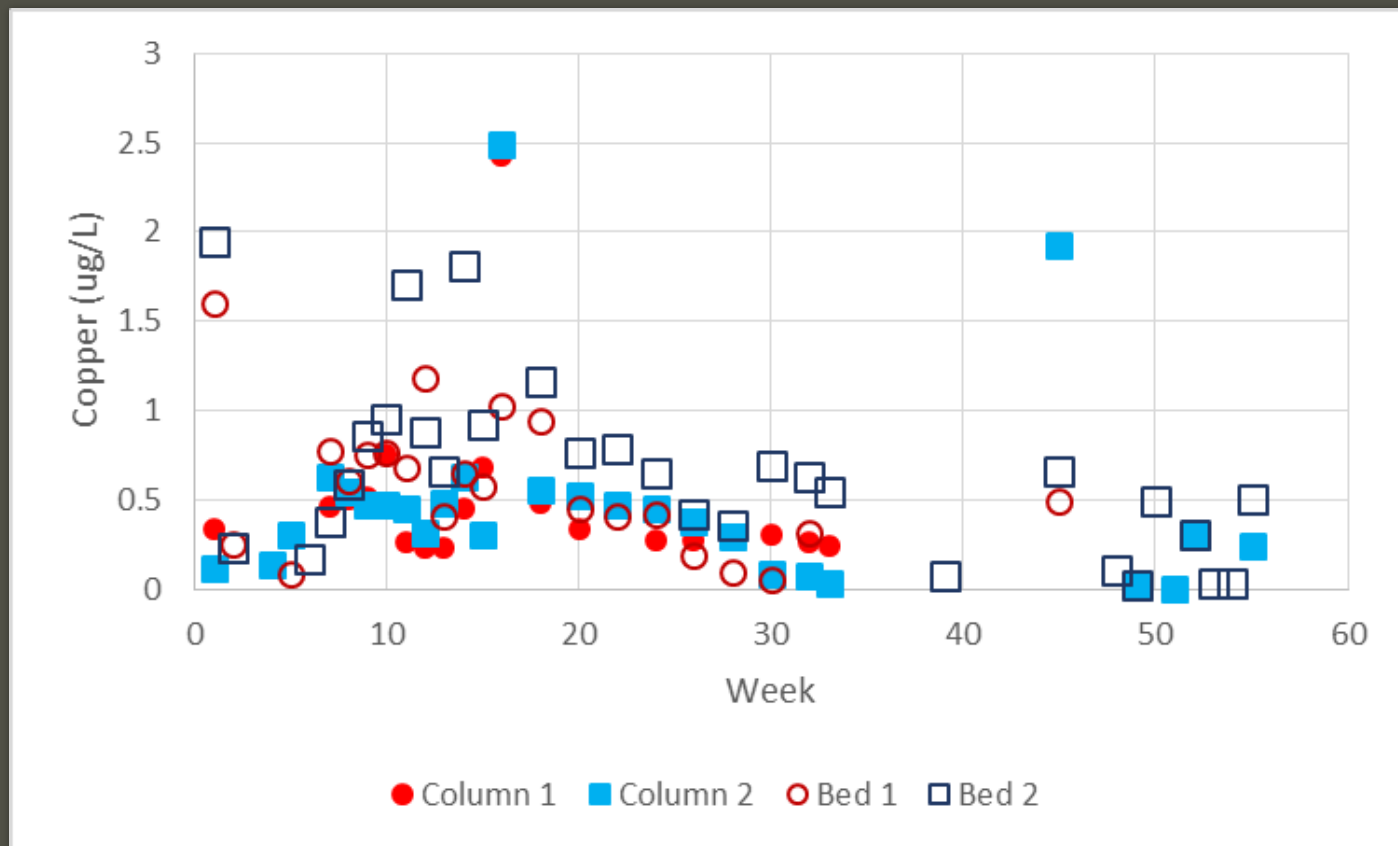


Results: Iron



Influent average: 50 mg/L

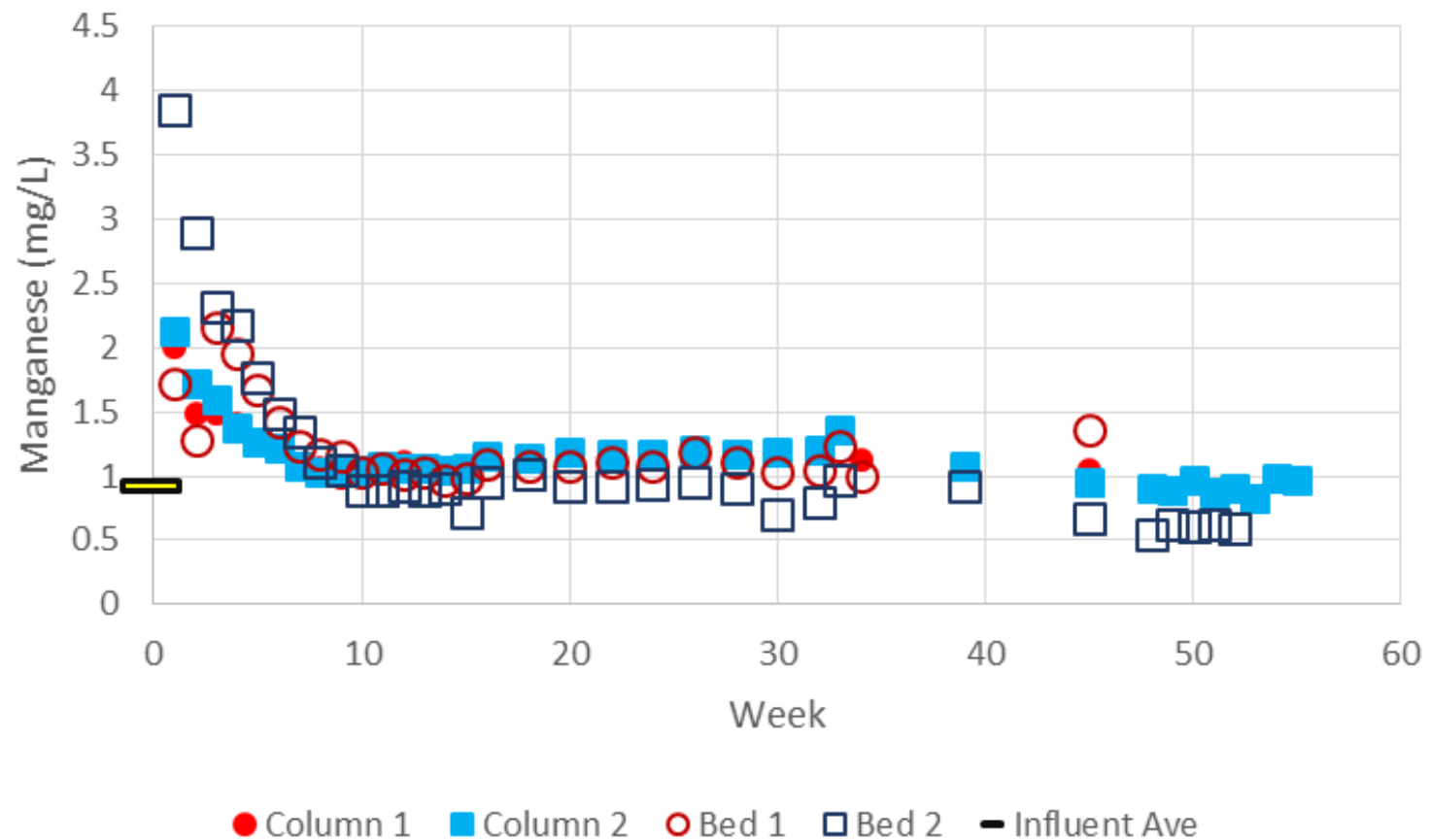
Results: Copper



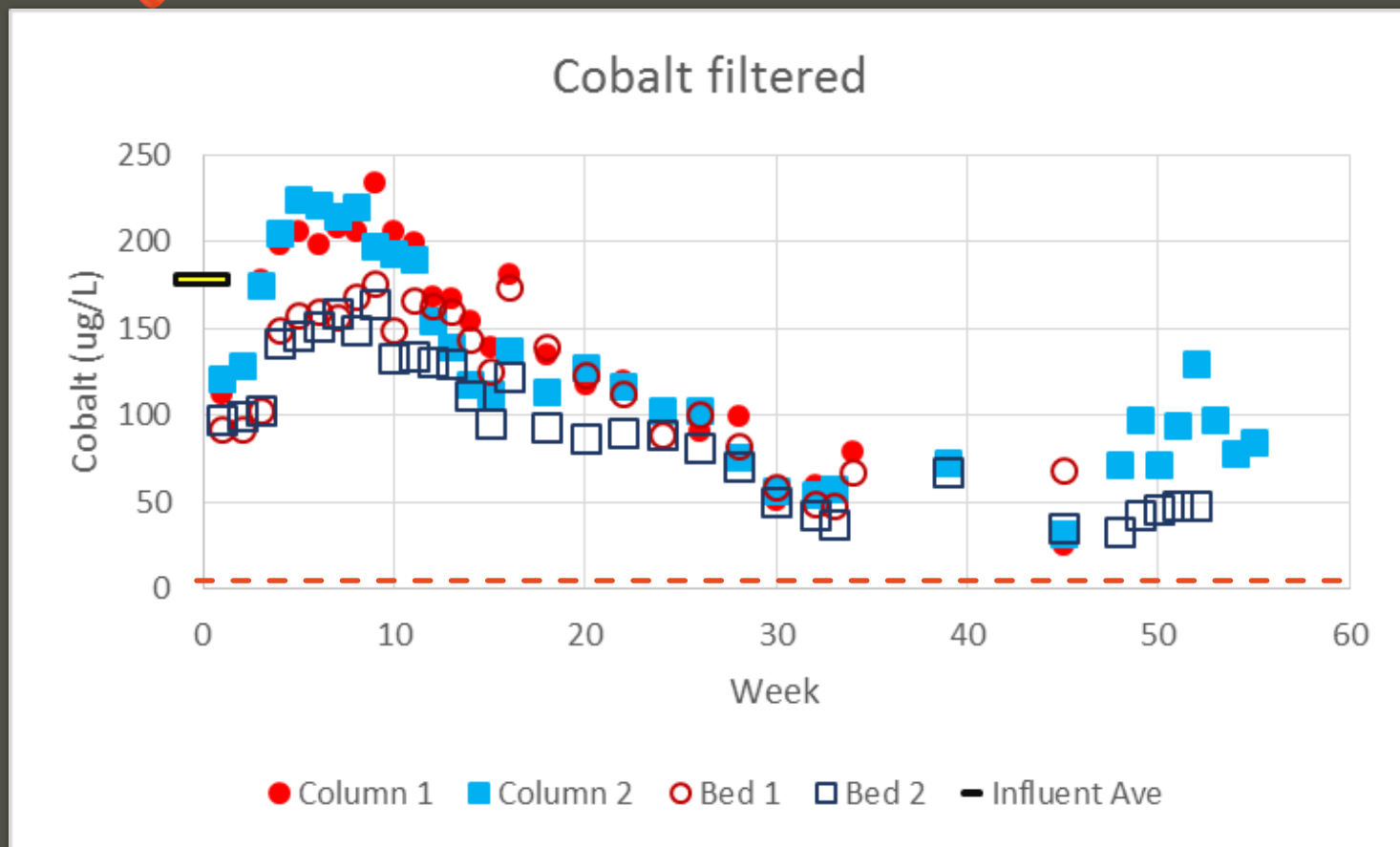
