What I Did Last Summer: Simulated Flood Events at a Uranium-Contaminated Field Site

UWM Geography Colloquium

Nov. 13, 2020

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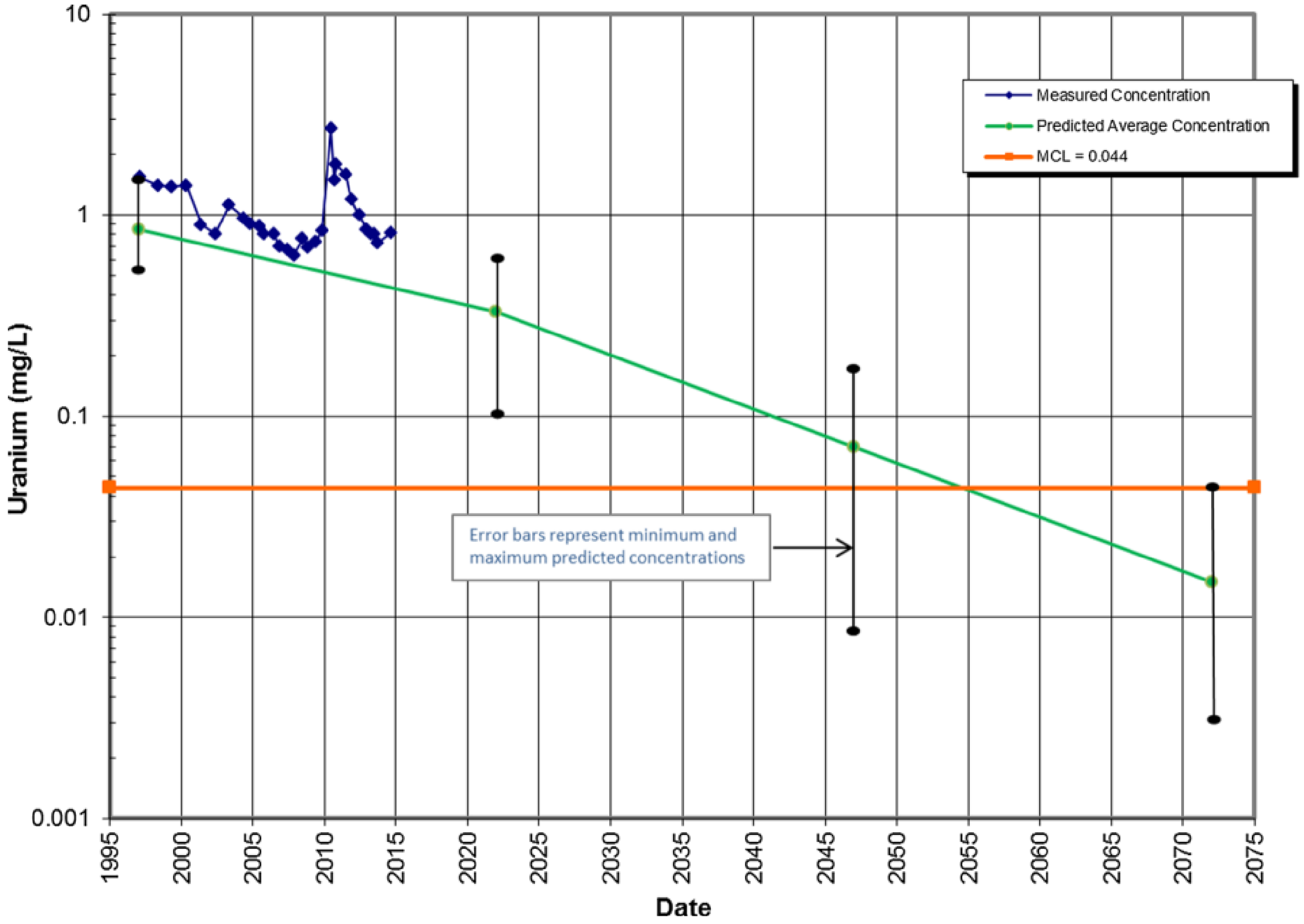
Objective and Methods

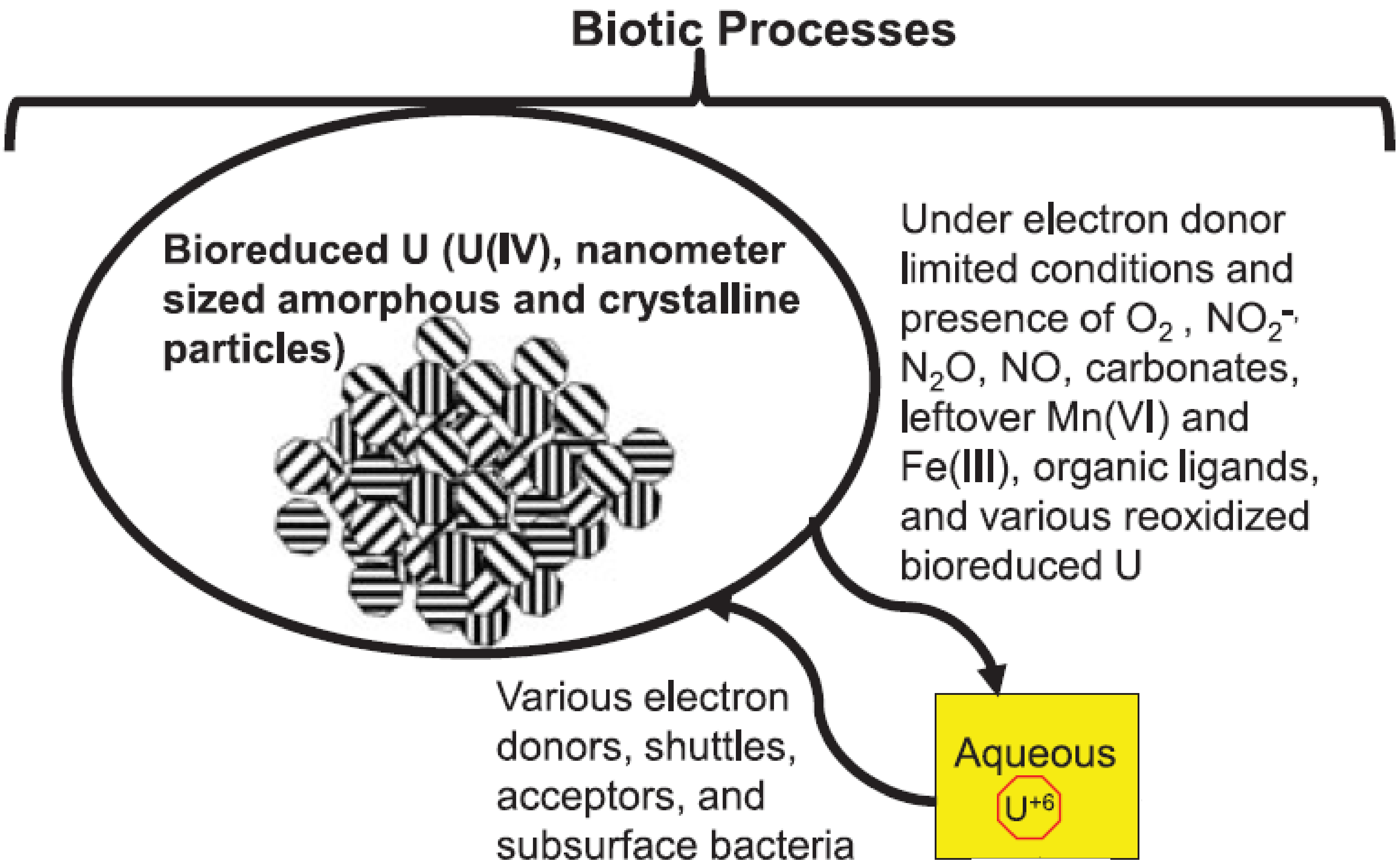
- Objective: elucidate the mechanism(s) of uranium mobility, e.g., de-sorption, re-oxidation, in groundwater during in-situ surface water flooding events
  - Driven by observation of increased uranium concentrations in groundwater during natural river flooding events
- Methods
  1. Conduct in-situ flooding experiments at small-scale experimental plot on the banks of river
  2. Model flow and transport of uranium with MODFLOW and PHREEQC
     - Start basic with MODFLOW code via ModelMuse GUI
     - Both open-source USGS

The Data, Model, & Motivation



Dam et al., 2015

Uranium Re-oxidation: Conceptual Model



Singh et al., 2013

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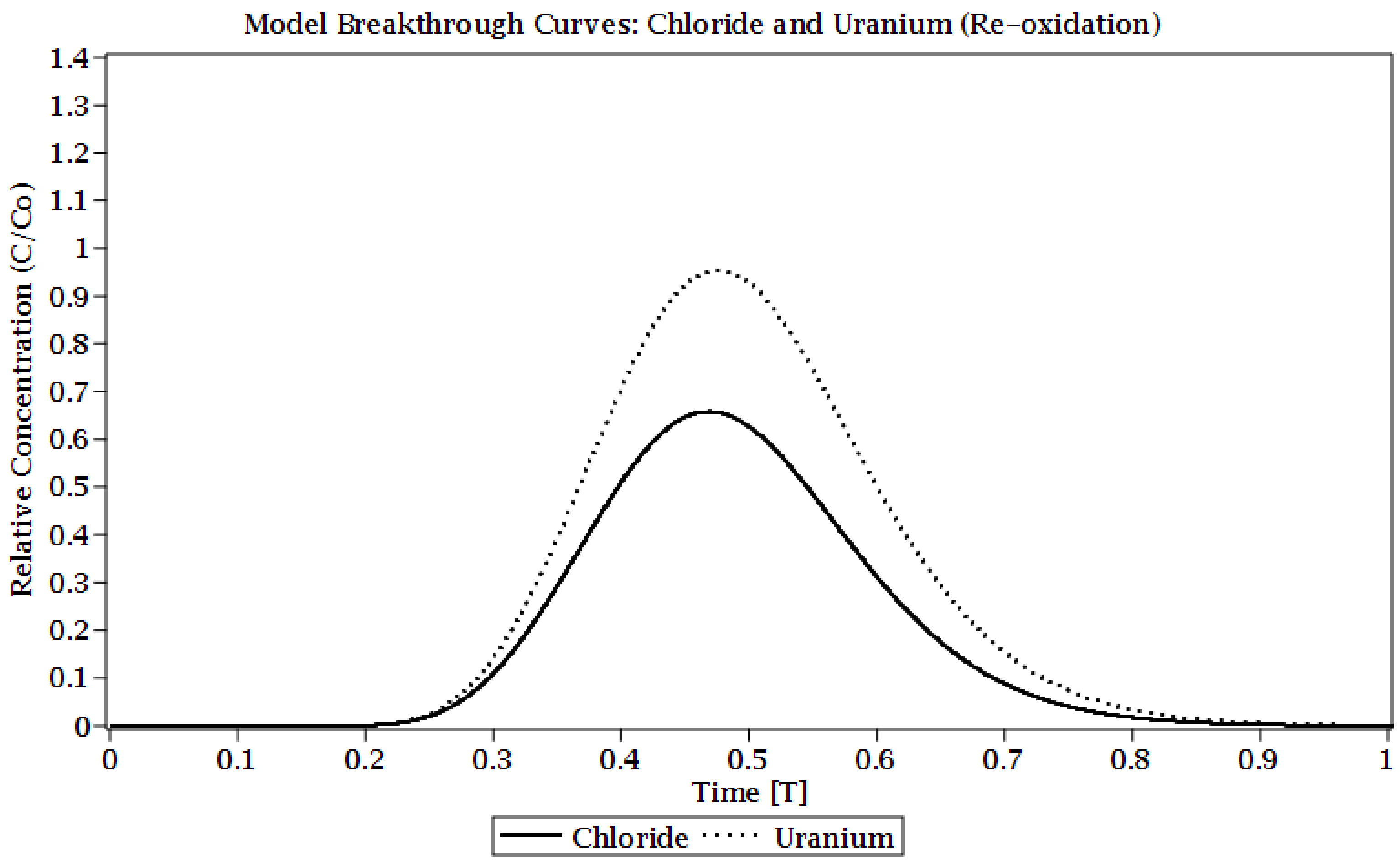
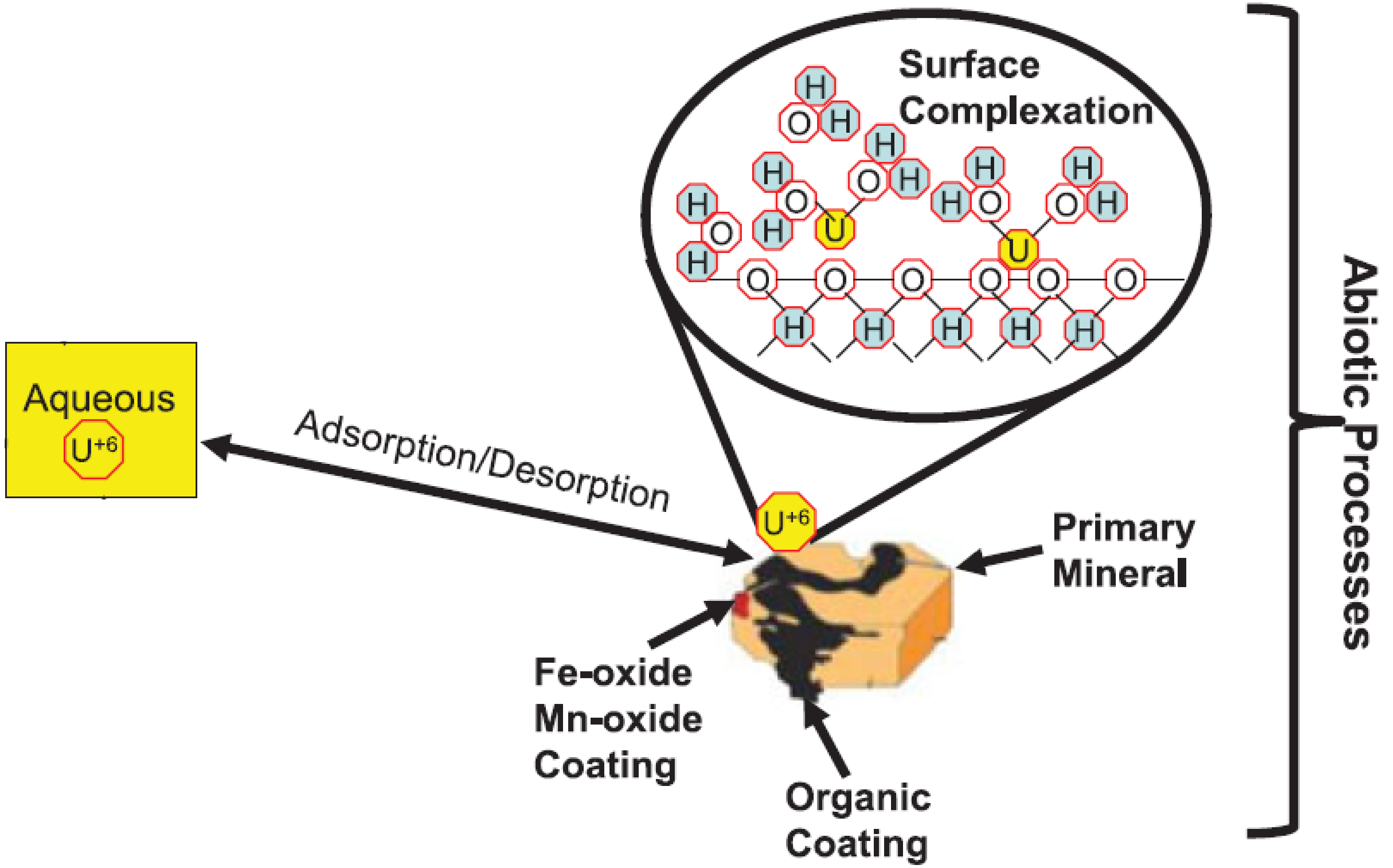
Uranium Re-oxidation: Quantitative Model



