DOH Review:
Navy Groundwater Flow Models & Related Issues with the Navy CSM for the Red Hill Facility

By:

The Department of Health Hawaii (DOH)
Technical subject matter experts
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In coordination with EPA, Region 9

October 19, 2021

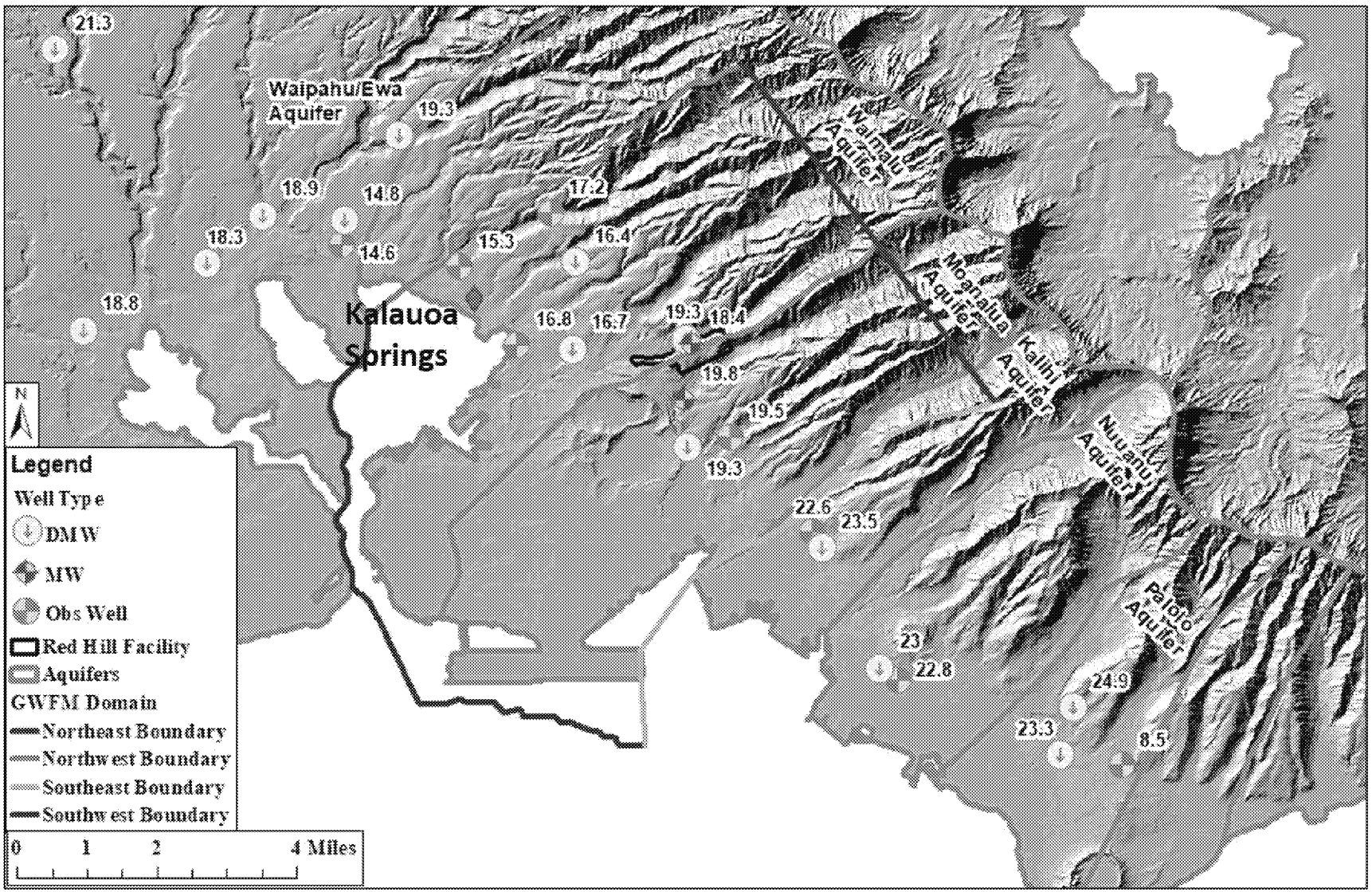
GWFM - Drinking Water Risk Concerns

1. GWFMs boundary conditions have uncertainty
   a) Chosen BCs are reasonable for primary models
   b) Data indicate other boundary conditions are probable
2. Validation doesn't ensure the model adequately replicates groundwater flow trajectories
   a) Currently used comparative data – g.w. gauging
   b) Verification simulations appear not to match elevations
   c) Alternative verification data sets
3. Model conclusions and data contrasts are problematic
   a) Critical question: Do the model results support the conclusions in the IRR Report?
   b) And future CF&T (Part II discussion)

Critical Drinking Water Risk Evaluation Questions

- Does pumping the Red Hill Shaft mobilize groundwater from beneath all tanks toward the Red Hill Shaft?
- Is there an unobstructed hydraulic pathway from beneath the tanks to the Halawa Shaft?
- Over-arching question:
  - Is the model informative for answering either or both of those questions?
  - Can the models adequately inform CF&T (Part II)?

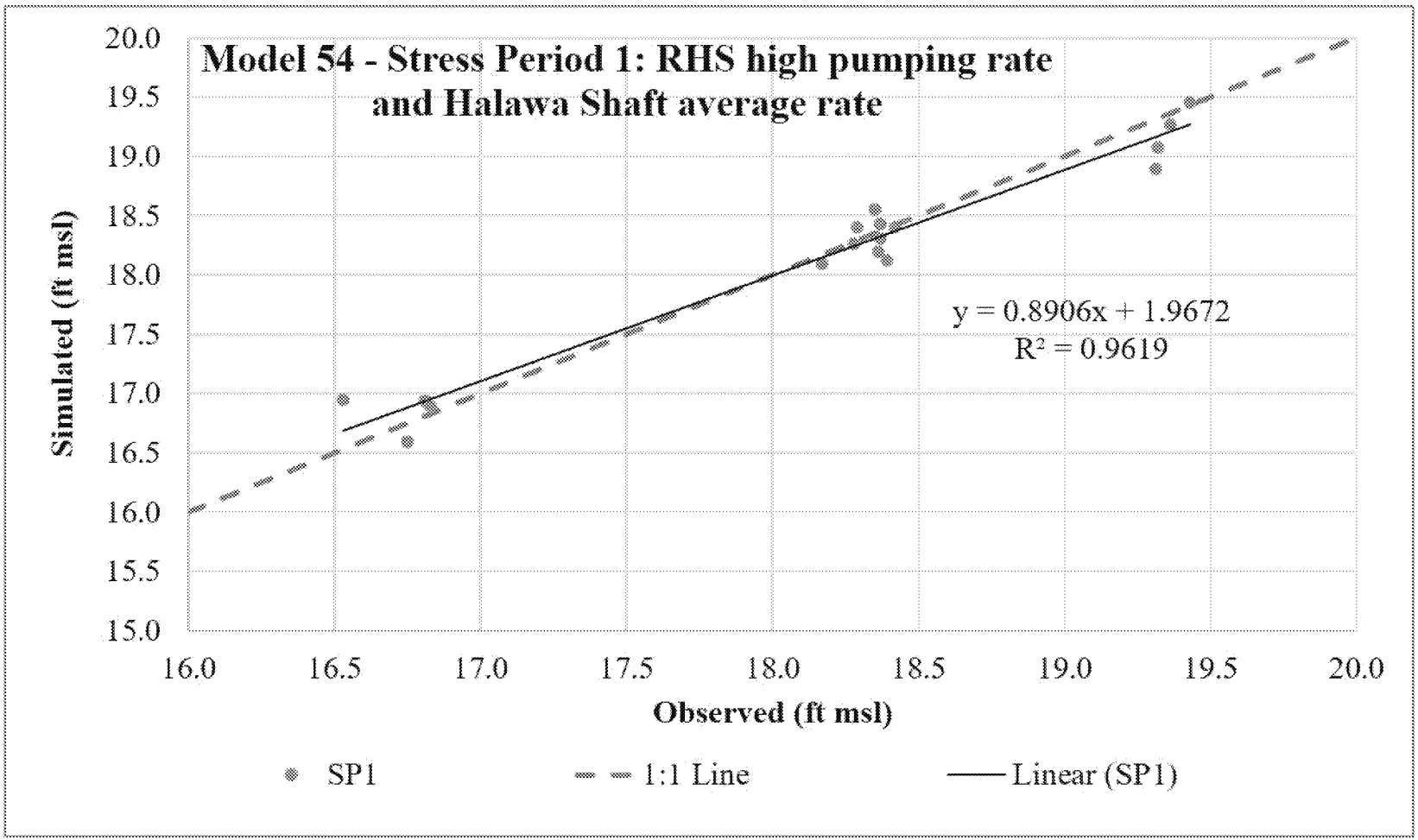
GWFM Boundary Conditions



Model Validation – Compare to Site Data

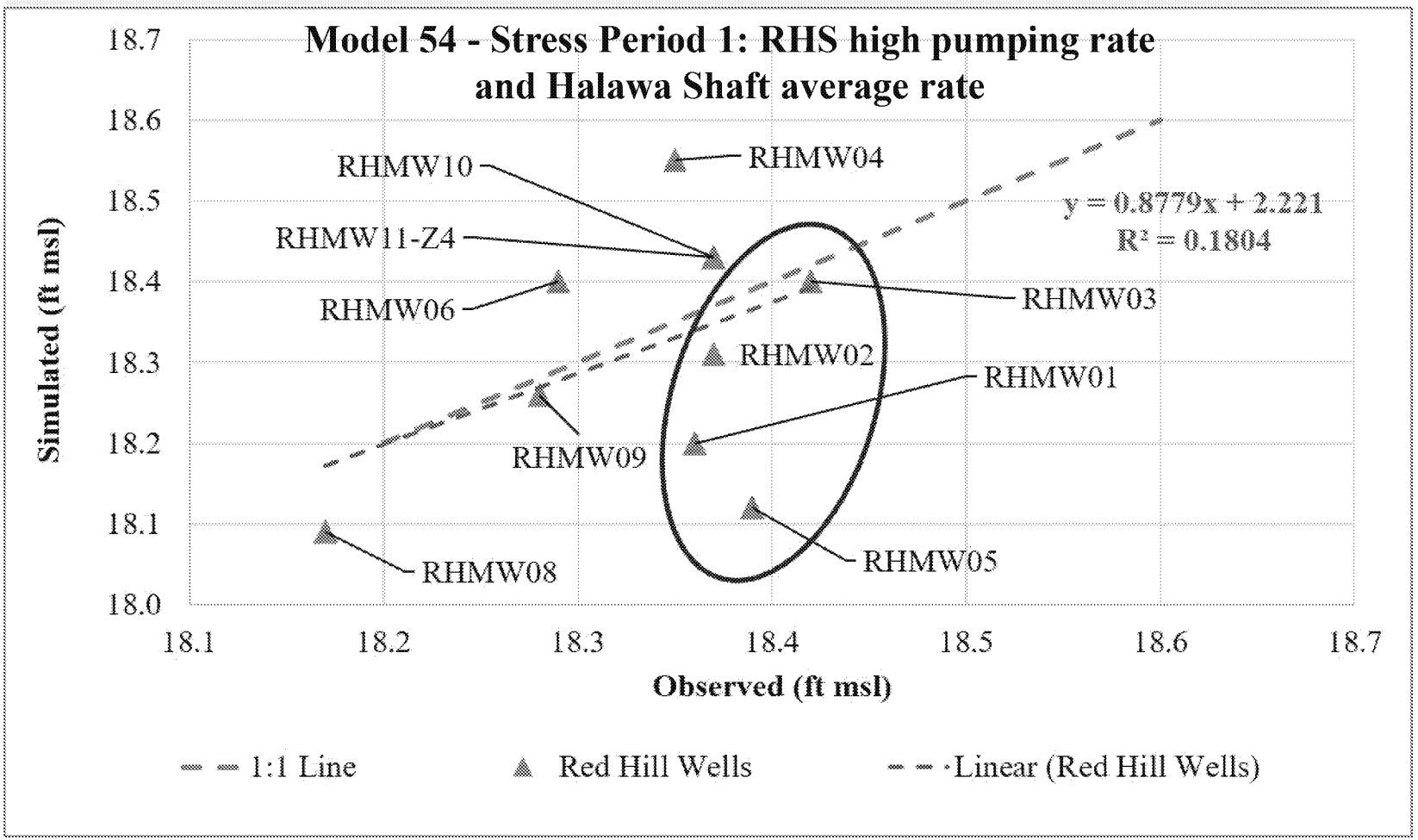
1. Methods & data currently used
   a) Groundwater elevations
   b) Transient responses
   c) Others
2. Concern with current comparative data
   a) Mis-match between modeled and measured gradients
   b) Groundwater elevations have low accuracy (Part II review)
3. Alternative groundwater behavior data
   a) Chloride and other natural tracers

