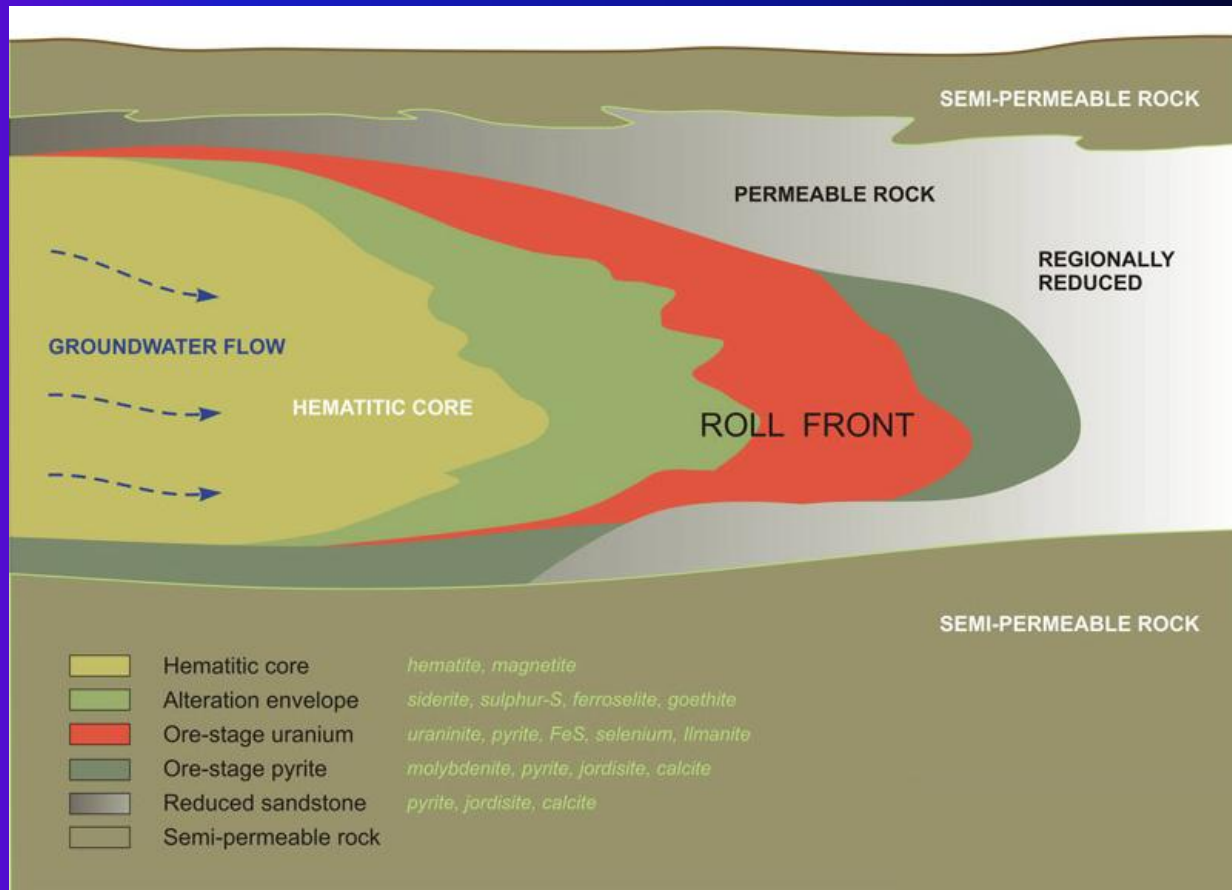
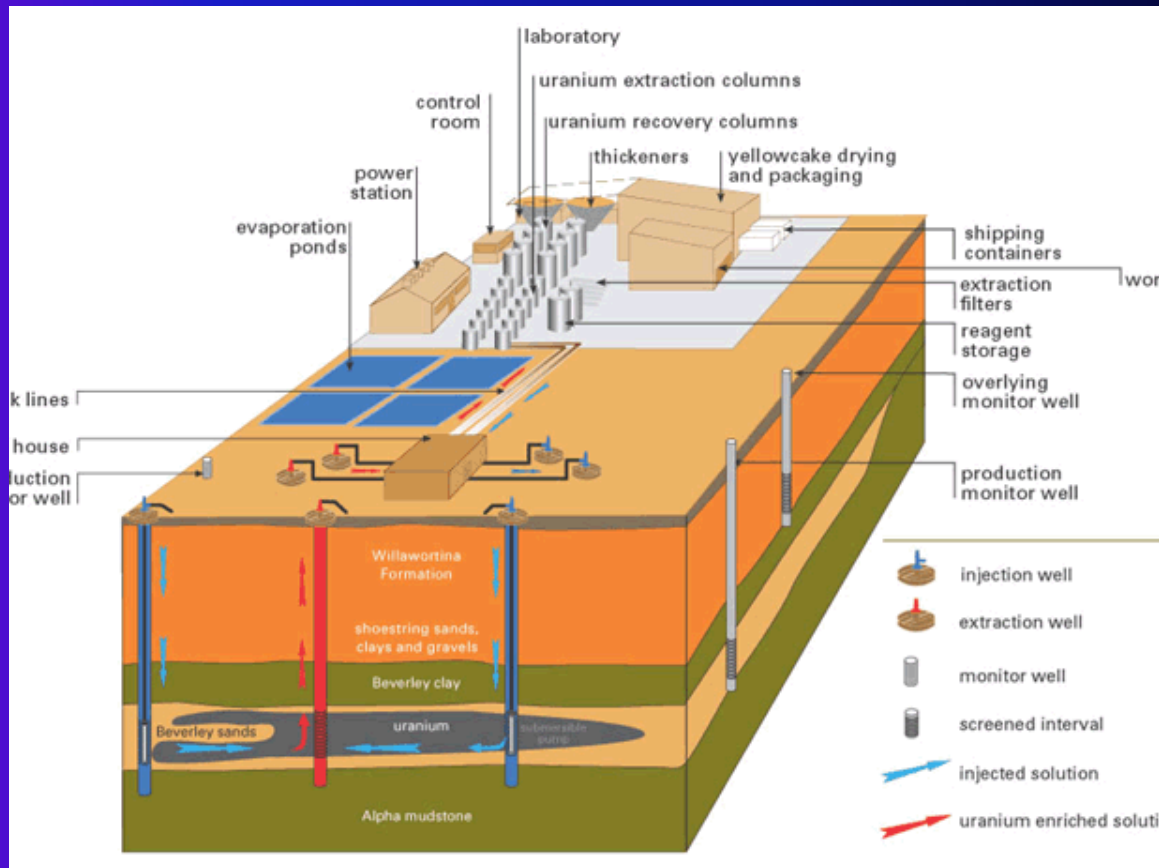


Evaluating the Effects of Uranium Kd on the Restoration of ISL Wellfields Using PHT3D



After Devoto, 1978



ISR MINING PROCESS

- Inject Lixiviant
- Recover Pregnant Solution
- Ion Exchange
- Reverse Osmosis
- Reinjection Lixiviant With Make Up Water With Reactants

