Trihydro

Improving the Accuracy of Mineral Scaling Risk Assessments: Insights from a NW Colorado Coal Mine

Kevin Wright, Logan Schultz, Anthony Gilden

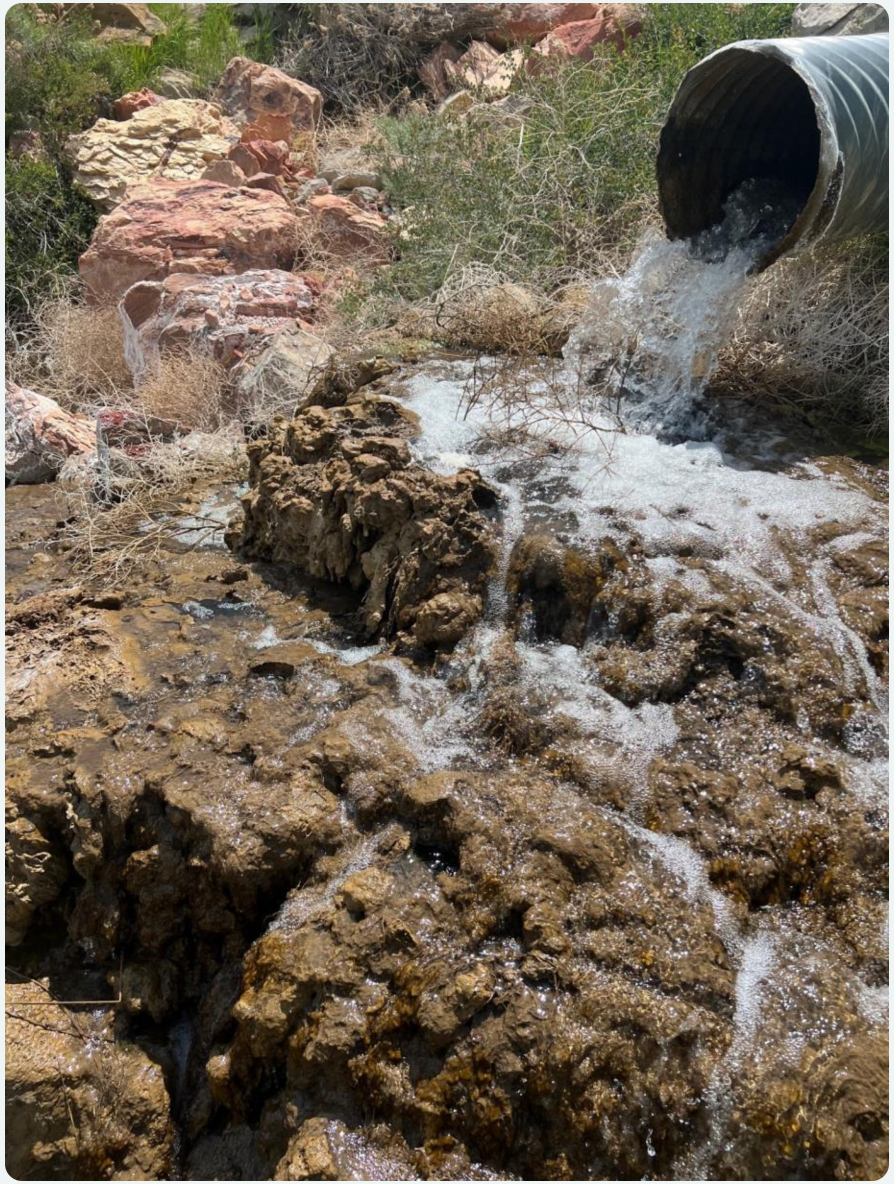
June 8th, 2026

www.trihydro.com

Project Background

- A natural stream at the toe of the reclaimed pile developed.
- By 2020, the stream was actively being monitored, as the water did not reach receiving river water quality (high TDS).
- Capture water before it daylights, transport 3.7 mi to evaporation pond.
- Build a pond sufficient to evaporate annual water flow in ~6 months with assistance from EcoVap system.

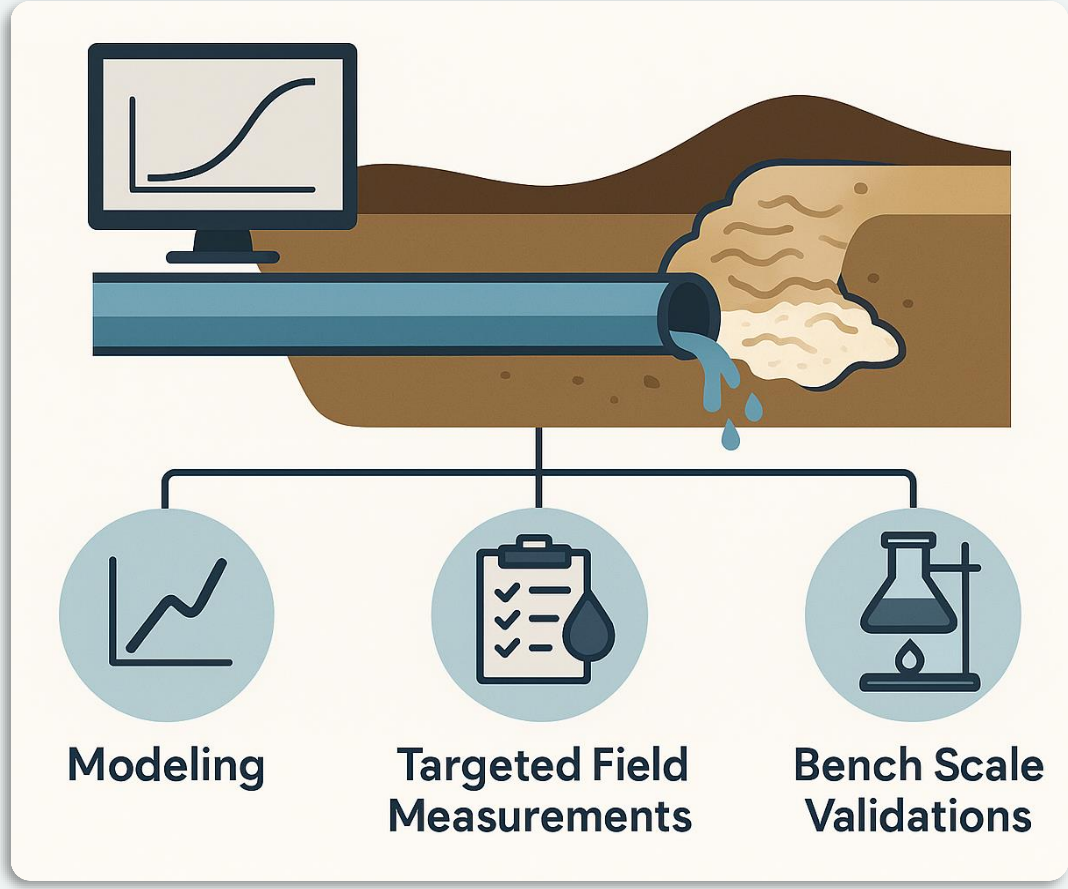
Potential Problems – Scaling & Waste Management



