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Geochemical model to predict aquifer restoration following low pH *in-situ* uranium recovery (ISR)

Purpose

Support regulatory review to allow low pH ISR

- Major Revision to Land Quality Division WY DEQ Permit to Mine
  - Low pH Technical Report and Environmental Report
  - Responses to Comments
  - Stakeholder outreach
- Amendment to URP Materials License WYSUA-1601
- Application for field leach trial

Objectives

- Demonstrate aquifer suitability for conducting restoration of wellfield post-mining
- Estimate number of pore-volumes necessary for aquifer restoration
- Show that restored water-quality could meet objectives

Contents

PHREEQC 3 Step Model

Wellfield during mining → Wellfield restoration → Post-restoration wellfield to perimeter monitoring wells

Mining and restoration models relate to column tests

- Column tests provided initial understanding for model
- Model provided insight and understanding for interpretation of column tests
- Model identified key reactions and other variables that could be evaluated in column test

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Mining model

Two key questions –

- What is the potential for aquifer plugging by mineral precipitation and/or gas formation?
- What will be the water quality be at end-of-mining?

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Mining model

- Wellfield modeled as single cell – lixiviant added as pore volumes
- Injection of H_2SO_4 lixiviant to decrease pH from 8 to 2
- Surface ion exchange of cations for H^+
- Dissolution of uranium minerals, calcite, pyrite, clay minerals and feldspars
- Production of CO_2
- Precipitation of gypsum ($CaSO_4$) and SiO_2
- Calculated changes in molar volumes of dissolved and precipitated minerals to address concerns about plugging
- End-of-mining is starting point for restoration model

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Mining model results

Mineral Dissolved (-) or Precipitated (+)	Volume Change cm^3
Calcite/Dolomite	-12.2
Clays/Feldspars	-1.4
Pyrite	-1.4
Apatite	-0.7
Gypsum	15
SiO_2 (am)	0.6
Net Volume Change	-0.1

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Mining model results

Carbon dioxide did not exceed the solubility of the gas in the water

Aquifer restoration model

Key questions –

- Can the aquifer be restored to meet target restoration values?
- How many pore volumes required?

Aquifer restoration model

- Mix of upgradient aquifer water/restoration water as a function of pore volume
- pH increases from 2 to 7
- Dual porosity to account for stagnant pores that contributes end-of-mining water as restoration proceeds (immobile porosity 30%)
- Surface ion-exchange to replace H^+ for cations
- Precipitation of hydrous ferric and aluminum oxides
- Sorption of uranium and other metals

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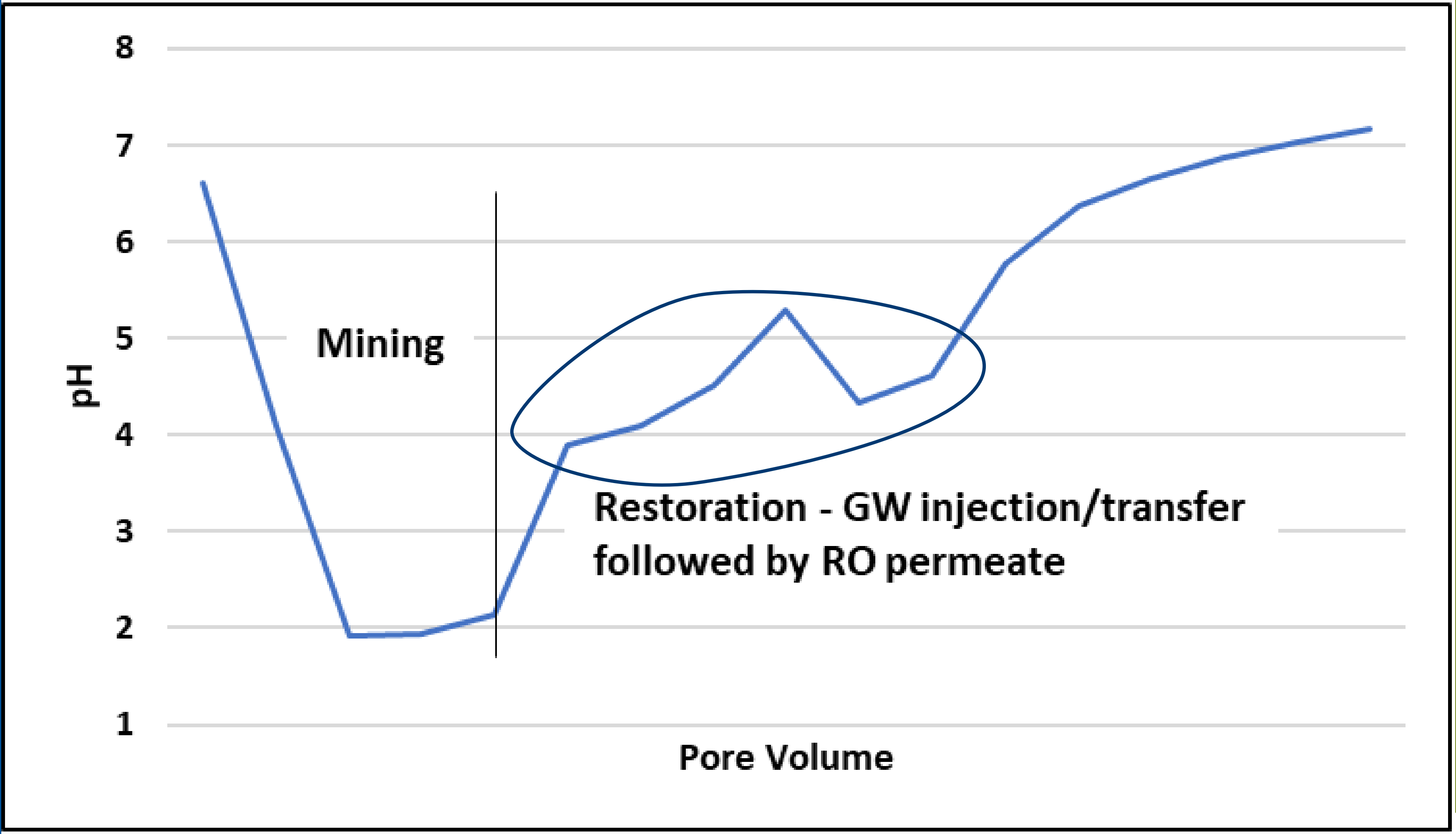
Mining and restoration pH change