What is K_d

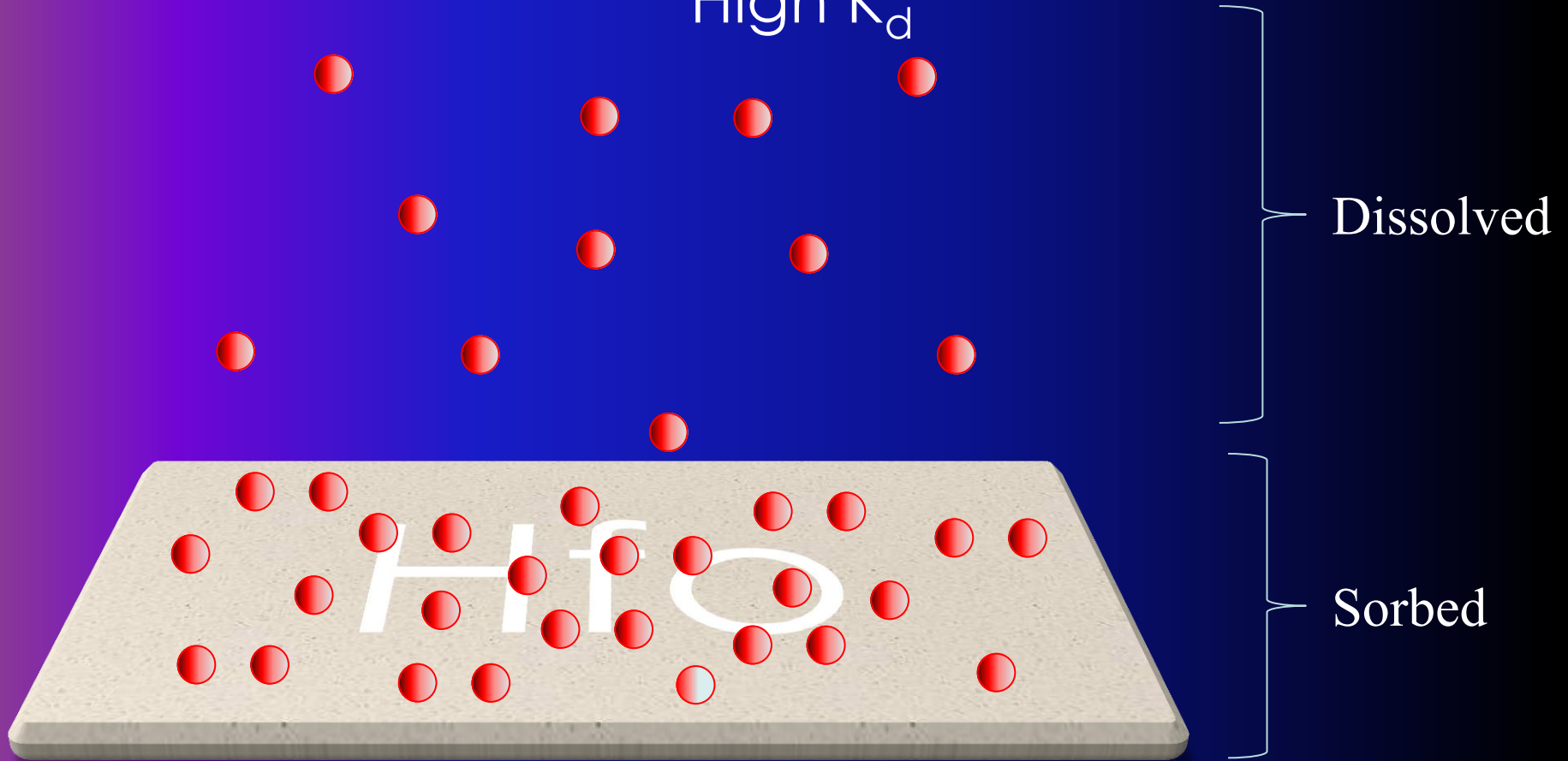
- Distribution Coefficient
- Related to Solute Retardation

$$R = 1 + \frac{\rho K_d}{n_e}$$

- $R = \frac{\textit{Groundwater Velocity}}{\textit{Solute Velocity}}$
- K_d is Proportional to the Solute Velocity
- $K_d = \frac{\textit{Concentration of Sorbed}}{\textit{Concentration of Dissolved}}$

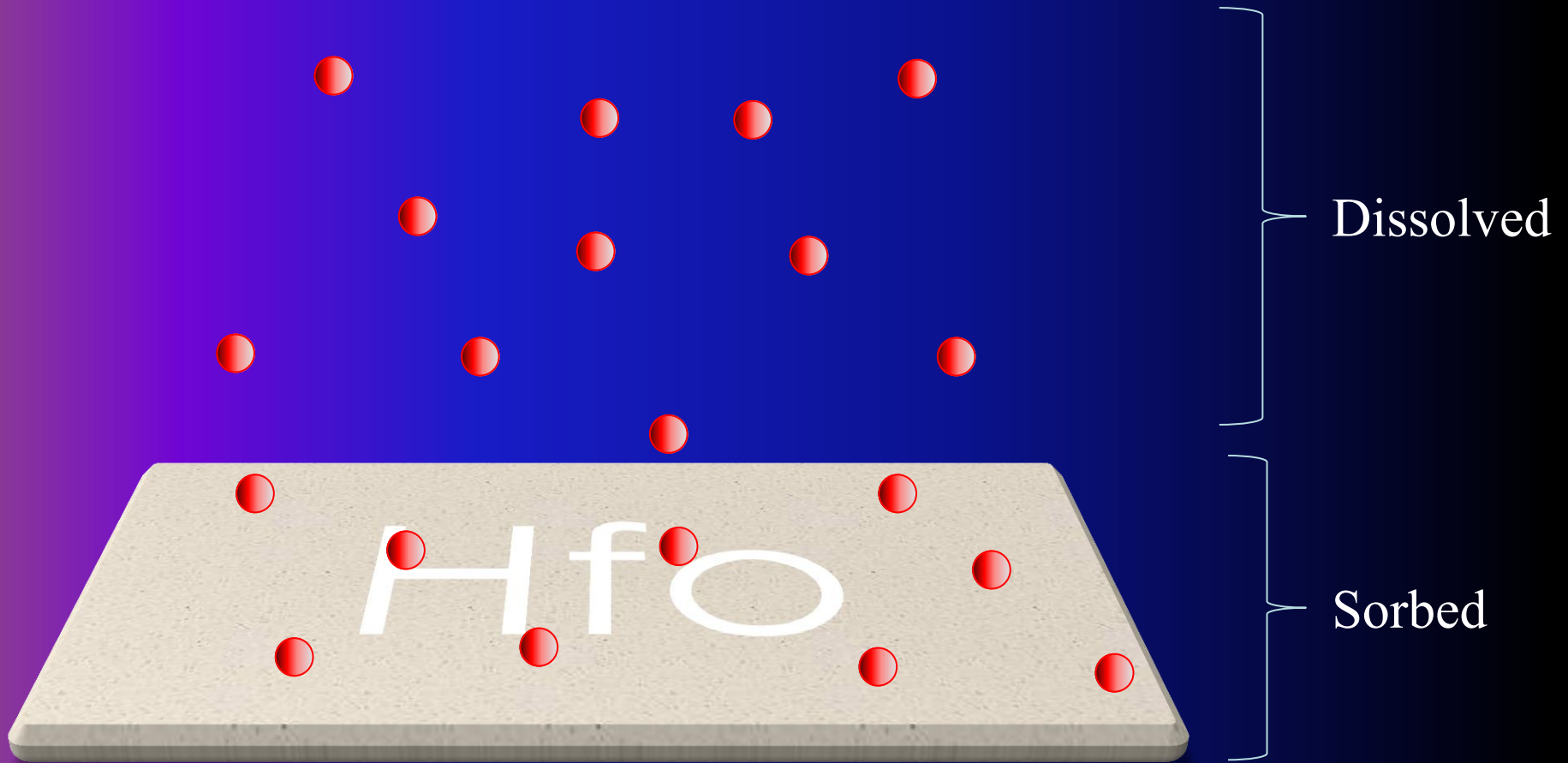
Surface Ionization and Complexation Model