Approach to Mineral Scaling Assessments

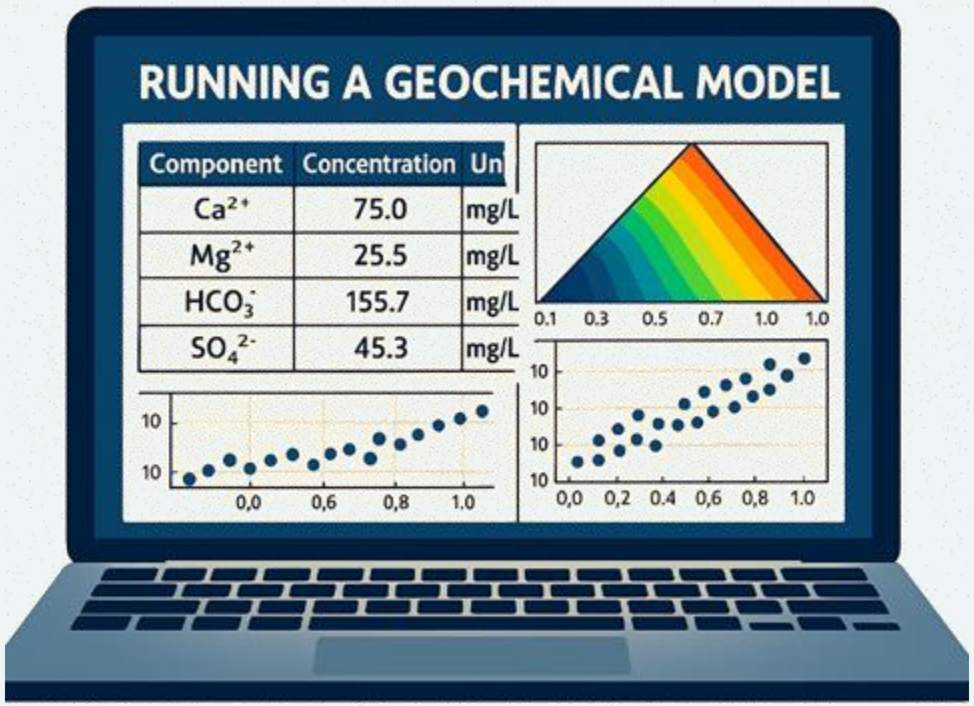
1. What is the expected mineral precipitation in the pipe?

2. What is the total volume of expected mineral precipitation in a scaling pond?



Preliminary Model Results

- **Near the stream source, models demonstrate 20+ minerals are supersaturated (SI > 0), suggesting precipitation is thermodynamically favorable across a wide mineral suite**
  - However, kinetic limitations likely prevent many of these minerals from forming under field conditions
- **To better constrain mineral precipitation (pipe and pond conditions), targeted field work focused on:**
  - Developing a general understanding of site conditions and controls
  - Measuring geochemical changes along the flow path to refine model inputs and improve accuracy
  - Collecting water samples for laboratory analysis and bench-scale testing
  - Collecting solid-phase samples for XRD characterization



Trihydro

Field Sampling Locations

Trihydro

Targeted Field Sampling

- Multiparameter Sonde (pH, ORP, DO, turbidity, temperature)

