GROUNDWATER MODELING WORKING GROUP MEETING NO. 14

RED HILL BULK FUEL STORAGE FACILITY

MARCH 15, 2019

MODELING OBJECTIVES, INTENT, AND ISSUES & ACTION ITEMS

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NAVY'S MODELING OBJECTIVE

The objective of groundwater modeling is to help ascertain potential risk to water supply wells as a result of a potential range of releases from the Red Hill Bulk Fuel Storage Facility under a range of reasonably conservative pumping conditions within the model domain. The results of this modeling effort will then be used to:

1. Inform decisions related to the Tank Upgrade Alternatives (TUA), and
2. Inform decisions related to potential remedial alternatives

Pursuant to the Administrative Order on Consent Statement of Work Section 6, Investigation & Remediation of Releases, and Section 7, Groundwater Protection and Evaluation

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GROUNDWATER MODELING WORKING GROUP INTENT

The intent of the GWM Working Group is to support the Navy's objectives relative to developing timely and technically defensible groundwater flow and contaminant fate & transport (F&T) models for Red Hill.

- Technical feedback from Subject Matter Experts (SMEs) for consideration by the Navy on key elements of model development
- Provide assistance in ensuring that all appropriate data are considered in development of the model
- Provide assistance in collecting relevant data

The GWM Working Group focus is on the deep technical issues related to technically defensible model development

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REGULATORY AGENCIES' CONCEPTUAL SITE MODEL TECHNICAL COMMENTS

CURRENT SCHEDULE FOR OCTOBER 2019 GROUNDWATER FLOW MODEL

2019:	Tasks:
Feb	• TFN/Synoptic Data Analysis/Calibration Curves • Development of Saprolite Variants for the Model Grids • Integration of Regional Geology (e.g. Saprolite, Tuffs, Basalt, VF, etc.) into the Refined Grid System • Development of Model Grids
Mar	• Sensitivity Analyses • Selection of Alternate Model Scenarios (Sensitivity Parameters) • Volumetric Budgets • Calibration to Synoptic and TFN (Including Alignment) • Steady State Calibration • Development of Pearl Harbor and Offshore Flow Boundaries
May	• Write Draft GW Flow Model Report
Jun	• Complete Draft Report
Jul	• Presentation of Draft Deliverable Content to the Regulatory Agencies • Regulatory Agencies to provide Responses to Draft Deliverable Content
Oct	• October 2019 GW Flow Model Report to Regulatory Agencies (October 5)

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CONCEPTUAL SITE MODEL UPDATE: HYDROGEOLOGY CONSIDERATIONS

CSM UPDATE – HYDROGEOLOGY CONSIDERATIONS:

GEOLOGY

RESPONSE TO AOC PARTIES' TOP 10 COMMENTS:
CONCERNS WITH THE INTERIM CSM

Comment	Response
1. Predominant strike and dip of basalt in the geologic model	Following a site visit between the Navy and DOH on November 28, 2018, the AOC Parties agreed upon 213.6 degrees as the dip azimuth and 2.9 degrees for the dip magnitude. This orientation is being incorporated into a new flow model grid and will also be used for further evaluation of potential LNAPL migration. Additionally, the Navy may conduct an initial sensitivity analysis for a dip azimuth of 184.6 degrees with a dip magnitude of 5.9 degrees, since there is inherent variability in basalt flows as evidenced by the bimodal distributions observed as part of the geologic study.

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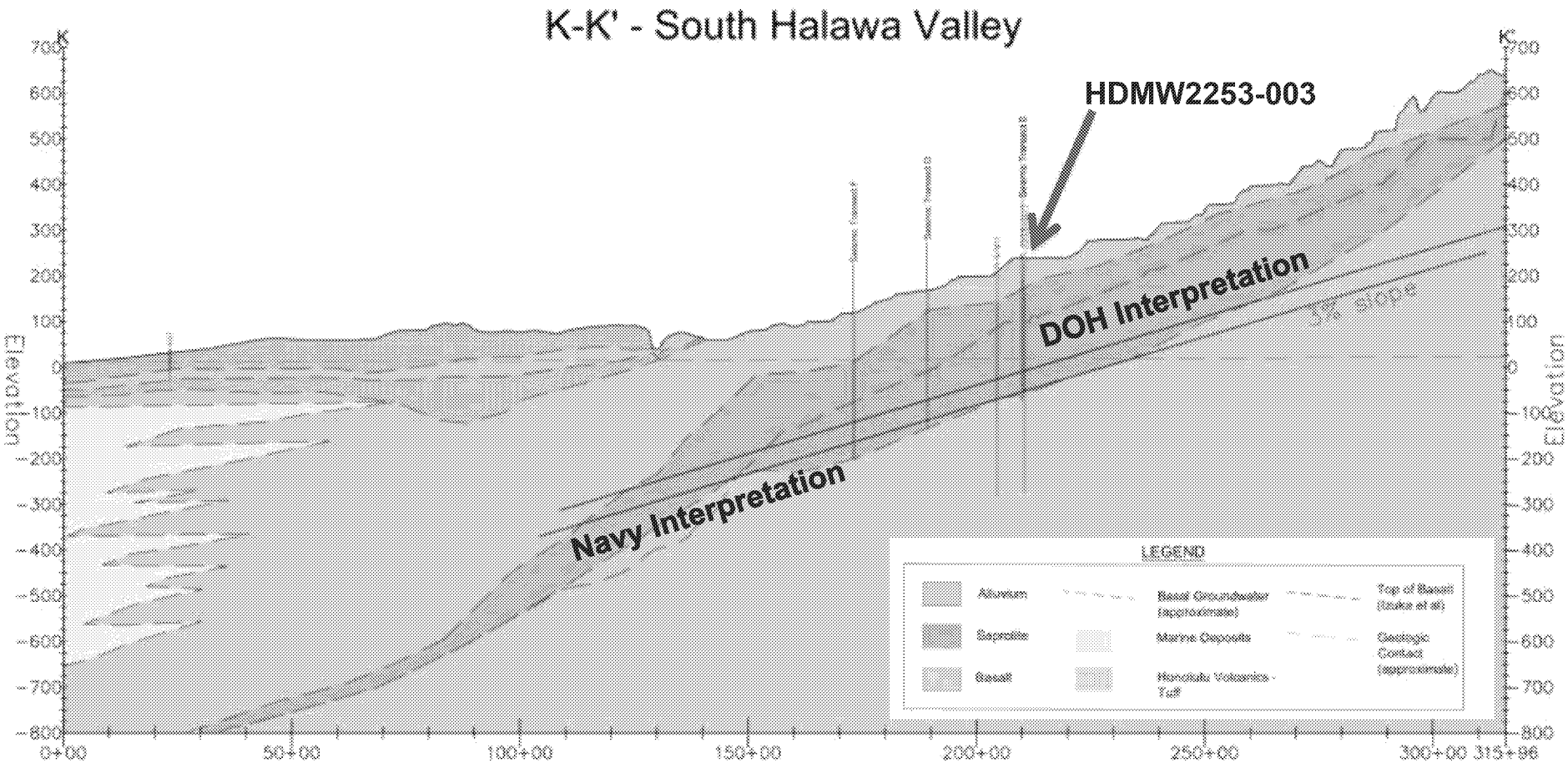
RESPONSE TO AOC PARTIES' TOP 10 COMMENTS:
CONCERNS WITH THE INTERIM CSM (CONT.)

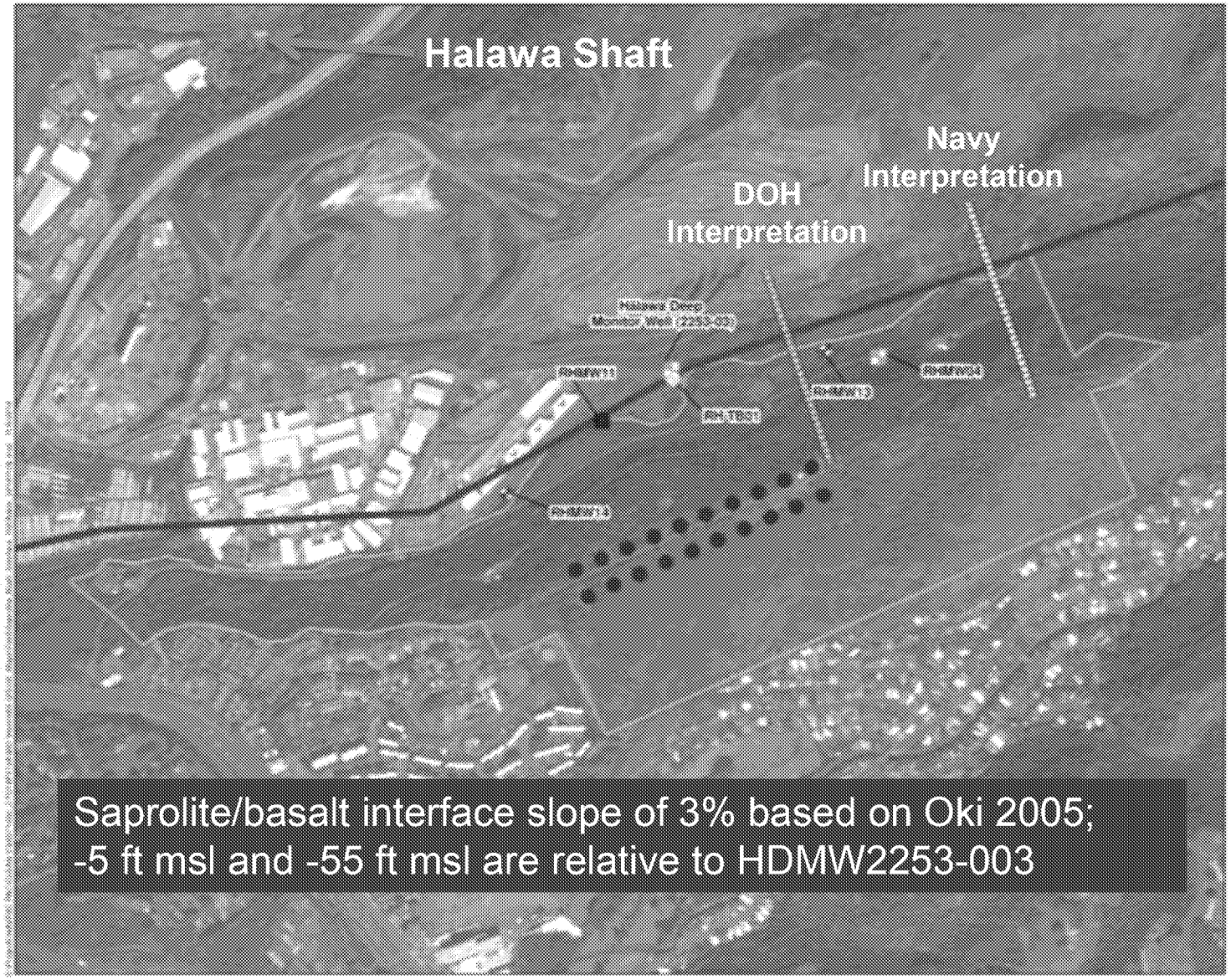
Comment	Response
2. Saprolite extent in the interim model vs. depths inferred by seismic profiling	The Navy has developed a 3-D geologic model that describes the lateral and vertical extent of saprolite (as well as caprock, marine sediments, tuffs, and basalt) in the vicinity of Red Hill. This model is based on (a) the seismic study conducted by Boise State University (Dr. Lee Liberty), (b) previous geologic studies in the area, and (c) interpretation of boring logs from key well locations within the area. The Navy has discussed two different interpretations of the Halawa Deep Monitoring Well (2253-03) boring log for the saprolite/basalt interface with the AOC Parties: (1) DOH's -5 ft msl and, (2) the Navy's interpretation of -55 ft msl. The Navy extrapolated where each pick would cross the air/groundwater interface (piezometric surface) of the regional basal aquifer in South Halawa Valley by projecting the base of saprolite up valley using a 3% slope, which is based on the Oki 2005 estimated projection. The Navy is developing two saprolite models to represent conditions in South Halawa Valley. The Navy will use their interpretation of the saprolite model, and will evaluate the model's sensitivity to the DOH interpretation. Drilling is ongoing in South Halawa Valley, and more is planned. If new data are not available by the time the October 2019 model is developed, the Navy plans to use the more conservative interpretation of saprolite geometry for groundwater flow modeling.