High K_d

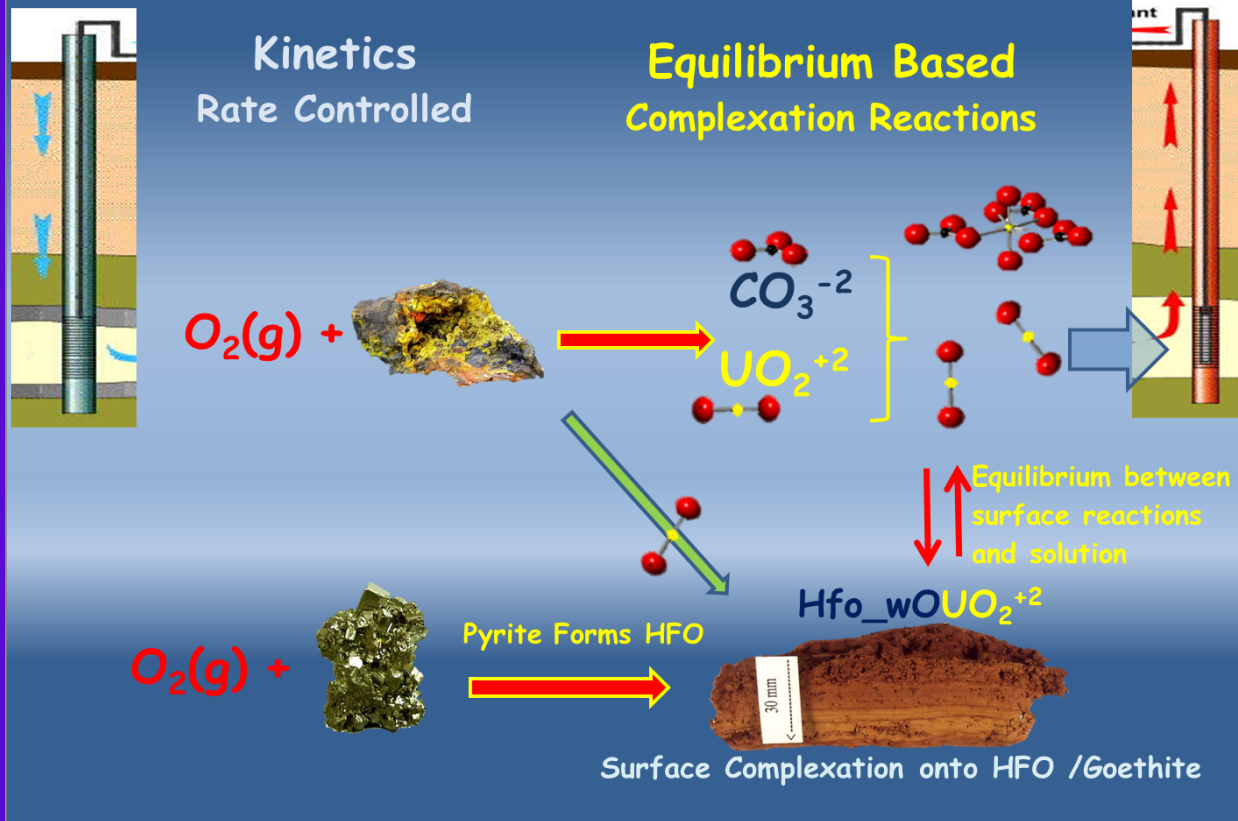


Surface Ionization and Complexation Model

Low K_d



Reactions Involved in ISR and Restoration



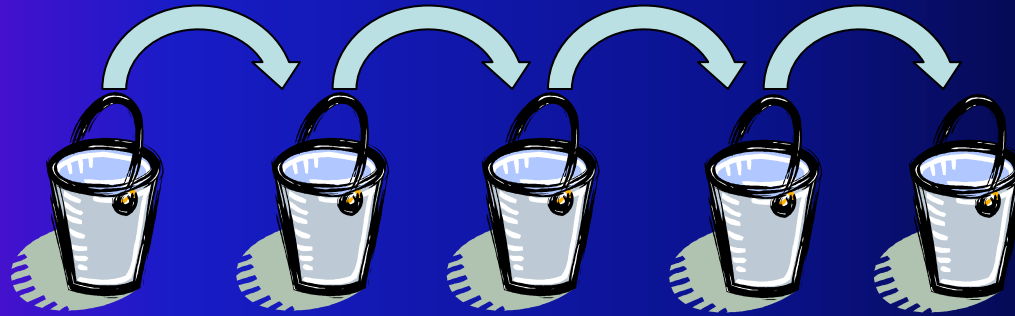
Surface Complexation

Uranium sorbing onto Hydro Ferrous Oxide (Hfo)

Modeling

How Do We Simulate All of the Processes

1. Obtain Publically Available “ADAMS” Data
2. Create a Modflow Flow Model
3. Create the MT3D Transport Model
4. Add PHT3D Reactive Transport and Surface Complexation Elements



PHREEQC

- One-Dimensional
- Fixed Groundwater Velocity
- Dispersion In One Direction
- Groundwater Is Passed Along a Line and Allowed to React With New Water And Minerals



PHT3D

1. Three-dimensional
2. Variable Groundwater Velocity
3. Dispersion In Three Directions
4. Each Bucket Represents A Model Cell