First-order re-oxidation, $dC/dt = kC$

Uranium De-sorption: Conceptual Model



Singh et al., 2013

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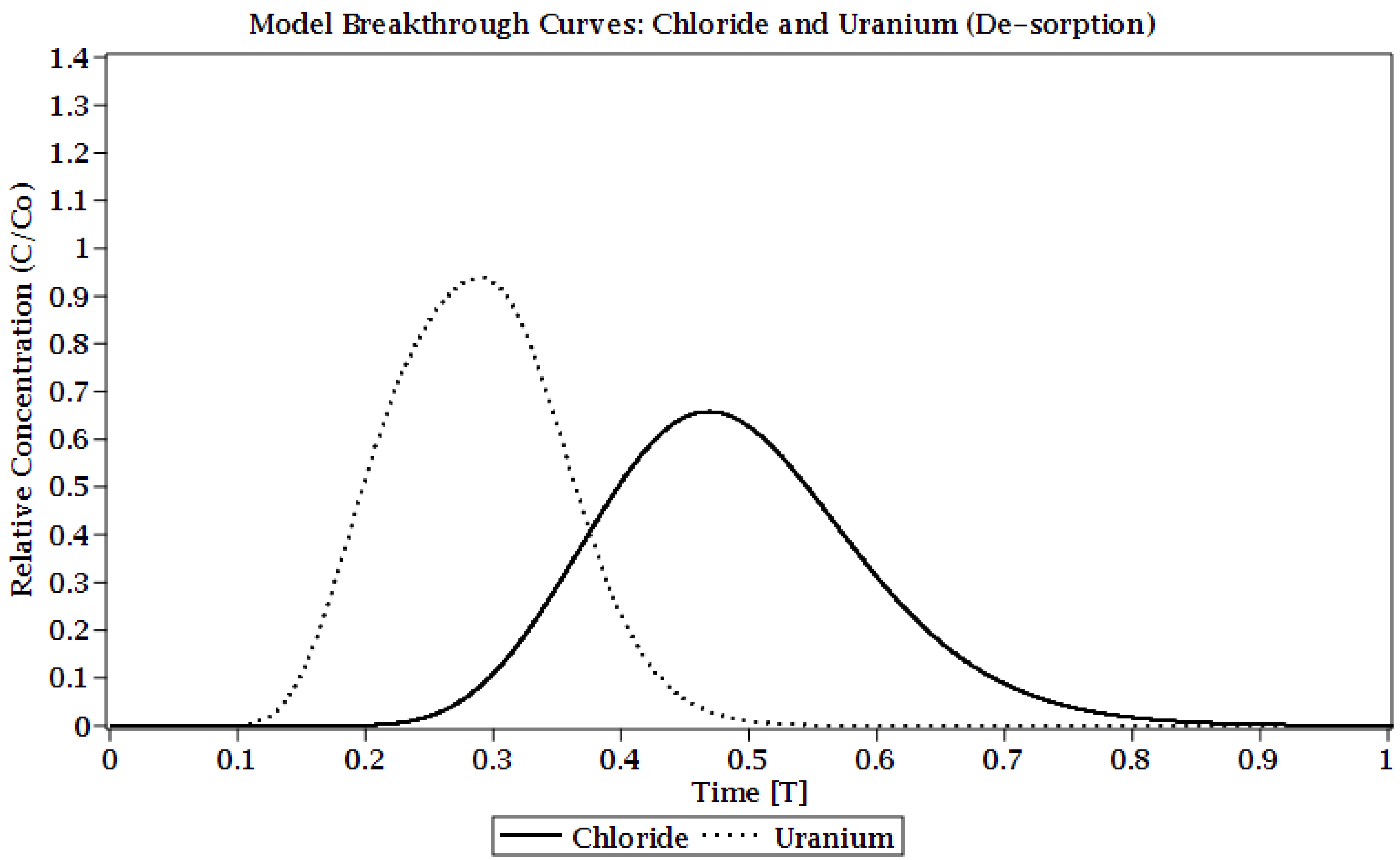
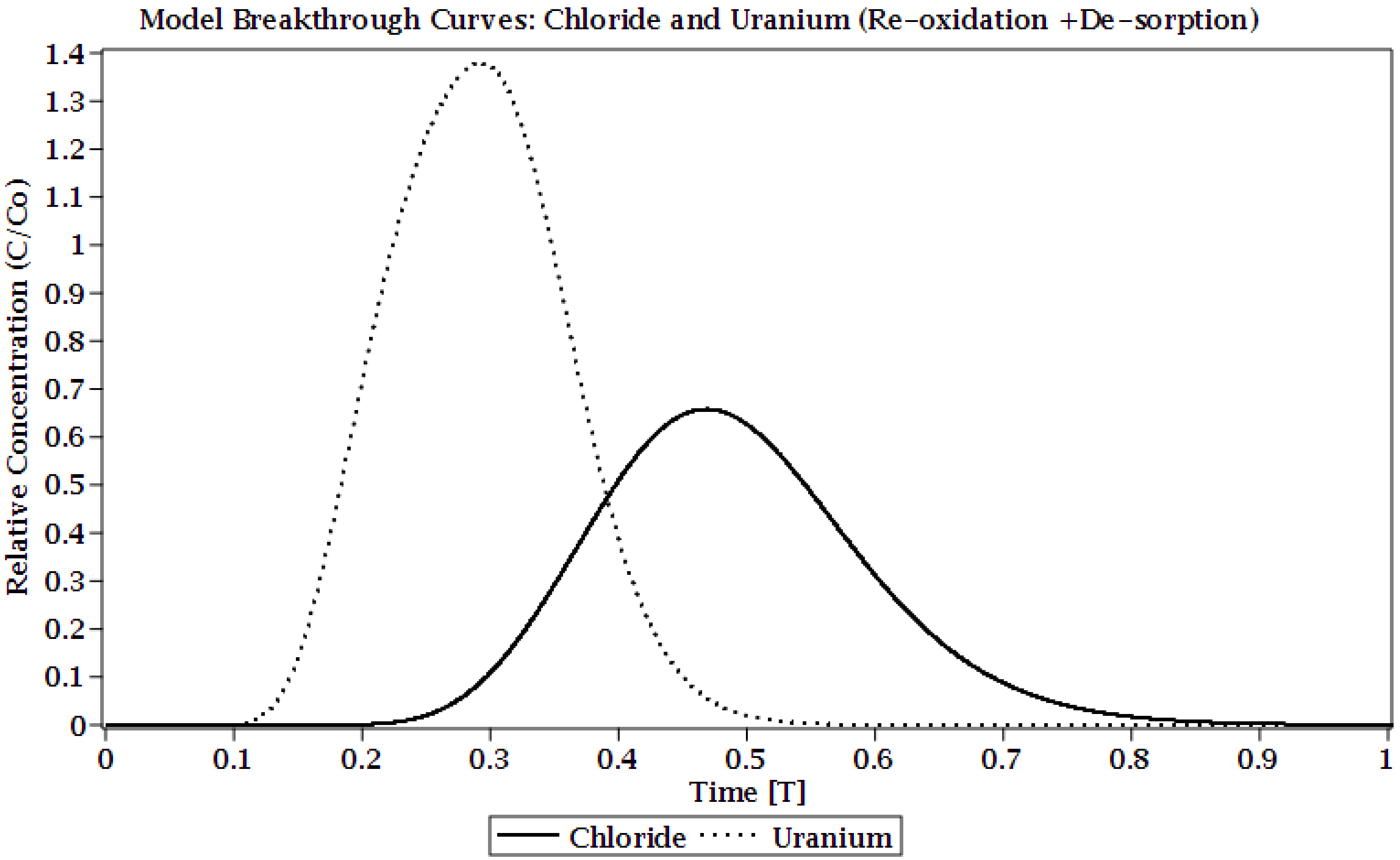
Uranium De-sorption: Quantitative Model



Linear equilibrium de-sorption, $S = K_d C$

Uranium Re-ox + De-sorb: Quantitative Model



First-order re-oxidation + Linear equilibrium de-sorption

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Why Re-oxidation and De-sorption?

- Consider mixing two fluids of different geochemistry
  - Fluid A: Groundwater
    - Reducing conditions (↓mV)
    - High concentration of uranium (↑C)
  - Fluid B: River Water
    - Oxidizing conditions (↑mV)
    - Low concentration of uranium (↓C)
- Consider fundamental chemistry
  - $U^{4+}_{(solid)}$ [Aquifer] - $2e^{-}$ [River water] → $U^{6+}_{(liquid)}$
  - ↑S [Aquifer] → k_d ↓C [River water]

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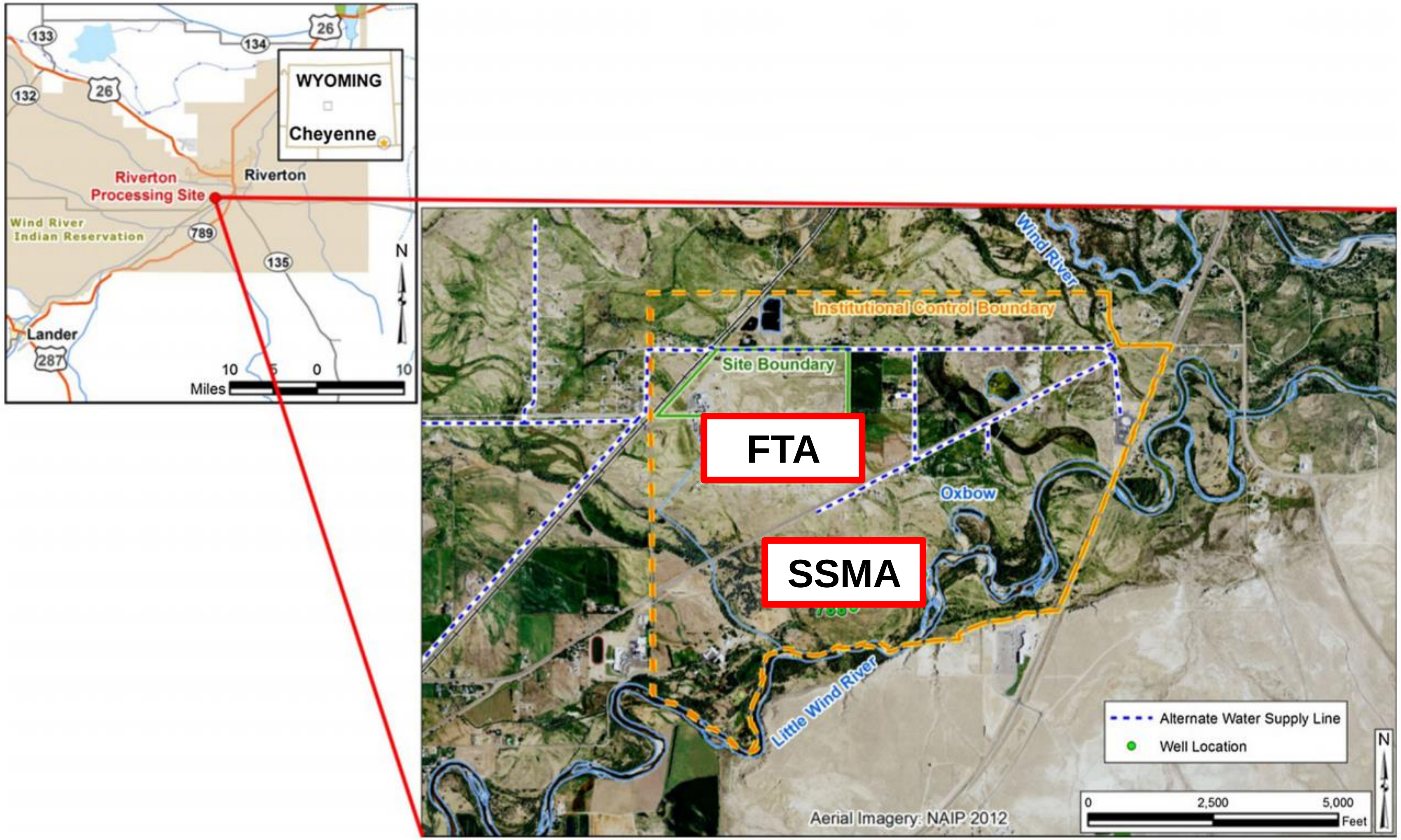
The Field Site: Riverton, Wyoming