SAPROLITE EXTENTS

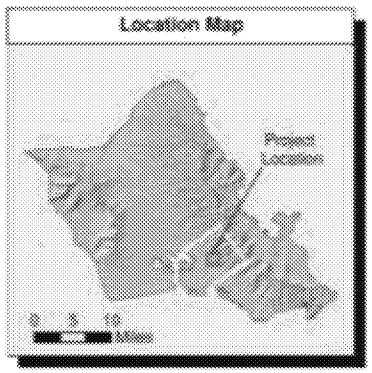


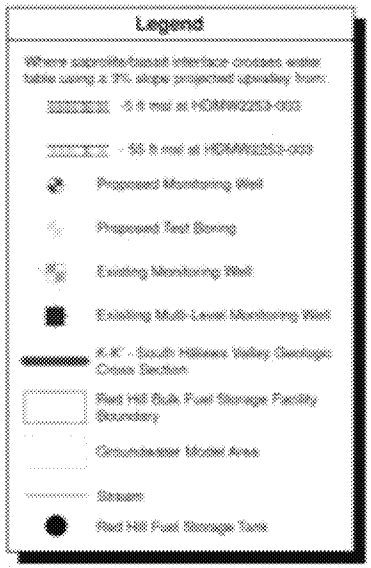
Saprolite/basalt interface slope of 3% based on Oki 2005;
-5 ft msl and -55 ft msl are relative to HDMW2253-003

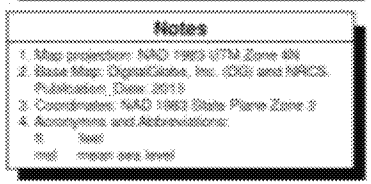
SAPROLITE EXTENTS



Saprolite/basalt interface slope of 3% based on Oki 2005;
-5 ft msl and -55 ft msl are relative to HDMW2253-003

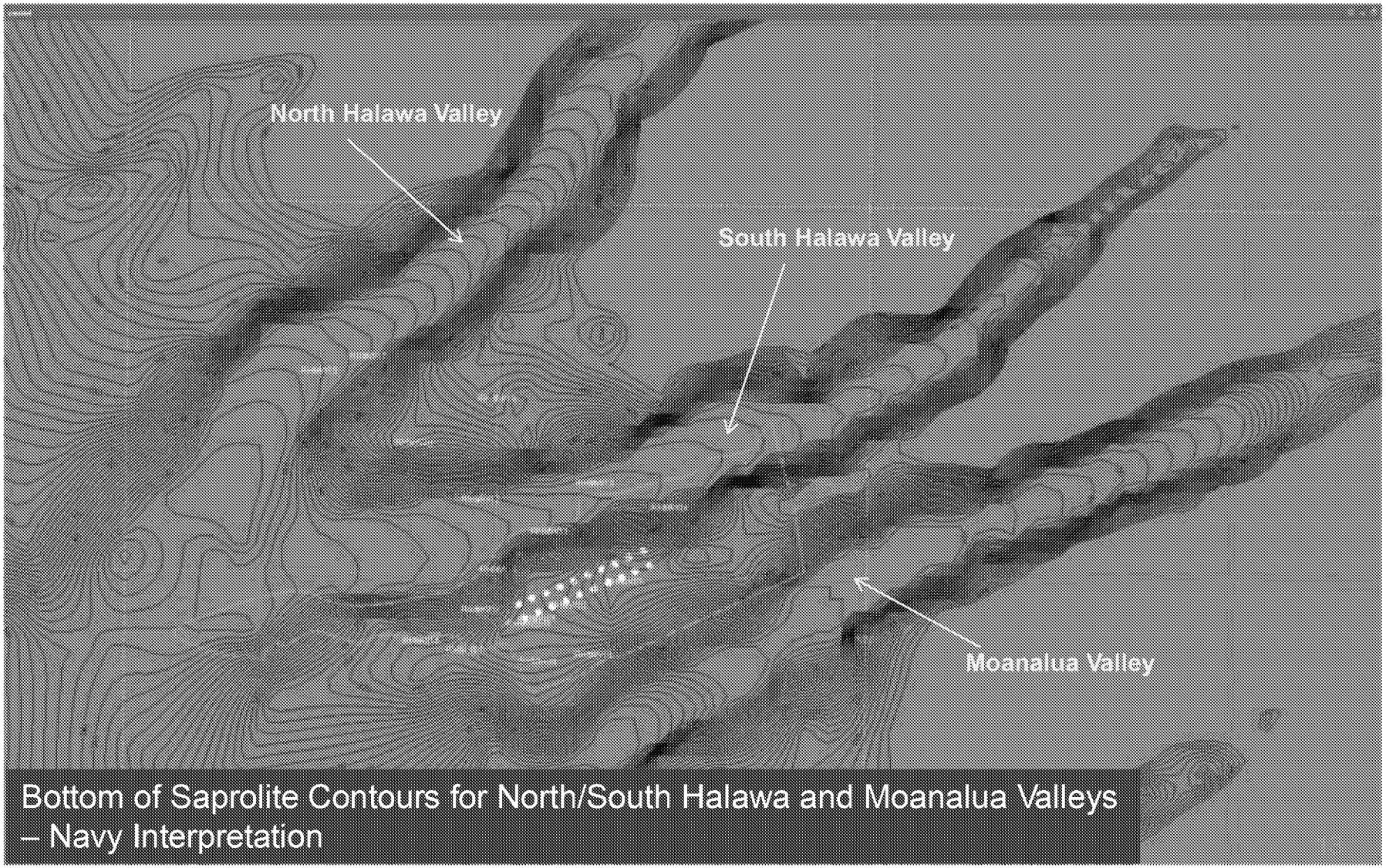






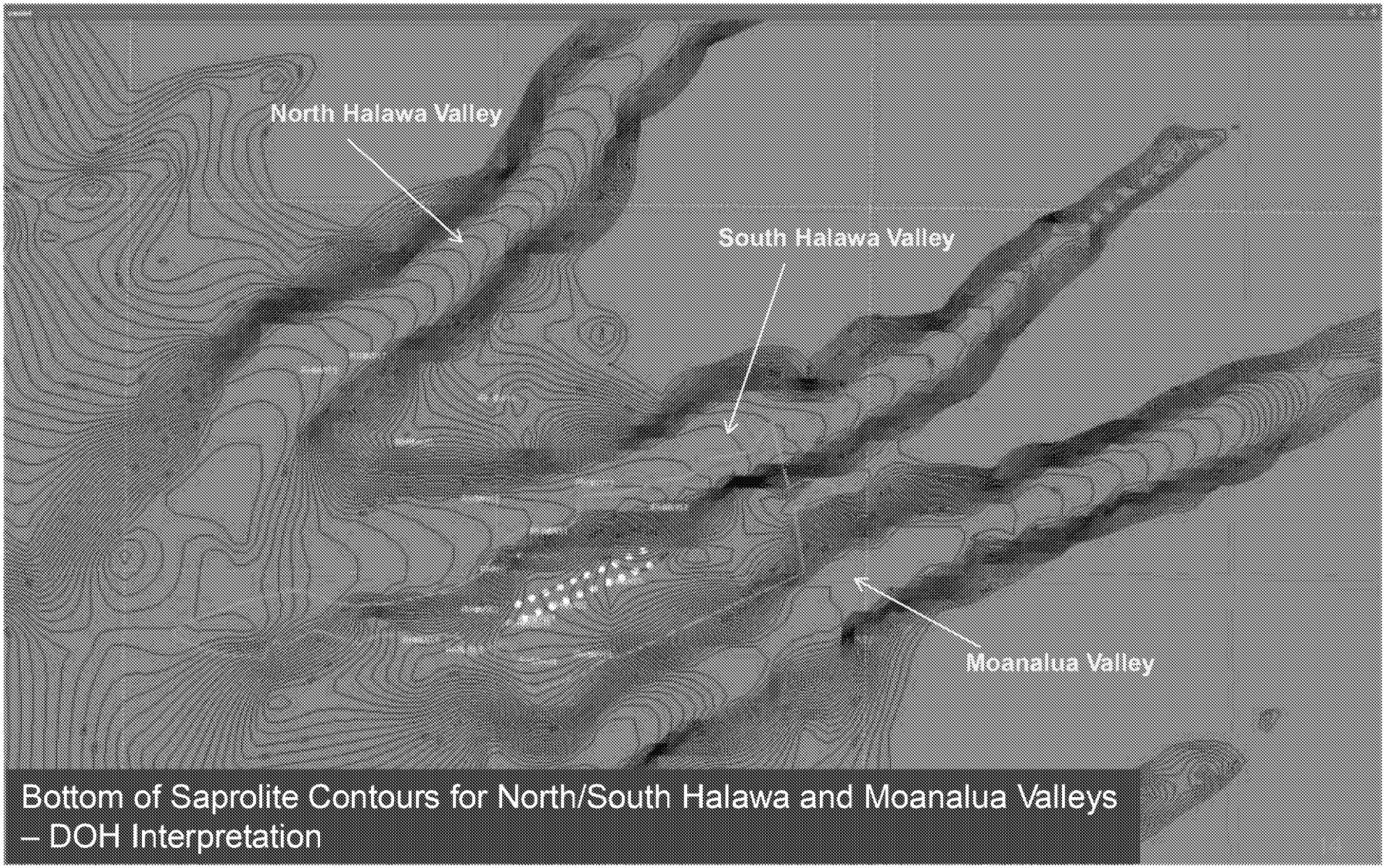
Saprolite-Basalt Interface
Red Hill Bulk Fuel Storage Facility
JBPHH, O'ahu, Hawai'i

SAPROLITE EXTENTS – NAVY INTERPRETATION



Bottom of Saprolite Contours for North/South Halawa and Moanalua Valleys – Navy Interpretation

SAPROLITE EXTENTS – DOH INTERPRETATION



Bottom of Saprolite Contours for North/South Halawa and Moanalua Valleys – DOH Interpretation

RESPONSE TO AOC PARTIES' TOP 10 COMMENTS:

CONCERNS WITH THE INTERIM CSM (CONT.)

Comment	Response
3. Preferential pathways	The Navy recognizes that there are potential preferential pathways that can affect groundwater and contaminant flow at Red Hill. Regarding lava tubes, various evaluations conducted by the Navy and presented to the Regulatory Agencies demonstrated that it is highly unlikely that a lava tube could provide a complete preferential pathway between the Red Hill Facility and Halawa Shaft. A sensitivity study as part of the interim modeling effort simulated a clinker zone beneath Red Hill to further evaluate preferential pathways related to highly permeable zones that could potentially impact Red Hill Shaft (and other areas). This type of approach will continue for the ongoing modeling efforts.

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RESPONSE TO COMMENT #3 (CONT.)