Reactive Transport Model

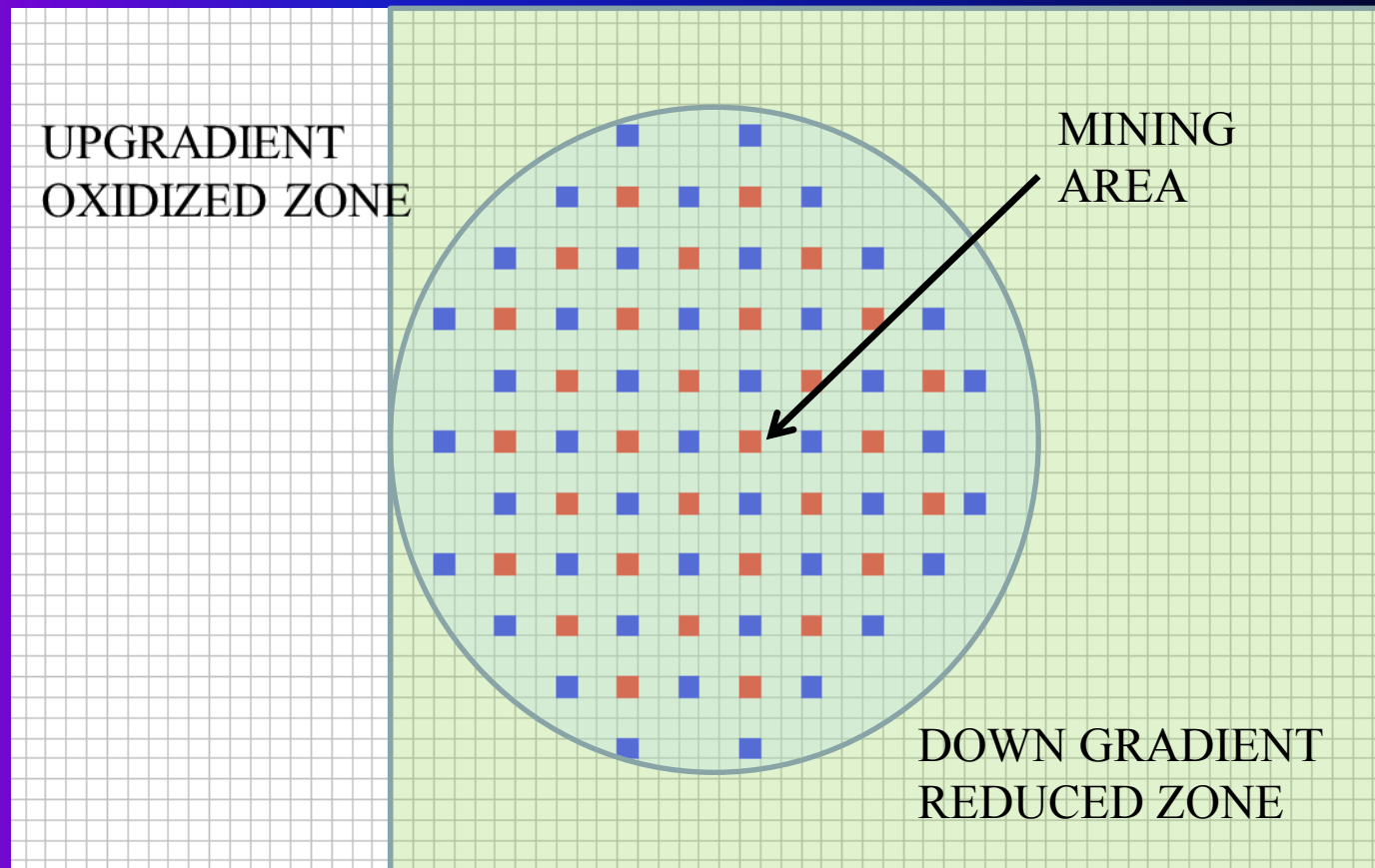
1. Still Conceptual in nature
2. Proof of Concept
3. What Effect Does Surface Complexation Have on Uranium Restoration
4. How Can We Keep the K_d Low
5. Can PHT3D Be Implemented to Solve These Problems

Mineral Phases Used in PHT3D

- Uraninite
- Pyrite
- Calcite
- Goethite Used For Complexation Sites
- Assume Quartz Inert

Components Used in PHT3D

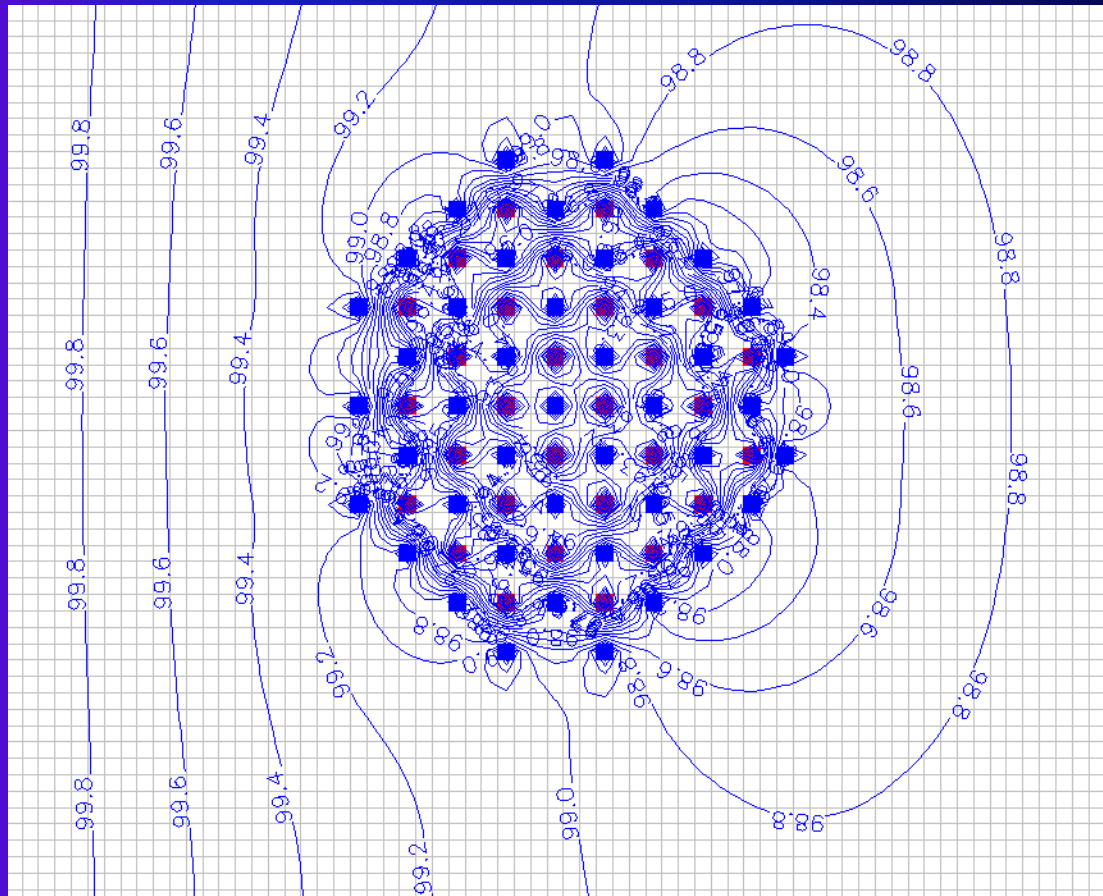
- Oxygen
- Carbon
- Sodium
- Chloride
- Sulfate
- Calcium
- Iron
- Potassium
- pH
- pe