Model showed successful aquifer restoration

- Reported in the literature
- Demonstrated by column tests
- Validated by model

Reactive transport from wellfield to perimeter wells

Key question –

- Will compliance be achieved at perimeter monitoring wells at 100 years?

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Reactive transport from wellfield to perimeter wells

- Simulation after natural hydraulic gradient re-established about 10 years post restoration
- PHREEQC 1-D reactive transport to model water quality along flow path 300 feet from wellfield to perimeter well
- Series of reaction cells along flow path
- GW flow velocity by defining length of reaction cell as flow distance per year and time shift between cells at one year
- Sensitivity analysis by varying controlling parameters – groundwater flow velocity and amount of hydrous ferric oxide for sorption of metals
- Worst case – assume constant water quality leaving the wellfield through time

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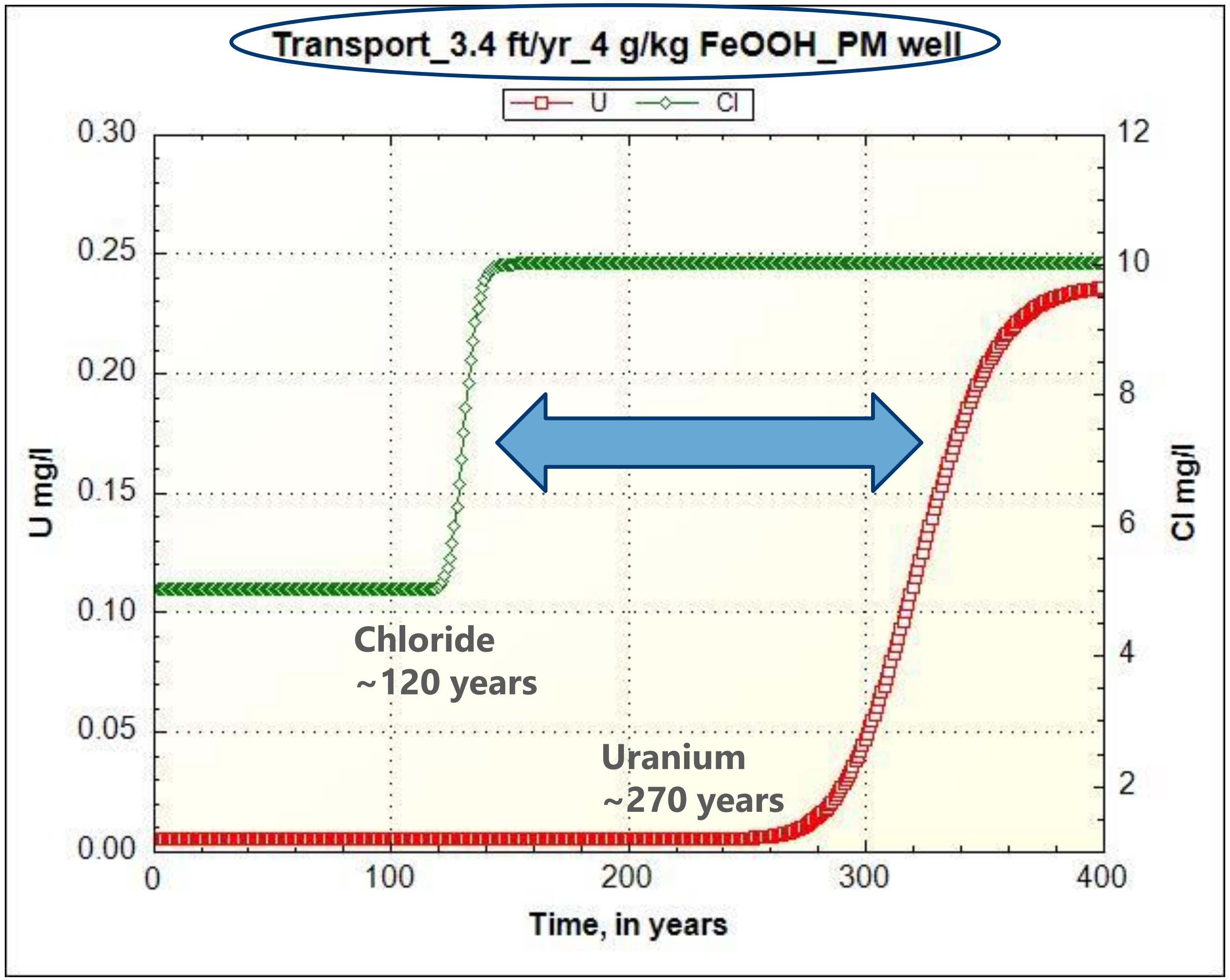
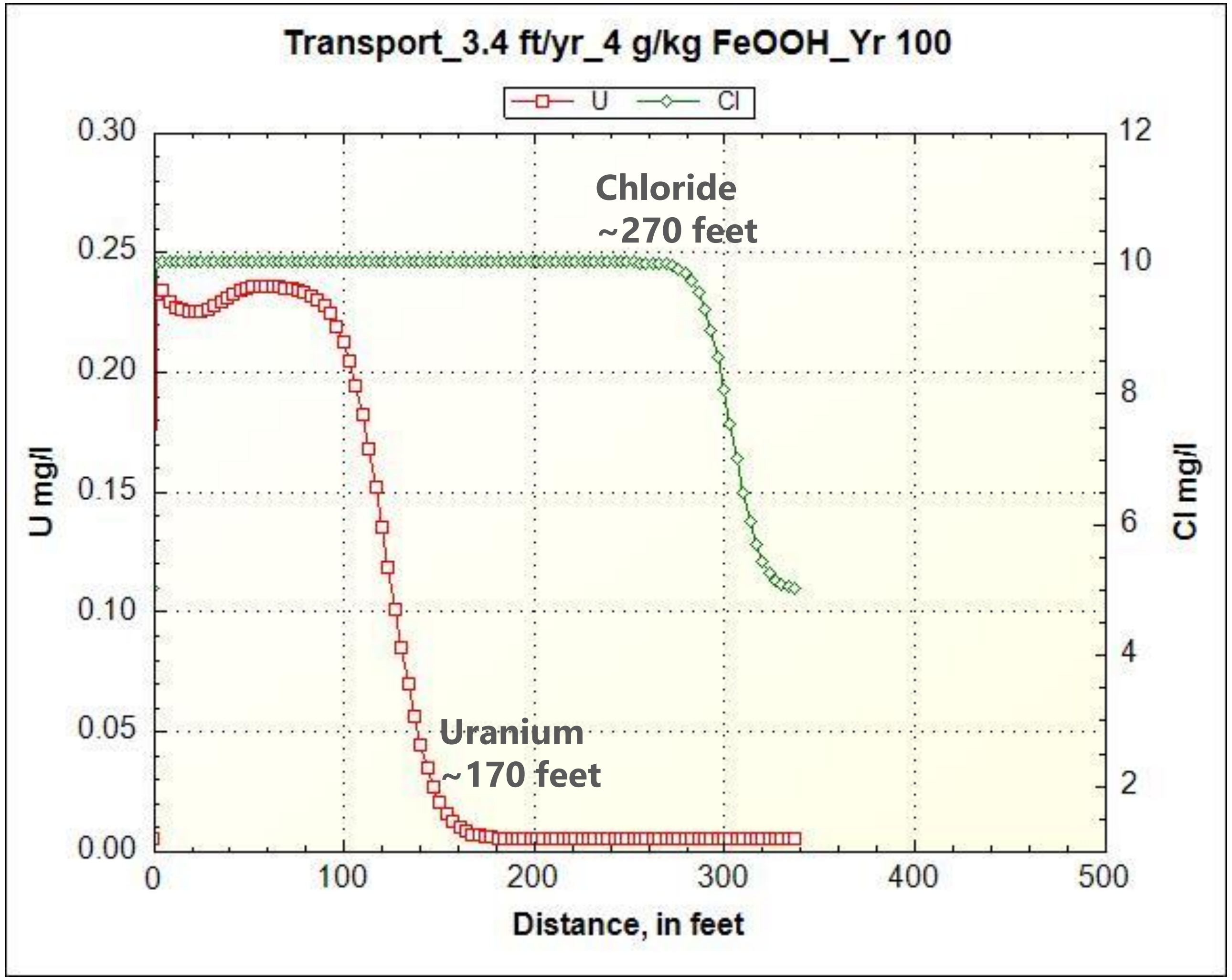
Uranium reaches perimeter monitoring well 250 years post aquifer restoration