Influent average: 180 ug/L

Permit: 17 ug/L

Results: Manganese



Results: Cobalt



Permit: 4 $\mu\text{g/L}$

**What is
wrong with
this picture?**



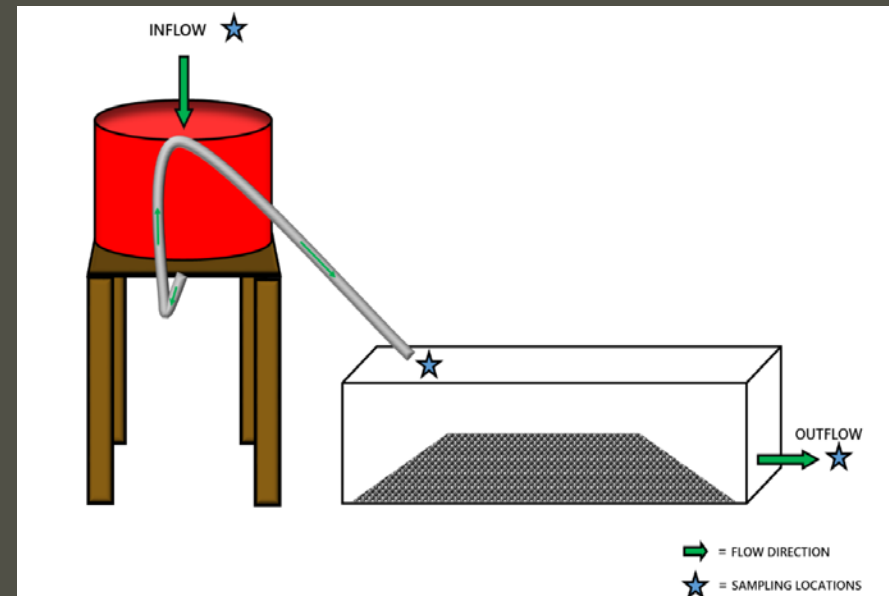
Problem!

- No Manganese removal
- Cedar?



Methods: Treatment System 2

- Column
 - Down flow
 - 8 inch diameter
 - Aspen wood chips coated with limestone sand
 - Flow rate allows for 24 hour residence time



Results

	Influent	Column effluent	Limestone Bed effluent
pH	2.5	6.8	7.4
Iron (mg/L)	38	0.8	0.8
Copper (ug/L)	97	36	26
Manganese (mg/L)	0.8	1.4	2.3
Cobalt(ug/L)	138	76	39

Any
other
great
ideas?