EXAMPLE ISR MINE UNIT

Up Gradient Groundwater Oxidized Carries Dissolved Uranium

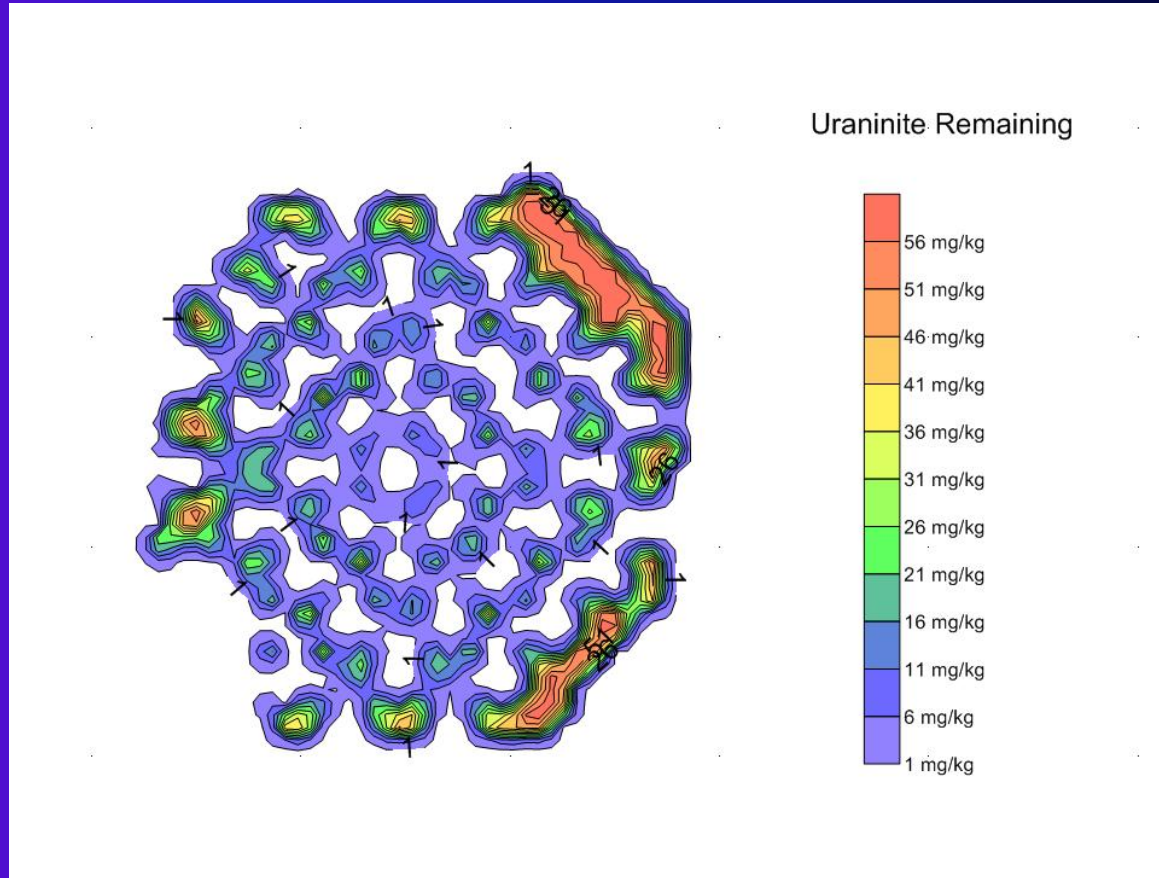
Reducing Zone Forced Uranium to Precipitate In Roll Front



THEORECTICAL ISR URANIUM MINE

MODFLOW

- Maintain Gradient Towards Well Field During Mining
- Recovery Flow Greater Than Injection Flow