Regional Water Levels

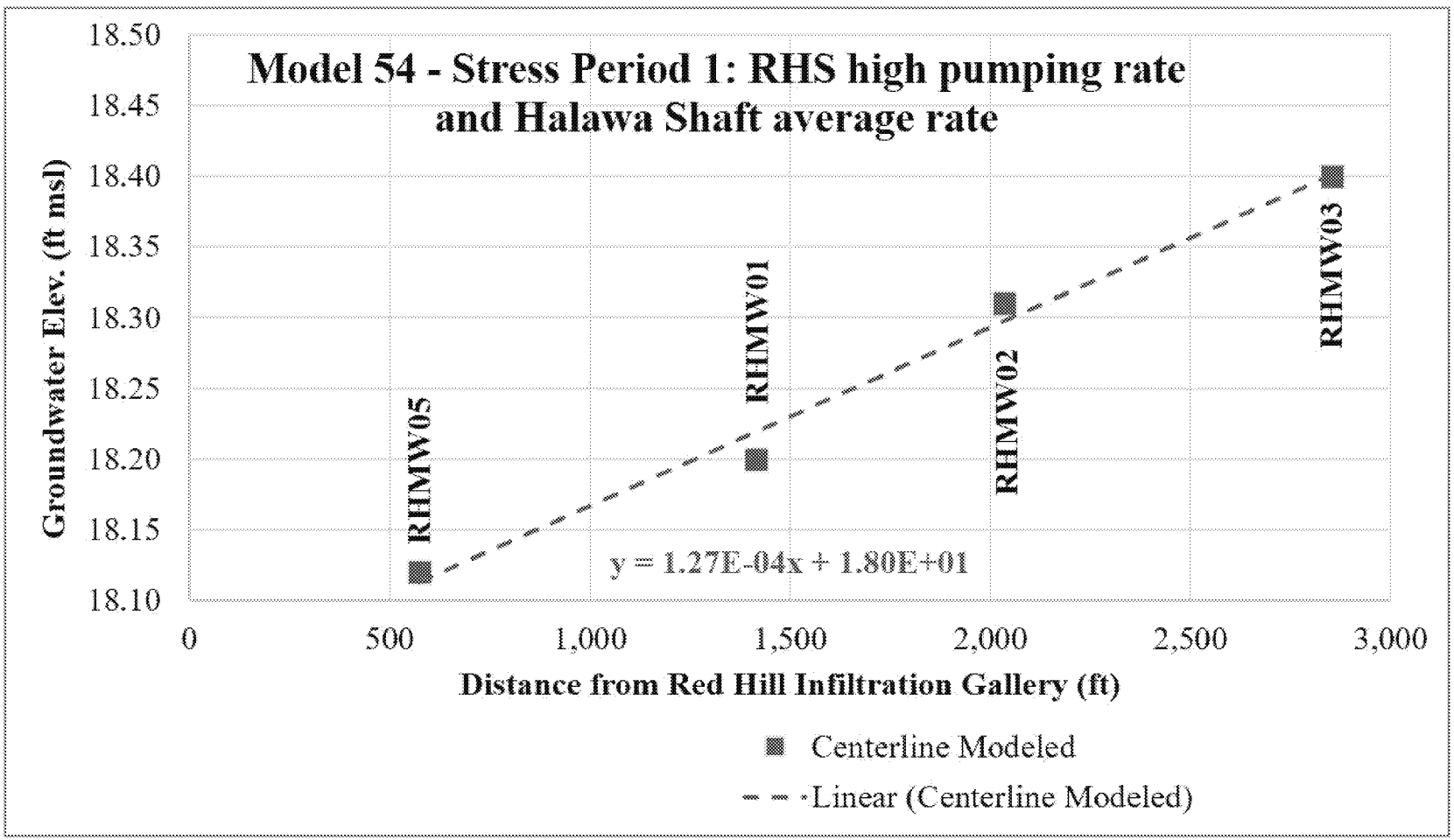


Local Water Levels

(Navy GWFMs do not match local data)

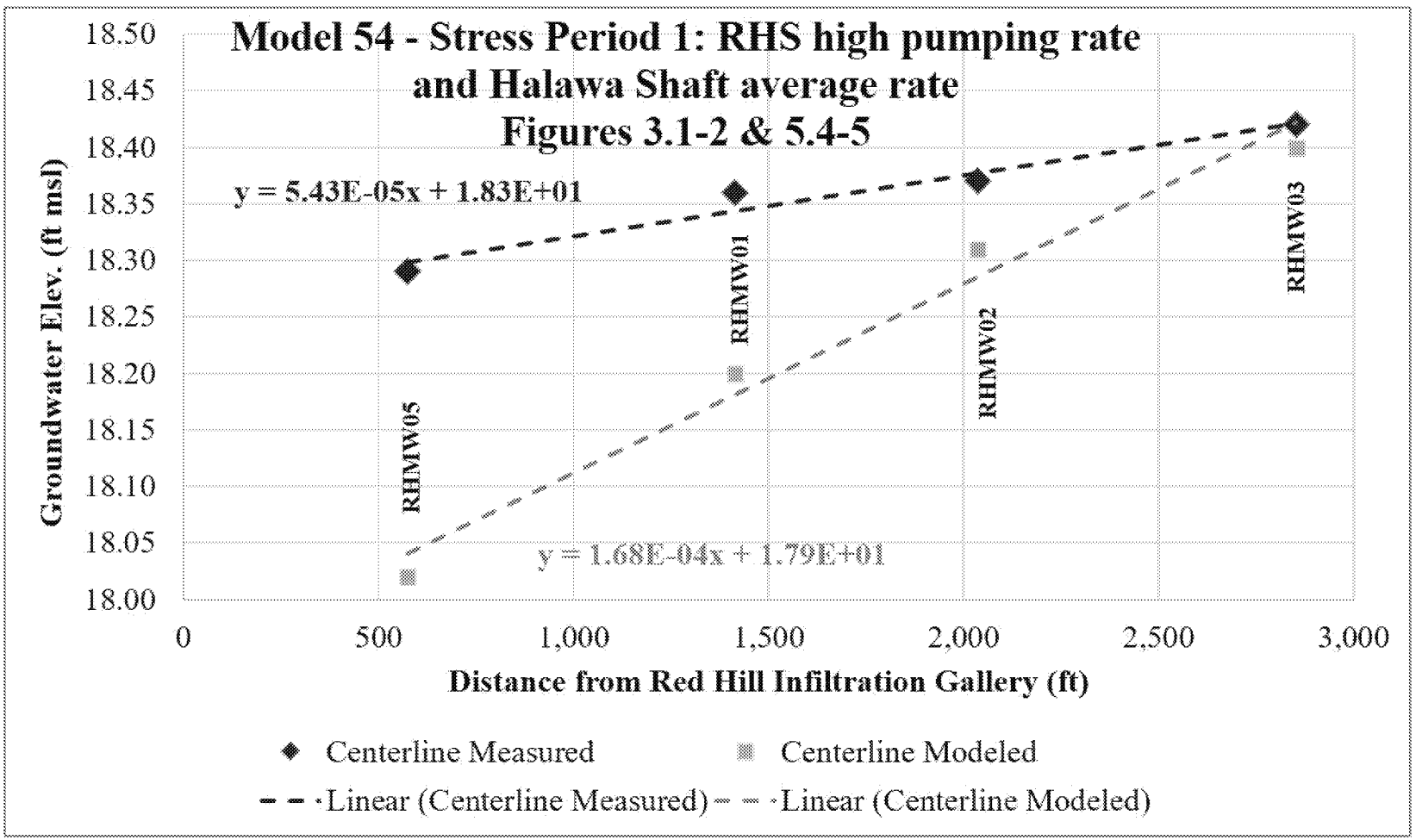


Gradient beneath and downslope of the tanks
(output from Navy GWFMs)

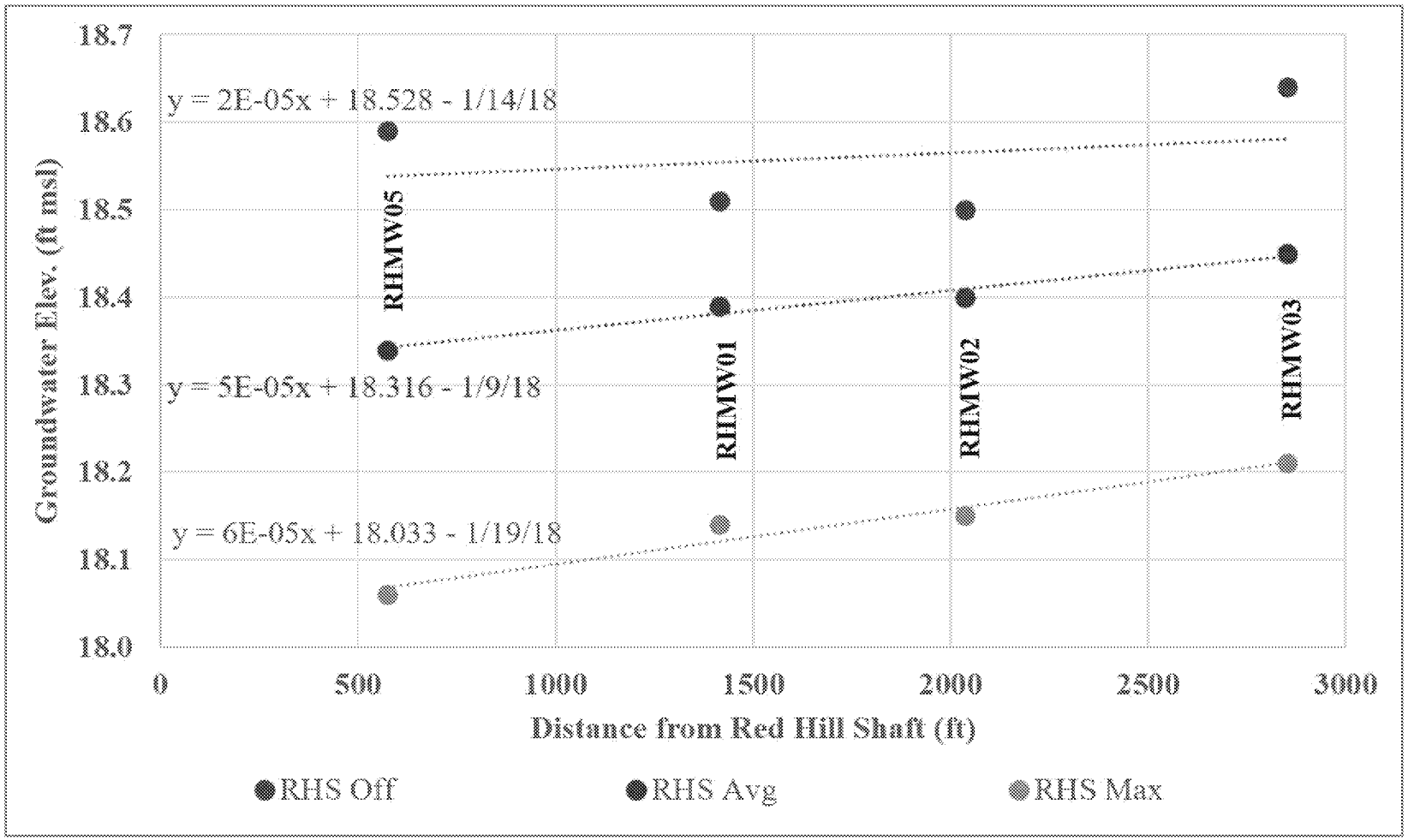


Measured vs. Modeled RH Ridge Gradients

(Gradient beneath and downslope of the tanks)



Red Hill Ridge gradient - under three different pumping conditions



Reliability of GW Elevation Data

magnitude and direction, which are a primary objective for the model. However, the measurements of absolute water levels or gradients between well pairs may incur errors due to datum measurements and borehole gyroscopic tape corrections for the reasons previously discussed. The spring fluxes at Pearl Harbor Spring at Kalauao and Kalauao Spring were also calibration targets with target values shown in Table 3-2. Weighting on these targets was determined after preliminary PEST simulations such that the flux magnitudes did not overwhelm water level targets in the objective function. Finally, the extraction rates at pumping wells were also included in the PEST multi-objective function to ensure that pumping did not reduce with bottom-hole conditions during calibration.