Dam et al., 2015

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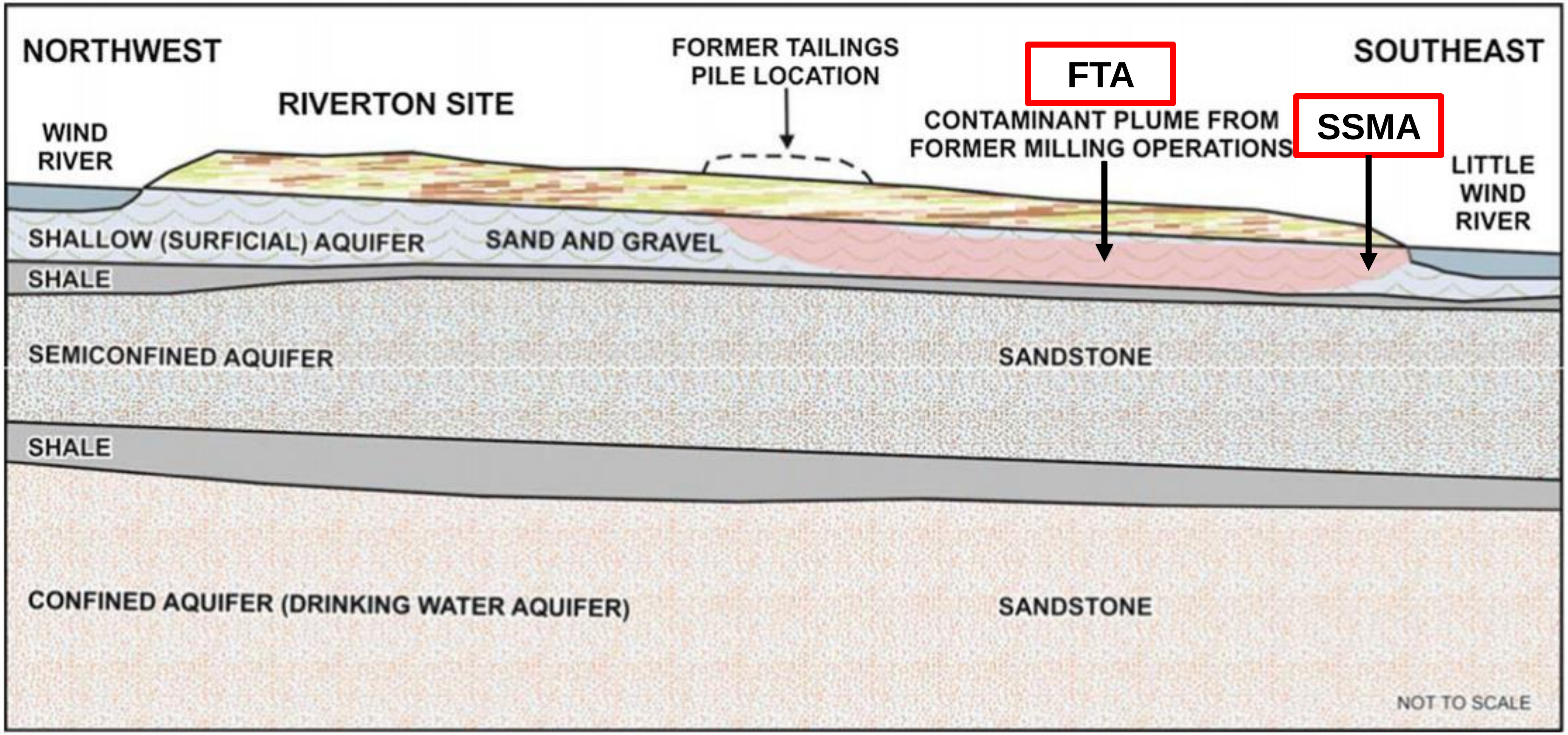
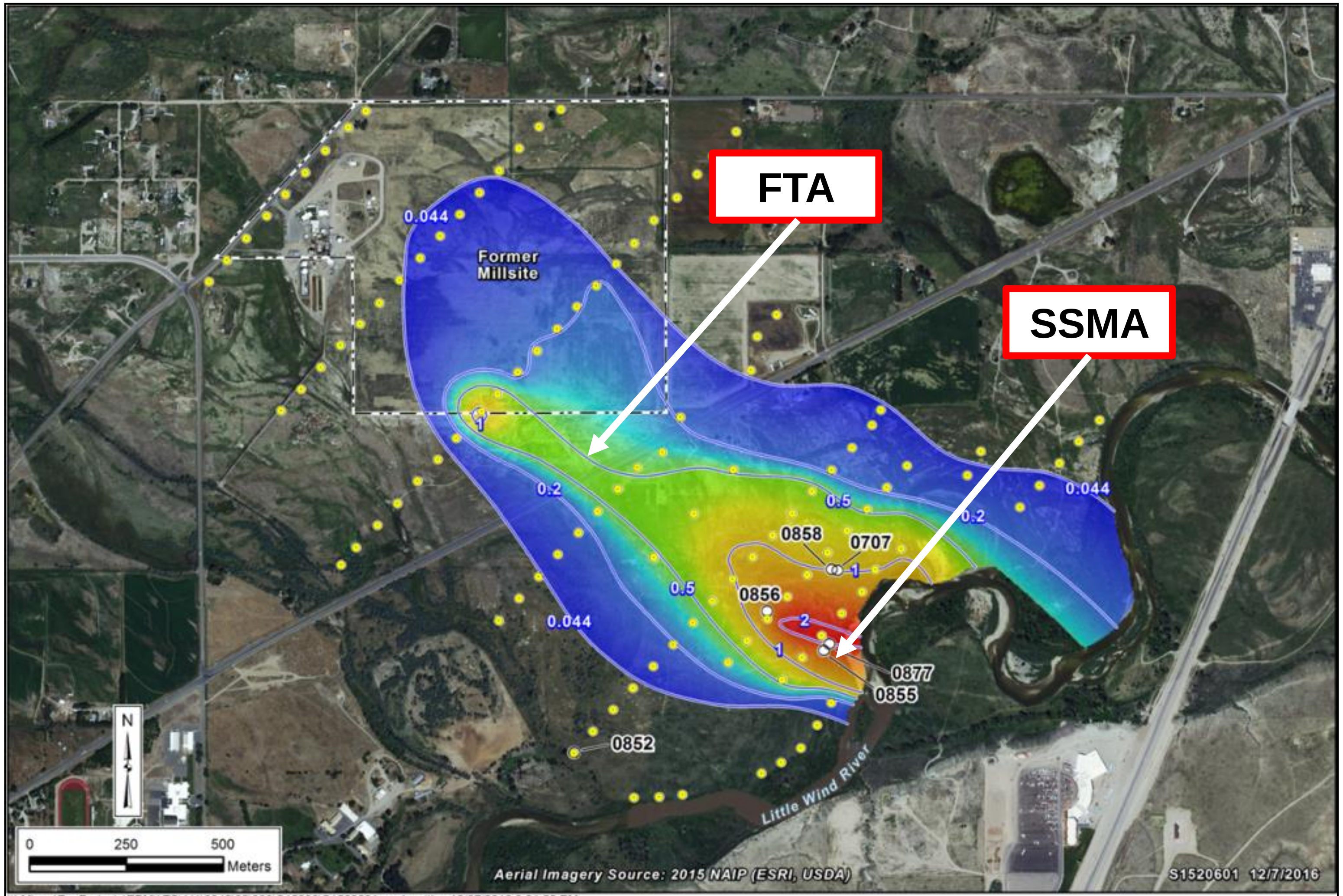
The Field Site: Hydrogeology



Dam et al., 2015

The Field Site: Uranium Plume



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The Field Site: Horses…

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Experimental Design & Grad Students

Cullen Meurer
MS Student

Jiyan Hatami
MS Student

Former Tailings Area (FTA)

- GW to GW Sat. Zone Injection (DONE)
- GW to GW Sat. Zone Injections w/added Alkalinity #1 (DONE)
- GW to GW Sat. Zone Injections w/added Alkalinity #2 (DONE)

St. Steven’s Mission Area (SSMA)

- SW to GW Sat. Zone Injection (DONE)
- SW to GW Unsat. Infiltration (DONE)
- SW to GW Unsat. Infiltration w/added Alkalinity (SU-21)

Rakiba Sultana
PhD Student

Kendyl Hoss
MS Student

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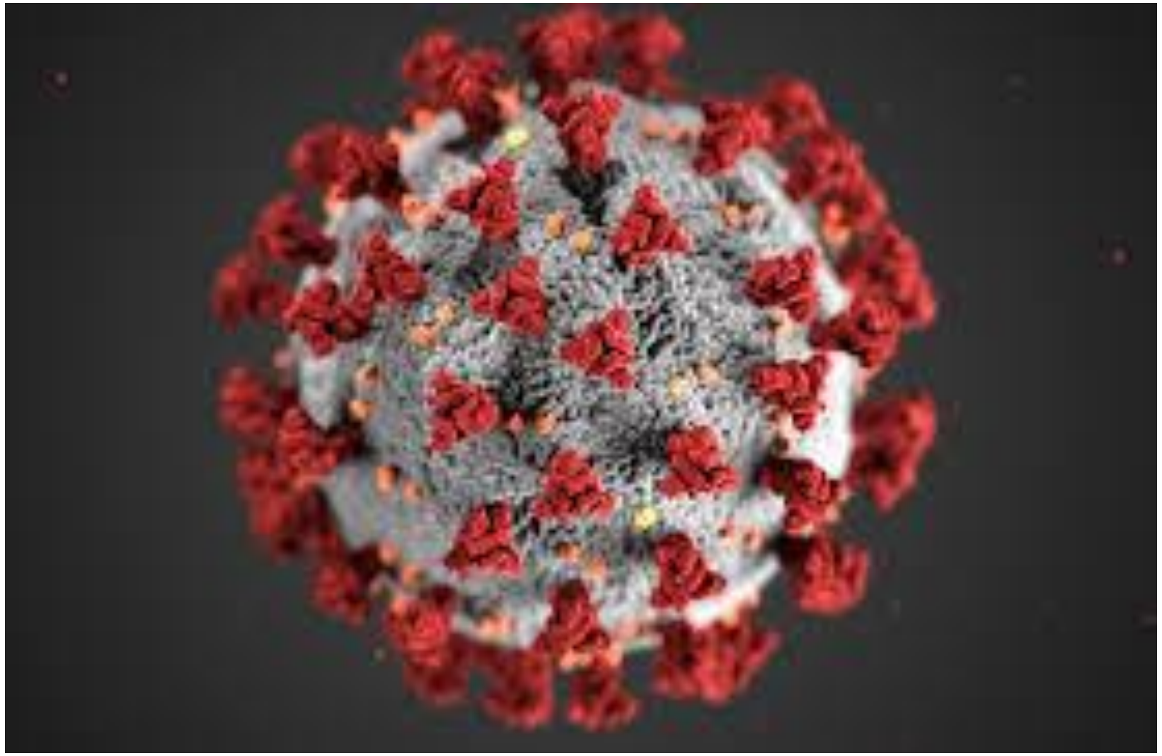
Experimental Design & Scale

- Former Tailings Area (FTA)
  1. GW to GW Sat. Zone Injection
     - 250 gallons injected in 8 hours
     - Test ran for 9 days after injection
  2. GW to GW Sat. Zone Injection with added alkalinity #1
     - 250 gallons injected in 8 hours
     - Test ran for 10 days After injection
  3. GW to GW Sat. Zone Injection with added alkalinity #2
     - 100 gallons in 4 hours
     - Test ran for 9 days after injection

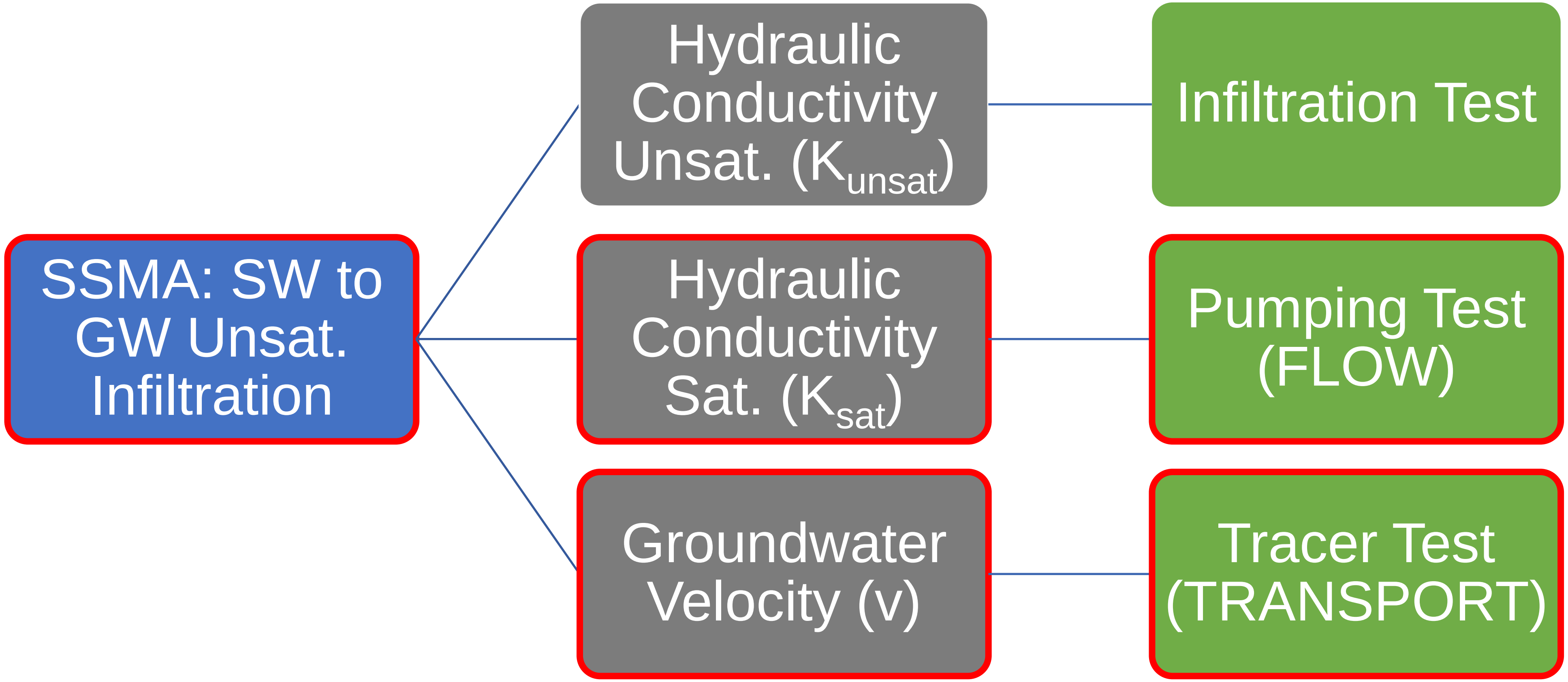
- St. Steven's Mission Area (SSMA)
  1. SW to GW Sat. Zone Injection
     - 100 gallons injected in 8 hours
     - Test ran for 18 days after injection
  2. SW to GW Unsat. Infiltration
     - 2000 gallons infiltrated over 8 days
     - Test ran for 21 days after the end of the infiltration
  3. SW to GW Unsat. Infiltration with added alkalinity
     - 2000 gallons infiltrated over 8 days
     - Test ran for 21 days after the end of the infiltration