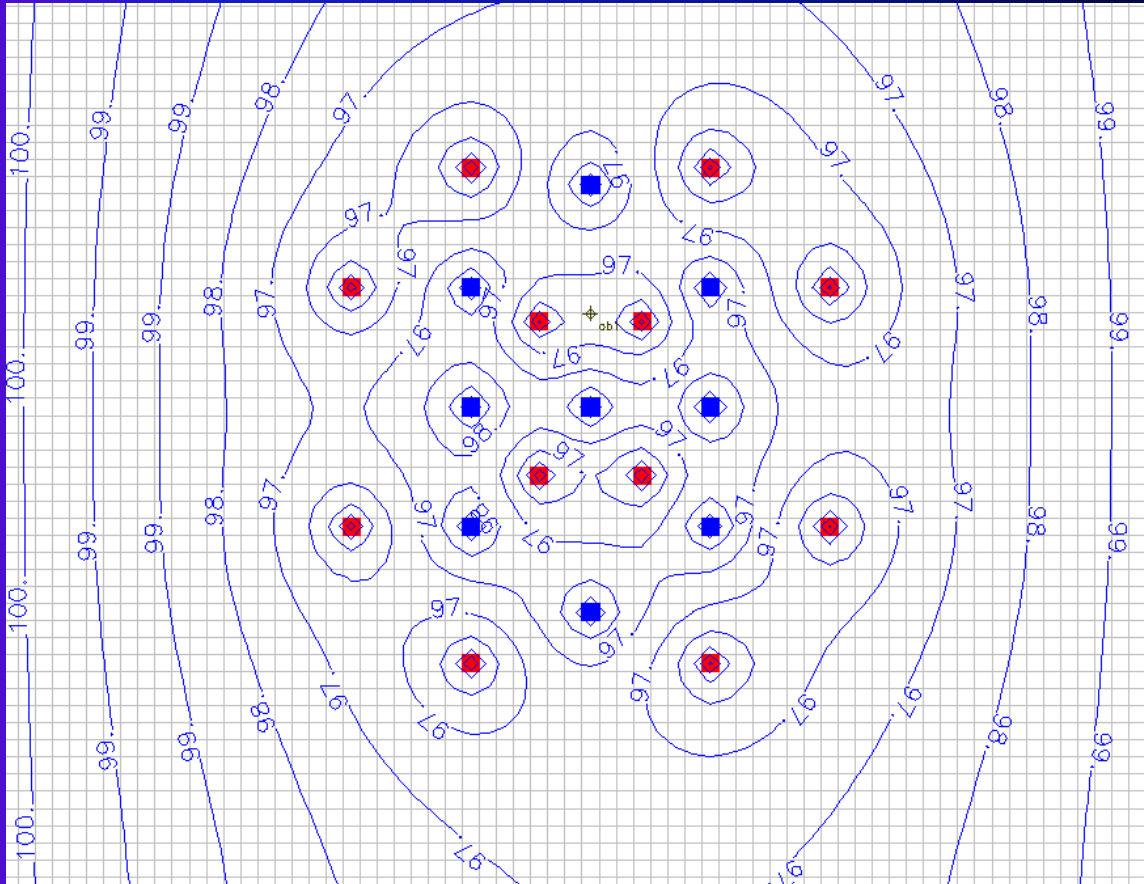


Post Mining Uraninite

Modflow/PHT3D modeling

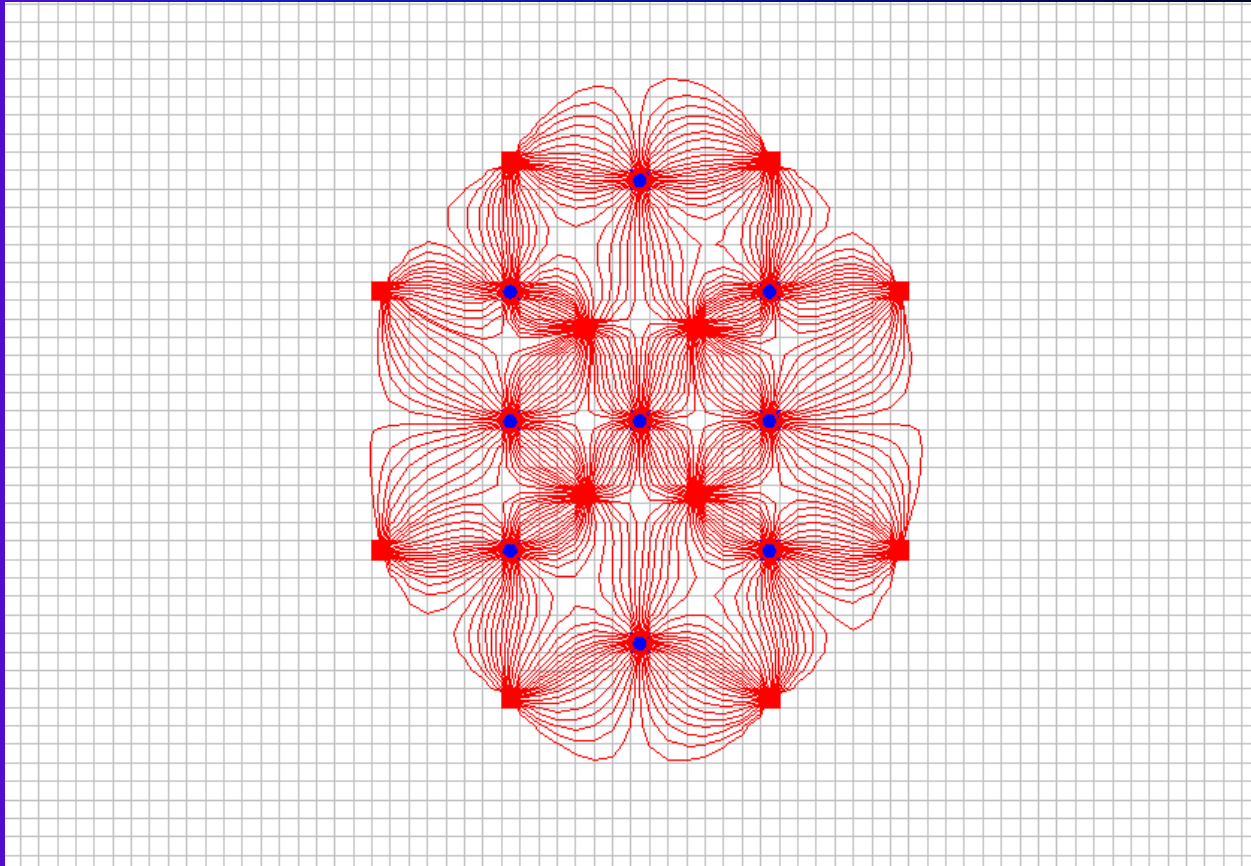
Restoration Model

- 2 ½ Years of Restoration
- Restoration Wells Different from Mining Wells
- Recovery Wells Below 30 µg/L
- Observe System for 7 Years After Restoration



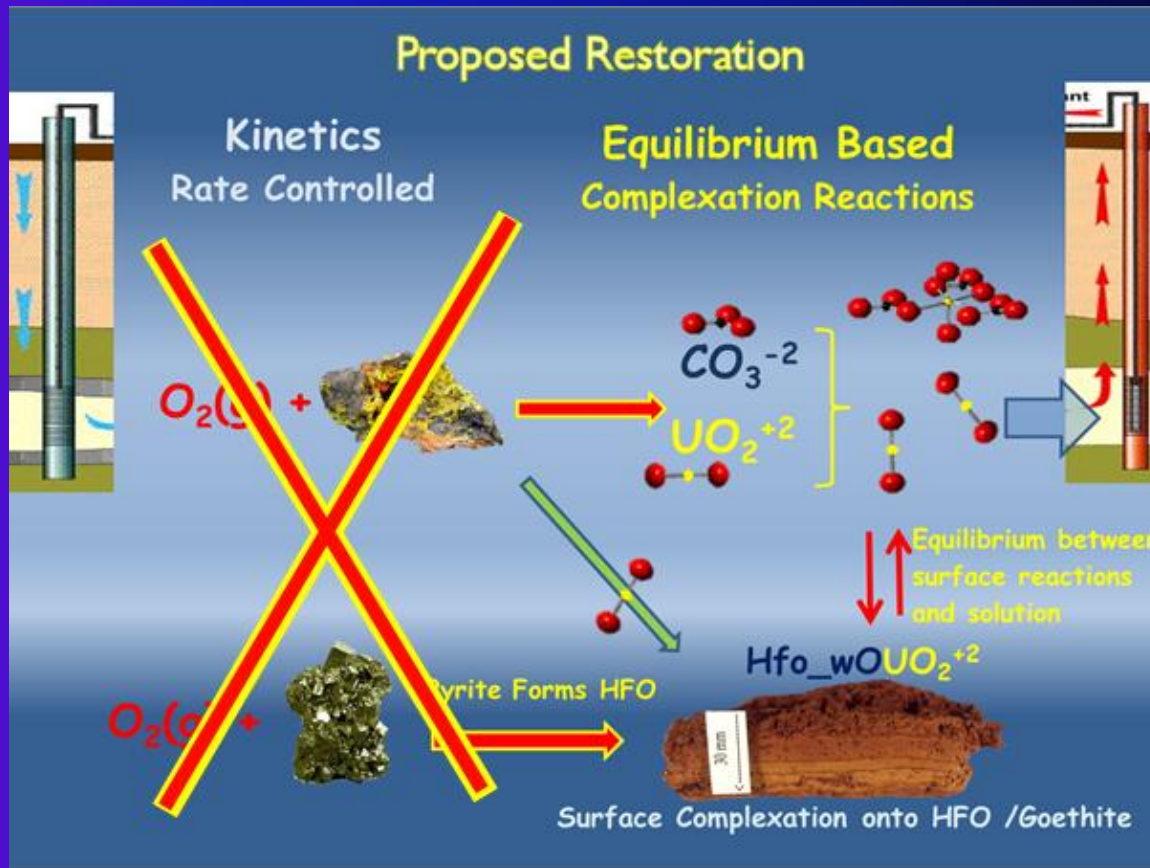
Example Reclamation of ISR Mine

- Maintain Gradient Towards Well Field During Mining
- Recovery Flow Greater Than Injection Flow



Particle Tracing

Illustrates Advective Flow Directions



Proposed Restoration

- Terminate O_2 injection
- Continue adding CO_3

CURRENT RECLAMATION

MINING PHASE	RESTORATION PHASE
DISSOLVE AND MOBILIZE URANIUM	CEASE DISSOLING URANIUM MOVE URANIUM TO SORPTION SITES
MINING O ₂ INJECTION	FLUSH WITH REVERSE OSMOSIS WATER
MINING NaHCO ₃ INJECTION	

PROPOSED CHANGES IN RECLAMATION

MINING PHASE	RESTORATION PHASE
DISSOLVE AND MOBILIZE URANIUM	CEASE DISSOLING URANIUM BUT MAINTAIN MOBILITY
MINING O ₂ INJECTION	
MINING NaHCO ₃ INJECTION	CONTINUE NaHCO ₃ INJECTION DURING RESTORATION