- Hach AL-DT Alkalinity Test Kit

- Solu-Blu CO_2 Monitor

- Water samples for laboratory analysis and bench-scale testing

Trihydro

Solid Sample Collection

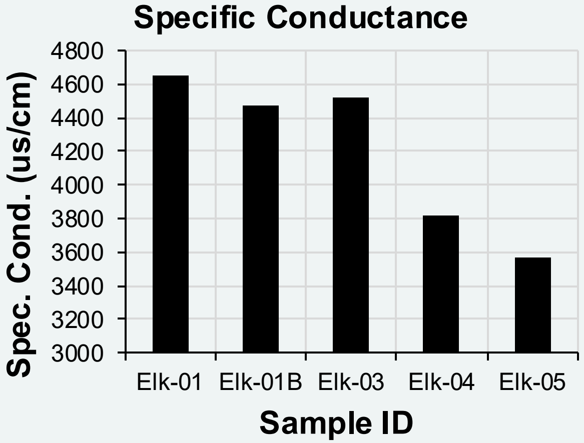
1

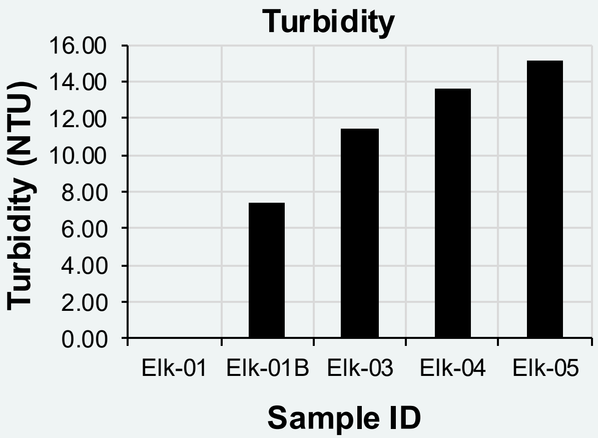
2

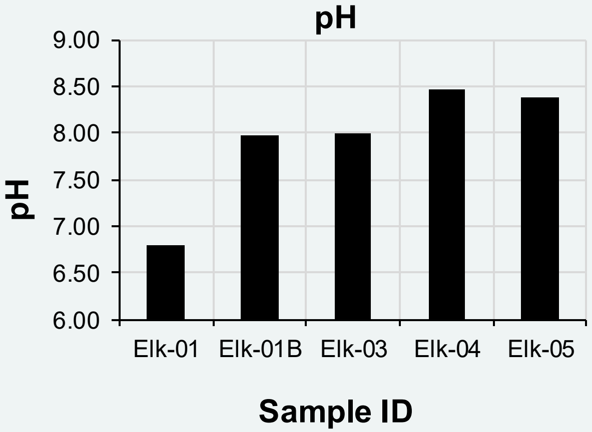
3

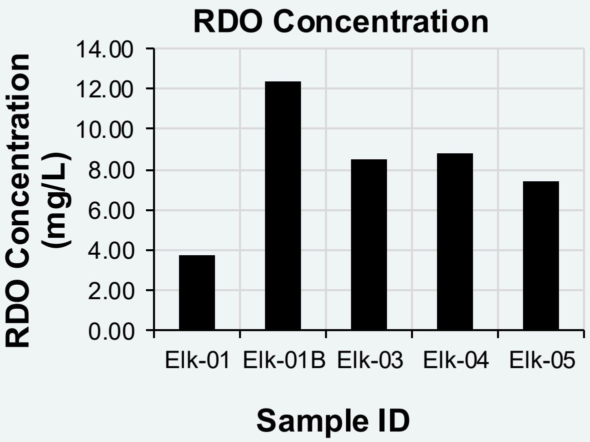
Field Test Results

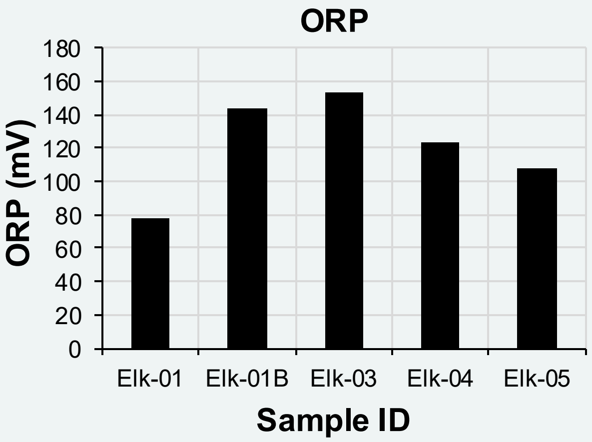
- **Results demonstrate notable geochemical changes driven by degassing, mixing, and mineral precipitation.**

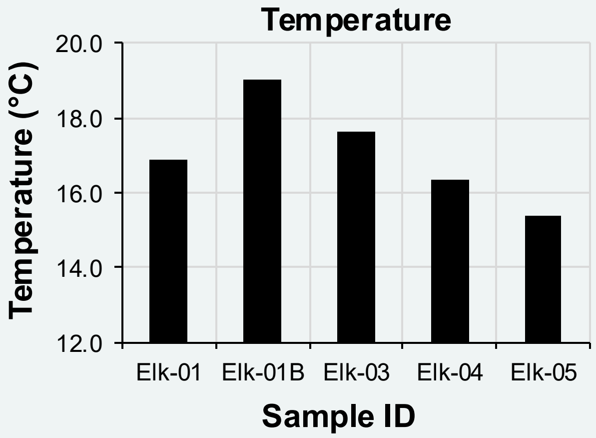


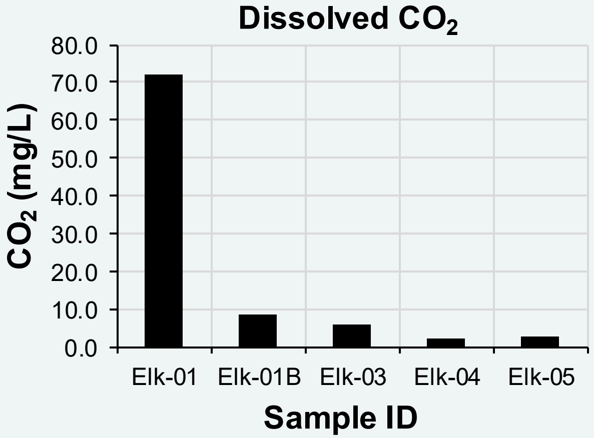












Mineralogical (XRD) Results

- **Three solid samples (Elk-01, Elk-01Flume, and Elk-03) were dried, crushed, and analyzed at the Montana State University Image and Chemical Analysis Laboratory.**

- **Elk-01 was identified as primarily sodium sulfate minerals (mirabilite, thenardite)**

- **Elk-01F was identified as primarily ferrihydrite (Fe_2O_3, amorphous iron oxide)**

- **Elk-03 was identified as primarily calcite ($CaCO_3$), with minor amounts of quartz and clays.**