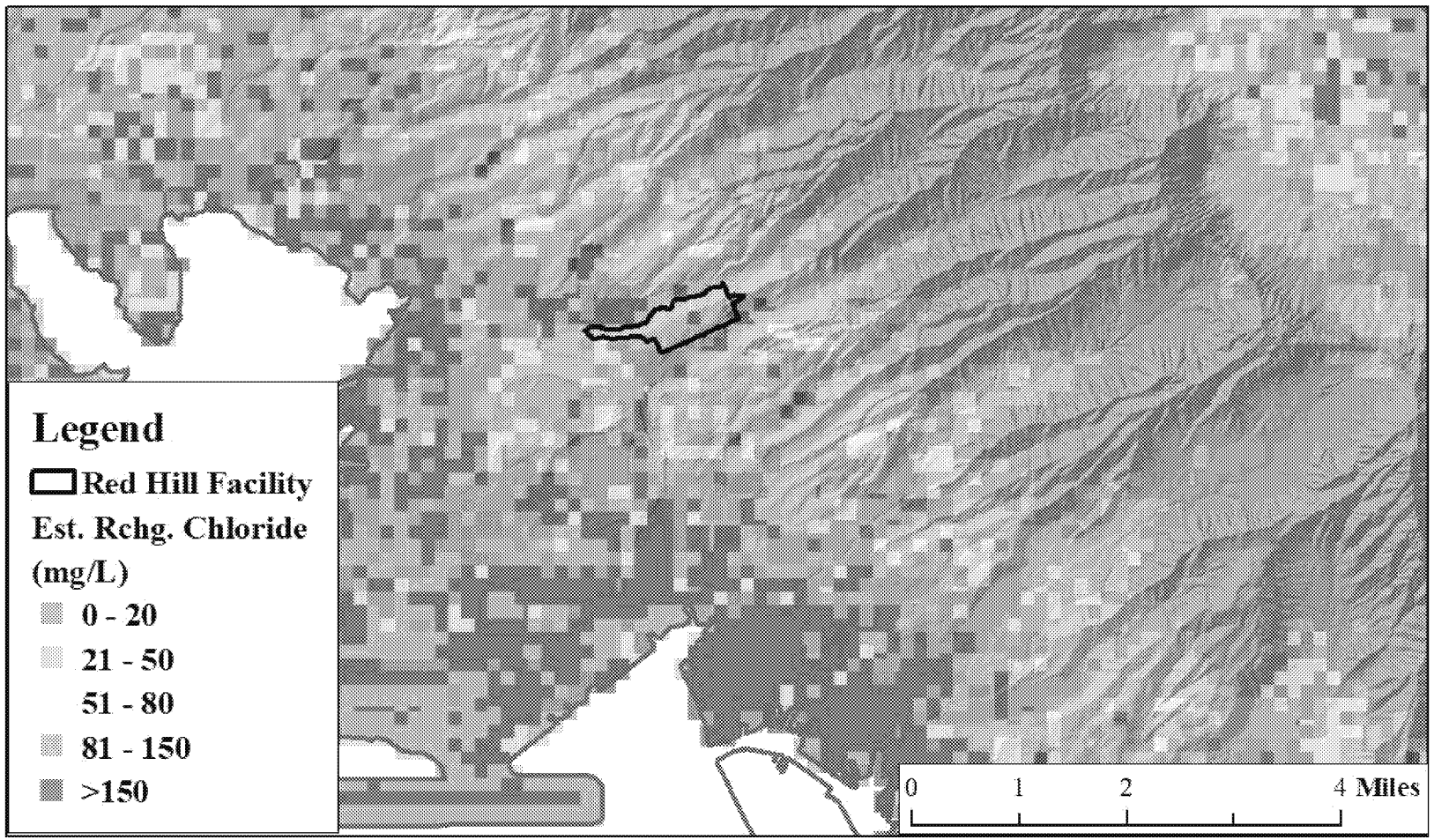
Additional Data – Natural tracers

9. Groundwater Data

Chemistry shows indication of a poorly mixed system

- Chloride conc. vary from ~40-
  >1000 mg/L
- Southeast very different from northwest
- Northwest chlorides still highly variable
- A large flux of groundwater down the Red Hill ridge should show better mixing

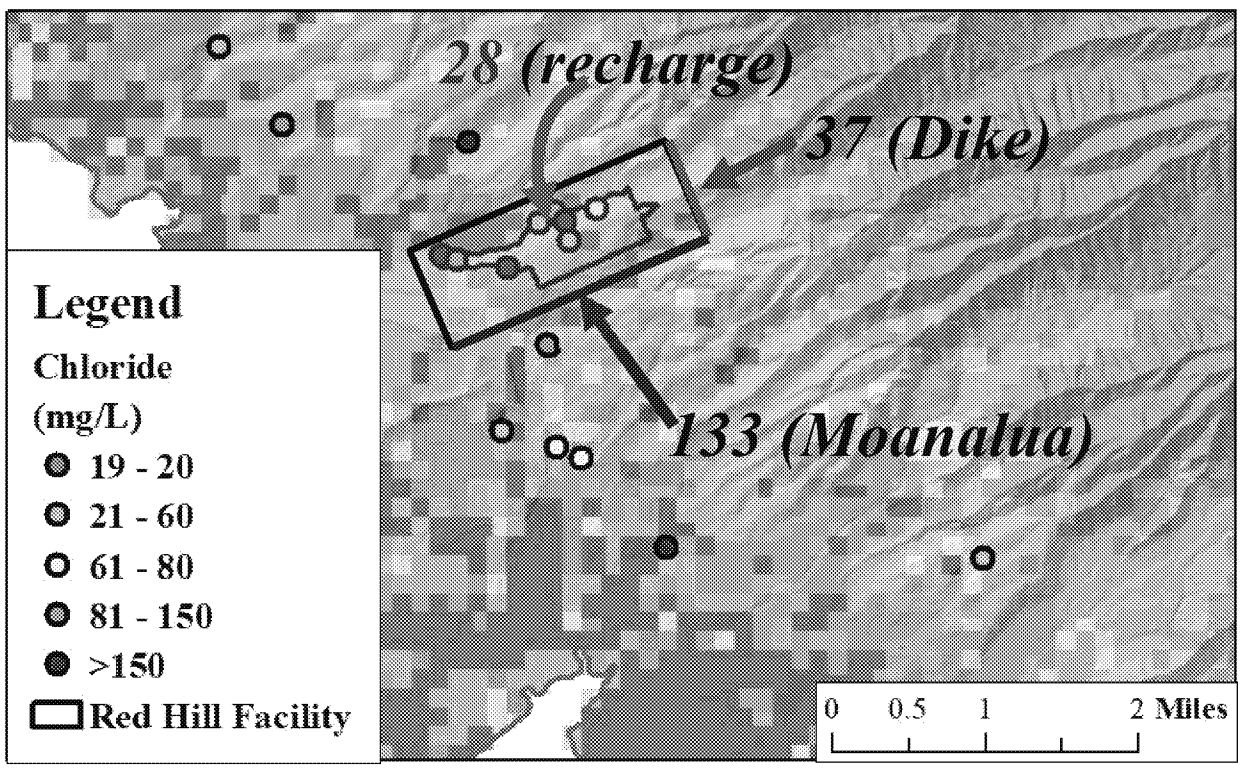
Estimated Chloride Conc. in Recharge

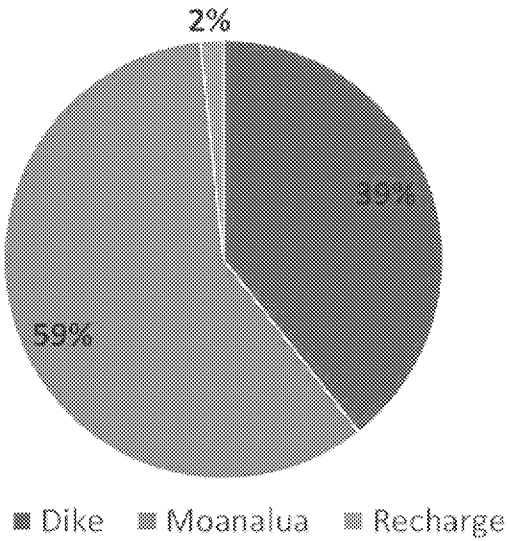


- Chloride in recharge estimated using the chloride mass balance approach
- Chloride concentration at the Facility <50 mg/L
  - Except for one pixel

Using Geochemistry to Refine Models
(without needing explicit CF&T simulations)