Field Research During COVID

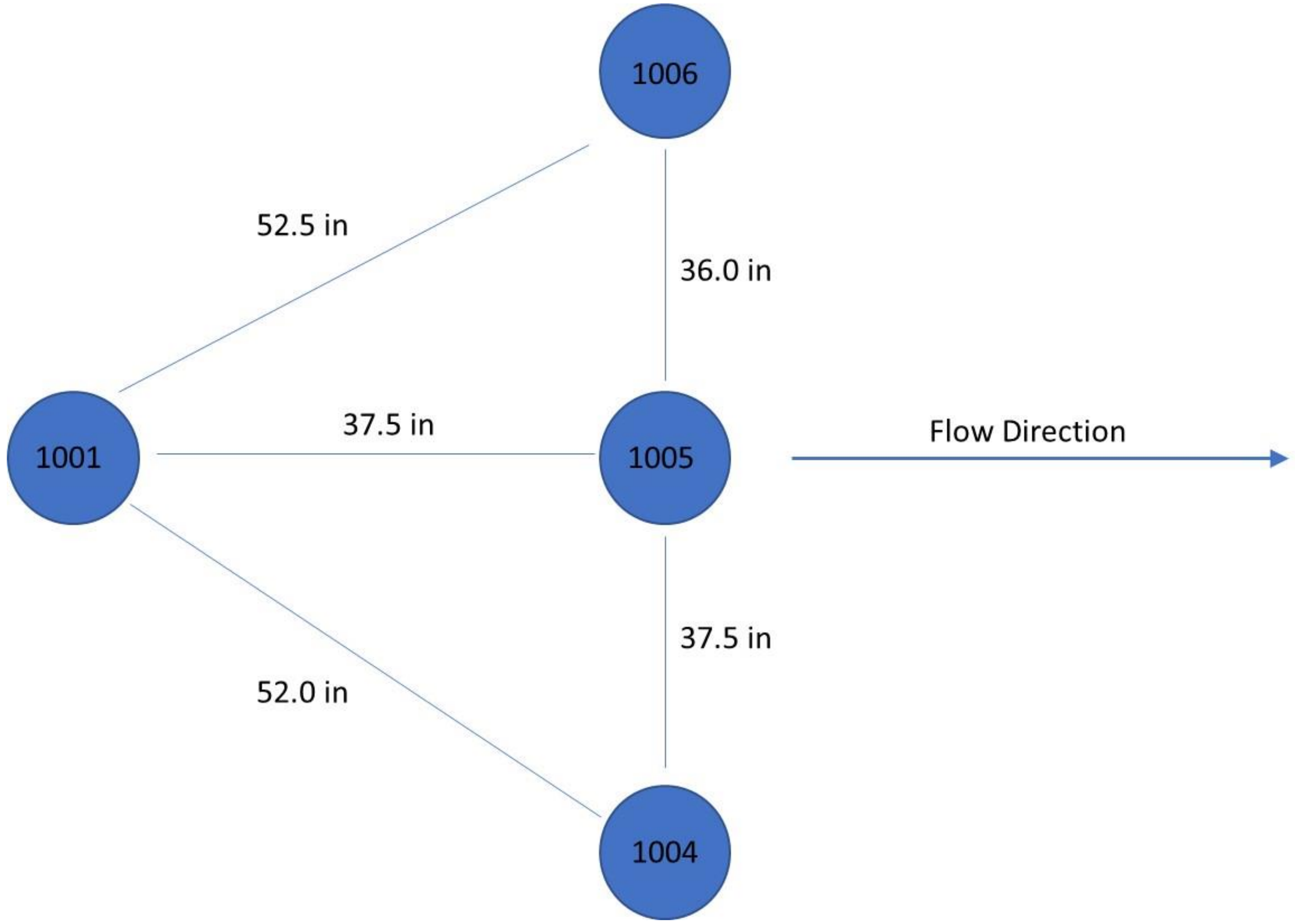
- Health & Safety Plan Approval
- Individual Transportation
- Individual Lodging
- Self Screening for Symptoms
- On-site Temperature Checks
- Social Distancing
- Disinfecting
- Contingency Plans



Pre-experiment Characterization: Model Input



Experimental Well Gallery: SSMA



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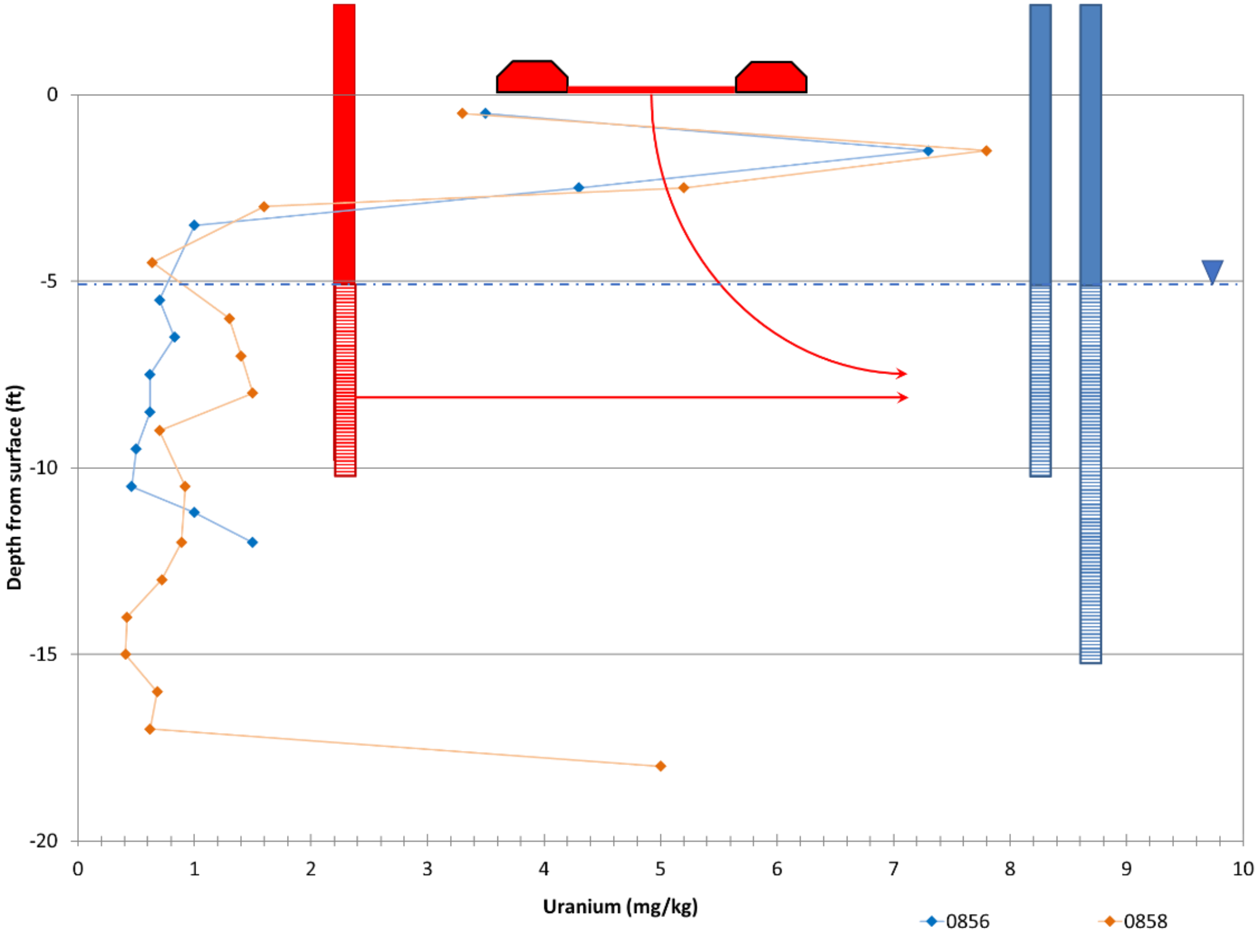
Experimental Well Gallery: SSMA



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Experimental Well Gallery: SSMA

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Experimental Well Gallery: SSMA

Modeling Approach

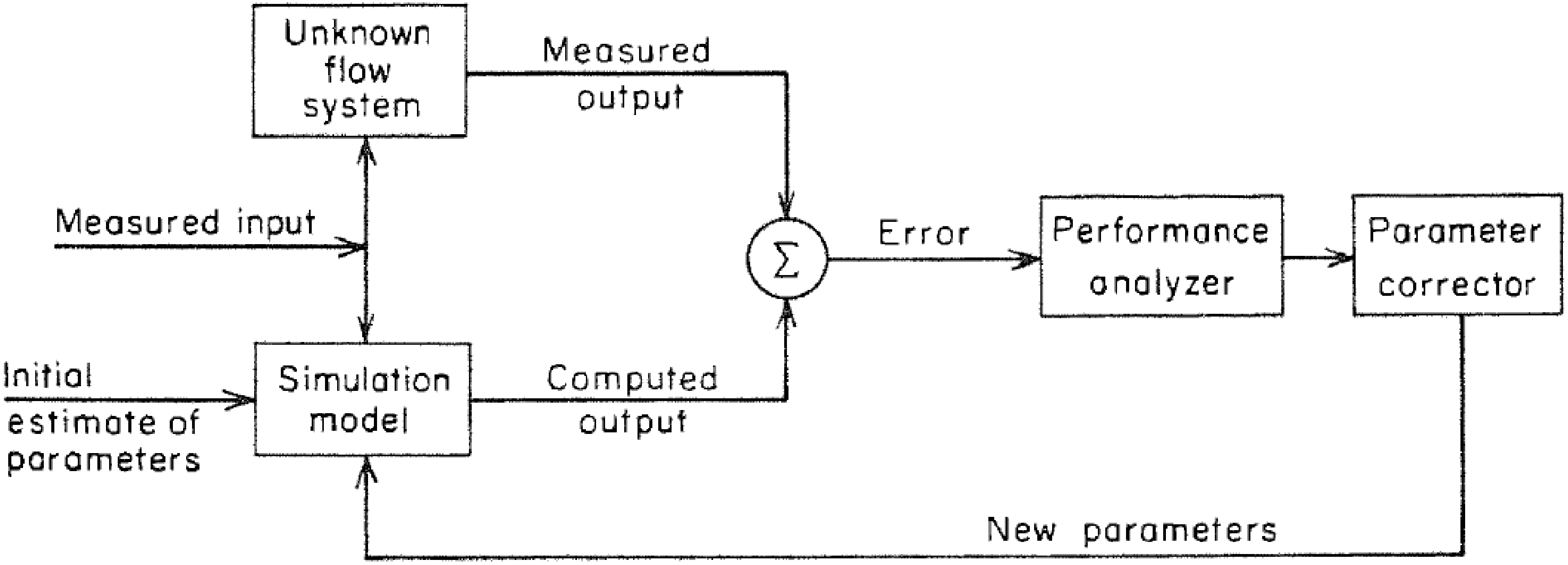
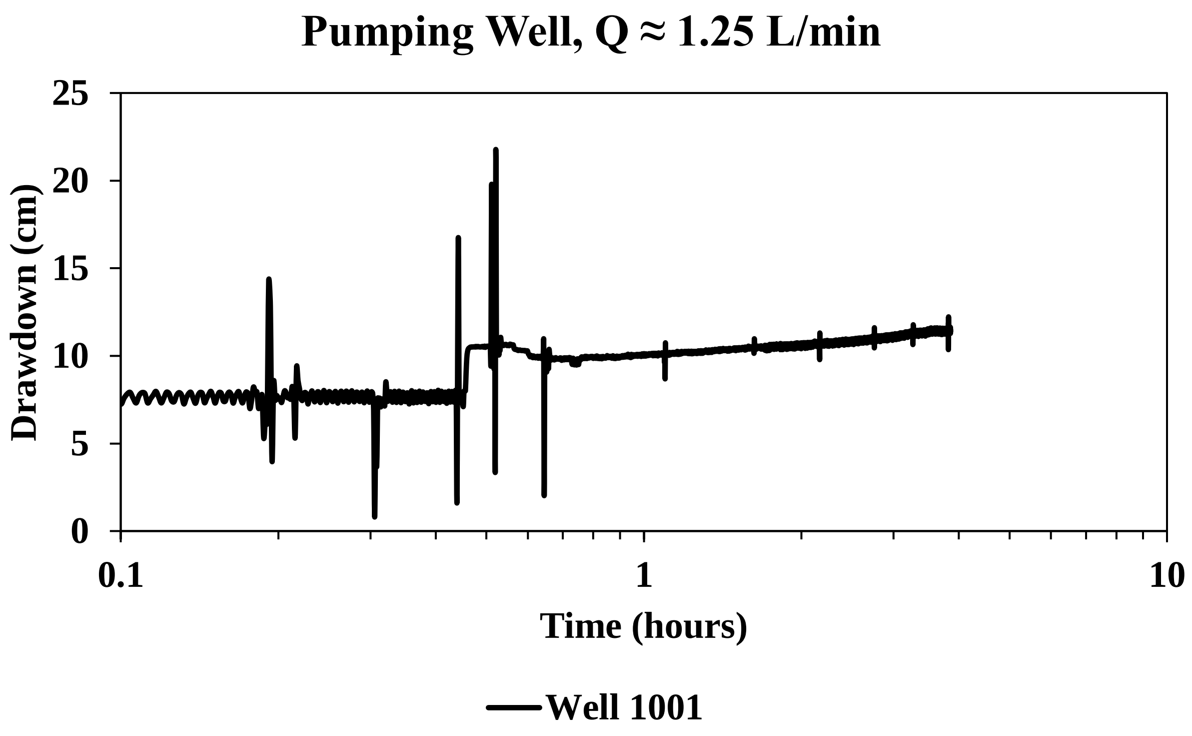
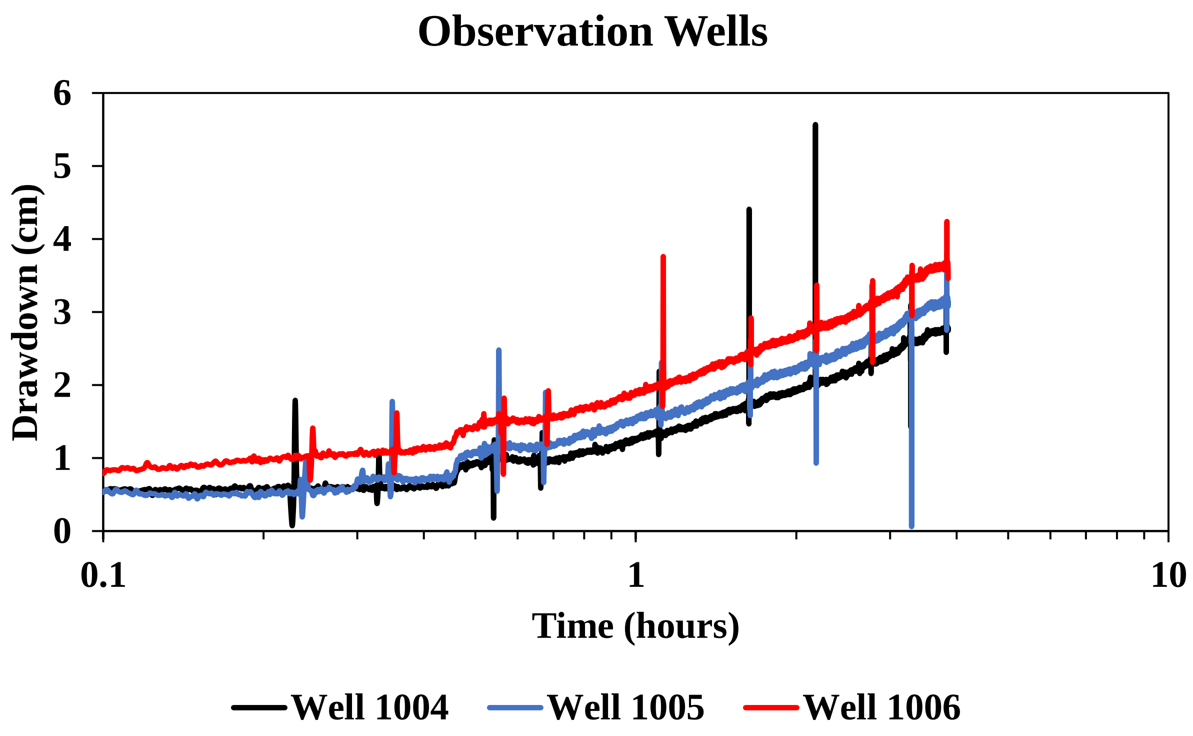


Figure 8.28 Flowchart of the trial-and-error calibration process (after Neuman, 1973a).