Key Findings - Targeted Field Analysis

- Data demonstrate the water at the flume (Elk-01) is slightly acidic, contains low DO, but is still in a slightly oxidizing environment (+ORP), and contains high levels of dissolved CO_2.
- As water flows downstream, CO_2 degasses rapidly (300ft downstream from source, dissolved CO_2 decreased by 87%).
- pH rises and calcite precipitates, especially in areas where degassing and aeration is enhanced (cascades).
- Ferrihydrite and calcite are the primary minerals most likely to drive pipeline performance issues and pond solids accumulation

Modeling Approach

All Simulations

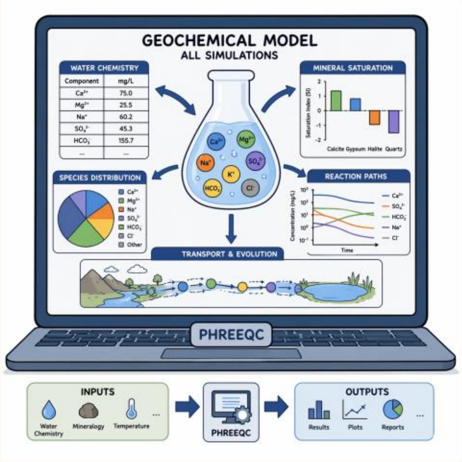
- Utilized empirical, lab analyzed data for metals concentration
    - Utilized field data for TDIC (CO_2), temperature, pH, ORP
- Utilizes PHREEQC to predict mineral precipitation allowing only certain minerals to precipitate
    - Since models tends to overpredict the more thermodynamically stable minerals (hematite > ferrihydrite)

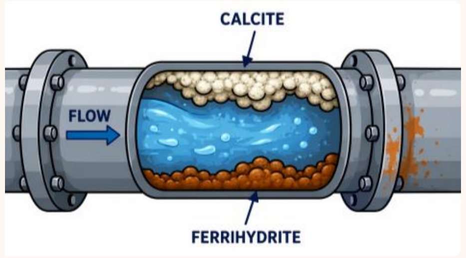
Pipeline

- No change in temperature
- Change in pH is relatively restricted
    - Allows CO_2 to degas up to a solution pH of 7.1 (based off field data reported in PACE results)
- Atmospheric pressure (~14.7 psi)
- Assumes a relatively closed system
    - Small amount of exchange with atmospheric CO_2 and O_2

Pond

- No change in temperature
- Change in pH is less restricted
    - Allows CO_2 to degas up to a solution pH of 8.46 (based off field data)
- Atmospheric pressure (~14.7 psi)
- Assumes open system
    - Unlimited exchange with atmospheric CO_2 or O_2





Modeling Results

Pipeline

- If water temperatures do not vary and CO_2 does not degas, the model suggests calcite should stay in solution
- Can anticipate roughly ~1 mg/kg of ferrihydrite

Pond

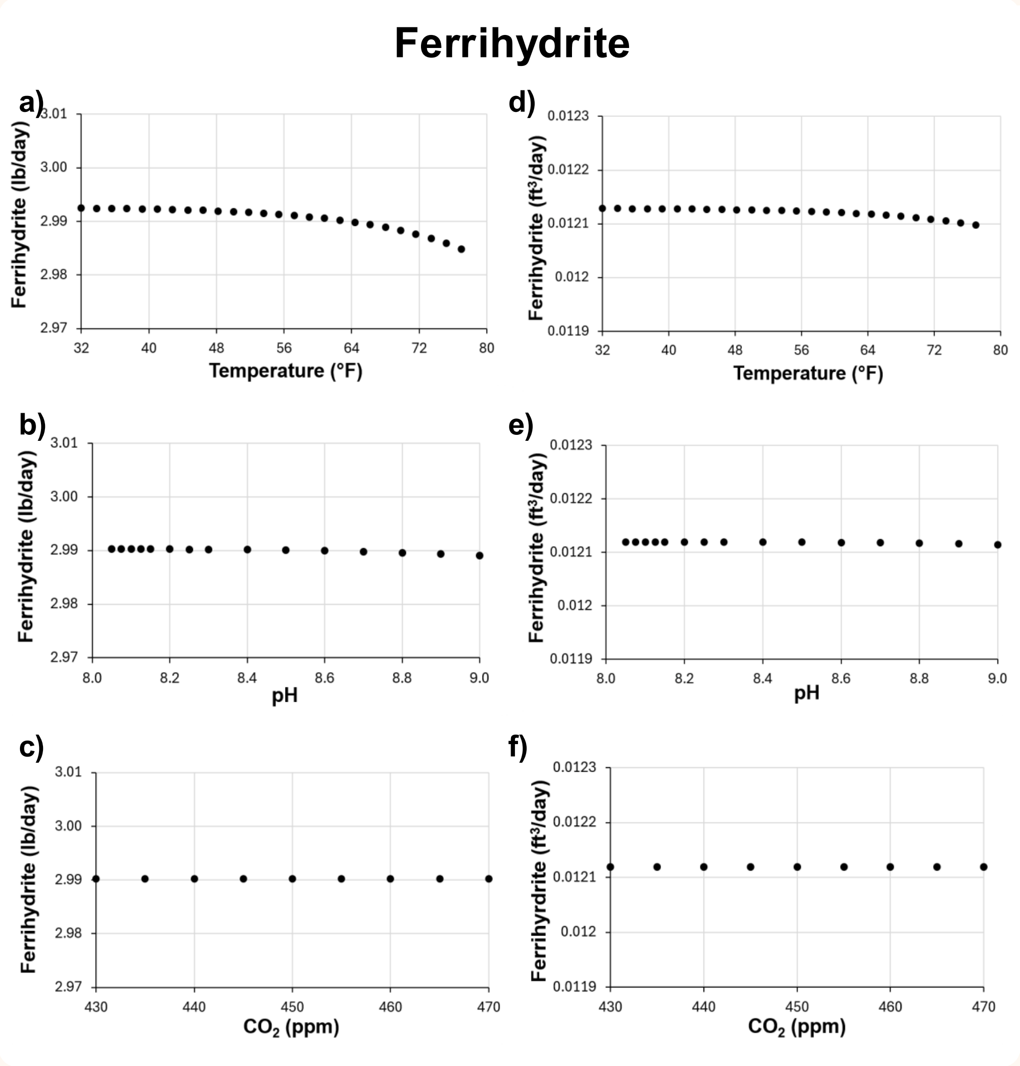
- PHREEQC predicts the following minerals will precipitate at a pH of 8.46
  - Calcite = 427 mg
  - Ferrihydrite = 0.788 mg
  - Total = 429.4 mg per kg of water