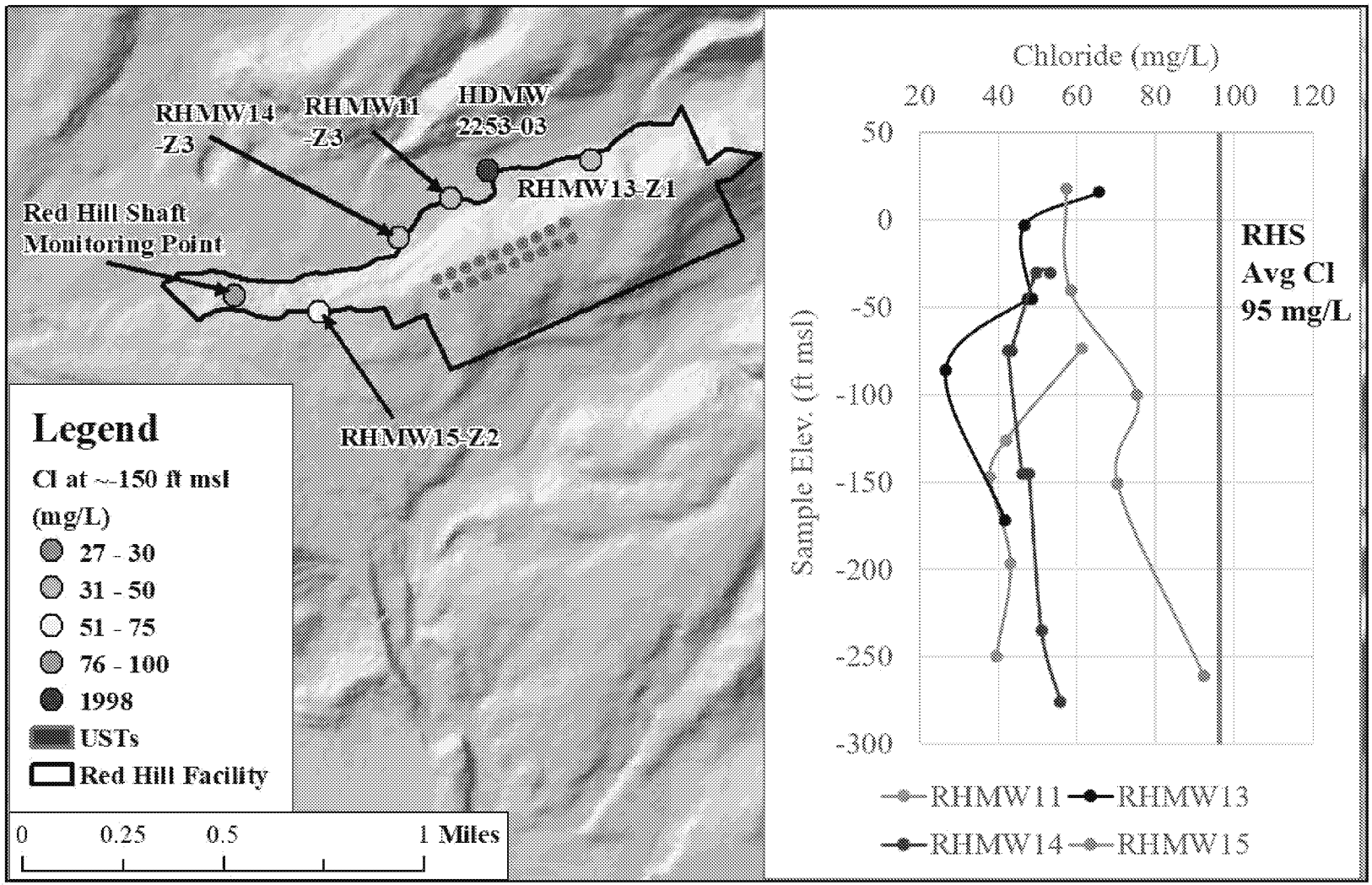
- Mixing Equation
  - $C_{mix}=(C_1*Q_1+C_2*Q_2+C_3*Q_3)/(Q_1+Q_2+Q_3)$
  - 93 mg/L = 2%*28 + 38%*37 + 59%*133
- Red Hill Shaft average chloride conc. ~ 95 mg/L
  - Chloride concentration is weighted Cl sum from the source areas





Numbers denote assumed chloride concentration

It is unlikely that chlorides originating in the Halawa region elevated the chloride concentration in the RHS



Application of model conclusions

13 **2.3.2 Overview of Preliminary Capture Zone Analyses**

14 The GWFM Report (DON 2020b) is published concurrently with this IRR Report. The GWFM Report
15 describes the various models that are part of the multimodel approach, including capture zone analyses
16 that pertain to each model (including certain variations for specific models). The reverse and forward
17 particle track analyses presented in the report are related only to potential groundwater flow relative
18 to the assumptions in a particular model, and do not relate to potential contaminant flow; contaminant
19 flow will be determined as part of the CF&T modeling effort. Certain conclusions based on model
20 capture zones and associated particle tracks are provided below:

21 • All available capture zones indicate that when Red Hill Shaft is pumping at slightly below its
22 permitted rate of [redacted] million gallons per day [mgd]) and Hālawa Shaft is pumping at slightly
23 above its permitted rate of 11.320 mgd, the Red Hill Shaft capture zone extends across the
24 entire tank farm. As such, potential releases from any tank would be contained in the Red Hill
25 Shaft capture zone.

- Investigation and Remediation of Releases Report; Page 2-18
- Issues previously discussed cast doubt on the assumption the Red Hill Shaft will contain the offsite migration of any contaminant plume
- The model results are currently not informative for developing release response plans
  - Questions regarding the ability of the RHS to capture a contaminant plume and the risk the Halawa Shaft remain unanswered

Further GWFM & CSM Review Items

DOH Technical Team:

Dr. Thomas & Rowland, UH
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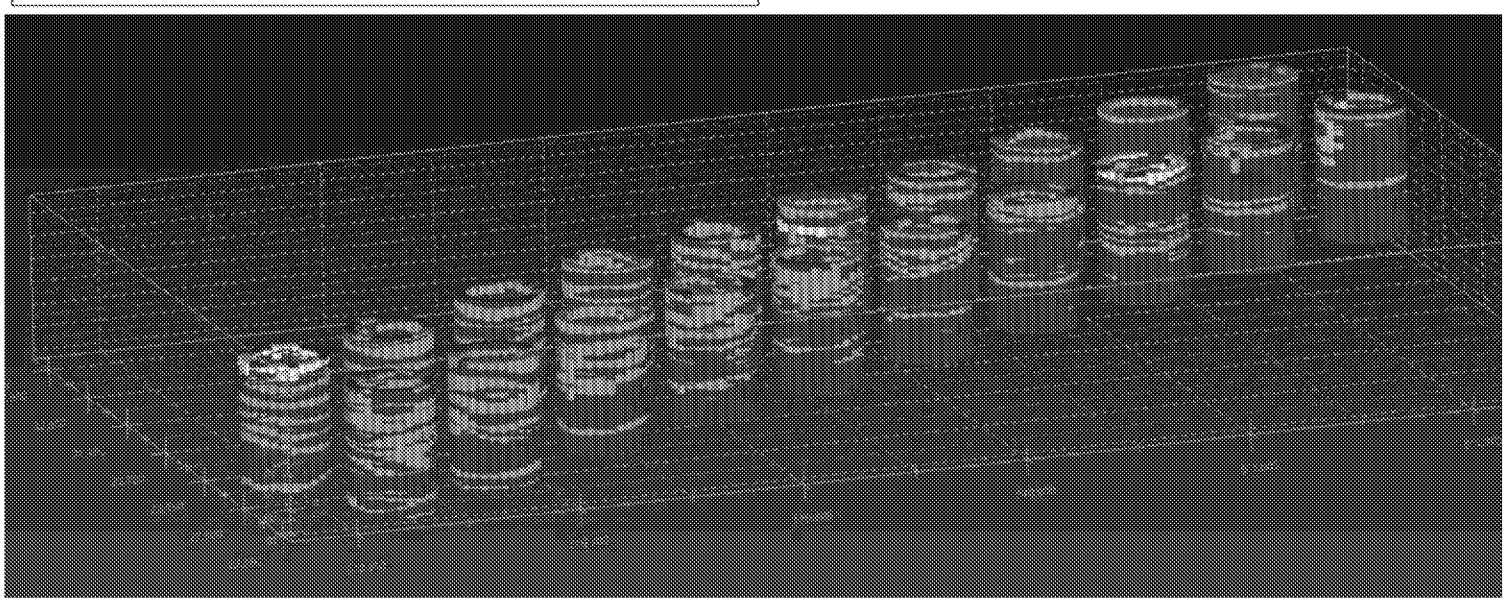
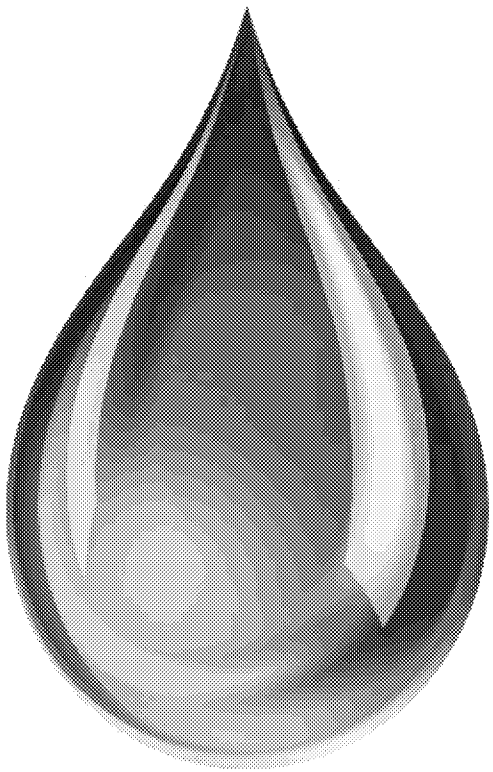
G.D. Beckett, C.Hg.
Anay Shende, DOH
Dr. Matt Tonkin, EPA (review)

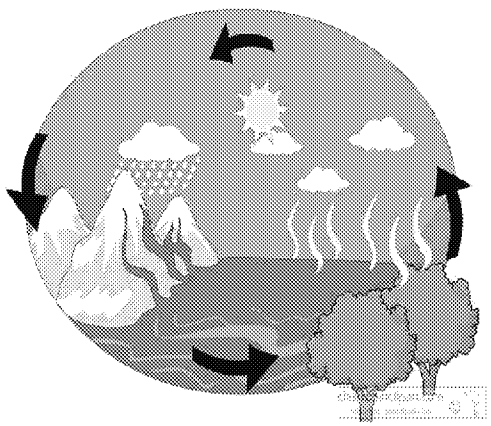


Key Groundwater Model Objective



- The purpose of this deliverable is to refine the existing groundwater flow model and improve the understanding of the direction and rate of groundwater flow within the aquifers around the Facility (AOC, 2015)
  - *To do this, the underlying hydrogeologic conditions must be refined and better understood in light of new data not available to prior modeling*