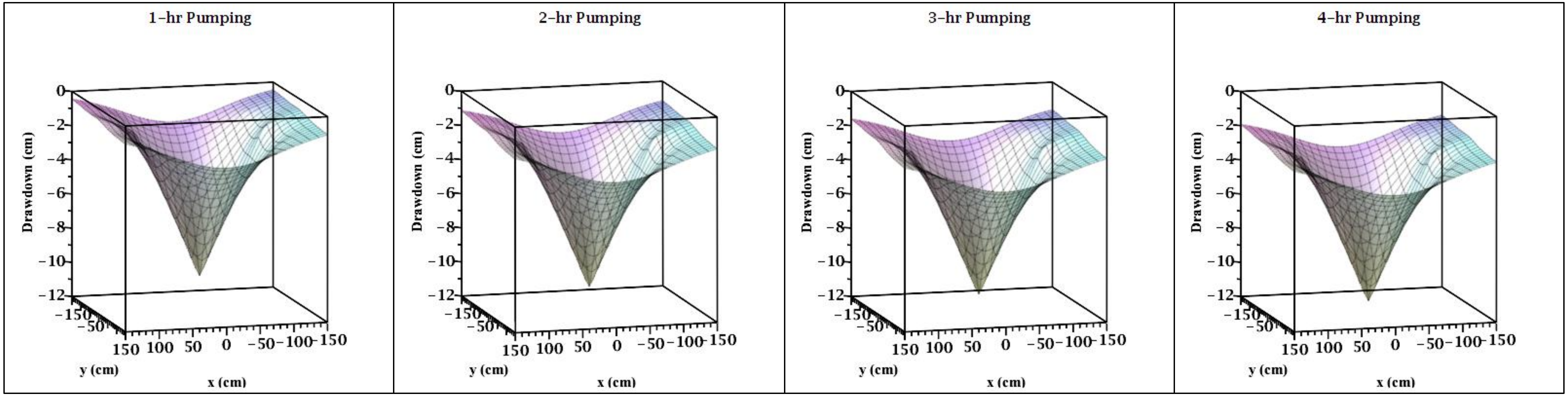
Freeze and Cherry 1979

Pumping Test Data

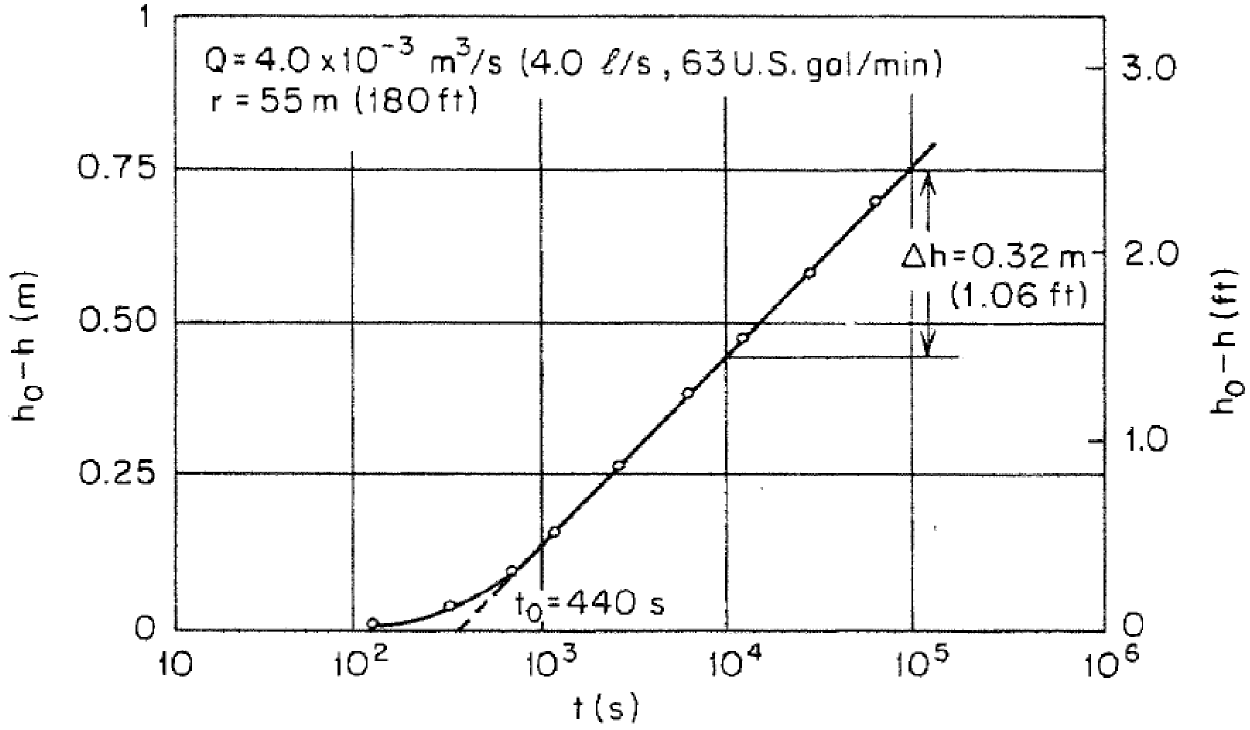




Pumping Test Data Visualization 3D



Cooper-Jacob Method for T, S_y, & K_{sat}

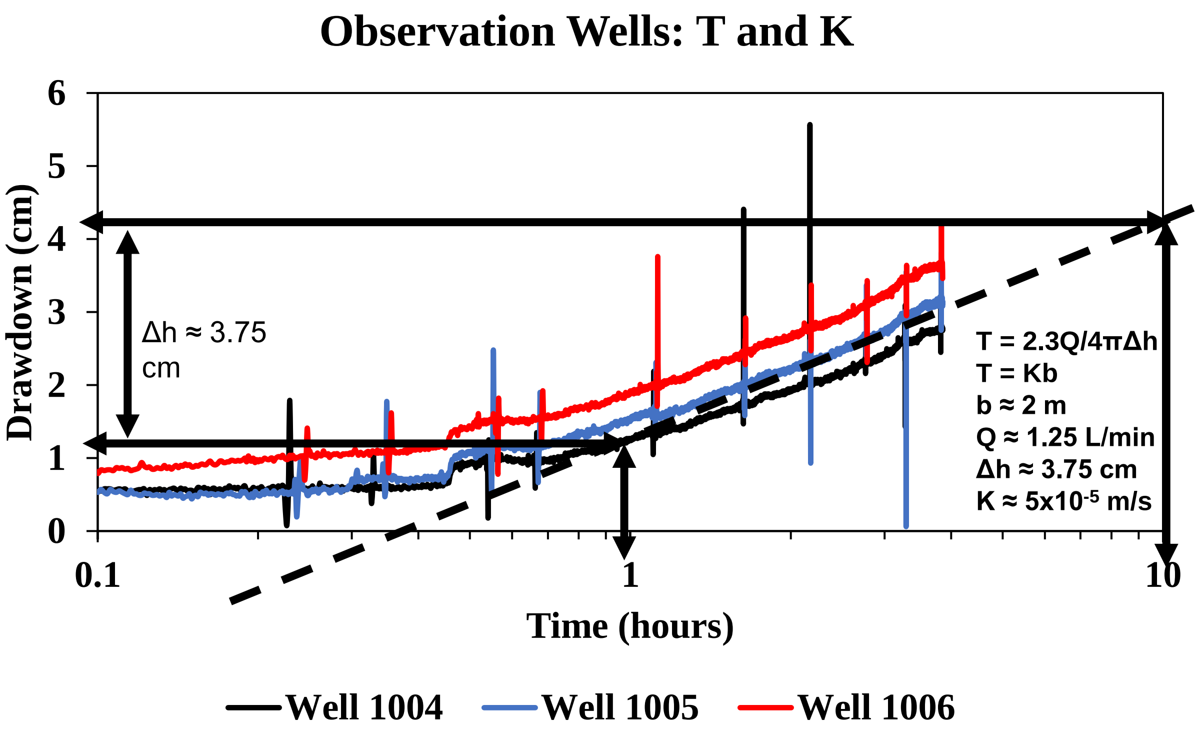


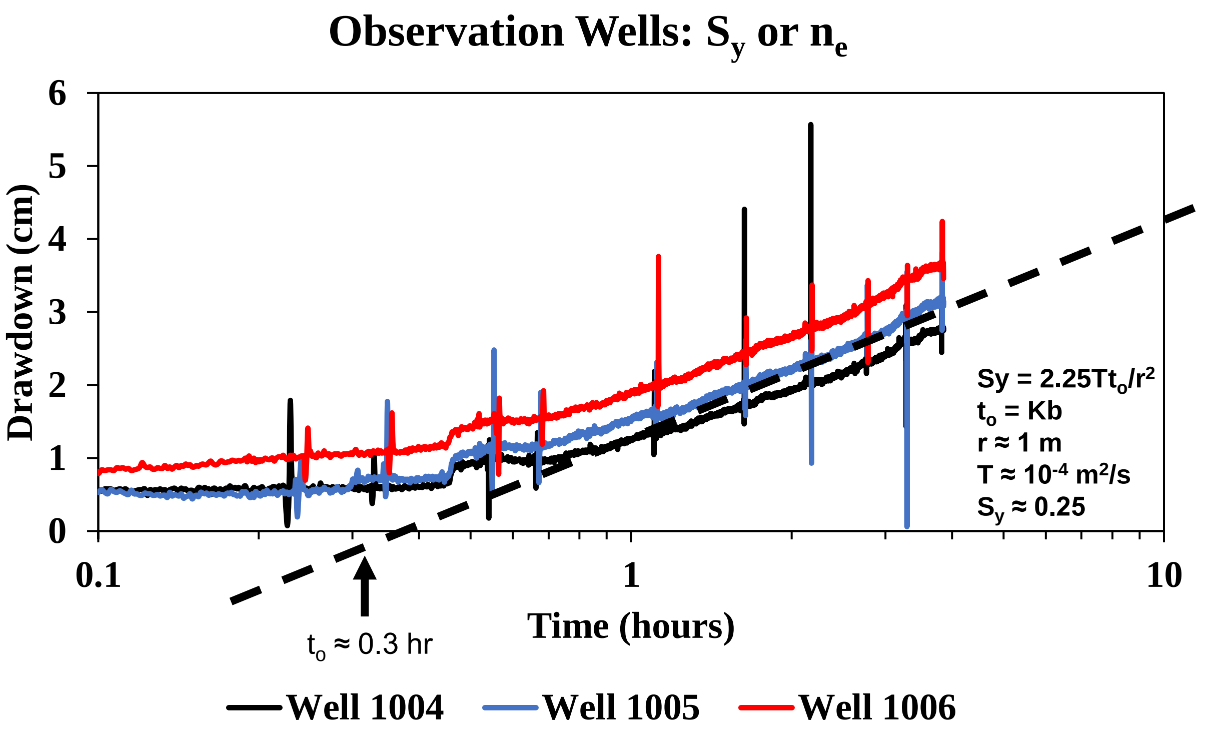
$$T = \frac{2.3Q}{4\pi\Delta h} = \frac{(2.3)(4.0 \times 10^{-3})}{(4)(3.14)(0.32)} = 0.0023\ m^2/s$$

$$S = \frac{2.25Tt_0}{r^2} = \frac{(2.25)(0.0023)(440)}{(55)^2} = 7.5 \times 10^{-4}$$

Freeze and Cherry 1979

Pumping Test Data Analysis





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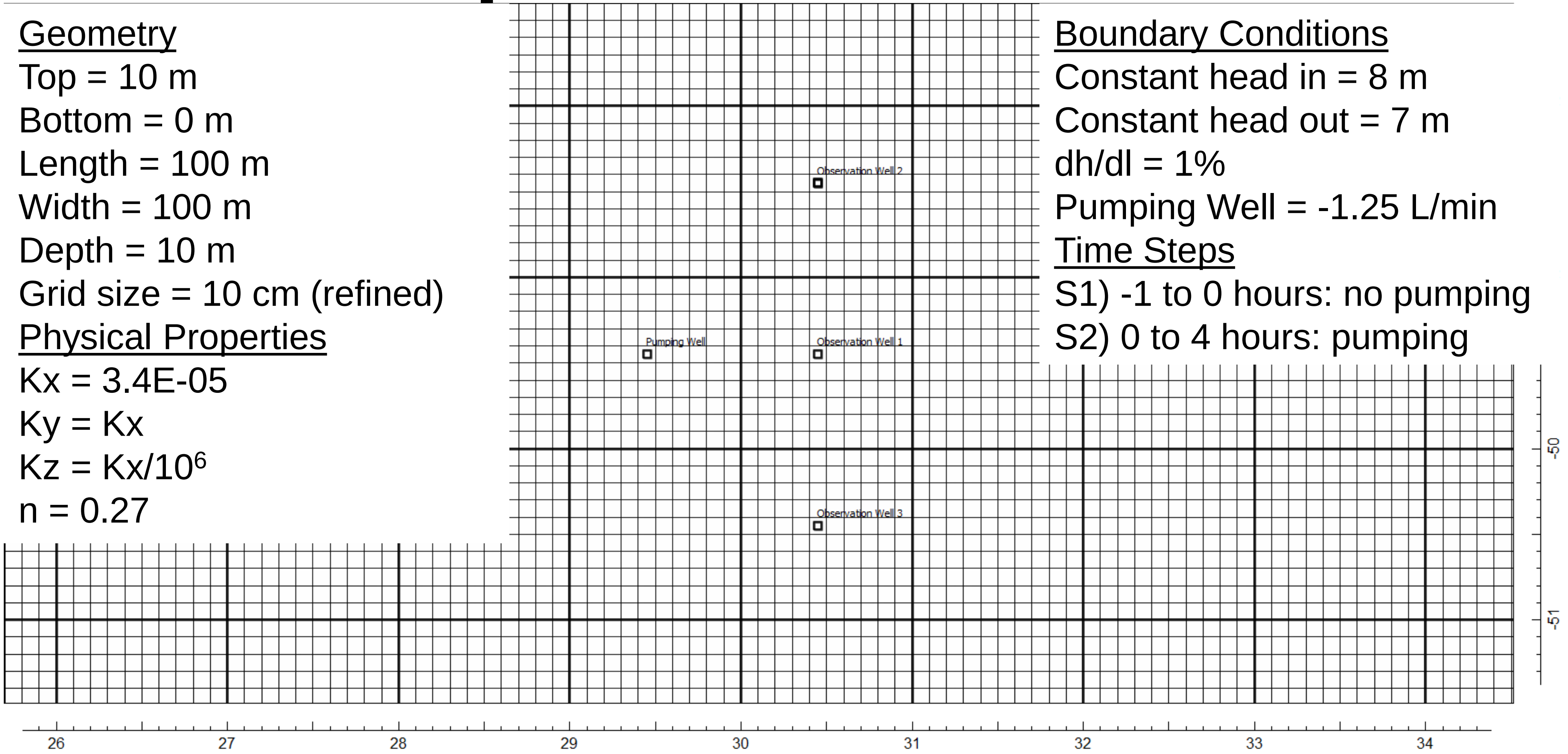
Model Input Parameters: MODFLOW