- Macdonald 1941 - *Geology of the Red Hill and Waimalu Areas, Oahu: "The lava flows form sheets 3 to 50 feet thick, with very irregular tops and bottoms, sloping gently southwestward. Many of them thin toward the southwest. The lavas moved down the slope toward the southwest as relatively narrow streams."*
- Hunt Jr. (1996) states that "*Wentworth and Macdonald (1953, p. 31) listed measurements for 22 historical flows on Mauna Loa and Kilauea on the island of Hawaii, which presumably are typical of flows on Oahu as well. The flows on Hawaii average about 15 mi in length and about one-half mile in width.*" The distance from the NW Rift zone of Koʻolau volcano to Red Hill is approximately 8 miles. Flow core widths could be significantly less than one-half mile; potentially hundreds of feet wide.
- According to Macdonald 1941, many flows thicken or thin rapidly across the ridge, and some pinch out altogether at Red Hill. This implies the existence relatively narrow flows.

RESPONSE TO COMMENT #3 (CONT.)

- Lava flows are controlled by topography and follow the natural drainage pattern. Recent thermal imagery of the flows in the Pahoa area of the big Island shows that flows do meander typically up to 45° relative to the baseline flow direction (fall line). At Red Hill, a meander in a lava flow would need to exceed one mile transverse to the axis of the flow to intercept Halawa Shaft.
- Macdonald 1941: "*The pahoehoe flows are fed by lava moving through tubes in the interior of the flow, most of them only a foot or two across but a few reaching diameters of tens of feet. Sometimes the liquid lava drains away from these tubes leaving them partly or entirely empty.*"
- Lava tubes are constrained by the width of a lava flow they are part of.
- The geometry that would allow a lava tube near the water table under the Red Hill Facility to be oriented across (under or around) the saprolite in modern-day North and South Halawa Valleys, and then extend beyond is unlikely.

RED HILL GEOLOGY

- Red Hill specific
  - Range of widths of basalt flows (in particular pahoehoe): Flows average about 15 miles in length and about one-half mile in width (Wentworth and Macdonald 1953).
  - Range of basalt flow thicknesses: 3–50 feet thick with very irregular tops and bottoms (Macdonald 1941); typically 5–10 feet thick.
  - Range of lava tube size (diameter or height and width): commonly small at 1–3 feet. Large lava tube greater than 20 feet in diameter encountered at upper elevations at Tanks 20 and 18.
  - Frequency of lava tubes across flows: present in pahoehoe flows, but frequency is difficult to determine as very few voids have been encountered during drilling
  - Evidence that lava tubes don't extend beyond a single flow field: there is no evidence at Red Hill, but generally at the flow front, the lava behaves much like a river delta, forming small distributary tubes that continue to branch until they consist of the same type of single flow-unit tubes (toes) that have been forming the flow the whole way downslope. A lava tube is a natural conduit formed by flowing lava that moves beneath the hardened surface of a lava flow. Tubes can drain lava from a volcano during an eruption, or can be extinct, meaning the lava flow has ceased, and the rock has cooled and left a long cave.
  - Range of meanders of flows off fall line: hundreds of feet to 1 mile.
  - Tendency of lava tubes to infill during weathering – lava tubes are conduits for water that can result in enhanced rock weathering

PREFERENTIAL PATHWAYS

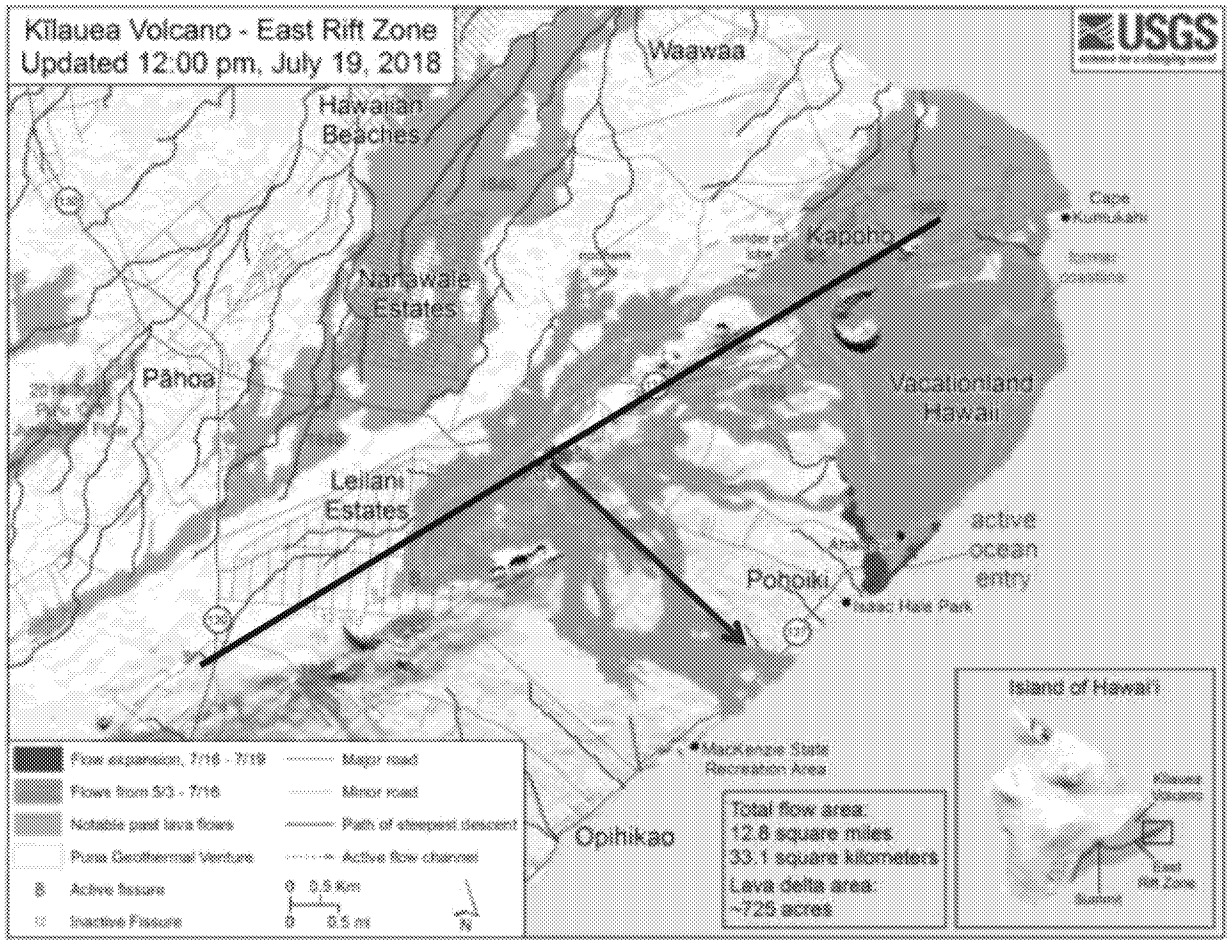
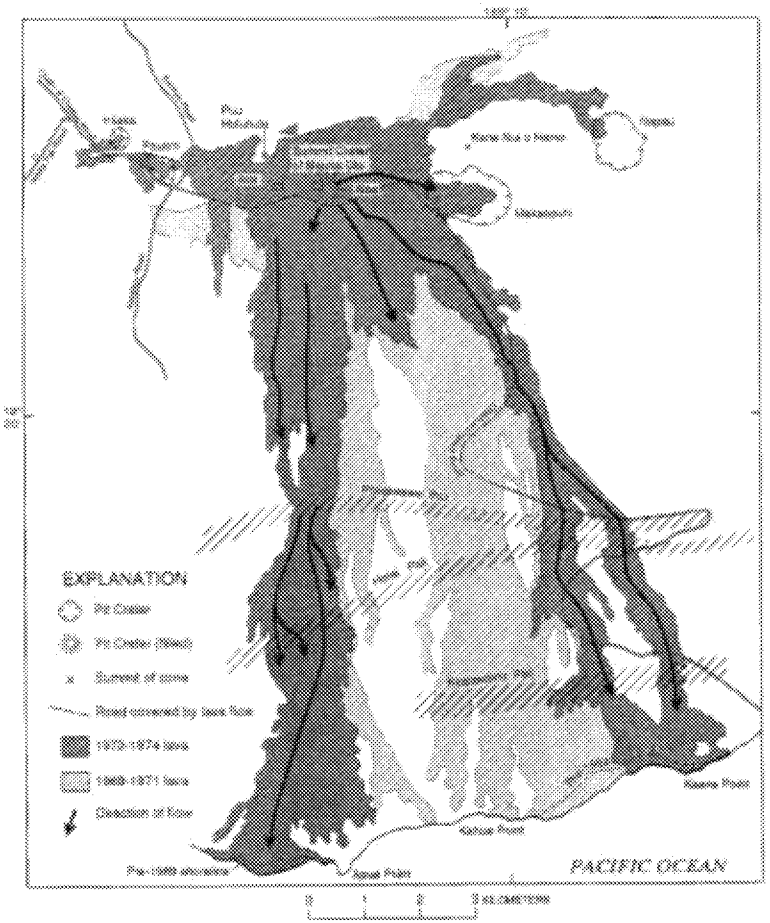


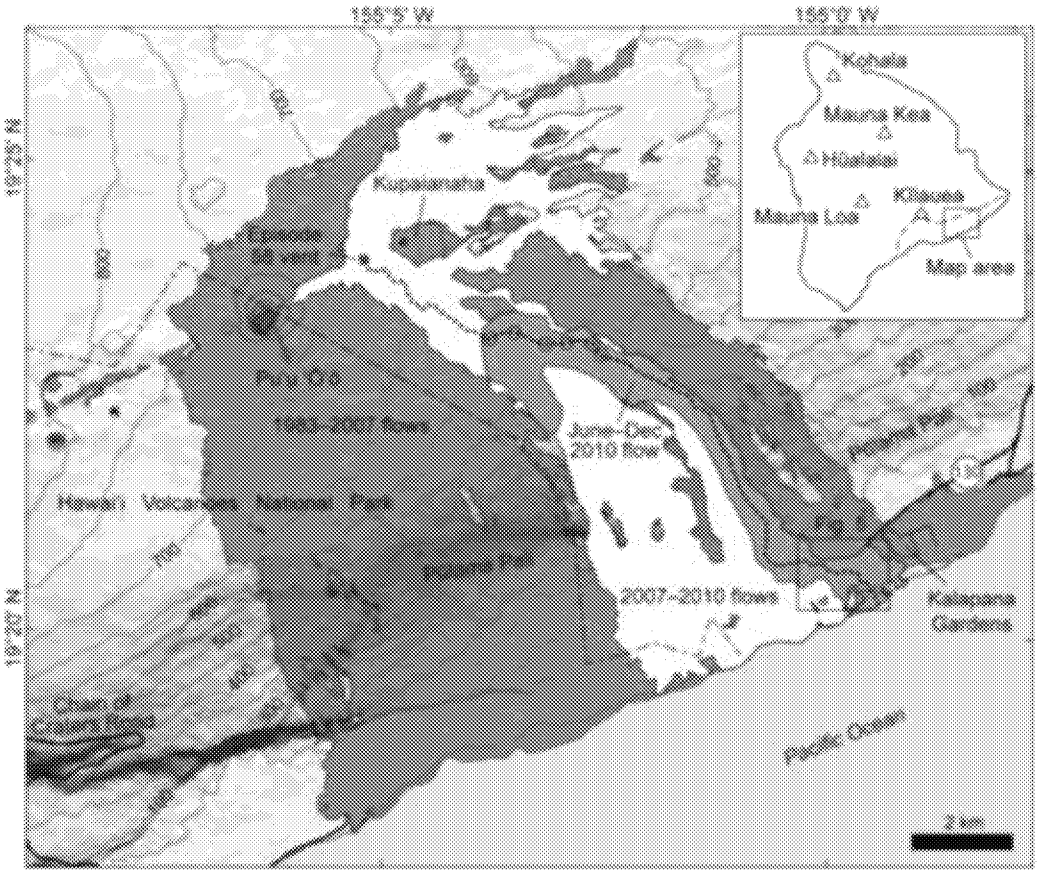
Figure 3.2 Geologic Map of recent lava flow directions from eruptions at the Kilauea Volcano, Hawaii. While the predominant downslope movement is roughly perpendicular to the East Rift Zone, there is significant variability in lava deposition pathways.