Solution	Flow Rate (GPM)	pH	Temp (°F)	Calcite (lbs/day)	Calcite (cf/day)
Lab 2/18/22	409	8.1	62	1484	8.79
Lab 9/12/23	86	8.1	34	37	0.22
Field 5/28/25	153	8.1	62	281	1.70
Field 5/28/25	153	8.46	62	697	4.13

Based off an average flow of 153 GPM, this could lead to an accumulation of 697lbs or 4.1 cf of calcite per day

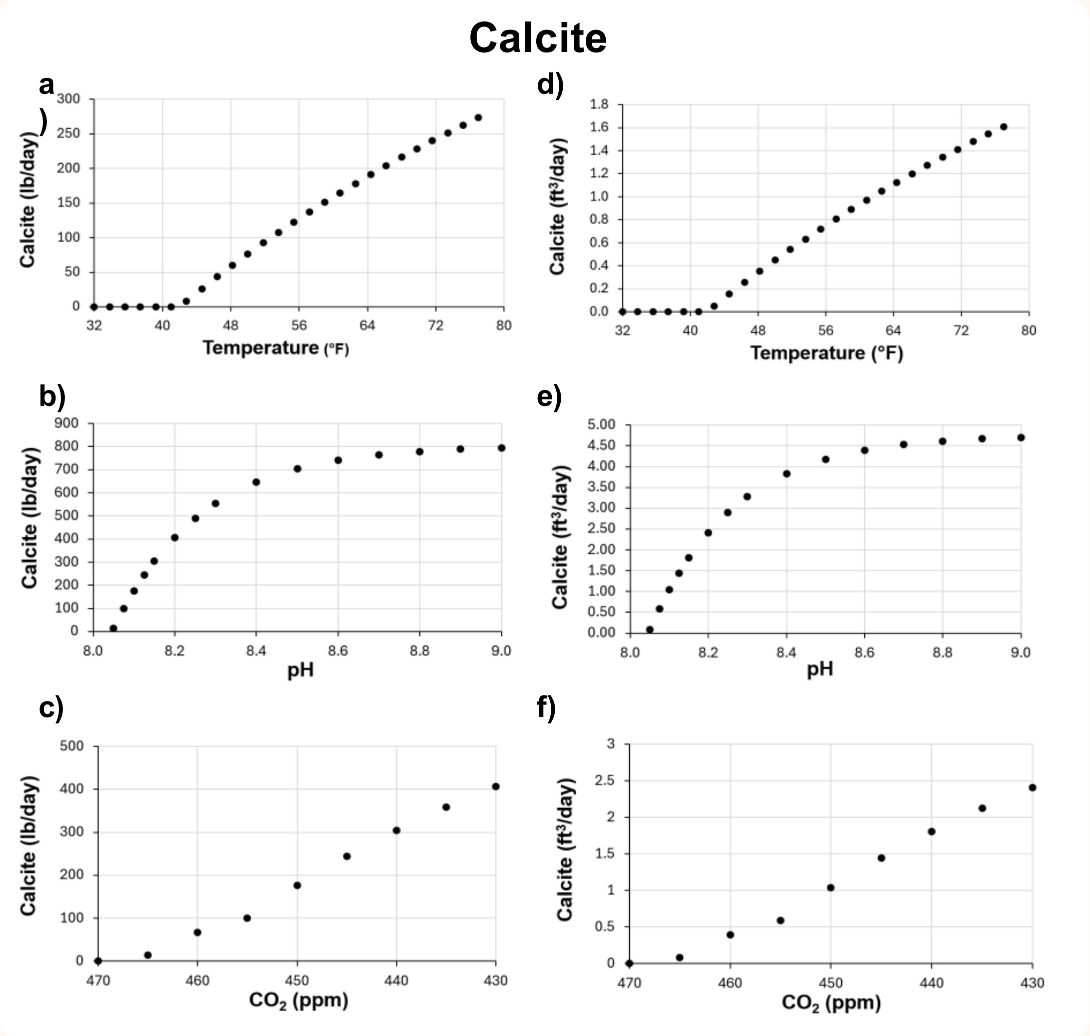
Sensitivity Analysis Results - Ferrihydrite

- Ferrihydrite is not sensitive to fluctuations in temperature, pH, or CO_2
- Therefore, it’s likely to persist in the pipeline and pond
- However, it’s not likely to form a hard scaling issue that could not be cleaned using pigging



Sensitivity Analysis Results - Calcite

- Calcite is highly sensitive to variations in temperature, pH, or CO_2
- Several important implications for pipe design
  - Keep pH < 8.1 to limit scaling
  - Insulate pipe to prevent warming
  - Reduce degassing to lower mineralization risk
    - Avoid air-relief valves
    - Minimize pipe diameter