Well	K	S_y or n_e	Gradient	Analyst
ID	m/s	-	-	-
1004	3.4E-05	0.25	-	KH
1005	2.7E-05	0.41	-	KH
1006	2.5E-05	0.17	-	KH
1004, 5, 6	5.1E-05	0.25	-	CP
Average	3.4E-05	0.27	1.1% 167° CW-N	KH,CP
Std. Deviation	1.2E-05	0.10	-	KH,CP

Model Set Up: MODFLOW/ModelMuse

<u>Geometry</u>
Top = 10 m
Bottom = 0 m
Length = 100 m
Width = 100 m
Depth = 10 m
Grid size = 10 cm (refined)

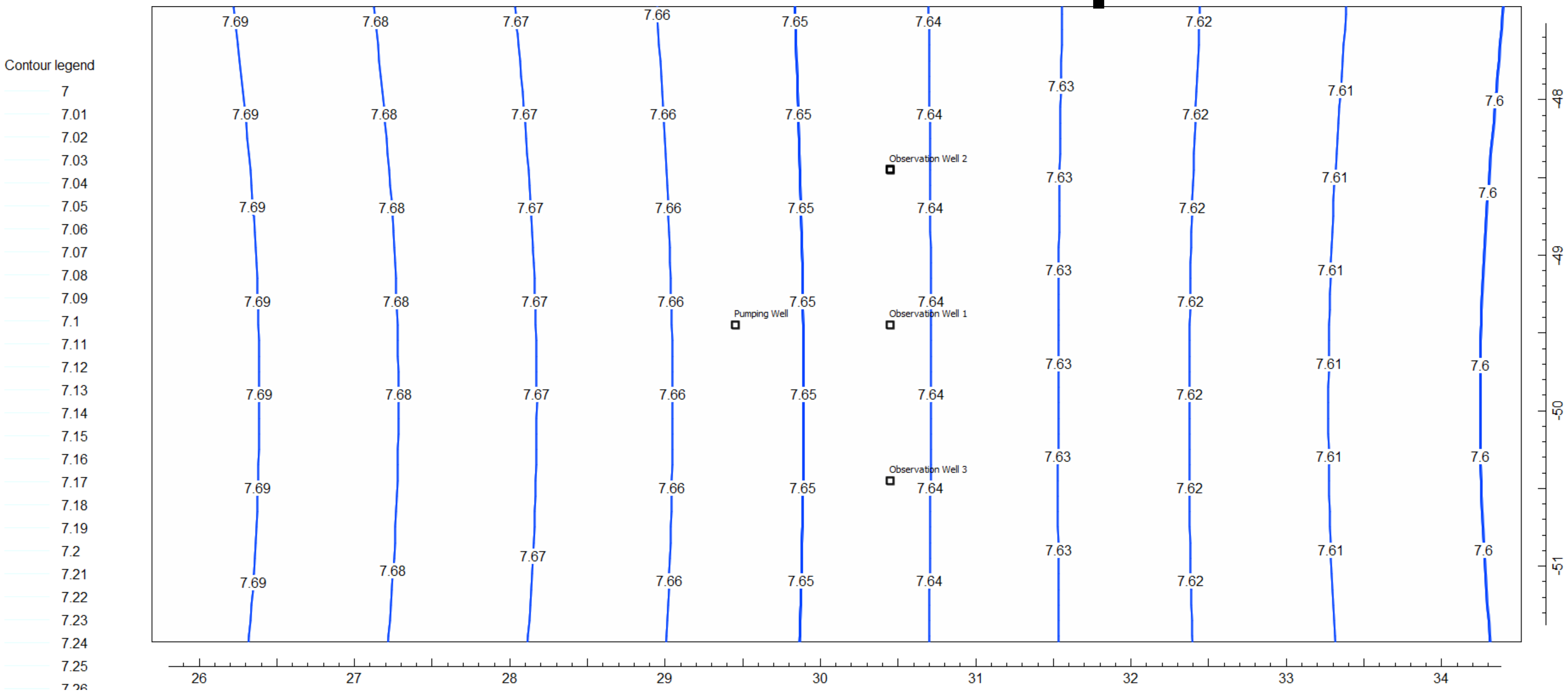
<u>Physical Properties</u>
Kx = 3.4E-05
Ky = Kx
Kz = Kx/10^6
n = 0.27



<u>Boundary Conditions</u>
Constant head in = 8 m
Constant head out = 7 m
dh/dl = 1%
Pumping Well = -1.25 L/min

<u>Time Steps</u>
S1) -1 to 0 hours: no pumping
S2) 0 to 4 hours: pumping

Model Simulation: Time Step One End



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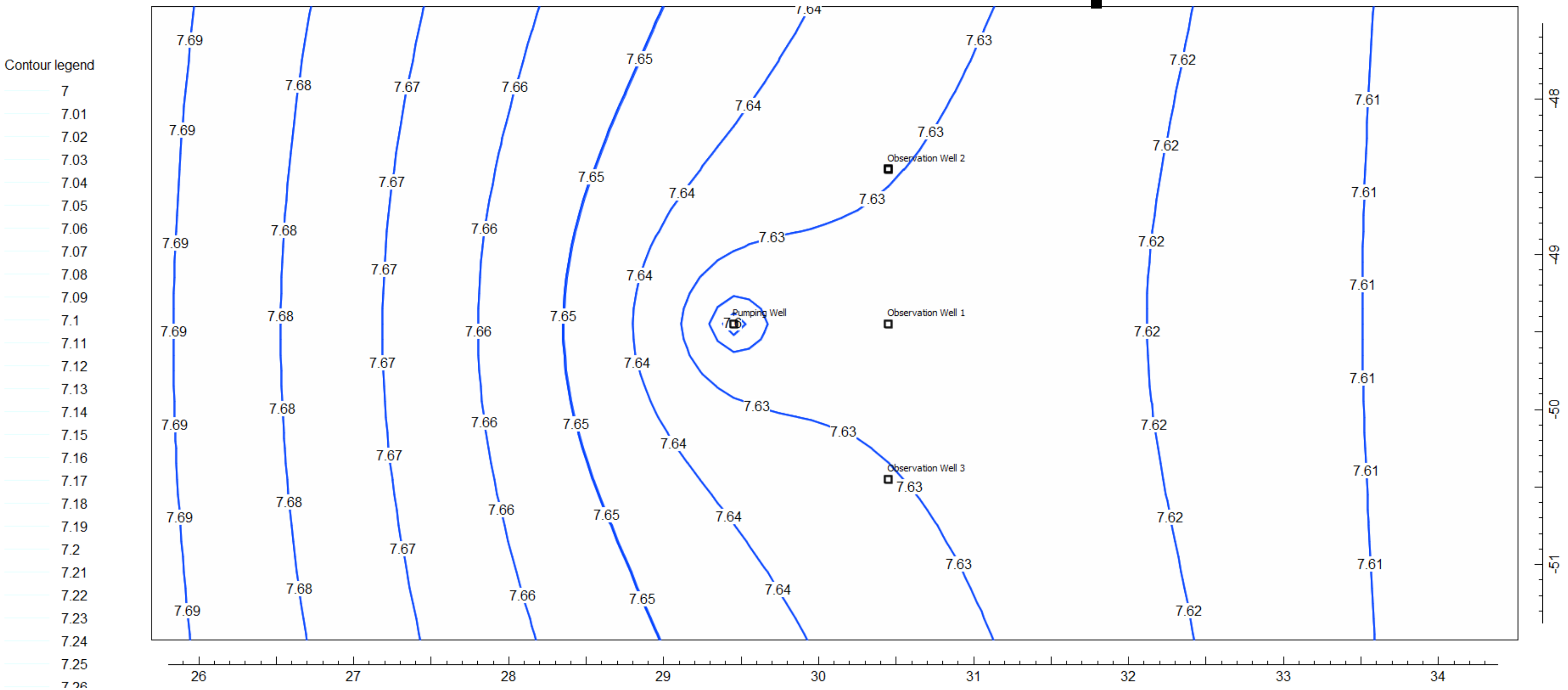
Model Simulation: Time Step Two End



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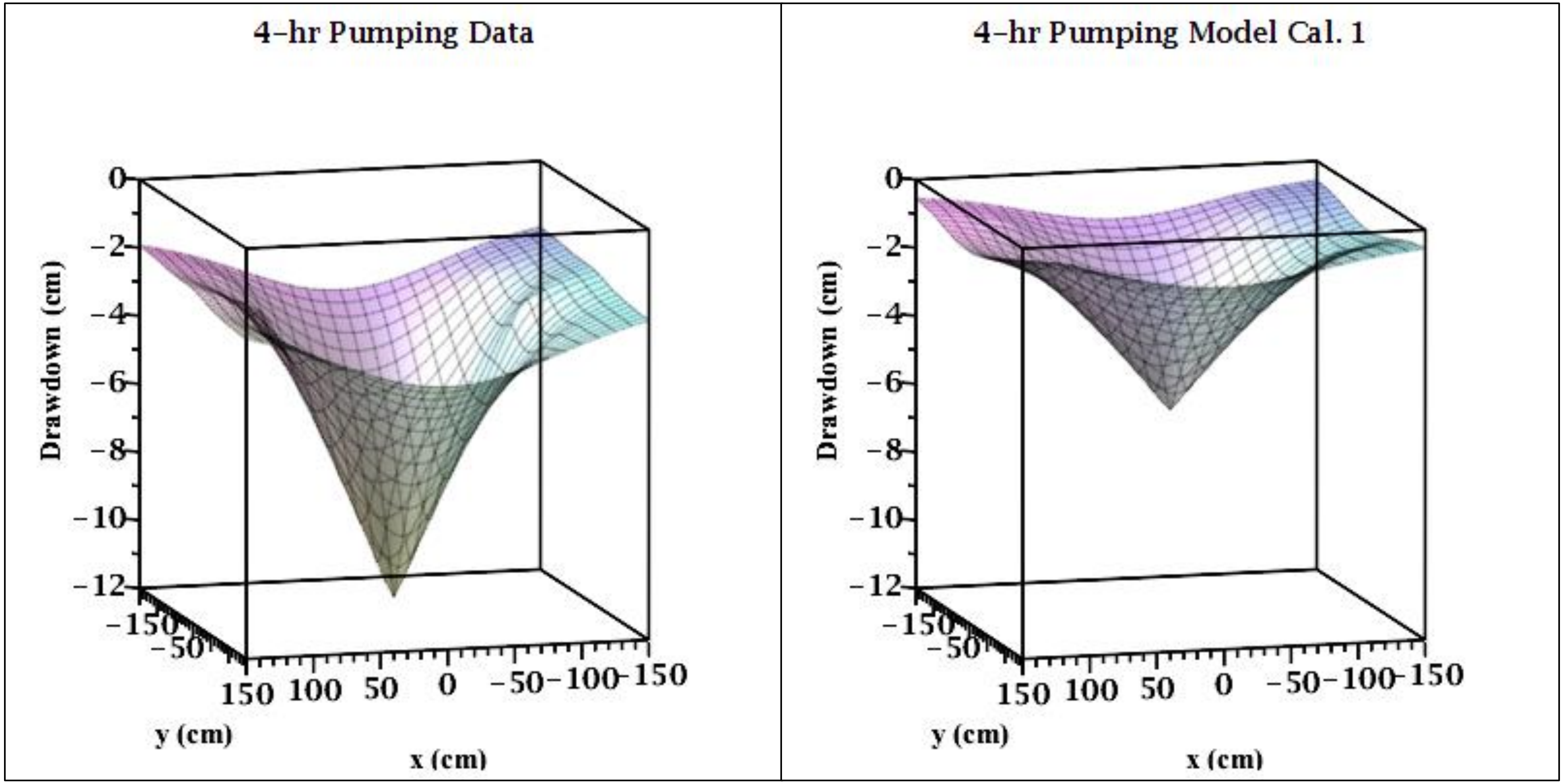
Data versus Model: Calibration 1