PREFERENTIAL PATHWAYS

PUBLICATIONS



Peterson et al. 1994



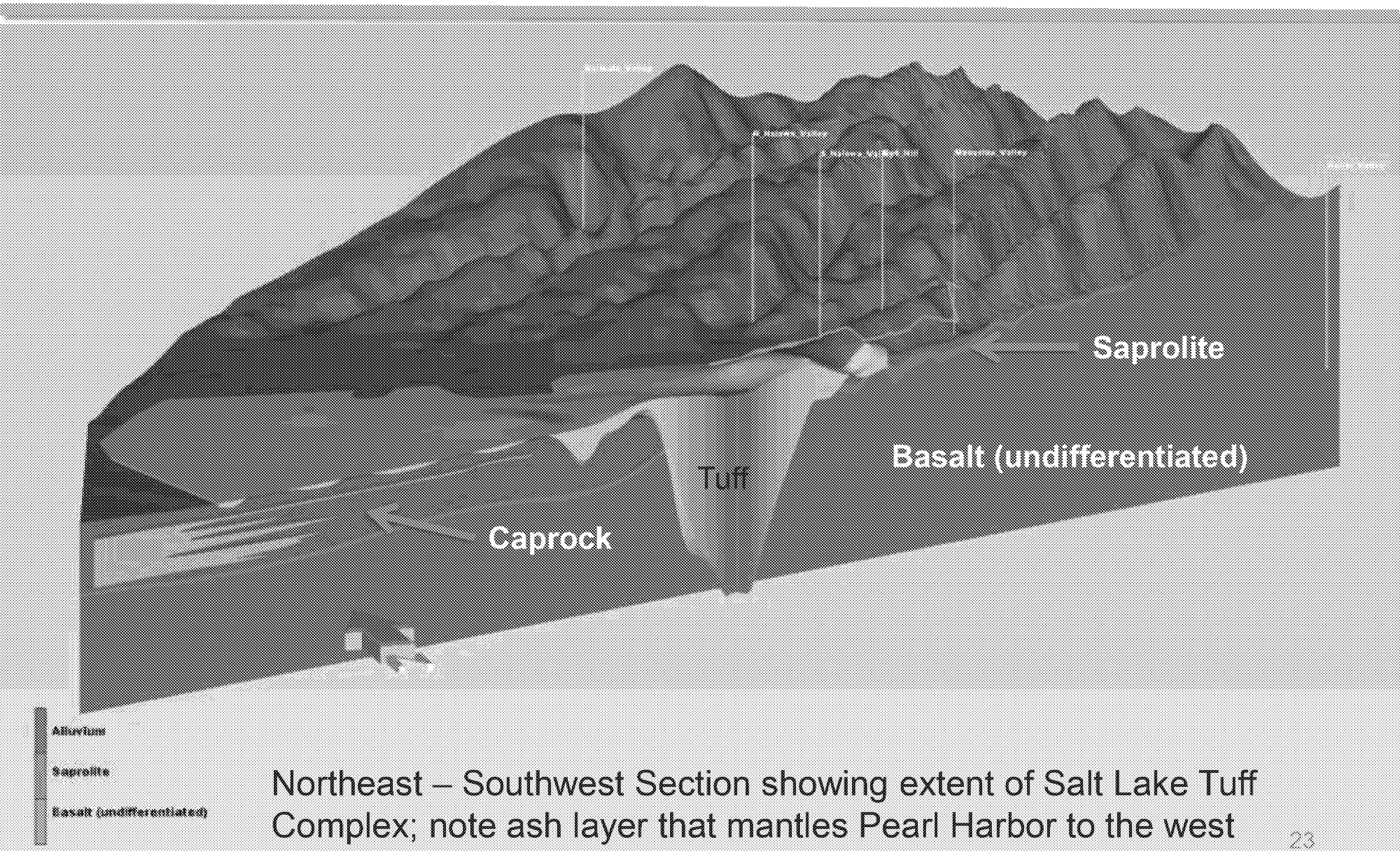
Orr et al. 2015

RESPONSE TO AOC PARTIES' TOP 10 COMMENTS:

CONCERNS WITH THE INTERIM GWFM

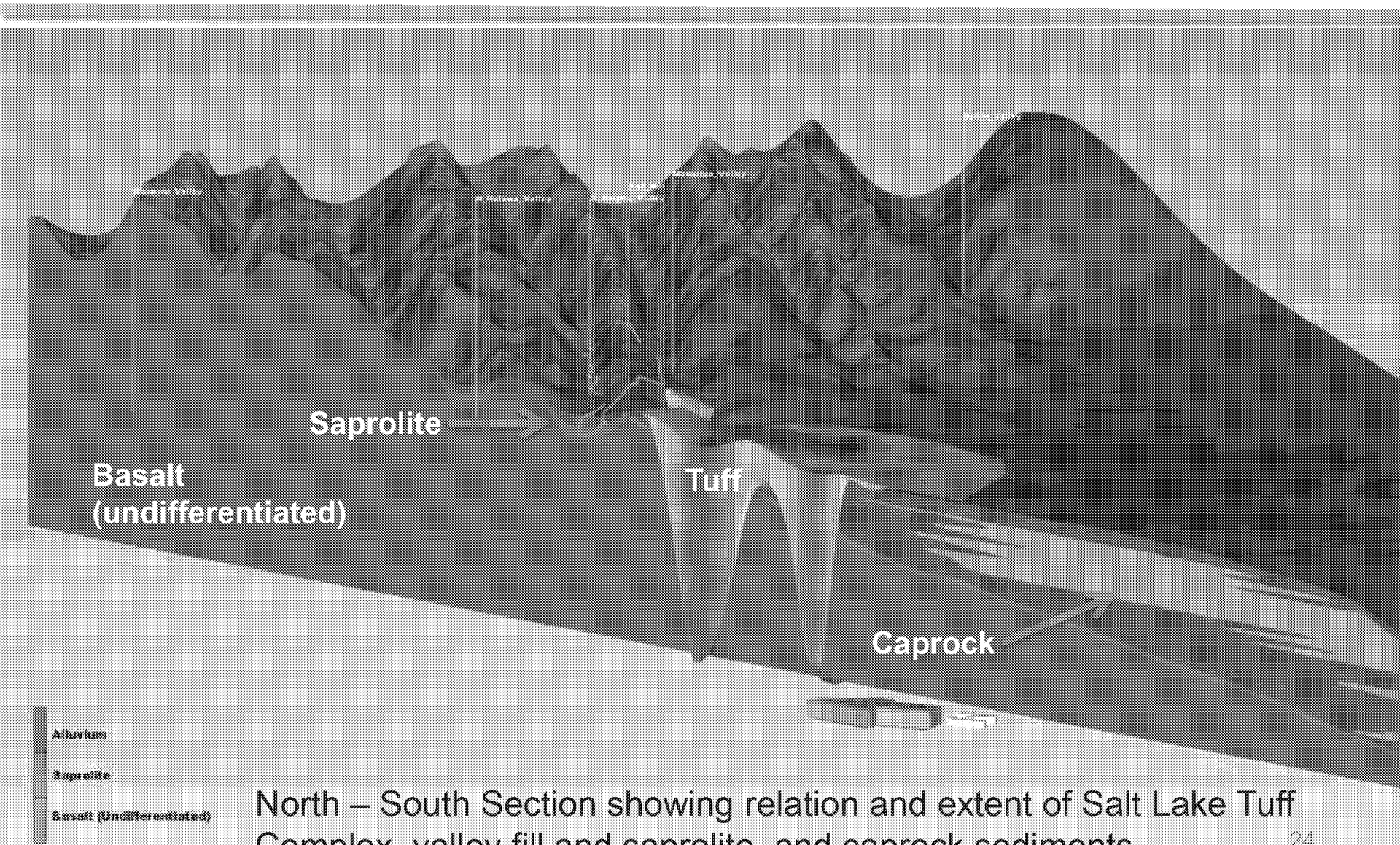
Comment	Response
4. Representation of caprock, tuffs, and sediments	The Navy's 3-D geologic model of the Red Hill area incorporates tuffs (associated with the Honolulu Volcanic Series), basalt, marine sediments, caprock, and saprolite. Interpretation of the marine limestone caprock geometry was largely based on borings from Stearns and Chamberlain (1967). The extent of ash deposits was based on a paper by Pankiwskyj (1972) as well as data from HART rail borings. The tuff cone vents were interpreted based on academic research papers on other similar Honolulu Volcanic Series tuff cones as well as tuff cones outside of Hawaii. Marine sediments and tuffs will be modeled as separate layers as part of the ongoing modeling effort.

CAPROCK, TUFFS, AND SEDIMENTS REPRESENTATION



Northeast – Southwest Section showing extent of Salt Lake Tuff Complex; note ash layer that mantles Pearl Harbor to the west

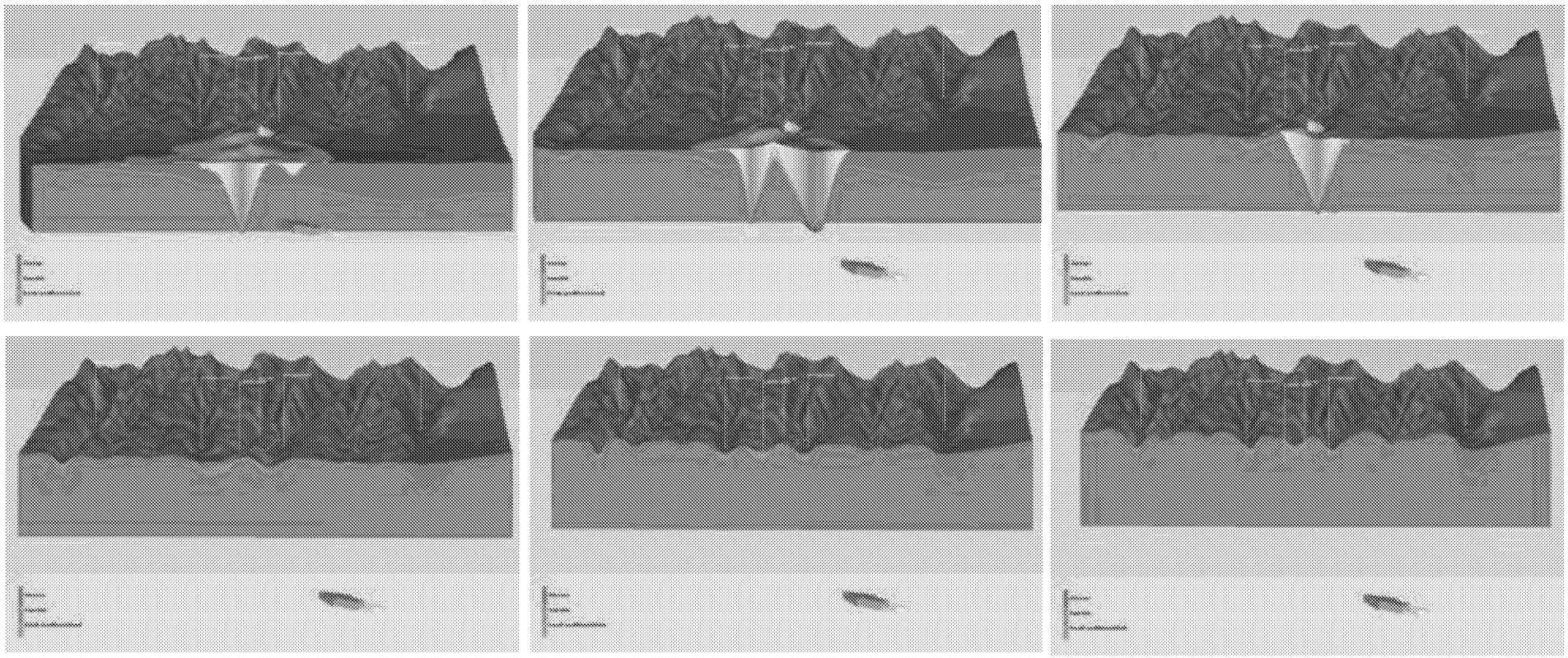
CAPROCK, TUFFS, AND SEDIMENTS REPRESENTATION



North – South Section showing relation and extent of Salt Lake Tuff Complex, valley fill and saprolite, and caprock sediments.