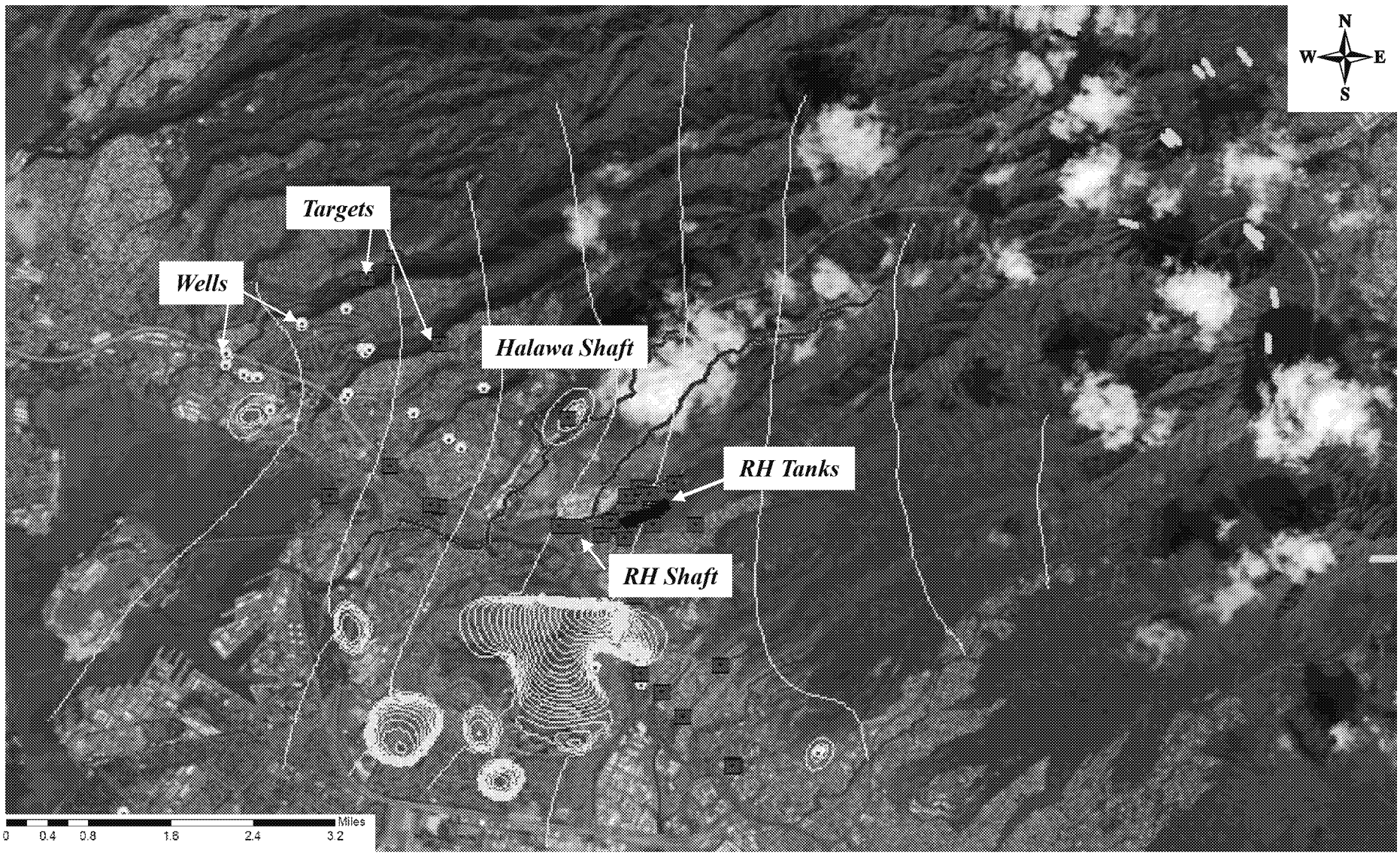
The Navy Has Delivered Multiple Models



- Key review questions:
  - Do the models represent local heads?
  - Gradients?
  - Transient aspects?
    - Pumping from Red Hill & Halawa shafts
    - Monitoring well response "groupings"
  - Do transient simulations better past models?
  - Are models consistent with geochemistry?
    - And with dissolved-phase patterns?
  - Are models parameters appropriate?
- Will the model(s) inform risk estimates?
  - Most uncertain aspect is NAPL
    - Where is it presently & in what state?
    - How far/fast could releases travel?
  - What are the key processes?
  - Are those adequately described & demonstrated?

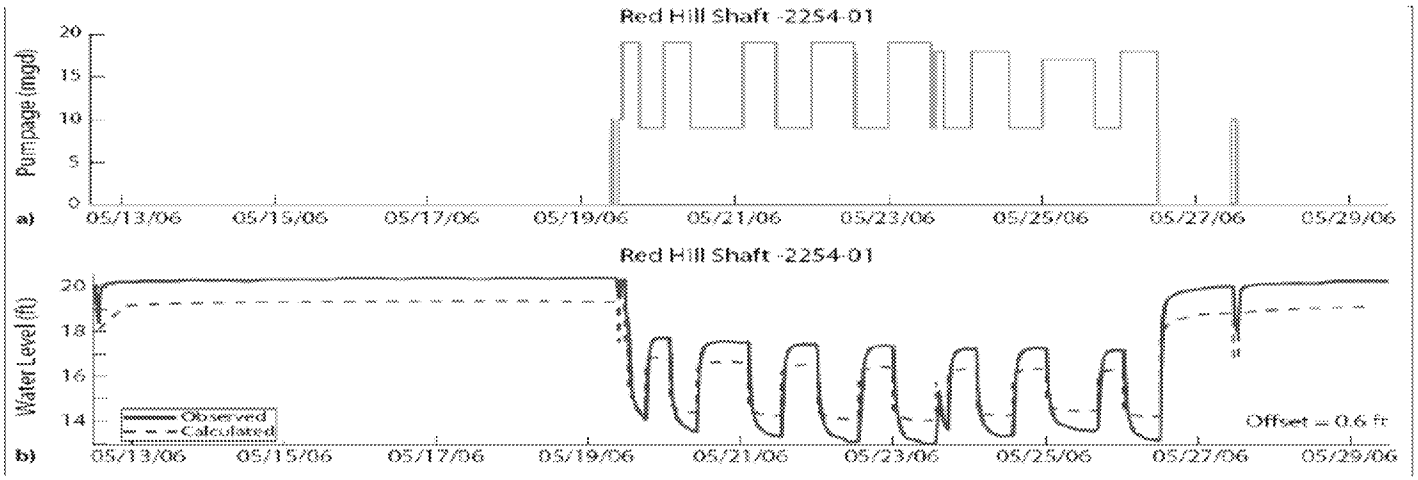
General Area/Model Map

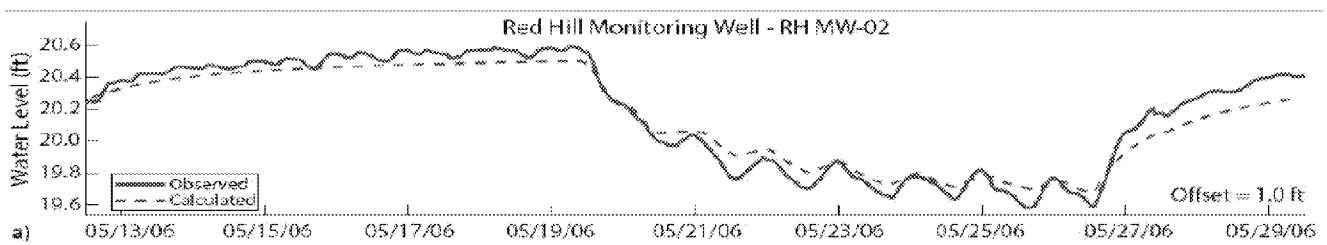
(Halawa Shaft On, RH Shaft Off)

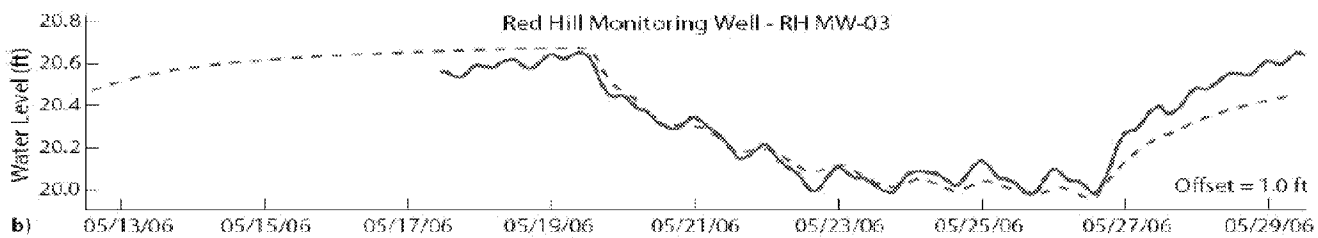


The Primary Issue with the Prior Model

(calibrated to drawdown, but not to heads; complexity)



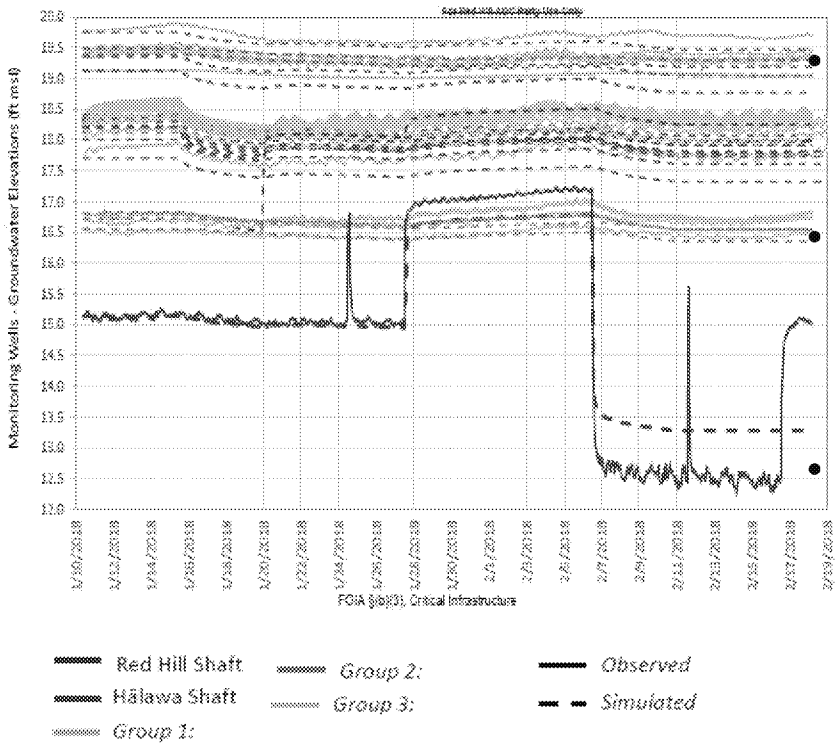




Kolja Rotzoll and Aly I. El-Kadi, 2007

Objectives of Verification Models

(GWFMs apparent mismatch to g.w. elevations)



Abbreviated legend

Figure 5.1.1-7, Redacted GWFM Rept, Mar 2020

Verification means just that
- A "blind" test of the GWFMs predictions
- How well do they agree with elevation data?

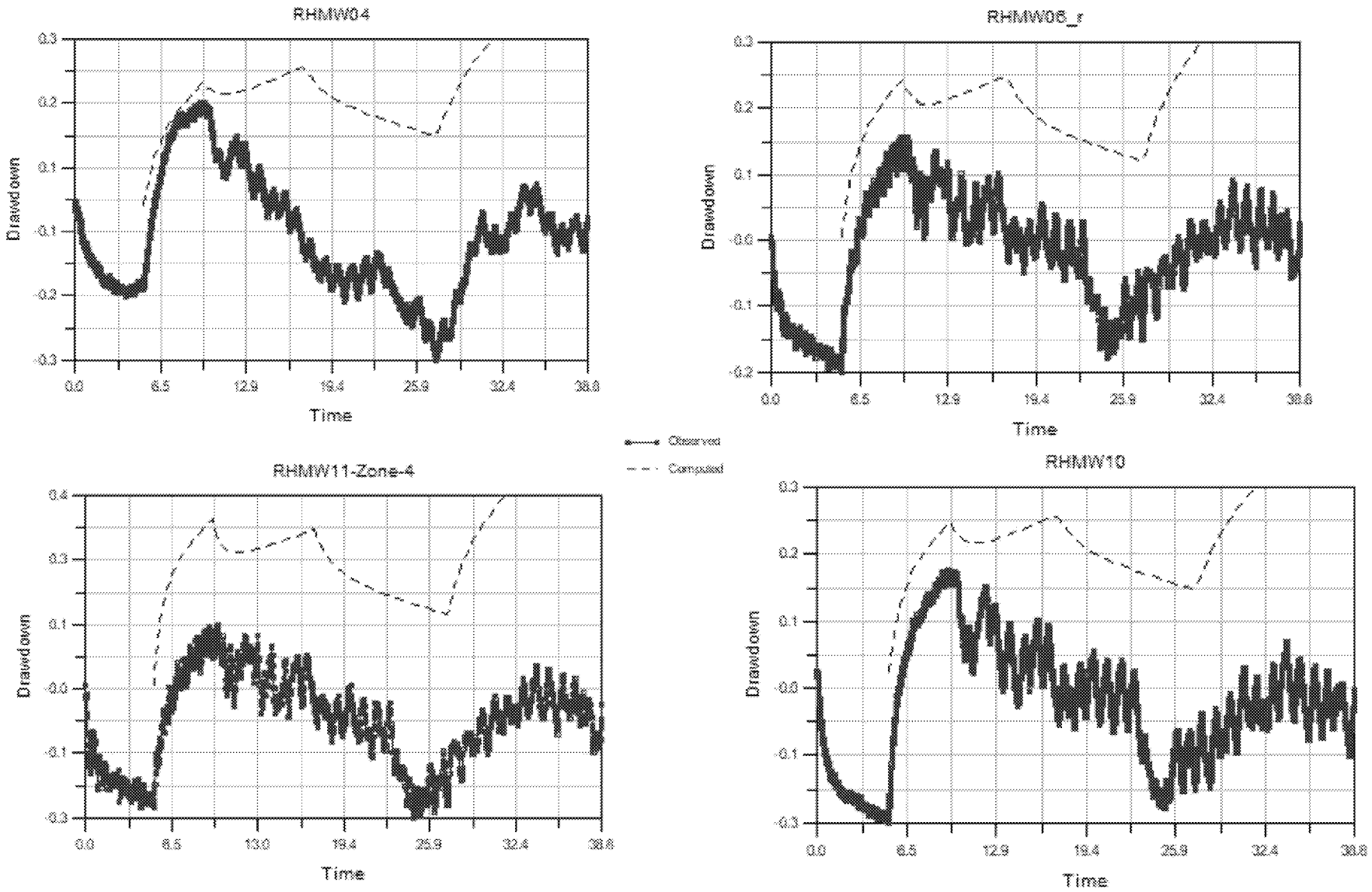
How is this typically implemented?
- Calibrate main models
- Run against site data from another time
- See how well each model reflects the data