Modeling Approach

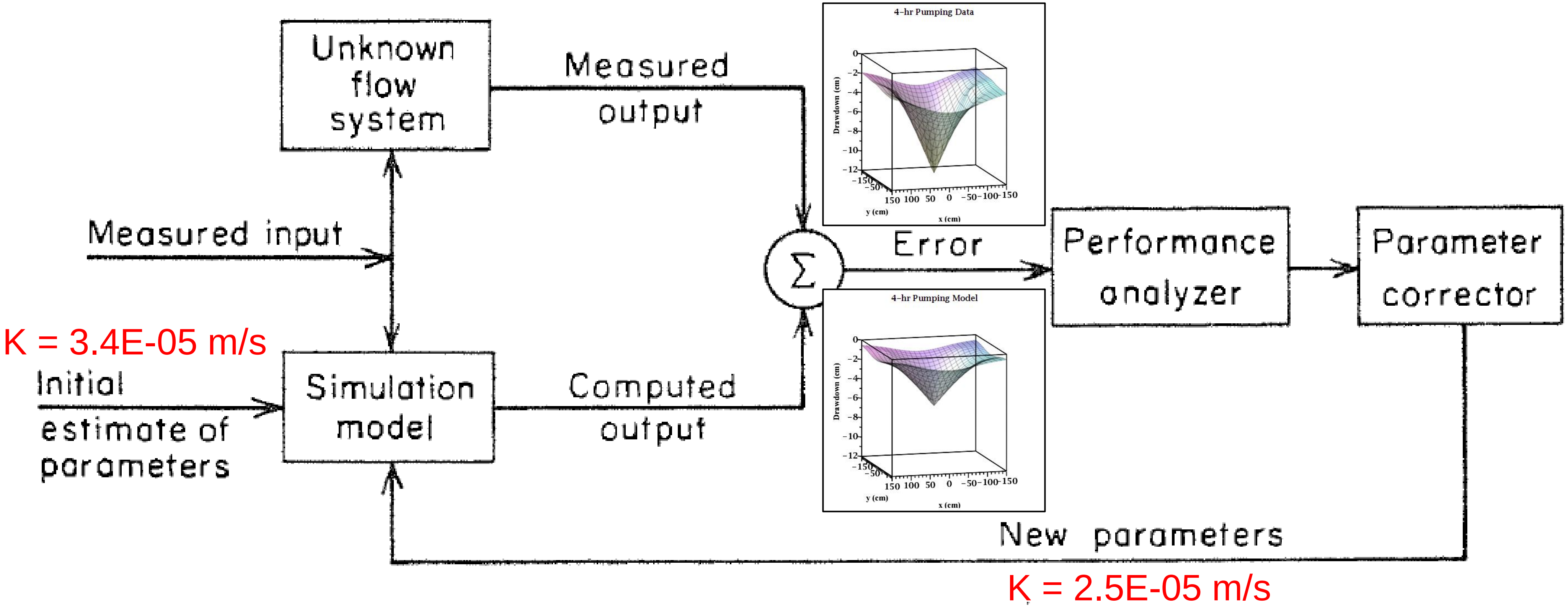
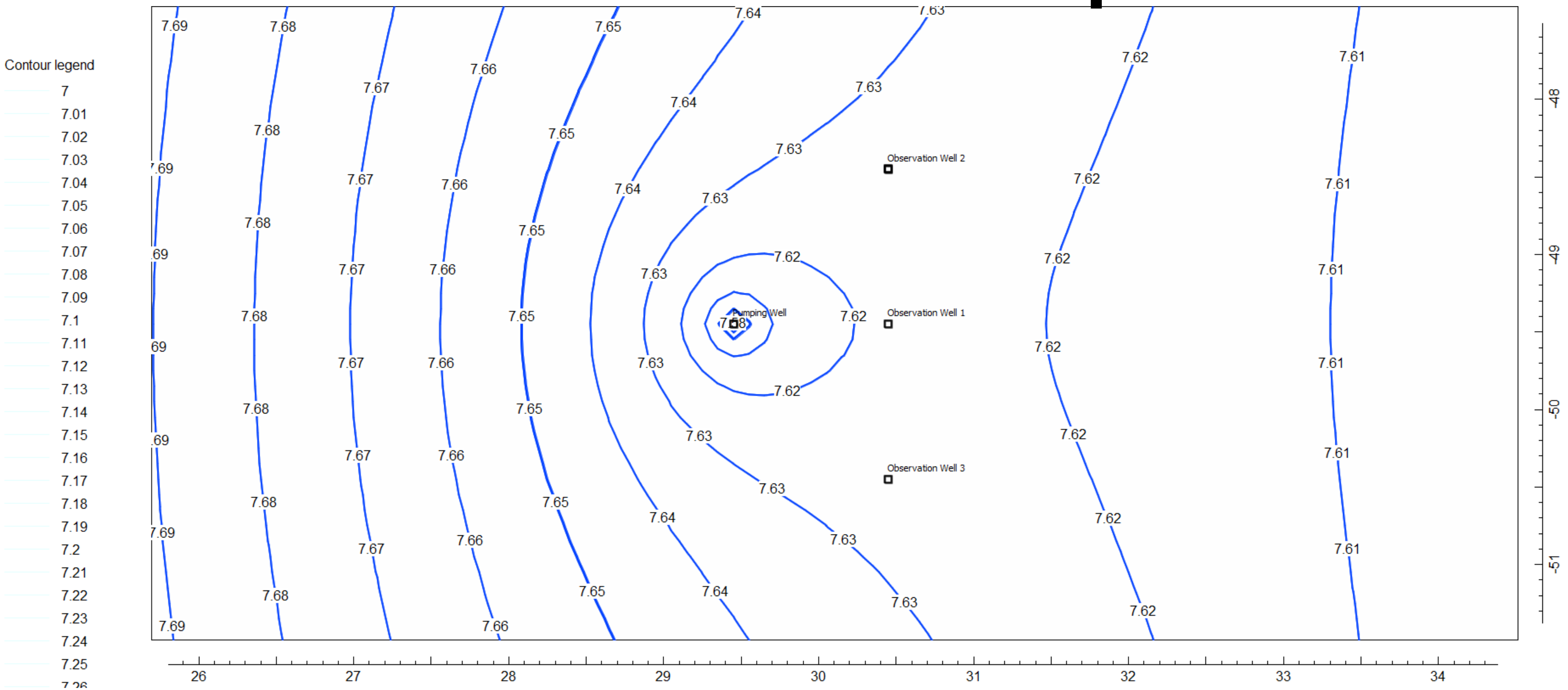
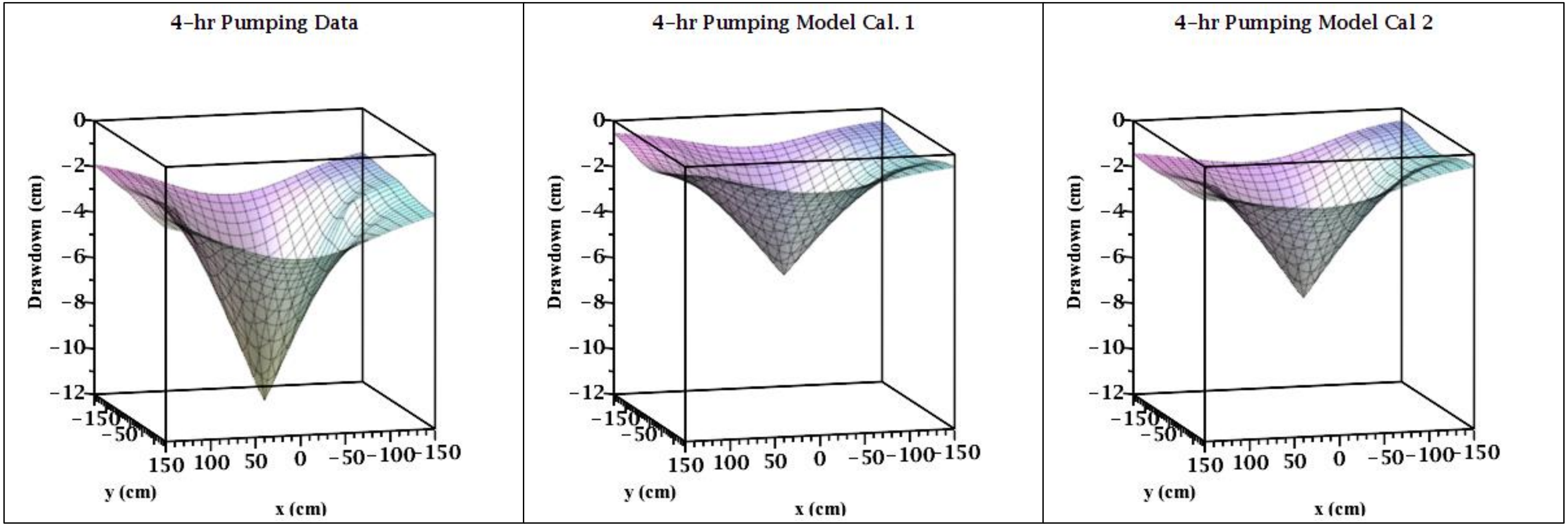


Figure 8.28 Flowchart of the trial-and-error calibration process (after Neuman, 1973a).

Model Simulation: Time Step Two End



Data versus Model: Calibration 2



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Modeling Approach

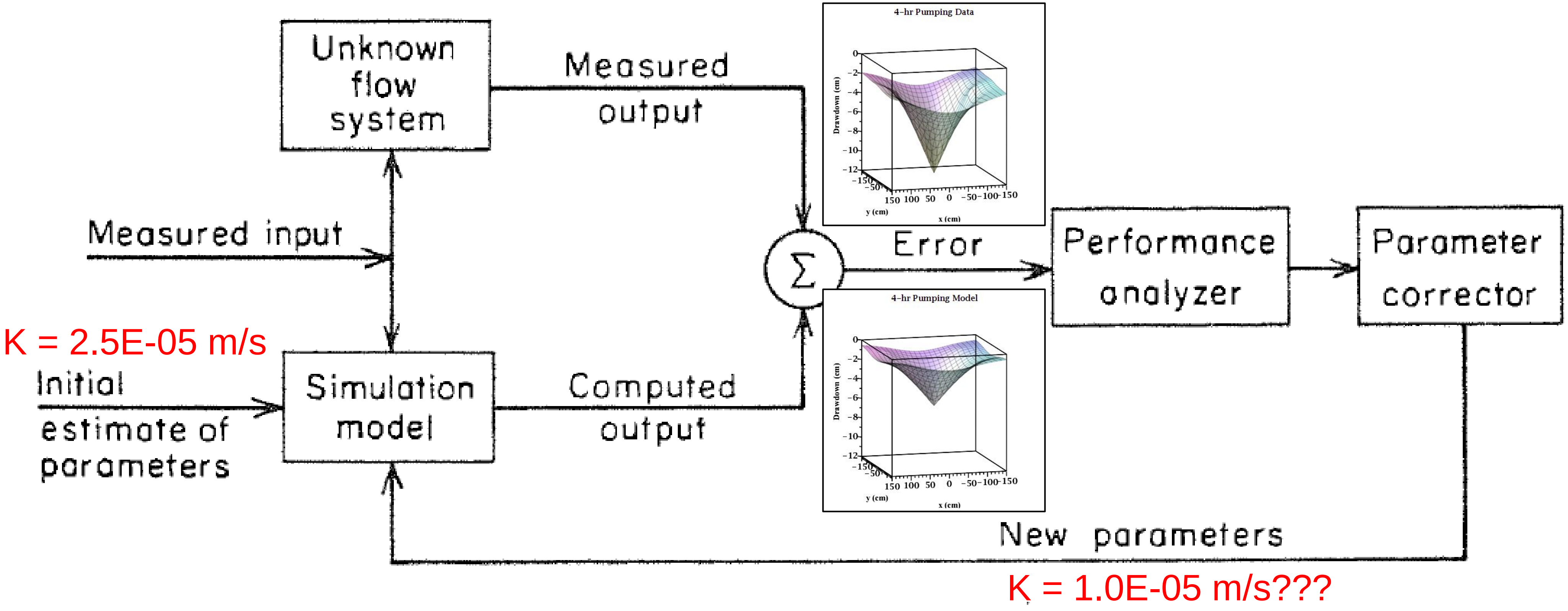
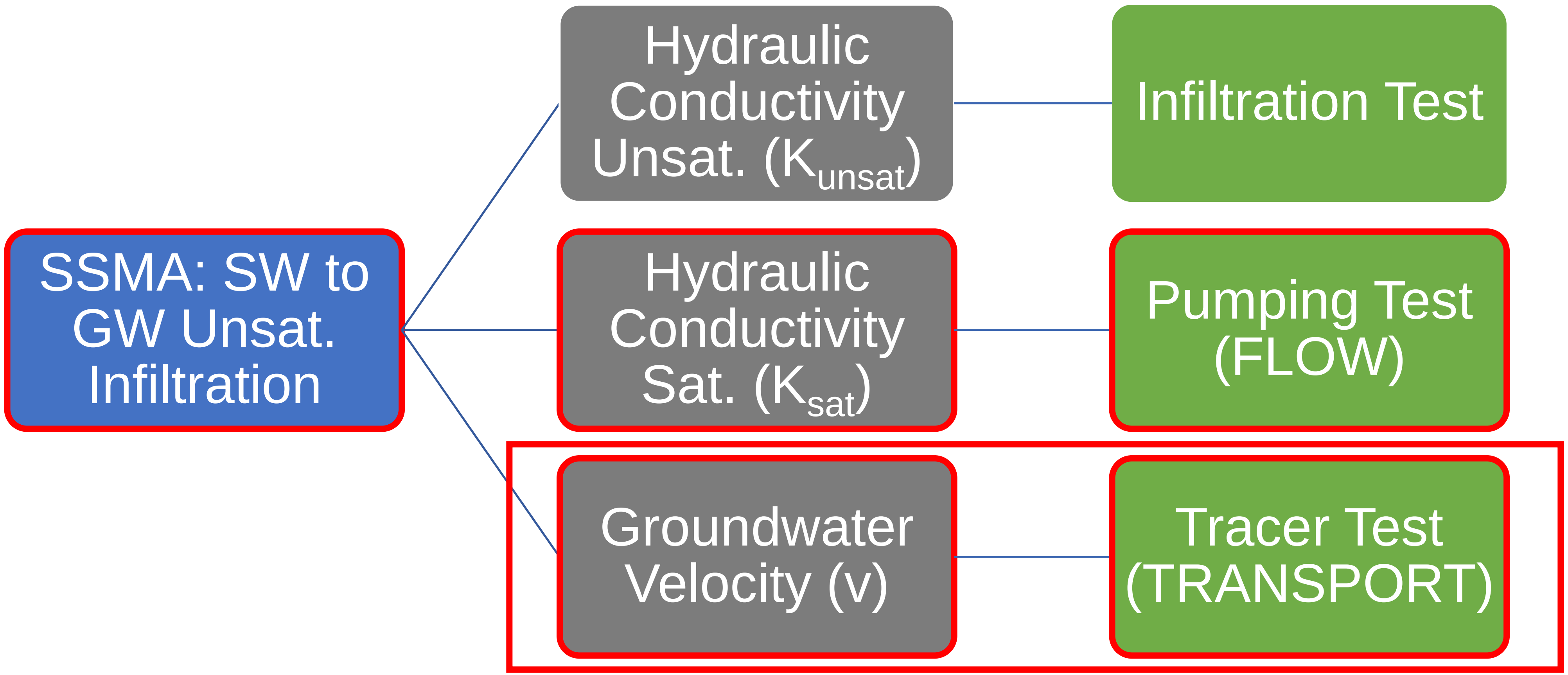


Figure 8.28 Flowchart of the trial-and-error calibration process (after Neuman, 1973a).