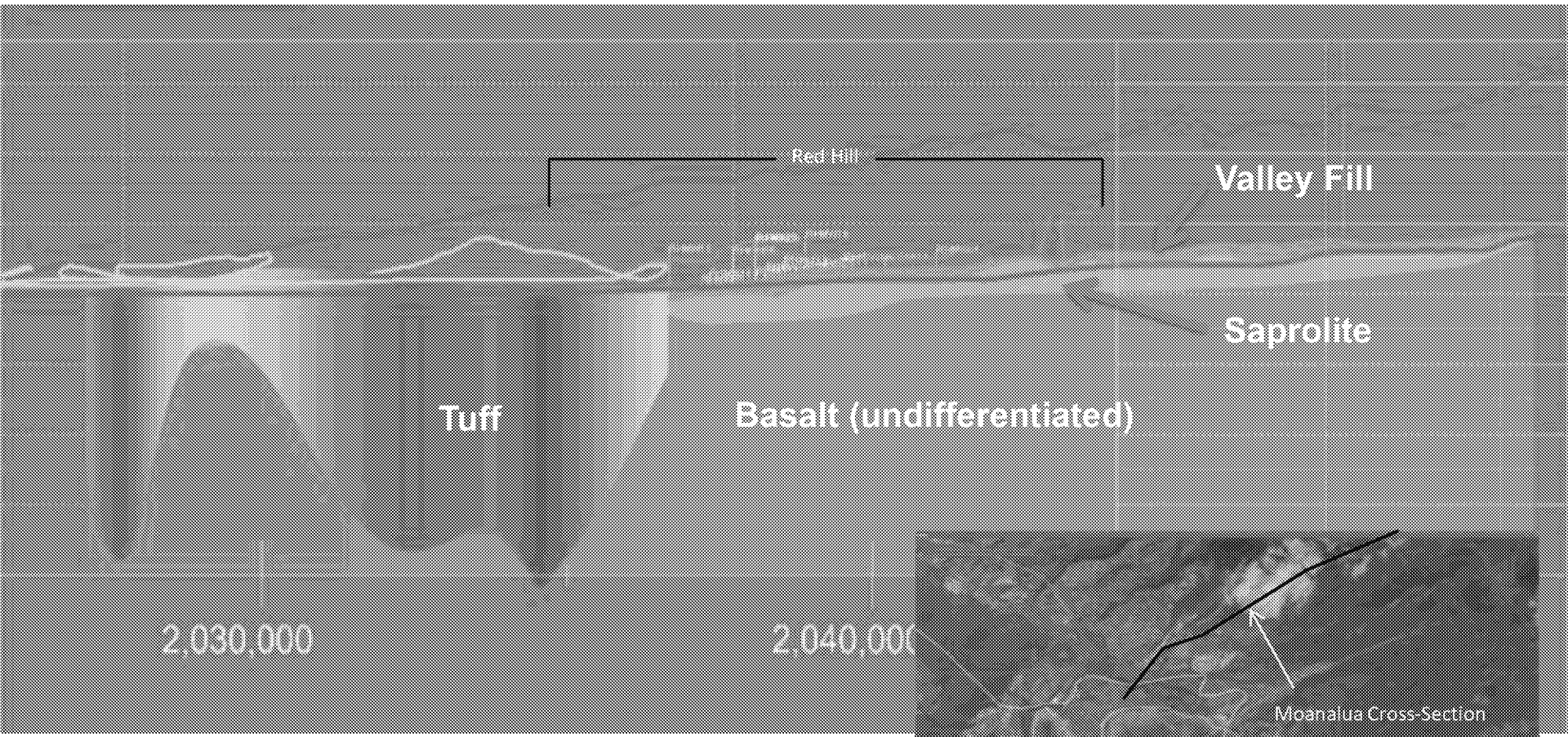
CAPROCK, TUFFS, AND SEDIMENTS REPRESENTATION

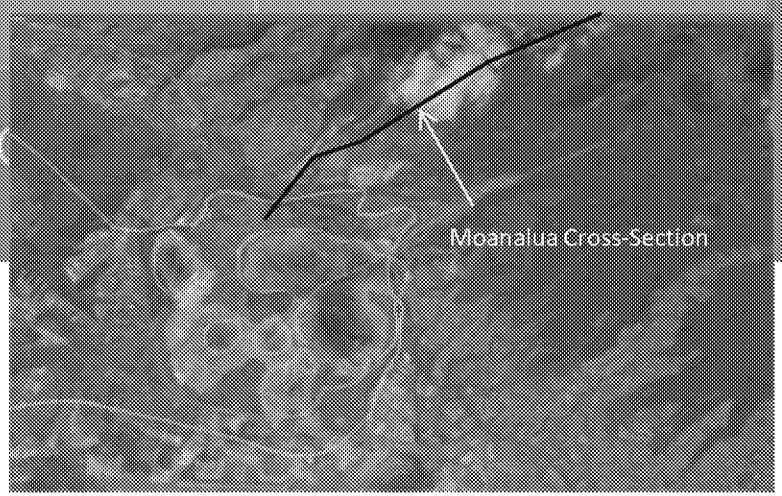
CAPROCK, TUFFS, AND SEDIMENTS REPRESENTATION



East – West Sections moving from South to North

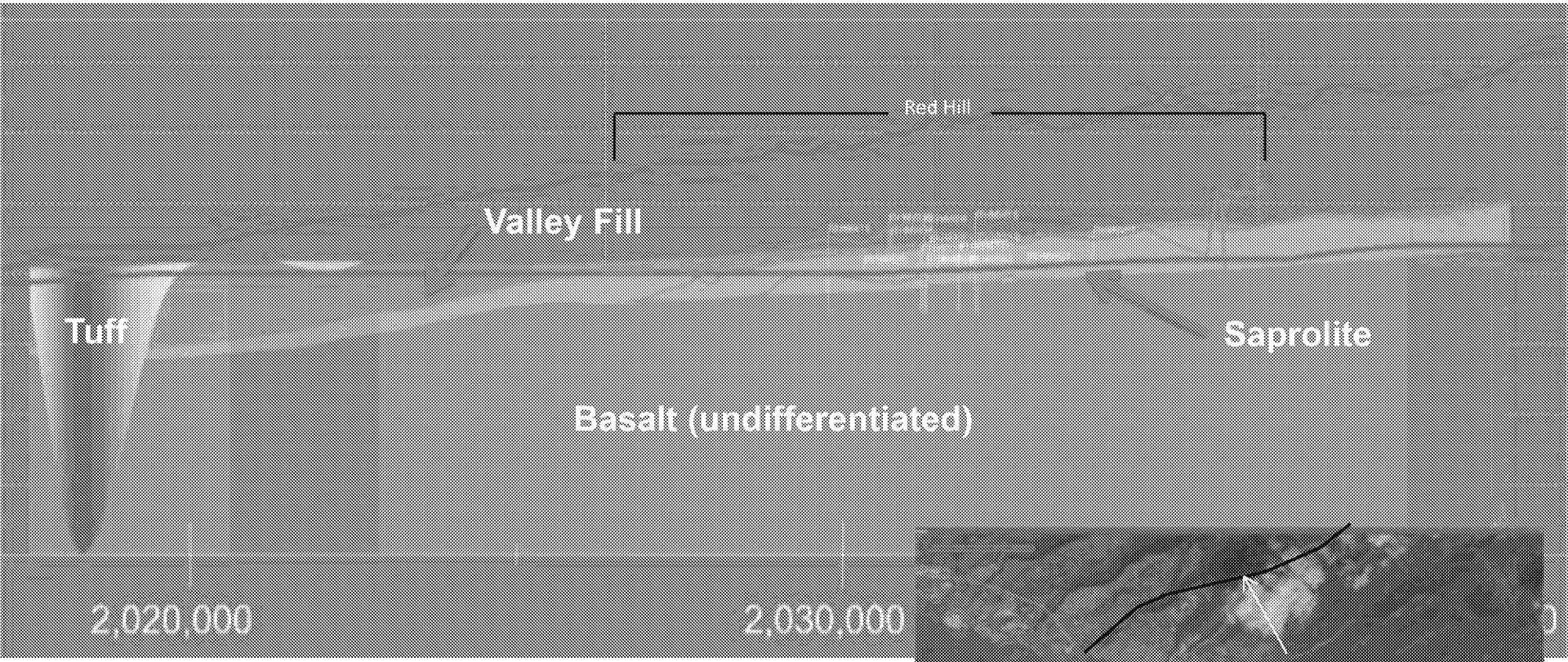
CAPROCK, TUFFS, AND SEDIMENTS REPRESENTATION WITH SAPROLITE EXTENT

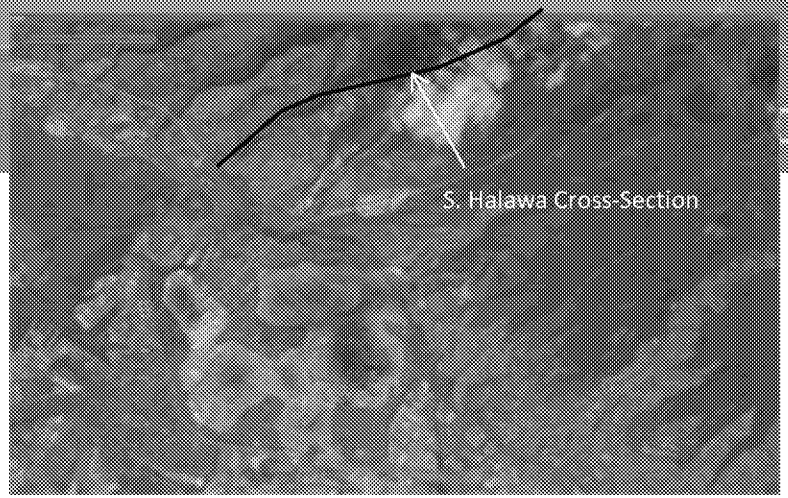




Moanalua Valley Cross-Section
View to the Northwest

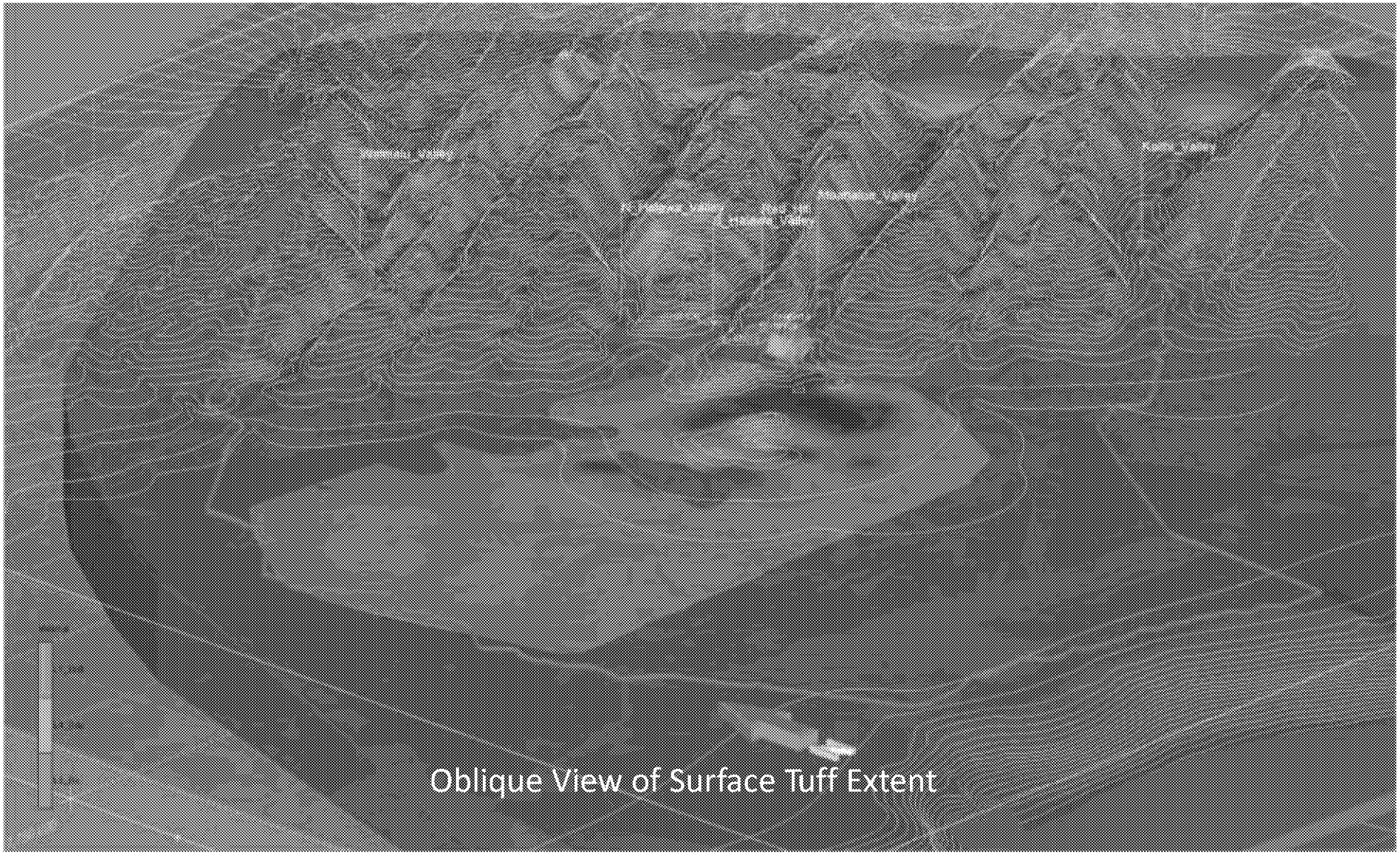
CAPROCK, TUFFS, AND SEDIMENTS REPRESENTATION WITH SAPROLITE EXTENT



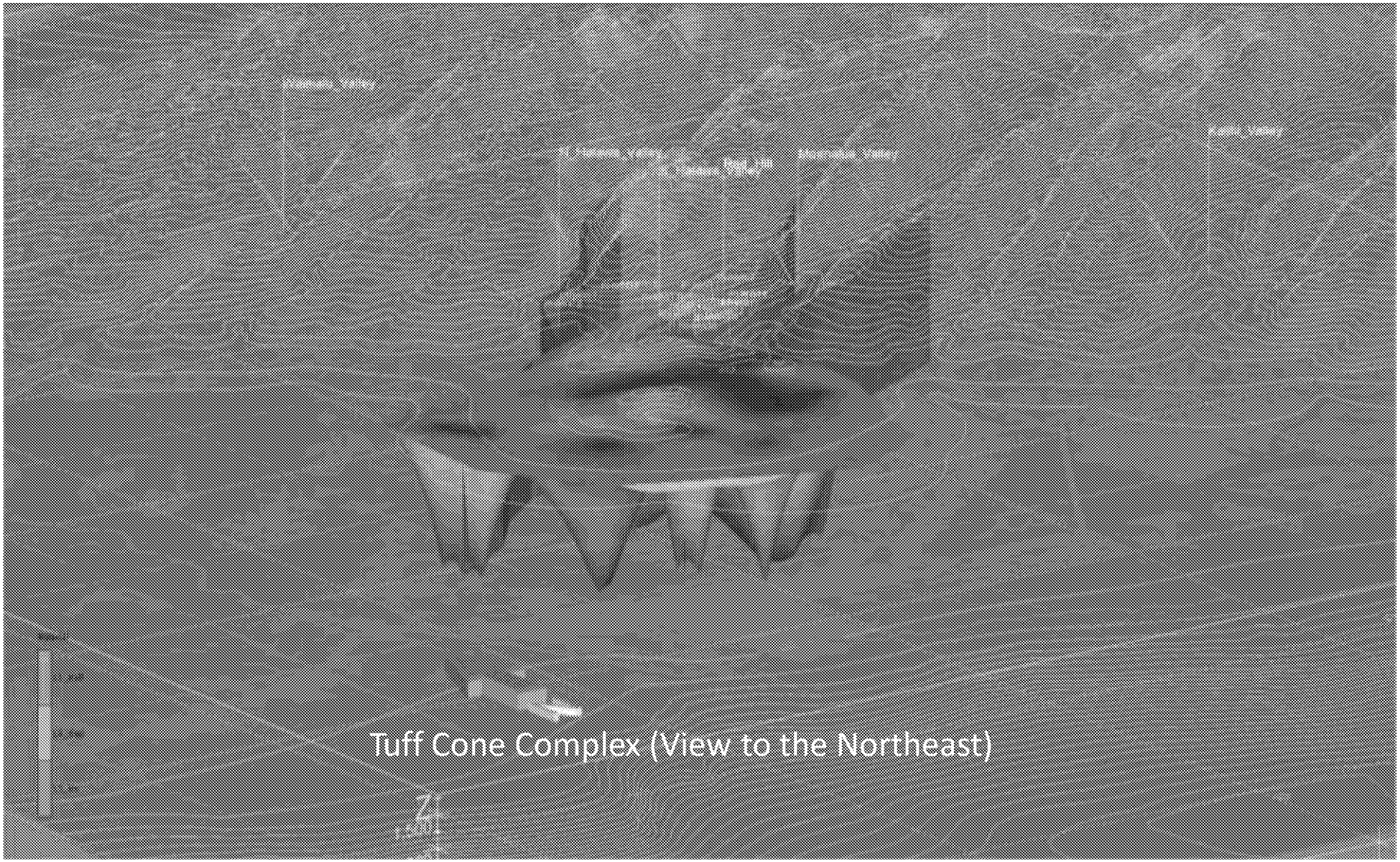


South Halawa Valley Cross-Section
View to the Northwest

CAPROCK, TUFFS, AND SEDIMENTS REPRESENTATION

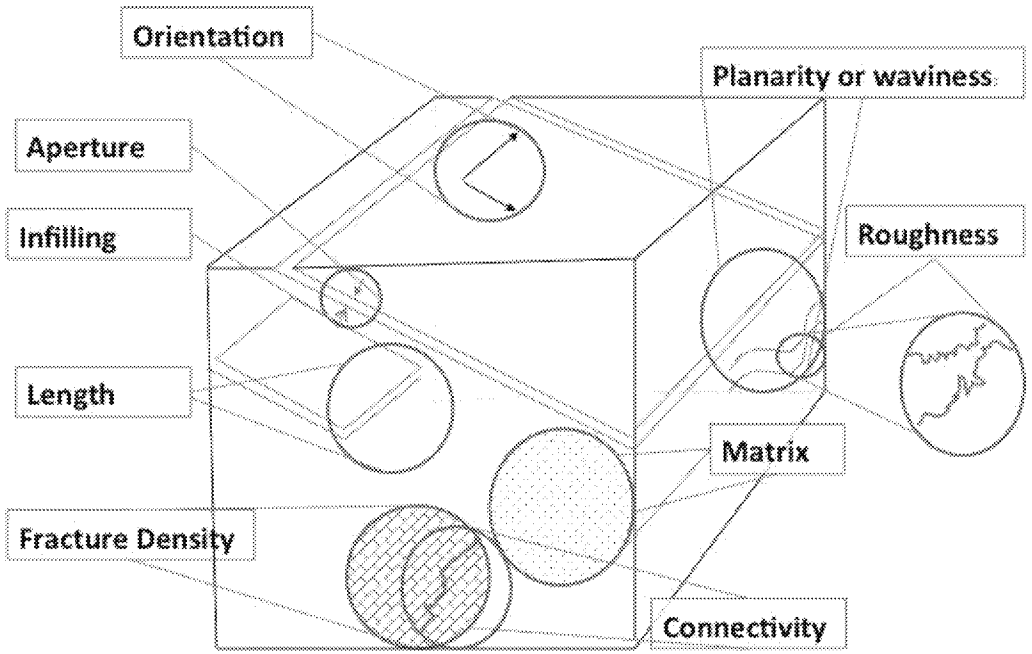