Purpose
- Identify deficiencies in main models
- Identify which are "best fits"
- Consider transient implications
- Consider compartmental responses (& others)

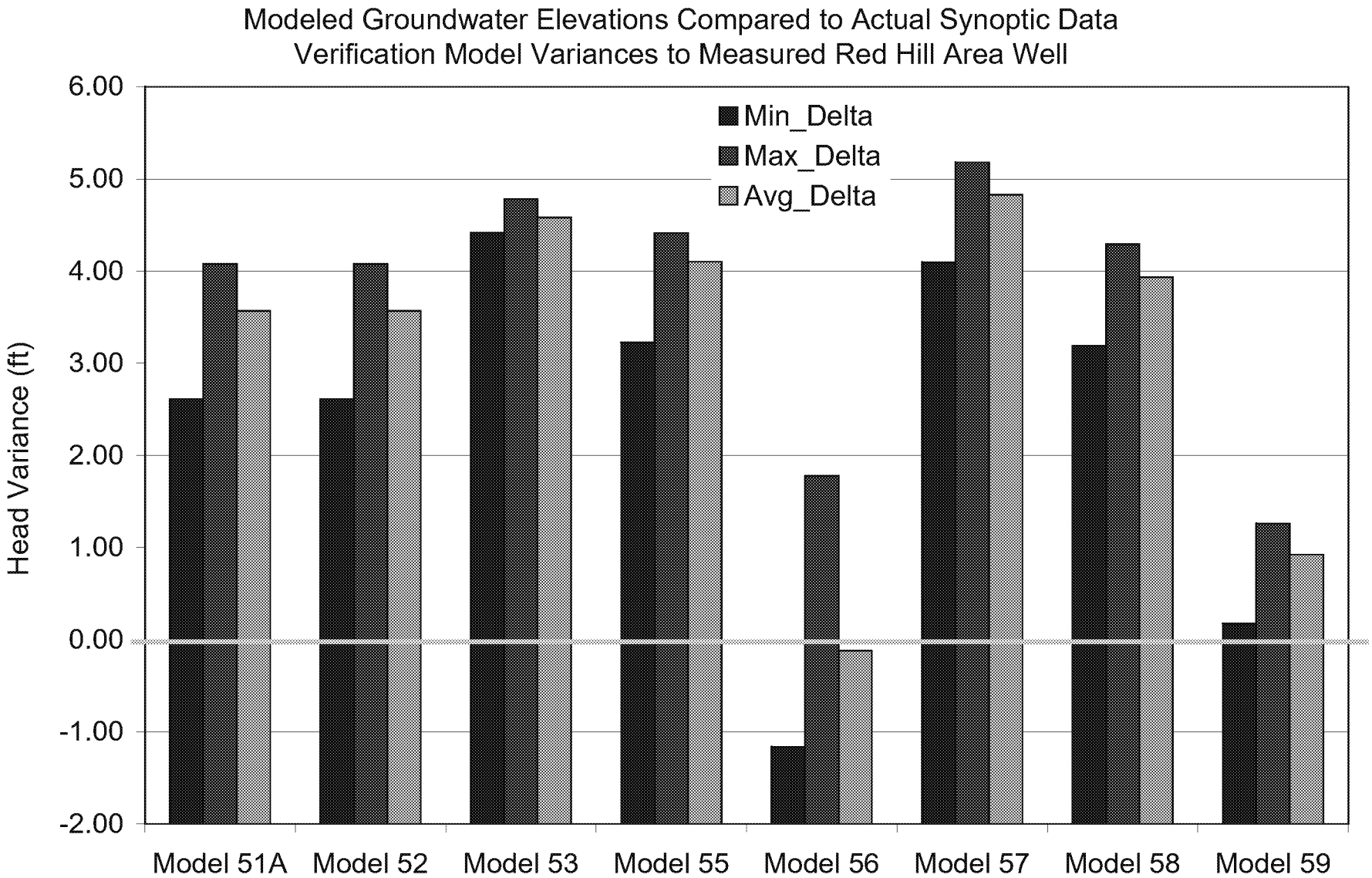
- Issue, we cannot replicate the reported results
  - Plots do not agree with modeled output
  - May be a superposition (drawdown upon measured)
- The g.w. elevation offset was prior model issue
  - Recall primary AOC objective

Example Hydrographs; M51a Verification

(charts are direct model output – GWV)

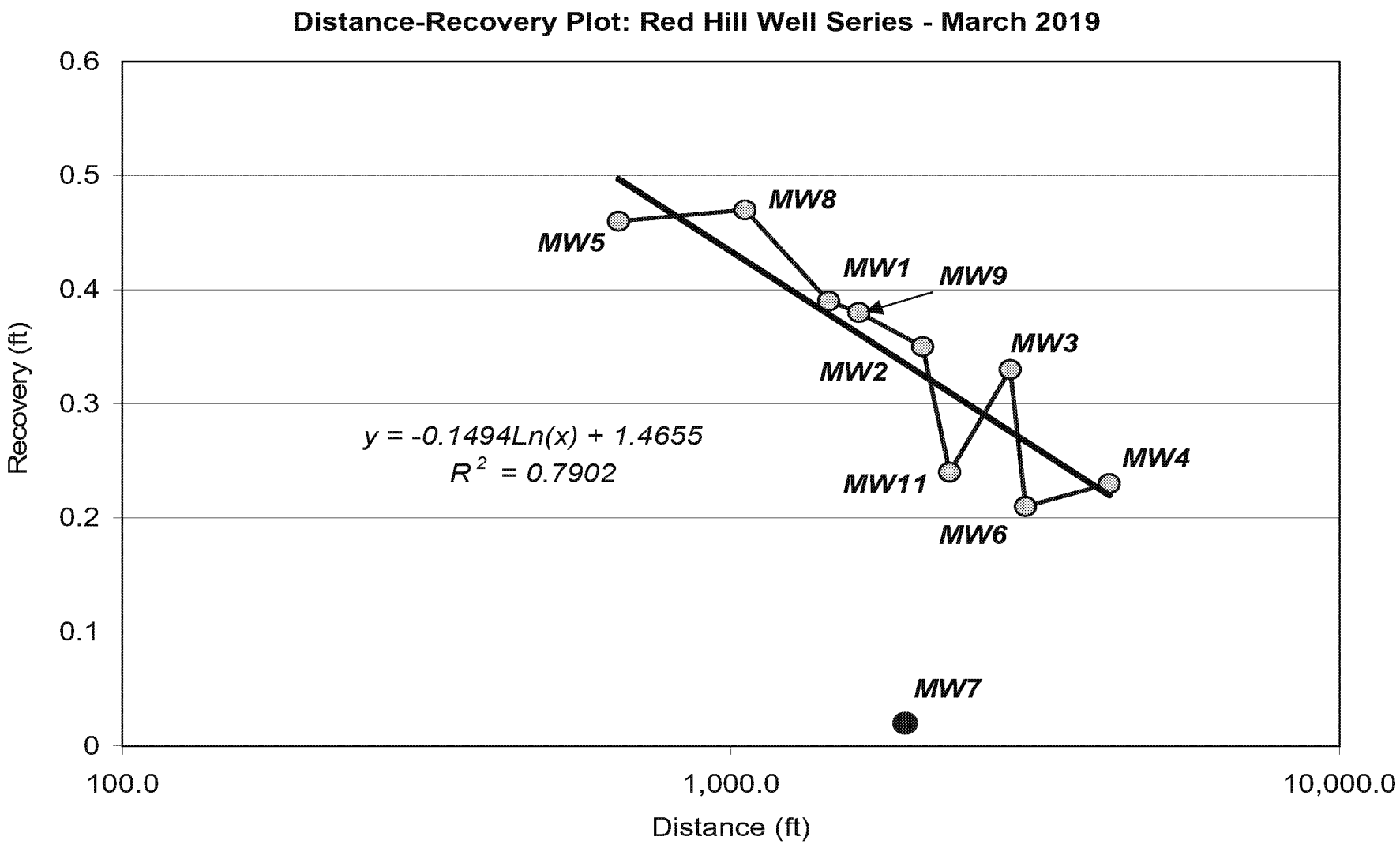


GW Elevation Variance – Transient Models



Non-Uniform Distance Drawdown Behavior

(indicates complexities not captured by models)

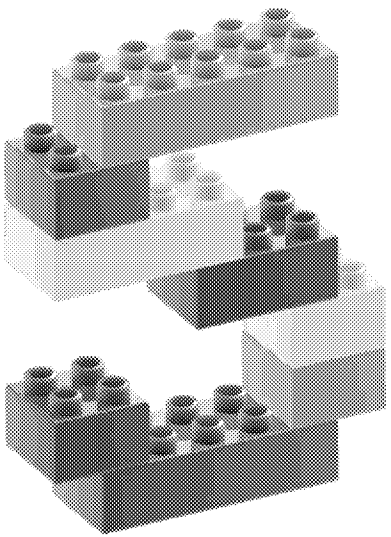


Prior Key Parameters v. Navy Models

(ranges are inconsistent & w/o explanations)

	Oki, 2005			Navy GWFM - avgs		
Hydrostratigraphic Unit	Kv	Kt	Kl	Kv	Kt	Kl
Volcanic-rock aquifer	7.5	1,500	4,500	65	1,000	2,999
Caprock, upper-limestone unit	25	2,500	2,500	0.01	500	500
Caprock, low-permeability unit						
Above Waianae Volcanics	0.3	0.3	0.3	0.01	1	1
Above Koolau Basalt, west of Waiawa Stream	0.01	0.01	0.01	0.01	1	1
Above Koolau Basalt, east of Waiawa Stream	0.6	0.6	0.6	0.01	1	1
Valley-fill barriers	0.058	0.058	0.058	0.01	1	1

Key Model Review Observations



- GWFMs do not match heads, diminishing reliability
  - Particularly in transient verification runs
  - Similar issue as in prior modeling (2007)
- GWFMs use atypical parameters for Hawaii aquifer
  - If retained, in-depth justification needed
- GWFMs do not use CSM geologic details – SSPA work
  - Impact of heterogeneity needs detailed evaluation
- GWFMs do not comport with natural g.w. tracers
  - Complex distributions may imply multiple source waters
- GWFMs capture zones not supported by field data at pumping rates similar to those modeled
  - Approaches used may overestimate capture potential
  - Gradient issues & complexity not covered
- The current GWFMs are not reliable for decisions
  - For CF&T, risk analyses and mitigation decisions
- Modifications will be needed (SSPA work follows)

Ongoing Issues with the Navy CSM

The CSM being the fundamental basis for the Navy GWFMs, future CF&T/Risk Evaluations and the overall key conditions at the Red Hill Bulk Fuel Storage Facility