Model Geochemistry

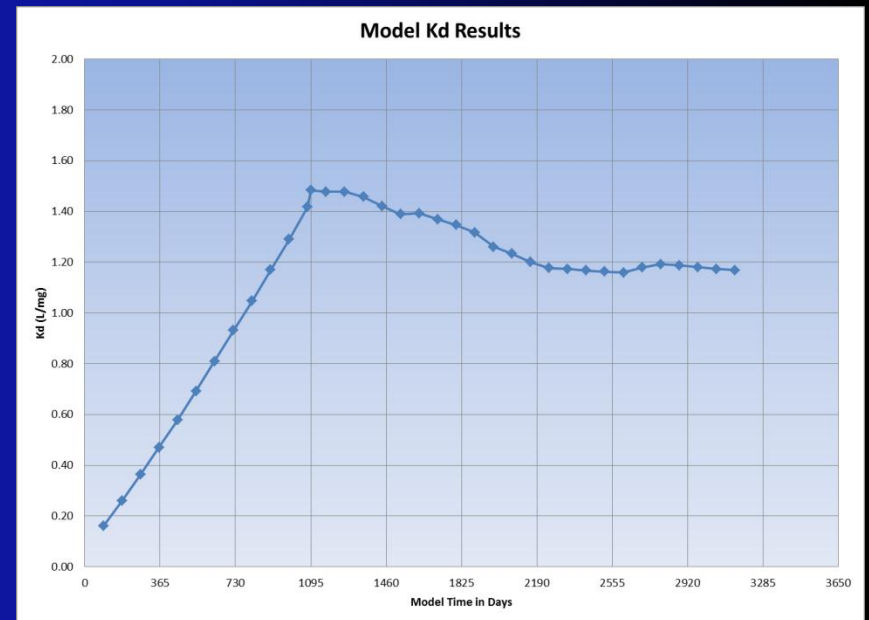
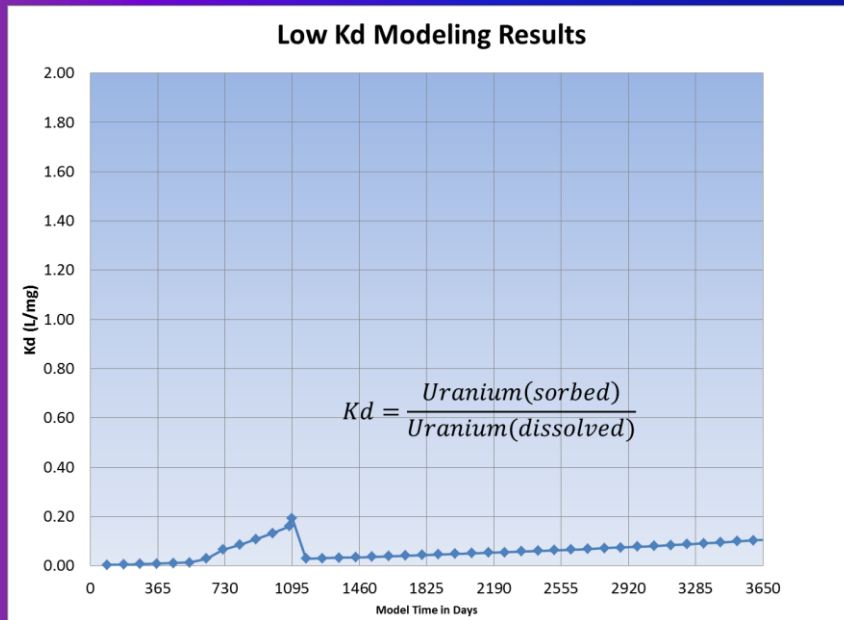
COMPOUND	UPGRADIENT CONCENTRATION (mg/L)	POST MINING CONCENTRATION (mg/L)	GRAMS/MOLE	UPGRADIENT CONCENTRATION (Moles/l)	POST MINING CONCENTRATION (Moles/L)	HIGH Kd INJECTION WATER (Moles/L)	LOW Kd INJECTION WATER (Moles/L)
Ca	44.1	313.4	40.078	1.10E-03	7.82E-03		
Mg	9	59.5	24.305	0.00037	0.002448056		
Na	12.2	80.8	22.98	5.31E-04	3.52E-03	0.0001	0.01
K	8	13.4	39.09	0.000205	0.000342799		
HCO3	215	720.2	61	3.52E-03	1.18E-02	0.0001	0.01
SO4	91	380.6	96.06	0.000947	0.003962107		
Cl	4.7	212.6	35.45	1.33E-04	6.00E-03		
ALK	177	591	100.9	0.00175	0.005857284		
Fe	0.05	0.05	55.84	8.95E-07	8.95E-07		
U	0.05	40.19	238.028	0.00000021	0.000168846		
O	7	0	16	4.38E-04	0.0	0.00044	0.00044
pH	8	6.78		6.78	8	8.2	8.2
pe	11	11		1.10E+01	1.10E+01	11	11

Mineral	MINIMUM PRE-RESTORATION CONCENTRATION (Moles/L)	MAXIMIM PRE-RESTORATION CONCENTRATION (Moles/L)
GOETHITE	1.13E-04	4.20E-04
URANINITE	0	4.90E-03
PYRITE	0	9.00E-02
CALCITE	0.1	0.1
Hfo	0.2	0.2

Model Resulting Average Model Kd

Model Average Low Kd
RO Water with NaHCO₃

Model Average High Kd
RO Water

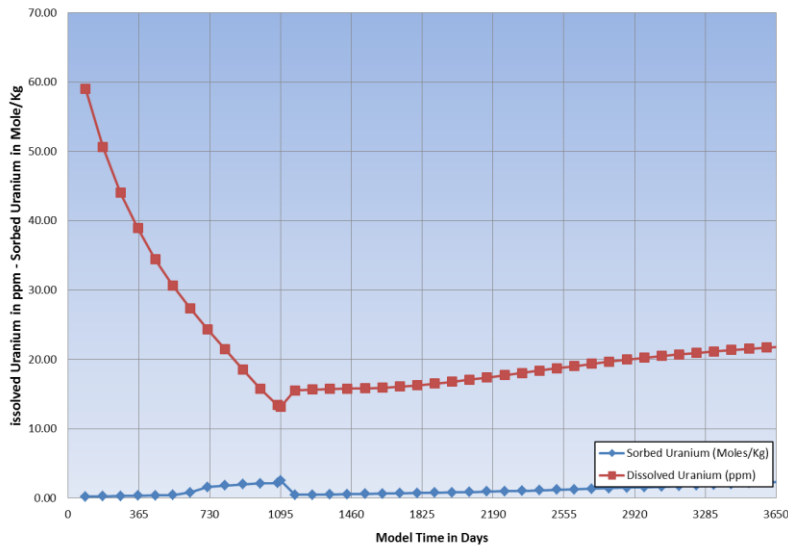


Model Resulting Average Uranium Concentrations

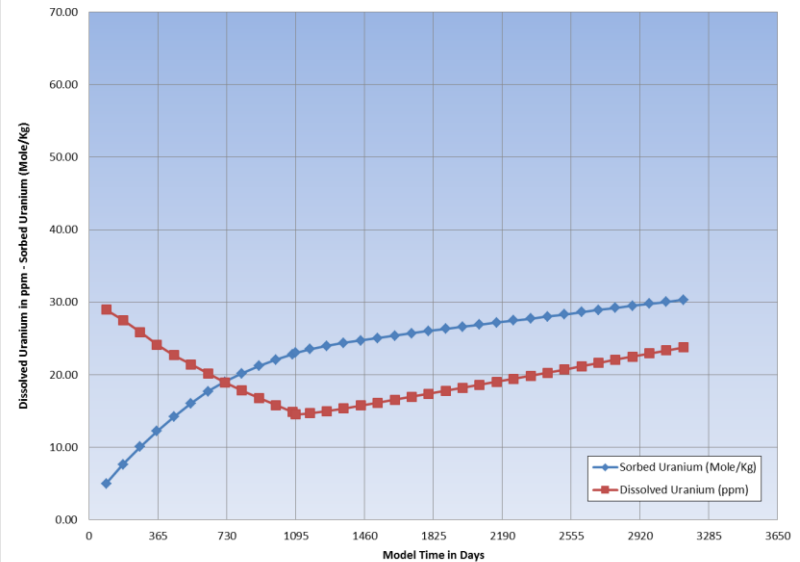
Model Average Low Kd
RO Water with NaHCO_3