Key Findings - Modeling

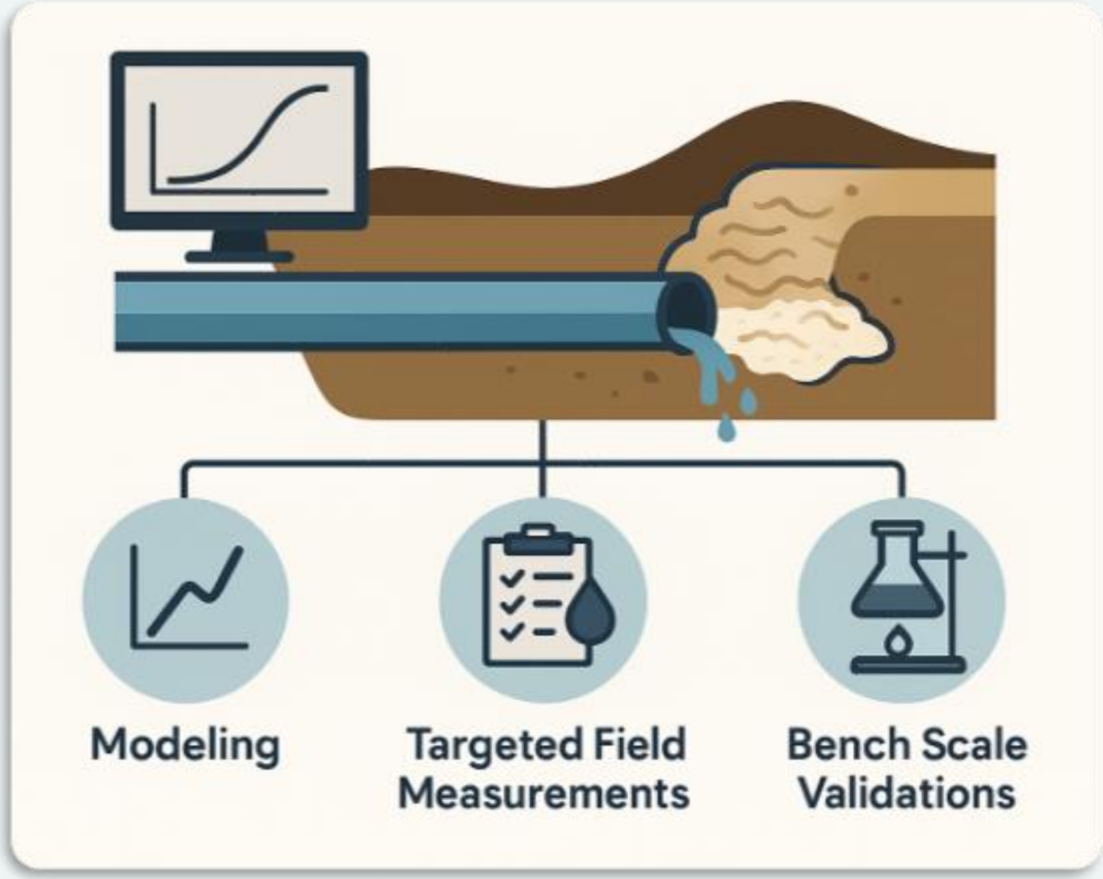
- Ferrihydrite is likely to precipitate in both pipelines and ponds and is insensitive to changes in pH, temperature, and degassing.
  - Can be removed with routine cleaning (pigging) if build up occurs
- Calcite is unlikely to precipitate in the pipeline if degassing can be limited (relatively full pipe, limited air relief valves)
  - However, to accommodate fluctuations in flow (150 → 450 GPM) the pipe may not be completely full
- Calcite precipitation in the ponds could be a significant volume that requires further investigation

Bench Scale Validations

1. **What is the expected mineral precipitation in the pipe?**

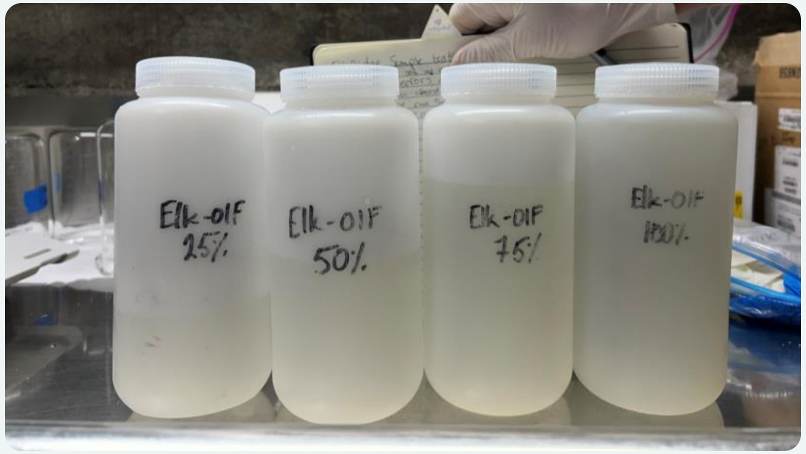
2. **What is the total volume of expected mineral precipitation in a scaling pond?**

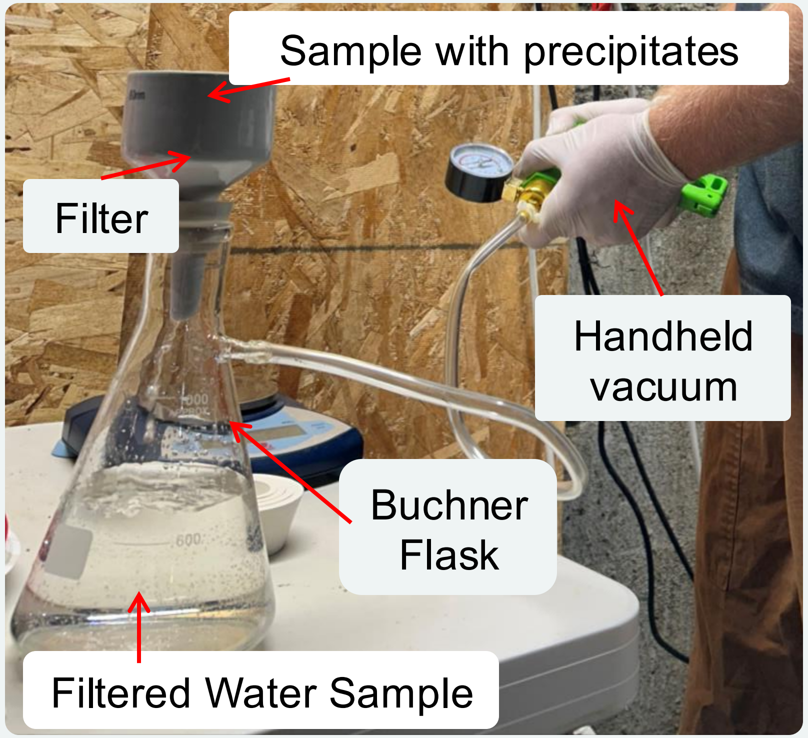
- Improved model predictions with field data, but additional validation was needed before major decisions
- The bench scale testing included
  - Partial fill bottle tests
  - Imhoff cone tests
  - Mass balance calculations