The Hawaii Hard Rock Release Experience

Source: Don Thomas, 2021

- Fuel releases often move quickly
  - Typically in complex pathways
    - Primary & secondary transport
  - Often difficult to characterize
- Fast-track/other geologic features exist
  - Lava tubes, voids, fractures, clinkers
  - Confining beds & non-volcanics
  - Preferred & random orientation scales
  - Often sparse distribution, large effect
- Weathering of rock is complex
  - Bulk rock properties may not apply
- For Red Hill
  - How is the architecture arranged?
  - How will fuel behave within that?
  - Effects on capture/remediation?
  - All relates to g.w. protection goals
    - And sole source aquifer preservation

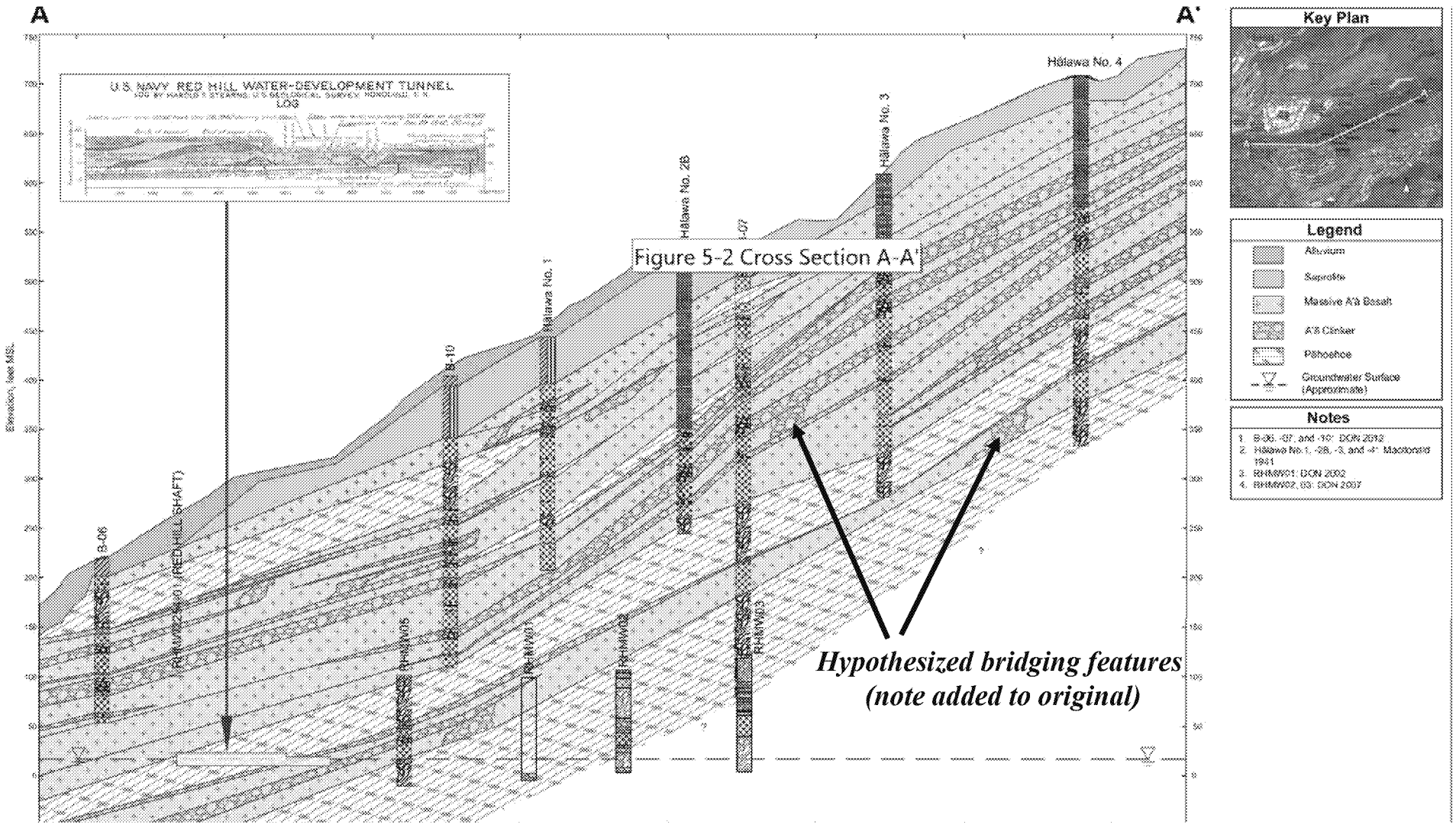
Overview – Unresolved CSM Issues

Source: Dr. Scott Rowland, 2021

- Red Hill is under-characterized
  - Compared to similar sites
  - Results in high uncertainty in the CSM
- Complex geology is noted in CSM
  - But, simplified in GWFMs
  - Insufficient basis for appropriate CF&T
  - G.W. & CF&T behavior appears more complex
- Data indicate TPH beyond RH Ridge
  - CSM interprets these as artifacts (generally)
- CSM interprets LNAPL migration to SW
  - But available data indicate otherwise
- CSM indicates fuel retained ~ 30-ft depth
  - Not supported by available data
- Fuel retention characteristics are unknown
  - Fuel/NAPL parameters inapplicable
  - Geometry unconstrained by data
  - Dynamics are critical to g.w. protection
- Many other issues remain
- In total, CSM is not reliable for g.w. protection

Example Navy CSM Cross-Section

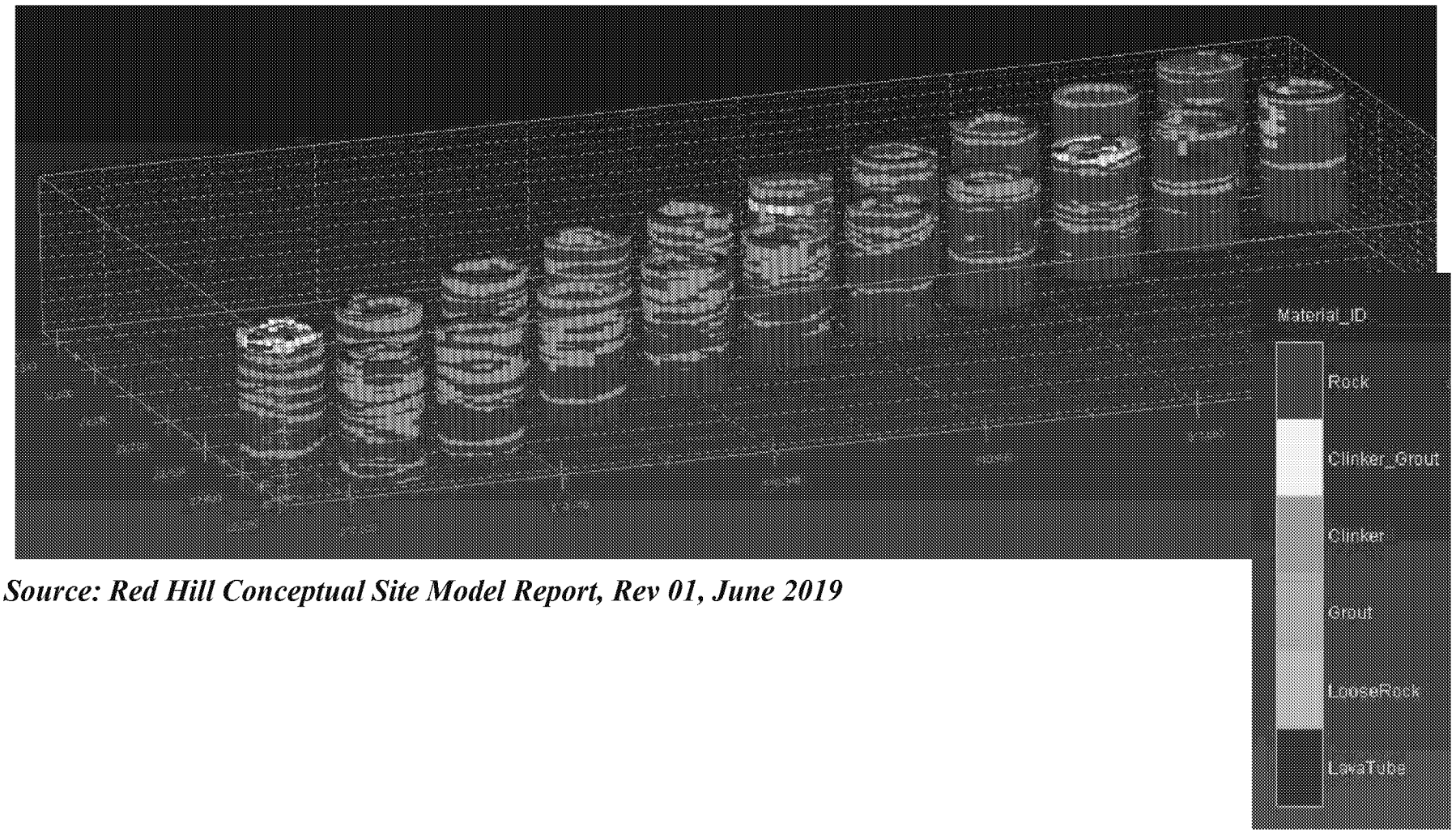
(schematic rendering, but details are not in GWFMs)



Source: Red Hill Conceptual Site Model Report, Rev 01, June 2019

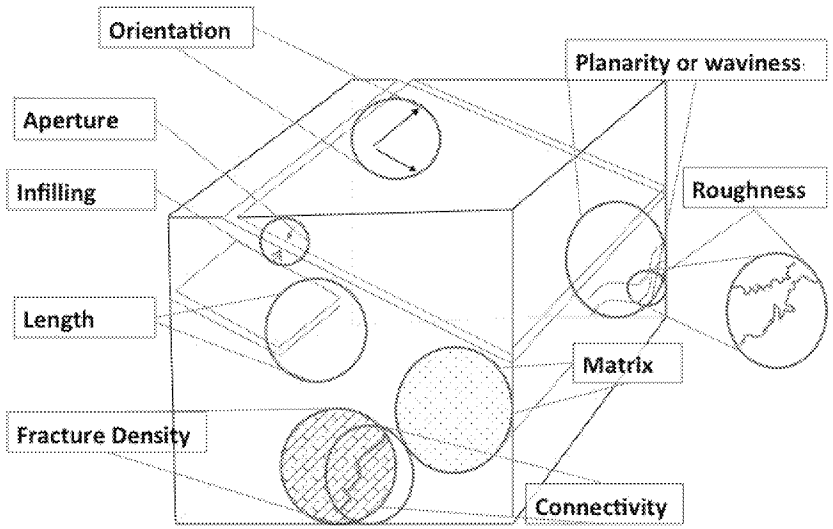
Navy 3D Lithologic Model – Barrel Logs

(same issue, Dr. Tonkin will address)