CBS

1ST & 10



08:27



DET 23

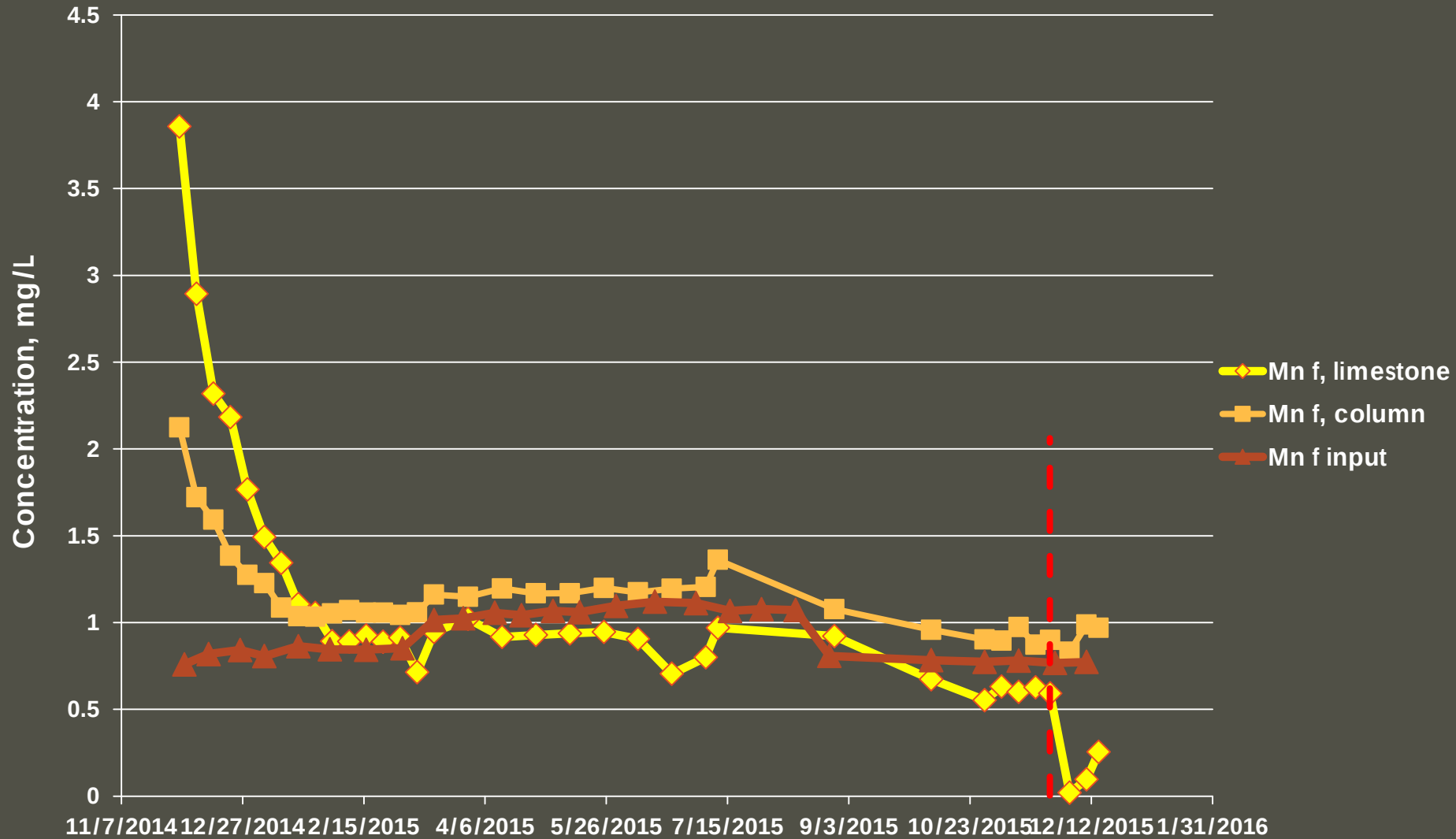
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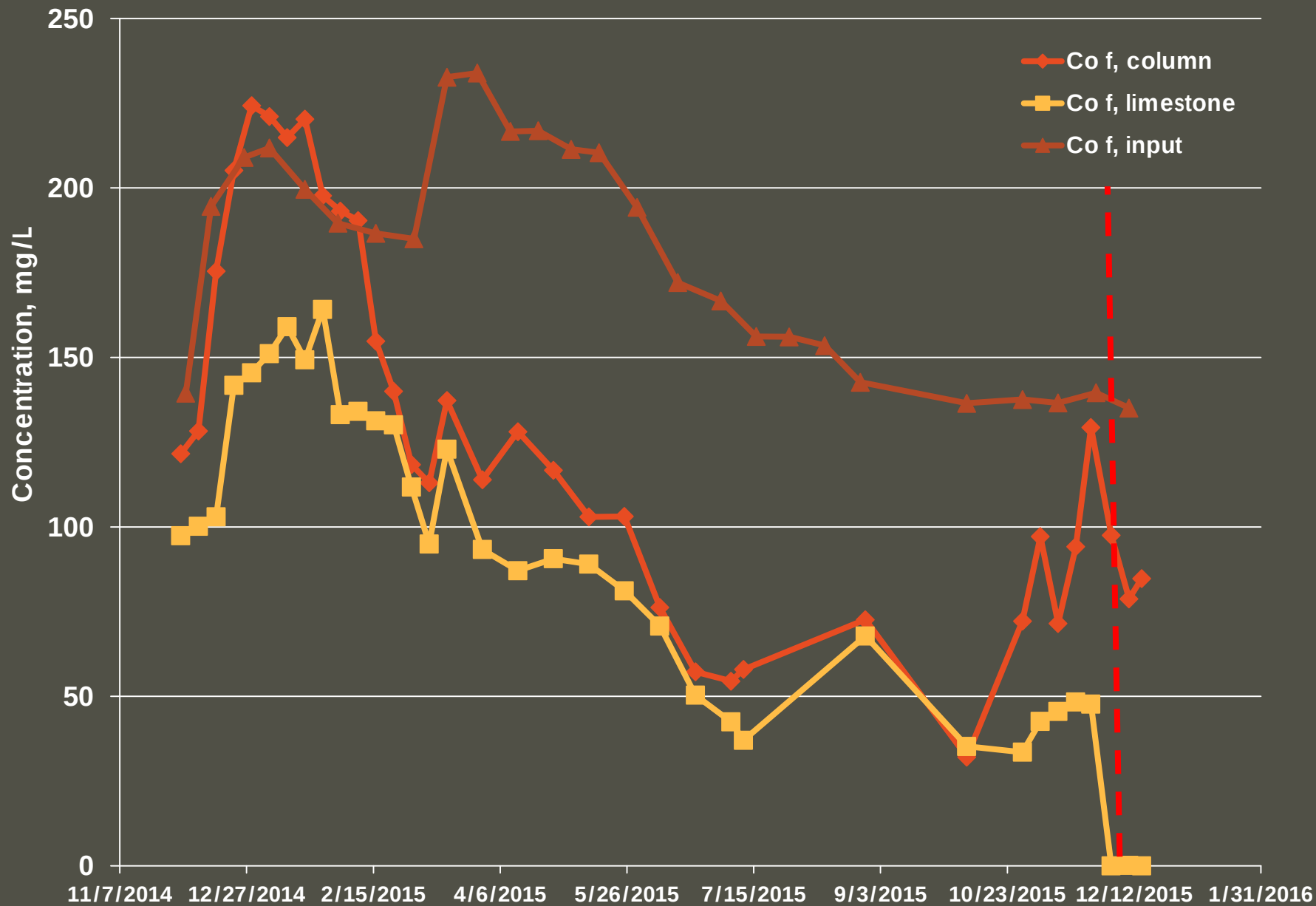
Hail Mary Option

- Pretreat limestone with Potassium Permanganate
- 100 mg/L solution
- Circulate through bed for 2 weeks

Manganese vs Time



Cobalt vs. Time



Conclusion

- Success
 - Column
 - Effectively raised pH
 - Precipitated iron
 - Coprecipitated/adsorbed copper
 - Limestone Bed
 - Effectively raised pH
 - Pretreated Limestone Bed
 - Precipitated manganese
 - Coprecipitated/adsorbed cobalt



Puzzlements

- Column
 - Mechanism of cobalt removal
 - Adsorption/coprecipitation
 - Increase potential as pH increases
 - Anaerobic conditions?
- Limestone Bed
 - Lack of manganese removal
 - Almost 1 year of testing



LEVEL NO. 27

2341 FEET BELOW THE SURFACE.
689 FEET BELOW SEA LEVEL.

BELL
FOR SAFETY ONLY

BELL
FOR SAFETY ONLY

Questions?



pH adjustment test

Parameter	initial	Step 1	Step 2
pH	2.5	4.2	5.6
Fe	57.3	9.6	4.0
Al	12.0	7.3	0.08
Cu	0.05	0.08	<0.008
Co	0.16	0.15	0.13

All metals in mg/l