Conclusion Flow Calibration

- We're gettin' there!!!
    1. Need to georeference wells (make sure orientation is good)
    2. Generate time vs. drawdown simulations at wells (gw chart package)
    3. Need to automate calibration (write some code)
    4. Need to quantify/minimize error (residual sum of squares)
    5. Need to build flow unsaturated zone (cal. w/infiltration test data)
    6. Need to build flow model for FTA (sat. and unsat. zones)
- Worth testing model inputs (K, i, and n) for transport?
    - Recall v = Ki/n = (3.4E-05m/s*1%)/0.25 ≈ 0.4 ft/day
    - Sure, let's give it a try…1-D analytical model (SIMPLE)

Pre-experiment Characterization: Model Input



Tracer Test Data and Model

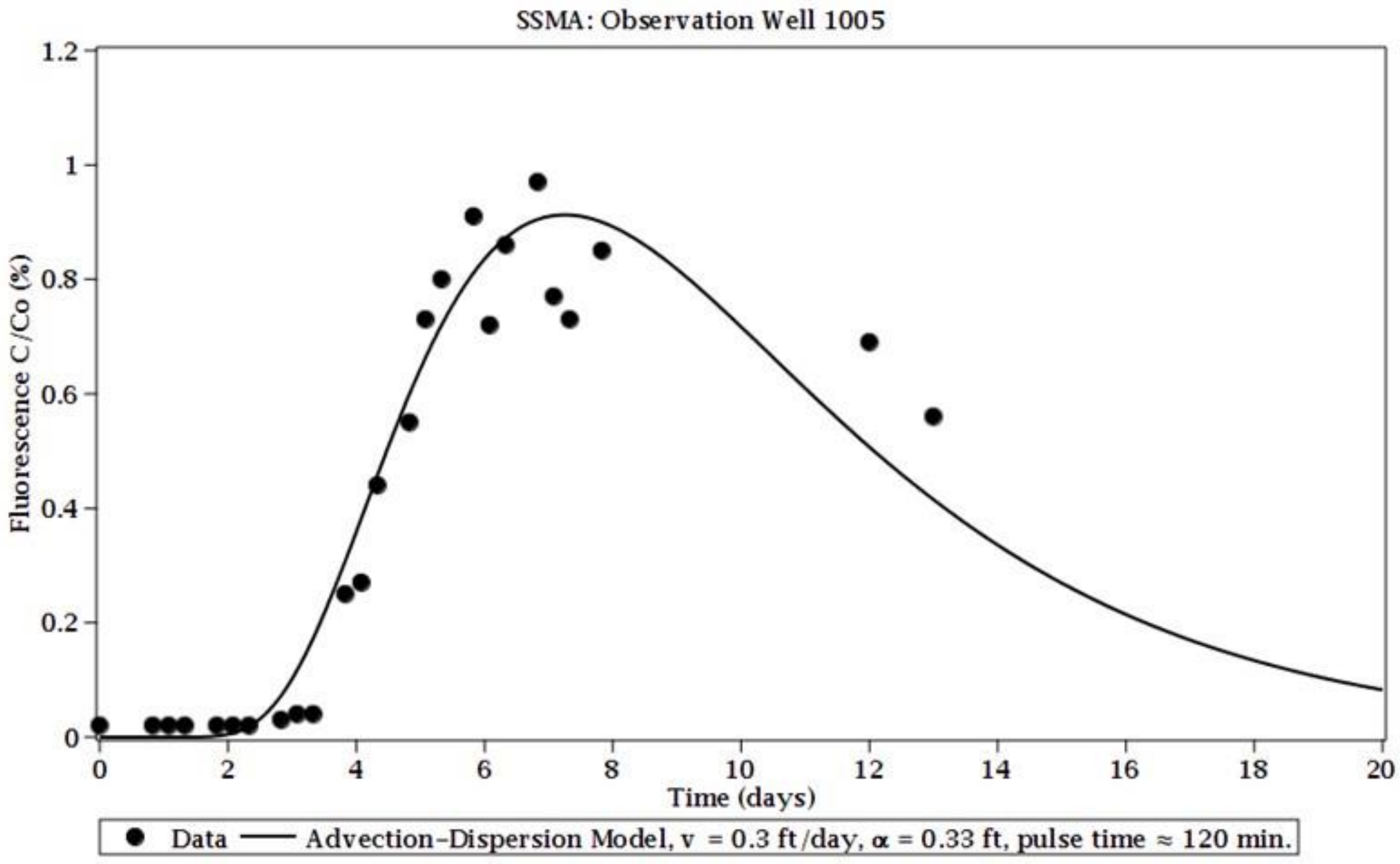


Fig. 6 Breakthrough curve of fluorescence in down-gradient observation well (1005) at the SSMA, radial distance between up-gradient injection well (1001) observation well (1005) approximately 3 feet, solid circles are data, solid line is 1-D analytical model

Decent fit of v, but some tailing…

What about the BIG experimental data?

- Some of the data is still in the analytical lab
- Data that is available is ready for analysis
- Want to get flow and transport model going from pre-experimental characterization
- Want to test how well model can predict experimental data
- Then calibrate models, if necessary, likely necessary...
- However, let’s have a look at some published data from similar tests at Grand Junction, Colorado site

Similar/Previous Study

Journal of Contaminant Hydrology 229 (2020) 103581

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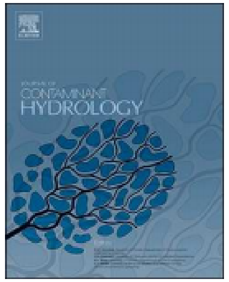
Contents lists available at ScienceDirect

Journal of Contaminant Hydrology

journal homepage: www.elsevier.com/locate/jconhyd



Field experiments of surface water to groundwater recharge to characterize the mobility of uranium and vanadium at a former mill tailing site

Check for updates

Charles J. Paradis[a,*], Raymond H. Johnson[b], Aaron D. Tigar[b], Kirsten B. Sauer[a], Oana C. Marina[a], Paul W. Reimus[a]

[a] *Earth and Environmental Sciences Division, Los Alamos National Laboratory, Los Alamos, NM, USA*
[b] *Navarro Research and Engineering, Inc., Contractor to the United States Department of Energy, Office of Legacy Management, Grand Junction, CO, USA*

Field Site: Banks of Gunnison River

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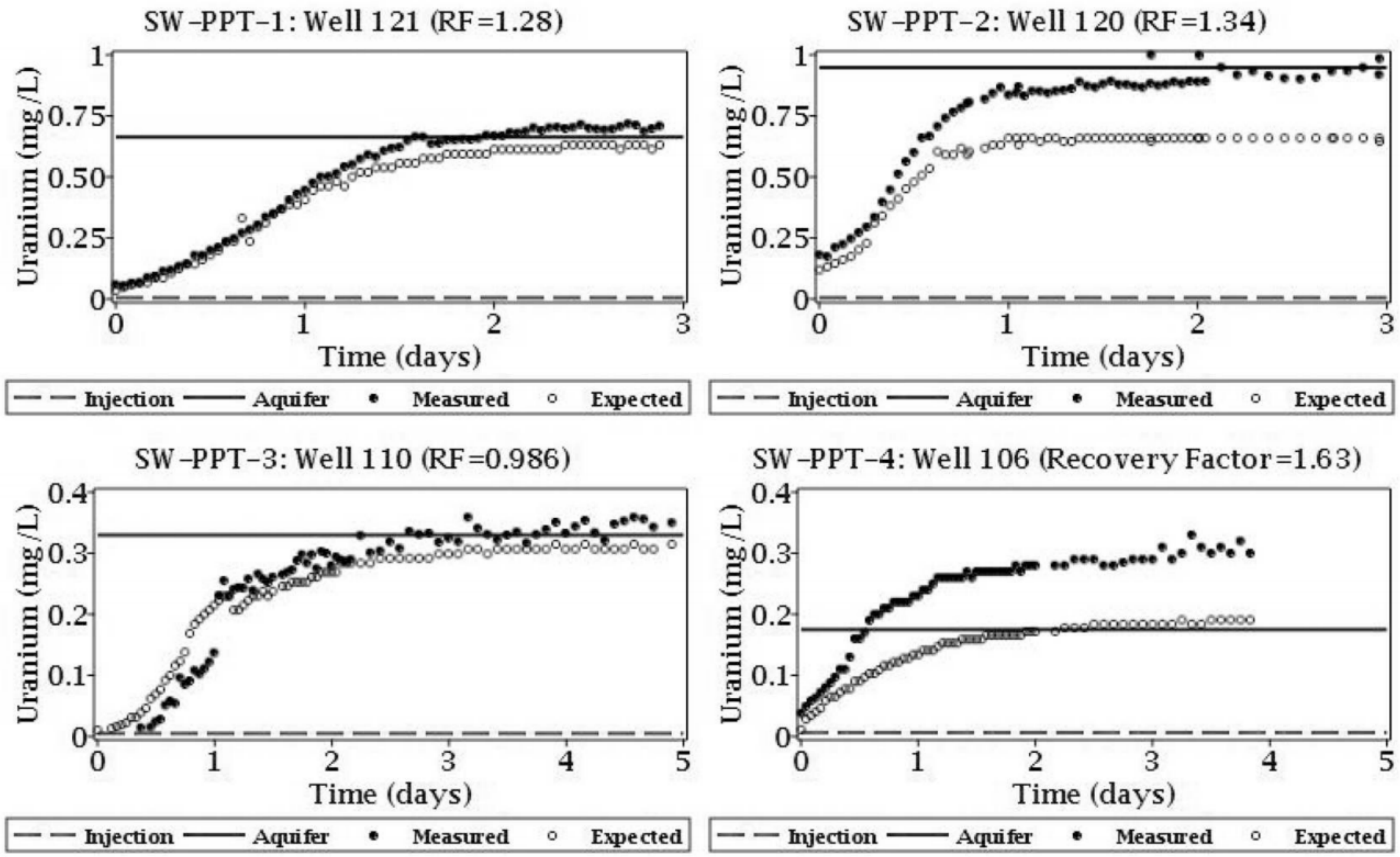
Data: River Water to Groundwater Recharge/Injection



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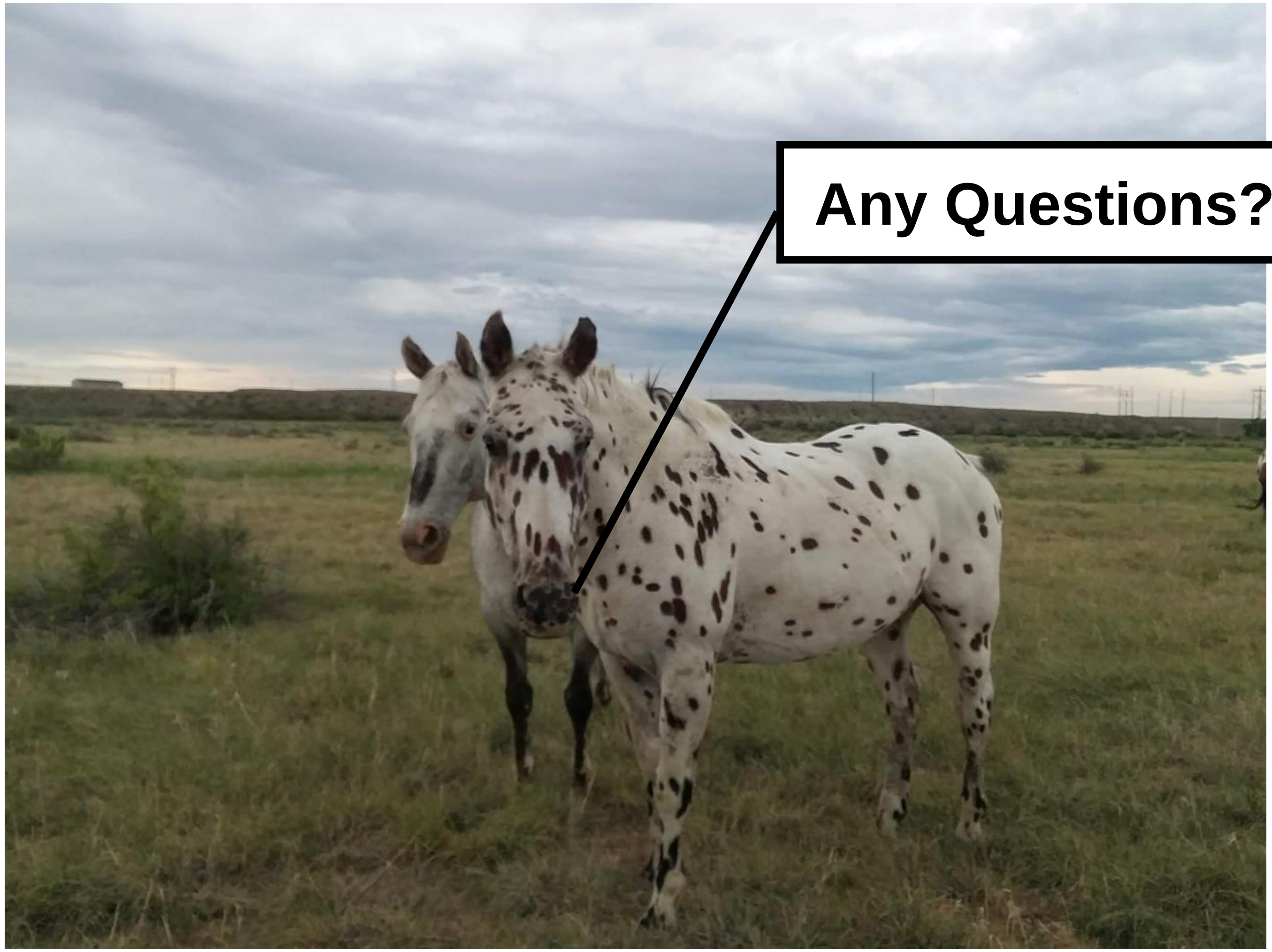
Conclusions & Future Work

1. Initial model inputs show good agreement to measured outputs
   - Need to include unsaturated zone in flow model
   - Need to calibrate flow model with field data
   - Need to run transport model, after flow model is calibrated
2. A ton of data in hand and in the queue and likely several stories to tell
   - Two sites (FTA & SSMA) and two tests (natural, added alkalinity)
   - Need Support for Undergraduate Research Fellows (SURF), Dec. 1 deadline

Acknowledgements

UWM Grads: Meurer, Hatami, Hoss, Sultana
UWM GeoSci: New faculty start up
UWM GeoSci: Nelson Cherkauer Lasca Legacy Scholarship
GSA: Graduate Student Research Grants

Navarro: Raymond Johnson, Aaron Tigar,
LANL: Paul Reimus, Katherine Telfeyan, Brent Newman, Nate Conroy
LANL: Graduate Research Assistantship


Any Questions???