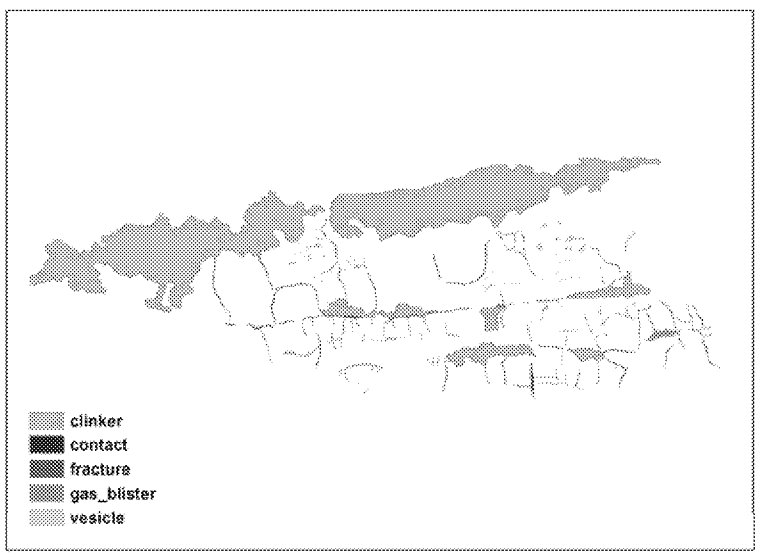


Source: Red Hill Conceptual Site Model Report, Rev 01, June 2019

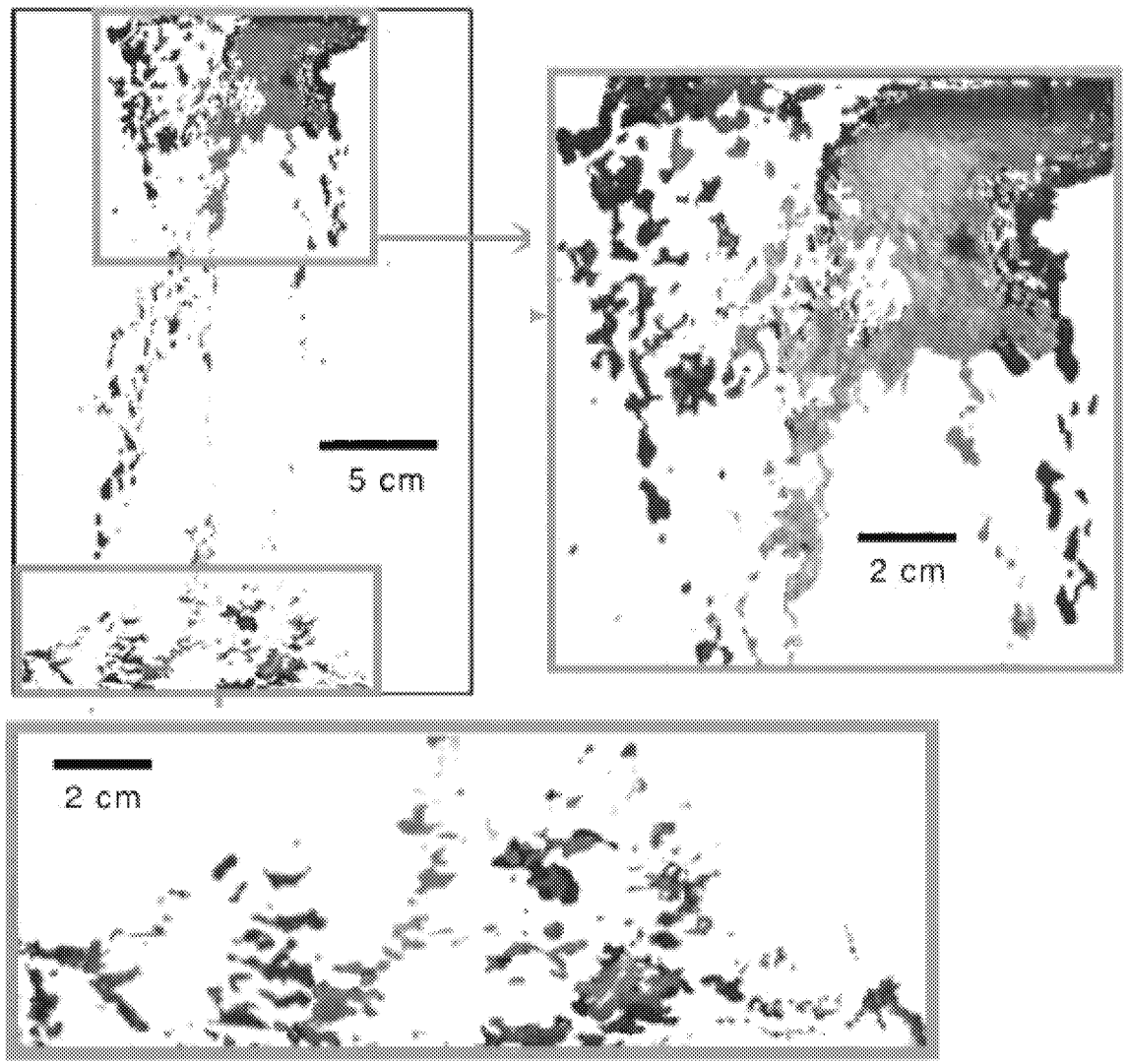
Outcrop Interpretation – Dr. Scott Rowland (UH)



Source: ITRC, 2017



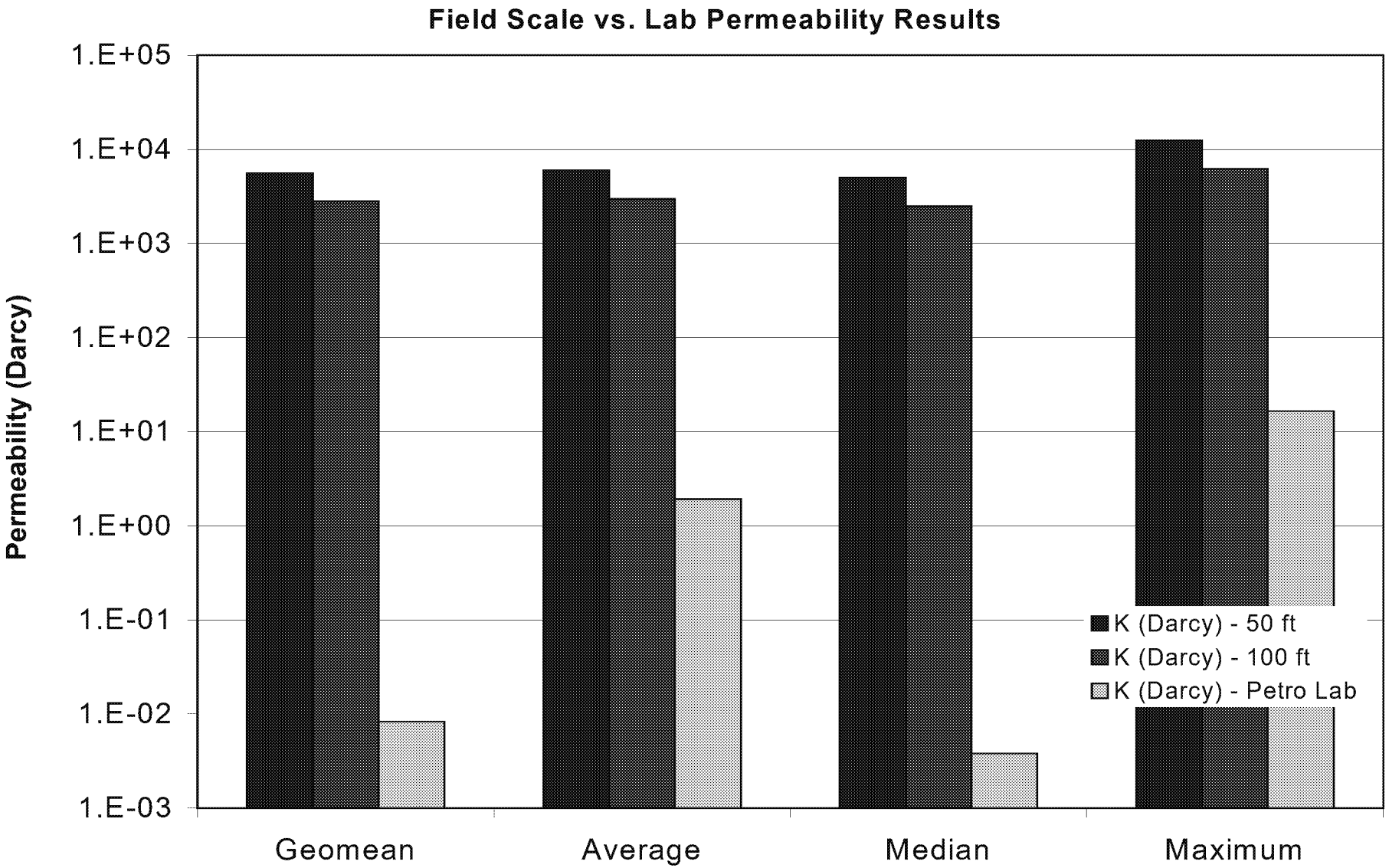
Complex NAPL Distribution in a Fracture



Geller et al., 2000

Lab vs. Field Scale – Permeability

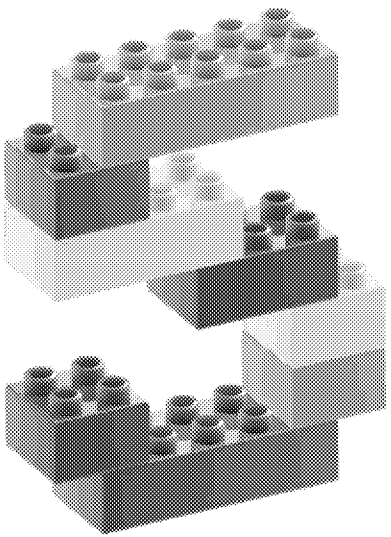
(Site lab data are not comparable to field scale)



Data source: Conceptual Site Model, June 2019, Rev 01

Summary of CSM Review (to date)

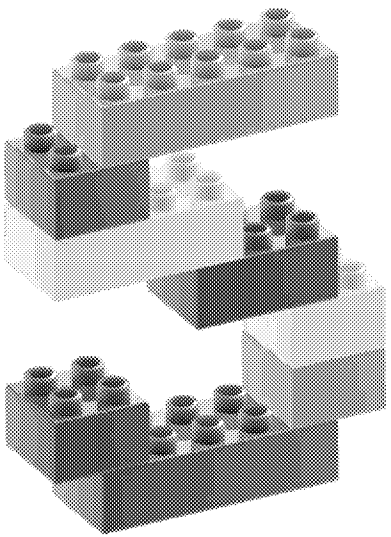
(broad issues, other details pertain)



- Issues have been ongoing, unresolved by new data
  - Or interpretations unconstrained by available data
- The site is not well characterized – (safety concerns)
  - Fate of 2014 & 2021 releases are undelineated
  - Data suggest fuel has reached the water table under RH
- Geologic complexity noted in CSM
  - But not explored at the needed level of detail
  - No assessment of EPM scale or applicability
- Groundwater flow paths and behavior is uncertain
- Distal detections are considered generally valid
  - Reported by certified labs & independently validated
  - There is TPH-range mass in GCs
  - Detections are consistent with other data/patterns
- NSZD rates are likely overestimated & uncertain
  - RHMW03 & RHMW01, net thermal profiles, no NAPL
  - Plume size and character likely larger than estimated
- The whole of the RH Tank Farm has likely had releases
  - CSM does not account for long & variable fuel history
  - And those implications for CF&T/risk/mitigation

Implications of CSM Concerns

(relative to groundwater protection matters & TUA)



- G.W. capture of releases is not demonstrated
  - By field data or adequately by GWFMs
- NSZD may not be reliable as a cleanup method
  - RHMW03 interpreted impacts remain > 20 yrs
- G.W. protection depends on several factors
  - How fuel migrates under release conditions
  - Speed and effectiveness of release detection & actions
  - Cannot be addressed by GWFMs alone
- Capture may not be an appropriate G.W. remedy
  - Fuel migration & remedy must be aligned
  - Capture is not a cleanup method – relies on uncertain NSZD
  - ***<u>However, g.w. treatment may protect water services</u>***
- Red Hill Shaft is indicated to be at risk from releases
  - Proximity & low-level TPH detections (including July 2021)
  - Dilution & NSZD make this both surprising & concerning
- Risk evaluations must be connected to a conservative CSM
  - Presently, there is insufficient conservatism in the CSM
  - Along with high uncertainty that is not addressed