Partial Fill Bottle Tests

- Collected 4 separate samples in 1 L bottles from source
  - 100% full → simulating full pipe flow with no head space
  - ~75%, ~50%, and ~25% full → simulating partial pipe flow
- Measured pH, specific conductance, and temperature
- Poured sample through filter with pressure applied with a handheld vacuum
- Removed filters, placed on labelled plate, and allowed to dry
- Weighed dried filters and filters sent to laboratory for XRD/XRF analysis





Partial Fill Bottle Results

- pH increased uniformly as proportion of fullness decreased
  - More headspace in bottles allowed for degassing

Table 1: pH, Temp, and Specific Cond. for each sample

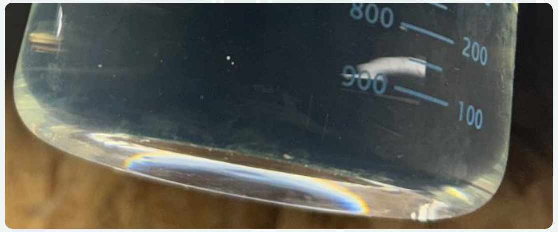
% Full	pH	SC(mS/cm)	T (°C)
100	6.9	4.59	9.3
75	7.1	4.63	9.3
50	7.3	4.63	8.1
25	7.5	4.64	9.4

Partial Fill Bottle Results

100%

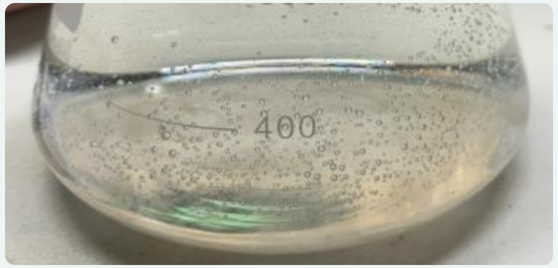
- Most precipitates were orangish/red, some white

75%



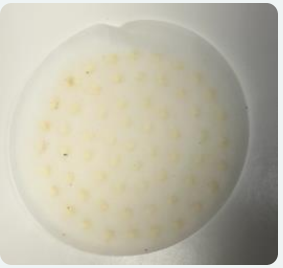
- No precipitates

50%



- Orange/red precipitates on filter
- Noticed bubbling in flask
  - Demonstrating degassing with atmospheric exposure

25%

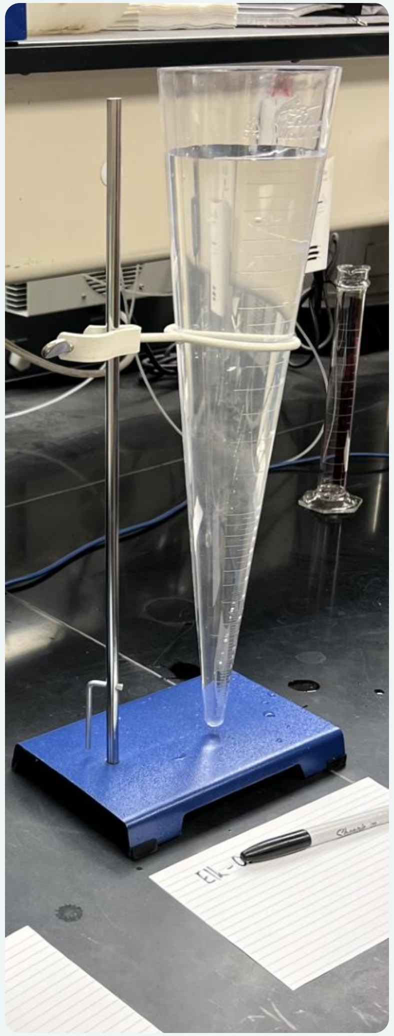


- Orange/red precipitates on filter
- Bubbling post filter (not captured in photo)

Imhoff Cone

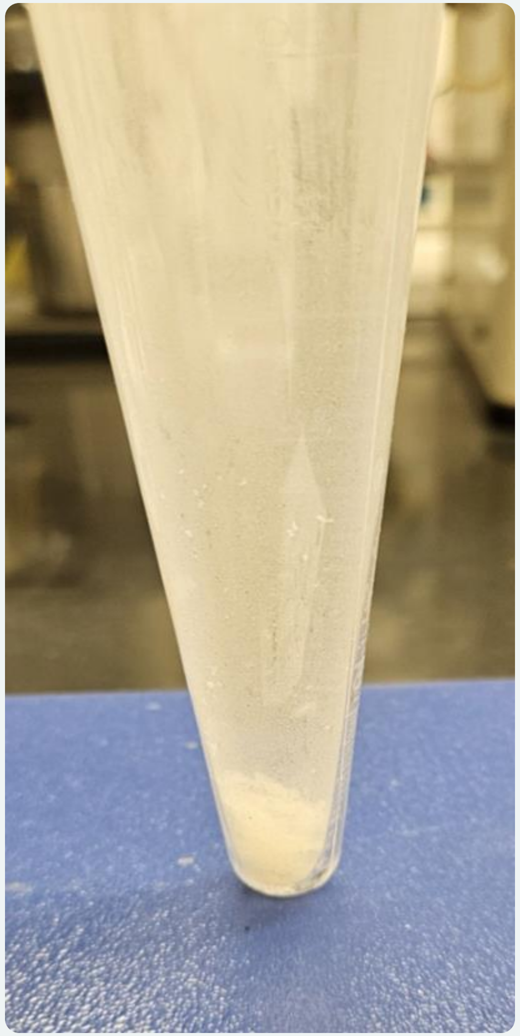
- Imhoff cone tests (1L) with readings at 0, 1 hr, 24 hr, and 2 weeks
- Undisturbed sample showed only trace precipitates after 24 hr
- Stirred sample produced ~33 mg of precipitates
  - Far less than the 427 mg predicted