Model Average High Kd
RO Water

Low Kd Modeling Results



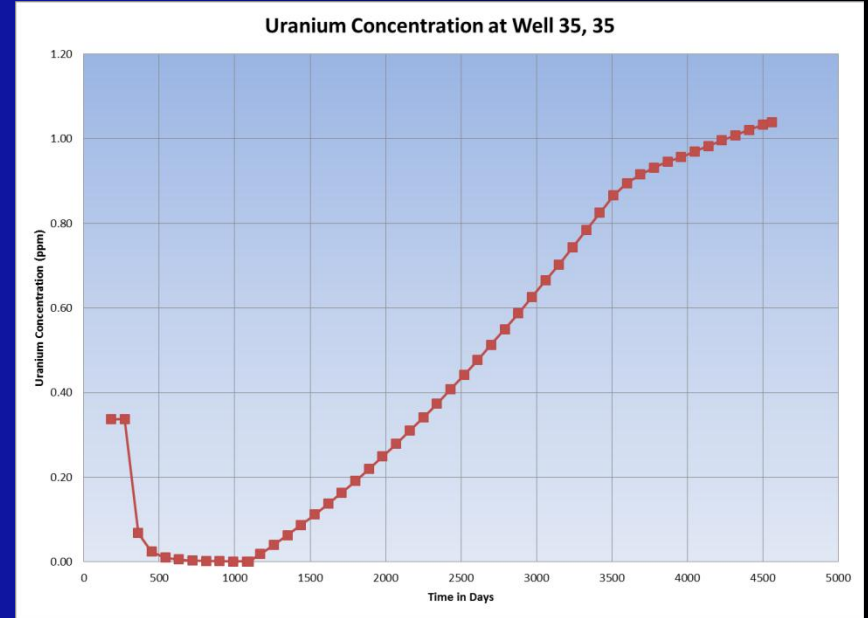
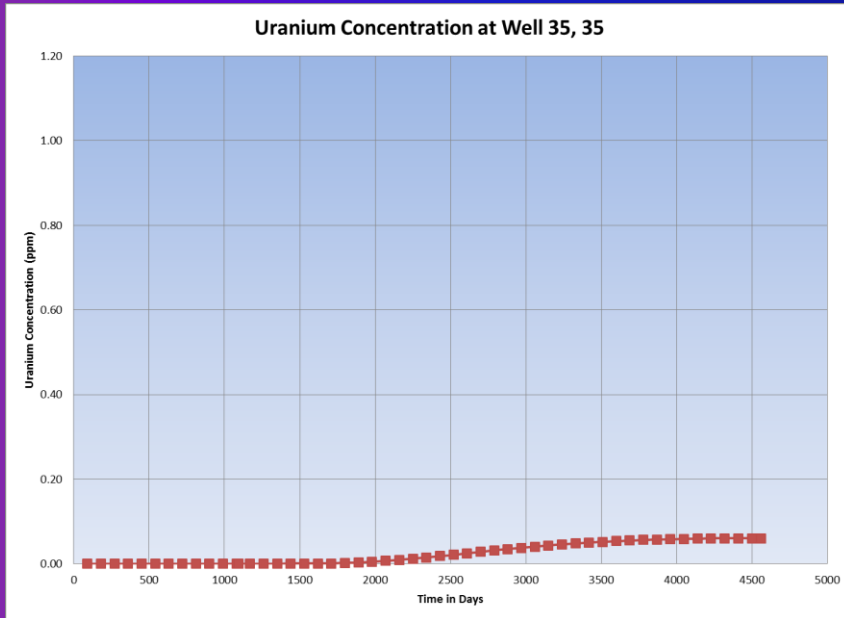
High Kd Modeling Results



Model Resulting at Extraction Well

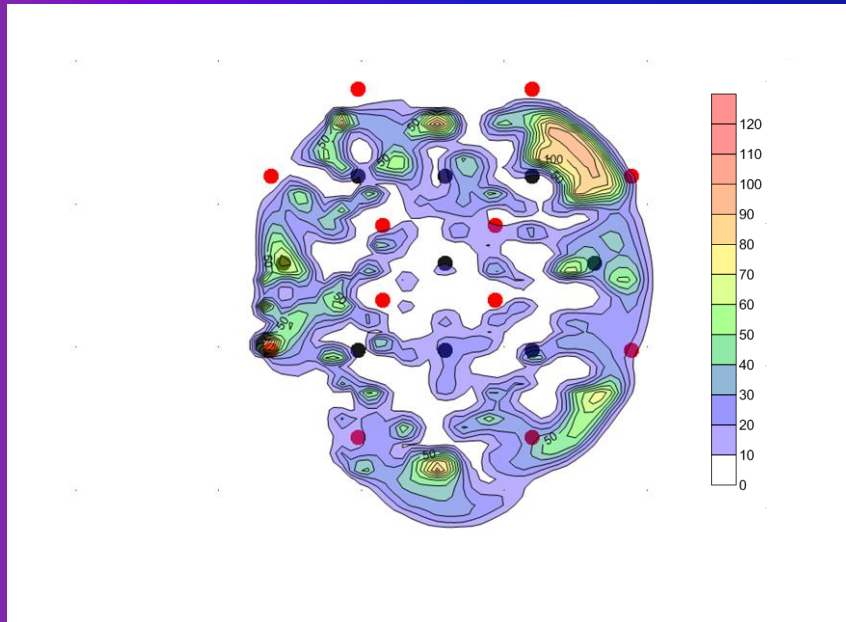
Low Kd Model
RO Water with NaHCO_3

High Kd Model
RO Water

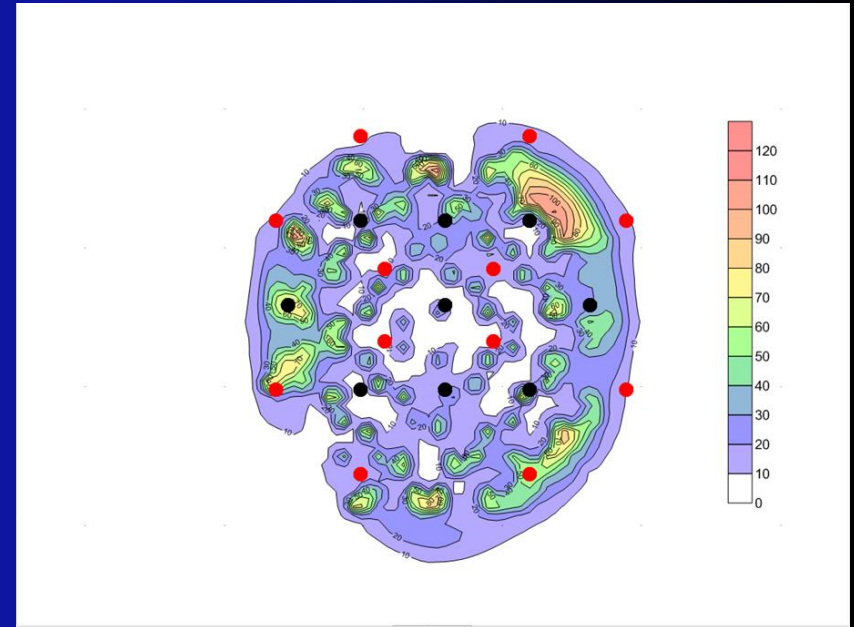


Final Sorbed Uranium (mg/kg)

Low K_d Model After Restoration



High K_d Model After Restoration



Conclusions

- PHT3D Can Model the Flow and Reactive Transport of ISR Mines in 3-Dimensions
- PHT3D Can Help Identify Potential Trouble Spots Before Restoration
- High K_d (RO Water) Restoration Injection Water Results in More Sorbed Uranium That Will Desorb With Time
- Low K_d (High NaHCO_3) Restoration Injection Water Results in less Sorbed Uranium and Less Rebound

Next Steps

- Obtain Real World Data to Better Evaluate PHT3D as an Effective Tool
- Evaluate PHT3D for Use in ISR Mining Optimization

Questions

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