Uranium about half-way to perimeter monitoring well after 100 years



Model status

- Mining and restoration models were confirmed and fine-turned by results of field trial
- Time for restoration of pH depends upon free-acid in wellfield at end-of-mining and surface cation-exchange capacity
- Improve realism of reactive transport model by incorporating declining uranium concentration in wellfield and actual iron concentrations along flow path

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Take-aways of geochemical models

- An effective tool to support regulatory review
- Answers questions posed by regulators and public
- Demonstrates compliance during and after operations
- Provides insight into understanding bench-scale testing
- Useful in support of operations
  - Model can be revised to evaluate operational modifications
  - Inform management of solids in recovery stream

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Questions?

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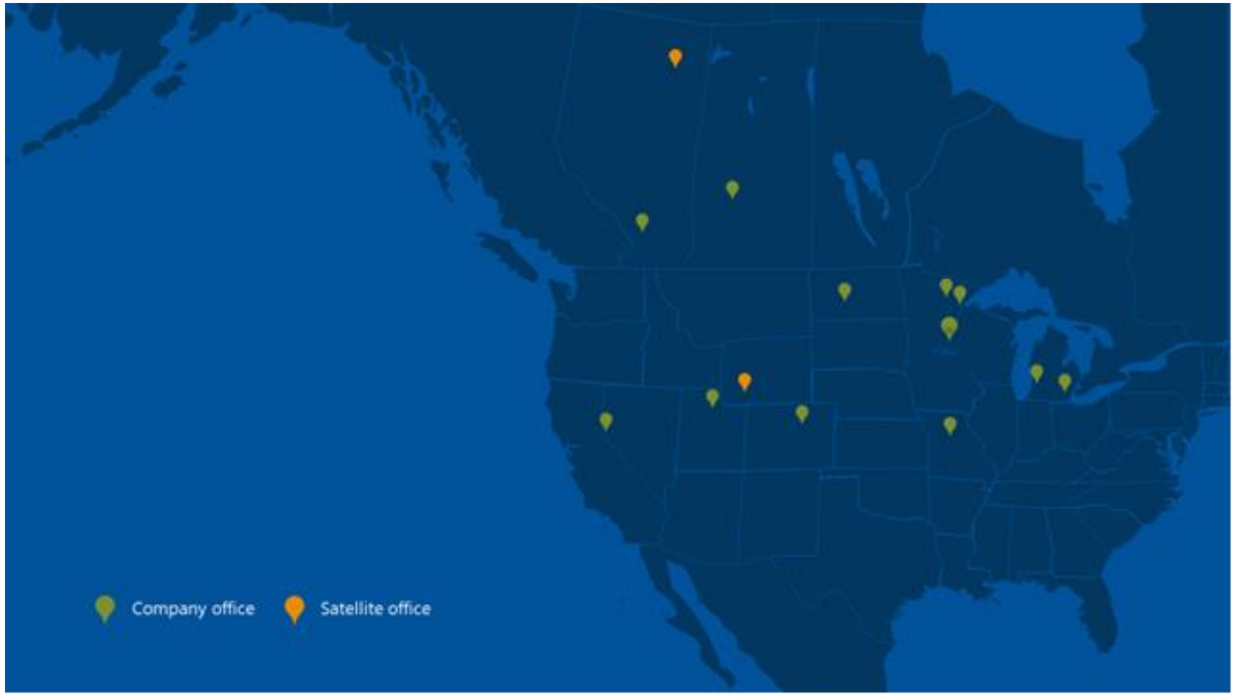

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