Undisturbed, 24 hr



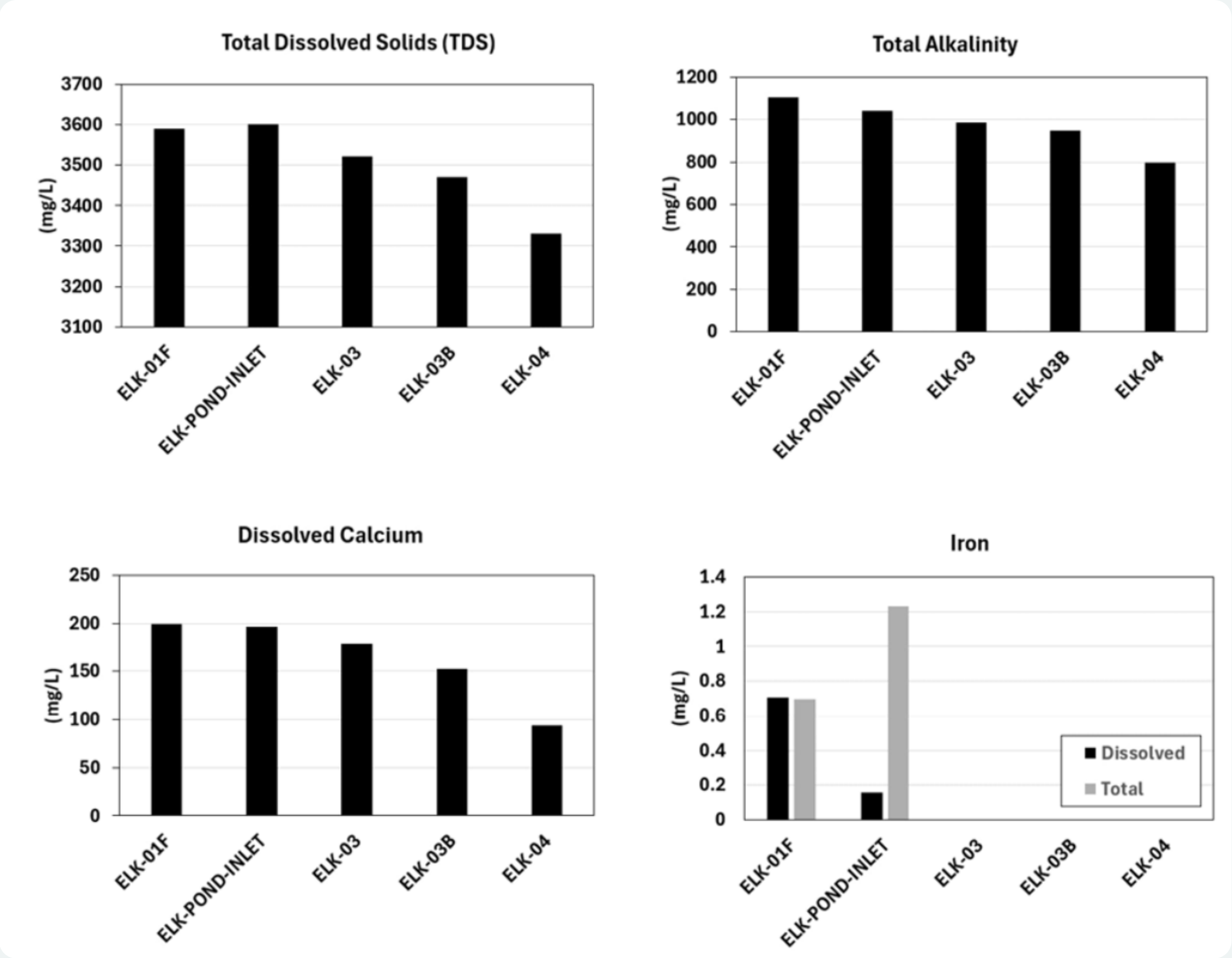
Stirred, 1 hr

Stirred, 24 hr



Mass Calculations

- Water flows into existing settling pond
- Collected samples before and after settling pond and analyzed for:
  - TDS
  - Alkalinity
  - Ca
  - Fe



Bench-Scale Results

- Bench-scale validations demonstrate calcite precipitation in an open-system (pond) is restricted to 60 – 101 lbs/day
  - Almost a factor of 10 times less than predicted by models
- They demonstrate mineral precipitation is restricted in a closed-system
  - Consistent with model predictions

Precipitated Calcite at Settling Pond				
	mg/L	mg/L	lbs/day	cf/day
Calcite from Dissolved Ca	45	45	82	0.49
Calcite from Alkalinity	0	55	101	0.60
Calcite from Imhoff Cone	--	33	60	0.36

Conclusions

- Models were helpful for defining the range of minerals likely present in the system
- Targeted field observations and mineralogical testing were critical to refine which minerals are likely to precipitate
- Sensitivity analysis and improved model simulations helped identify how changes in temp, pH, and degassing affect precipitation
    - Minimize degassing & warming → calcite stays dissolved; ferrihydrite forms
- Bench-scale tests reduced the overpredicted precipitate mass by the model
- Small upfront costs for a single field sampling event can lead to major long-term design, construction, and management savings