CAPROCK, TUFFS, AND SEDIMENTS REPRESENTATION



ITRC FRACTURED ROCK CSM - ARCHITECTURE

ITRC Fractured Rock CSM - Architecture



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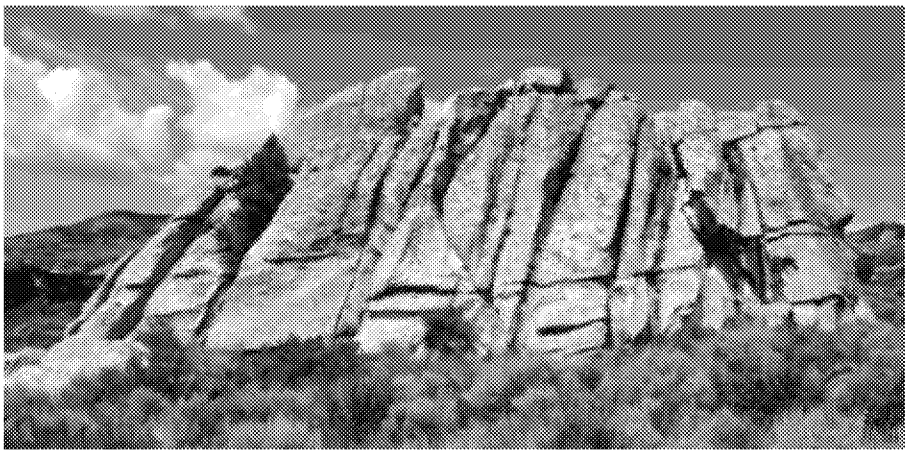
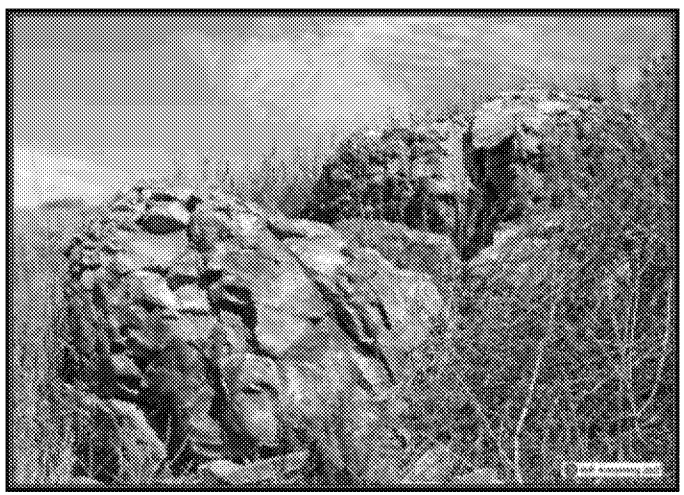
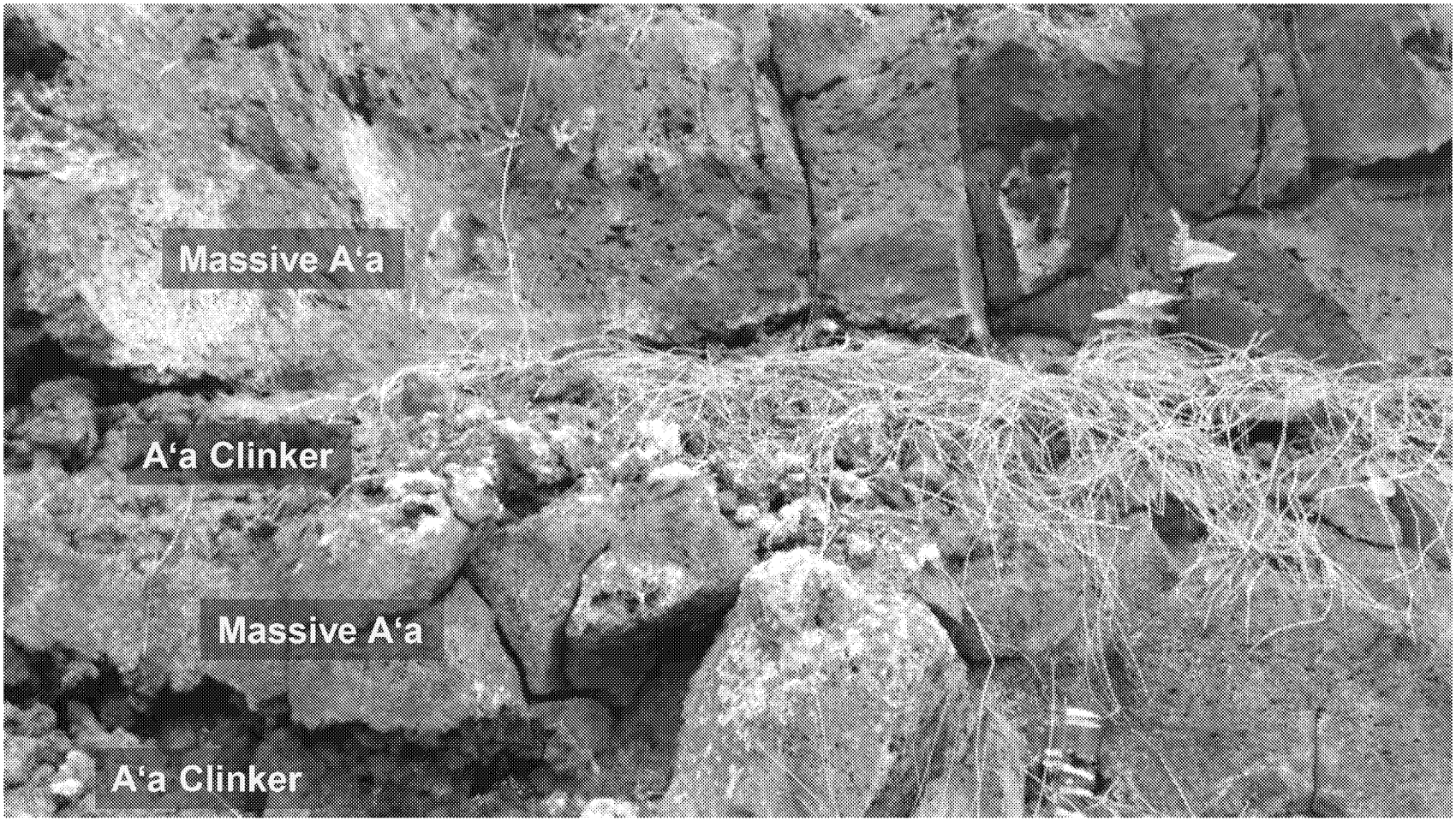
CONTINENTAL GRANITIC AND VOLCANIC ROCKS





HAWAIIAN BASALTS – DISCONTINUITY OF FRACTURES ACROSS BEDS



From Regulators' Presentation at AOC Technical Working Group Meeting on February 13, 2019

CSM UPDATE – HYDROGEOLOGY CONSIDERATIONS:

SYNOPTIC WATER LEVEL STUDY UPDATE

SYNOPTIC STUDY DATA REVIEW:
PURPOSE

Previously analyzed Synoptic Study data to:

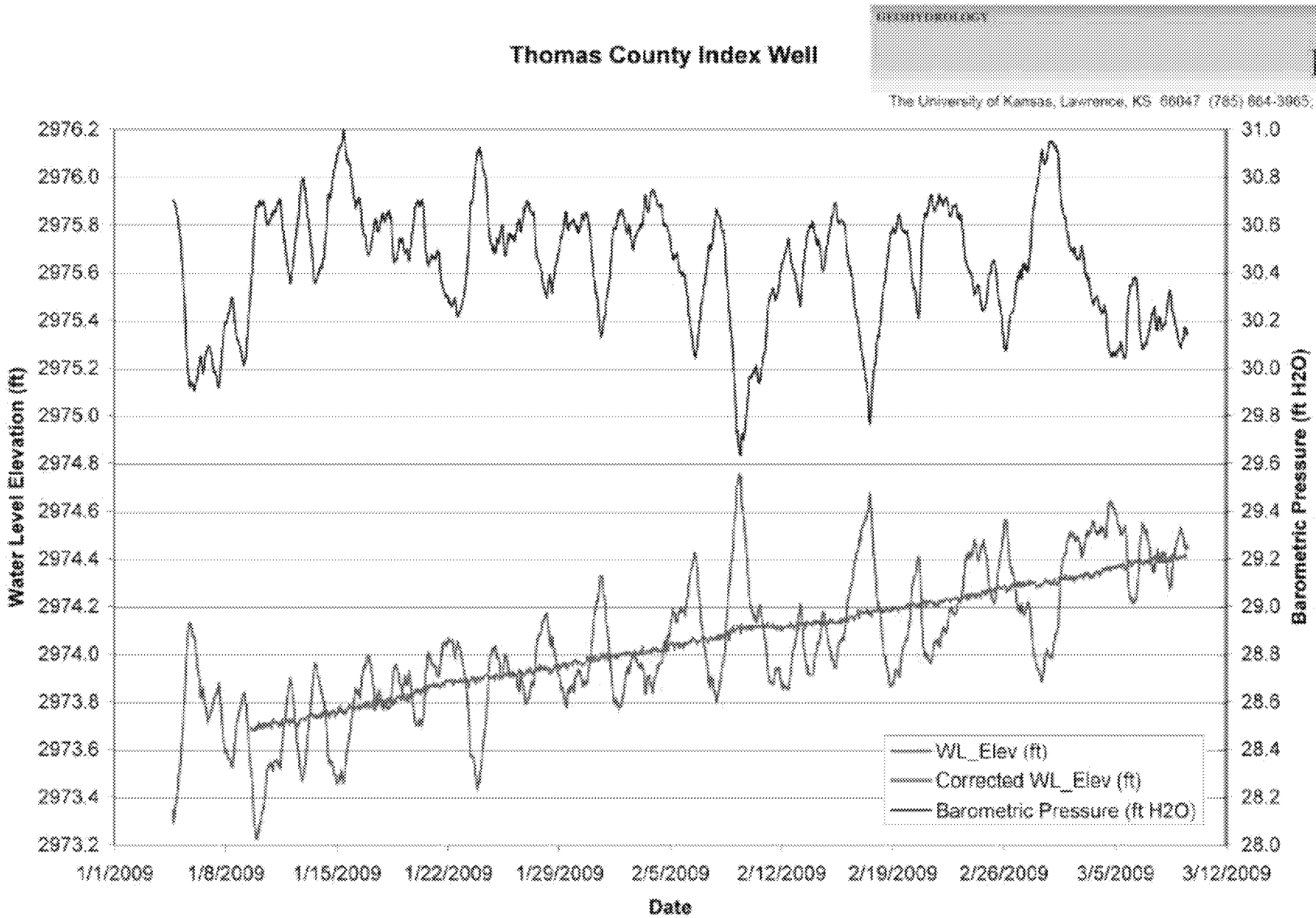
- Evaluate regional basal aquifer response to pumping from
  - BWS Halawa Shaft
  - Navy Aiea Shaft
  - Navy Red Hill Shaft
  - BWS Moanalua Wells
- Evaluate hydraulic head changes in the regional basal aquifer
  - Various pumping conditions/combinations
  - Non-pumping conditions (locally)
- Evaluate regional basal aquifer response to
  - Barometric pressure fluctuations
  - Tidal fluctuations
  - Rainfall and streamflow conditions
- Estimate regional basal aquifer properties
  - Transmissivity and hydraulic conductivity
  - Storativity
  - Anisotropy

Re-analyzed Synoptic Study data to account for:

- Barometric pressure influence on water level data
- Revised estimates of aquifer properties based on corrected water level data

SYNOPTIC STUDY DATA REVIEW:

KANSAS GEOLOGICAL SURVEY BAROMETRIC RESPONSE FUNCTION SOFTWARE

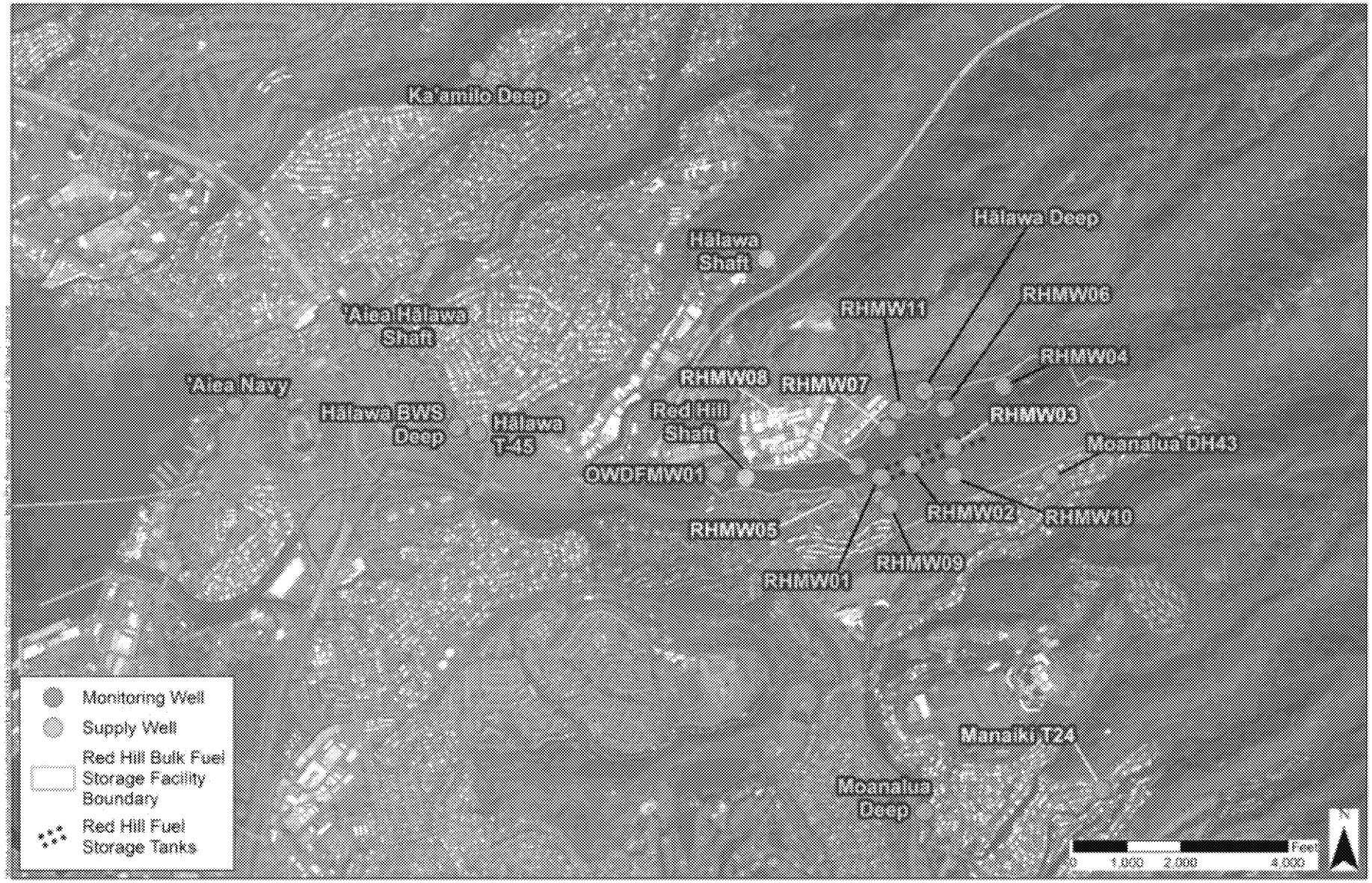


SYNOPTIC STUDY DATA REVIEW:

KANSAS GEOLOGICAL SURVEY BAROMETRIC RESPONSE FUNCTION SOFTWARE

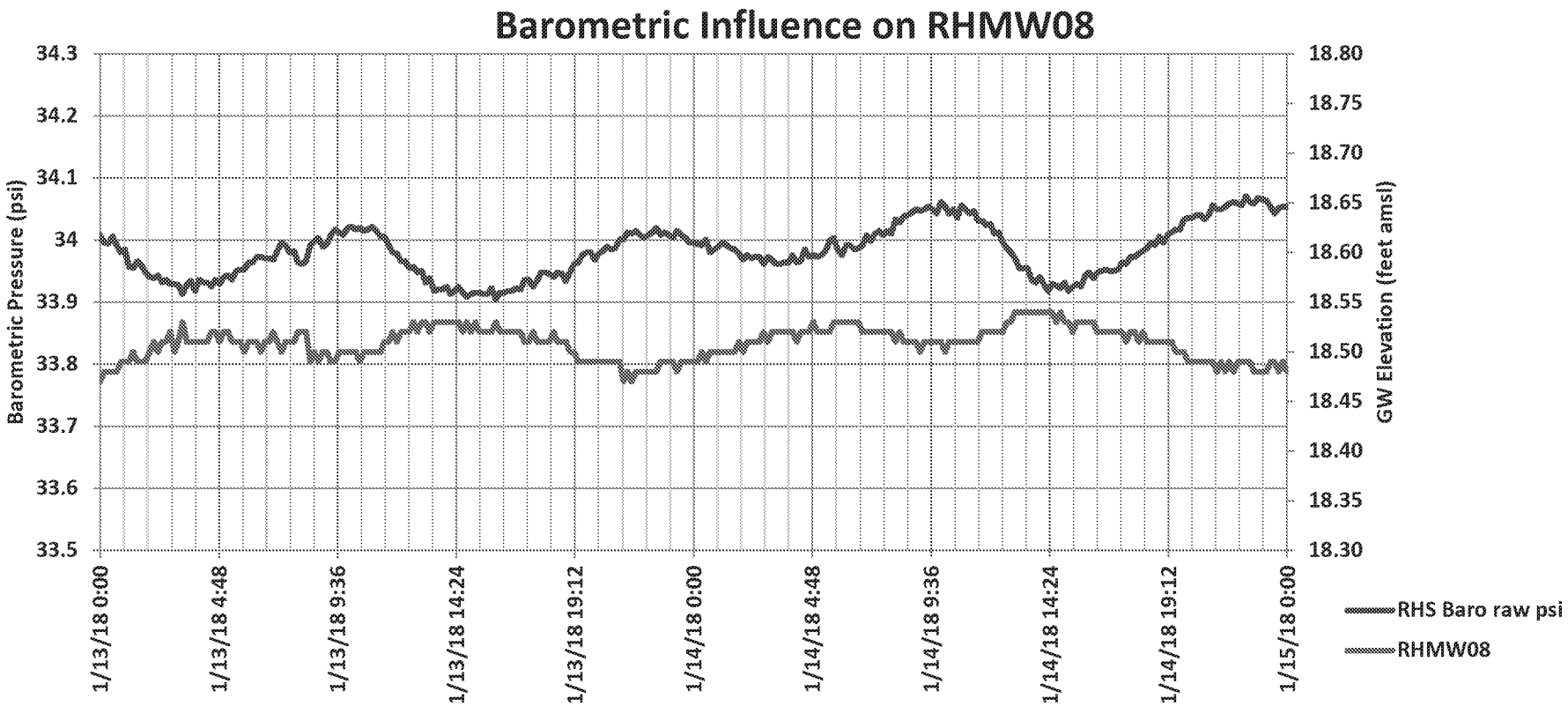
	A	B	C	D	E	F	G	H	I	J
1	Copy your data into this template then press Compute BRF or Correct WL button. Use Fill Gaps button to interpolate across gaps in data.									
2										
3	Update the yellow cells appropriately. This information will be passed on to output BRF worksheet.							Fill Gaps		
4	Comment:	A note to yourself								
5	Well:	RHMW10								
6	Water Level Units:	feet						Compute BRF (and correct W L)		
7	Barometric Pressure Units:	feet								
8	Earth Tide Units:			(Not used if Number of ET Lags = -1)						
9	Sample Interval:	0.00694								
10	Sample Interval Units:	days						Correct W L (with selected BRF)		
11	Number of BP Lags:	11		Max BP lag:	0.076388889 days					
12	Number of ET Lags:	89		Max ET lag:	0.618055556 days					
13	BRF Data Start:	1/11/18 12:00 AM								
14	BRF Data End:	1/15/18 9:50 AM		☑ Detrend				Selected BRF:		BRF 3
15	Correction Data Start:	1/10/18 9:00 AM								
16	Correction Data End:	1/19/18 10:00 PM								
17										
18	Paste your data below these headings (starting in row 20); ET not used if Number of ET Lags = -1; Header labels do not affect computations									
19	Time	WL (ft)	BP (feet)	ET						
20	1/10/2018 9:00	18.3	34.00551	0.334						
21	1/10/2018 9:10	18.3	34.0032	0.368						
22	1/10/2018 9:20	18.3	34.01937	0.402						
23	1/10/2018 9:30	18.3	34.00551	0.436						
24	1/10/2018 9:40	18.3	34.01013	0.443666667						
25	1/10/2018 9:50	18.3	34.0032	0.451333333						
26	1/10/2018 10:00	18.3	34.00089	0.459						
27	1/10/2018 10:10	18.31	33.99627	0.485333333						
28	1/10/2018 10:20	18.31	34.01244	0.511666667						
29	1/10/2018 10:30	18.31	33.99858	0.538						
30	1/10/2018 10:40	18.31	34.00089	0.541						
31	1/10/2018 10:50	18.31	33.99396	0.544						
32	1/10/2018 11:00	18.32	34.0032	0.547						
33	1/10/2018 11:10	18.32	34.01013	0.557						
34	1/10/2018 11:20	18.32	33.98472	0.567						
35	1/10/2018 11:30	18.33	33.99627	0.577						
36	1/10/2018 11:40	18.33	33.99165	0.566333333						

SYNOPTIC STUDY DATA REVIEW:
LOCATION OF RHMW03, RHMW05, RHMW07, RHMW08, AND MANAIKI T24



SYNOPTIC STUDY DATA REVIEW:

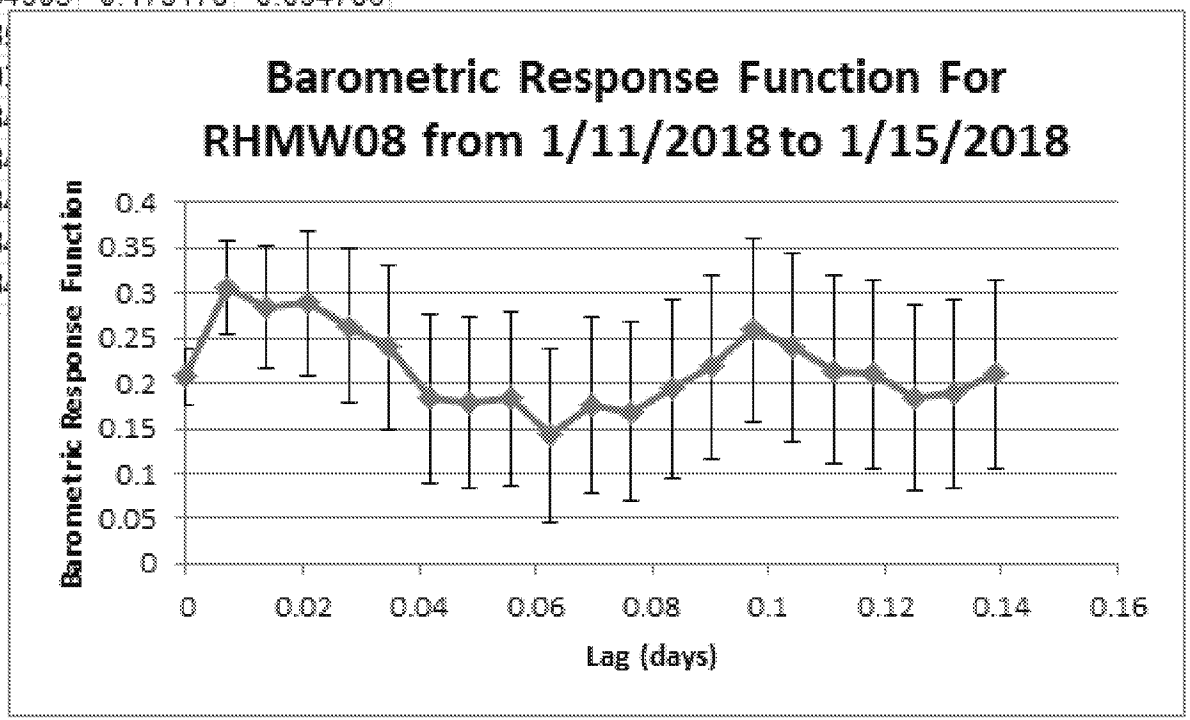
BAROMETRIC RESPONSE DURING NON-PUMPING AT RED HILL SHAFT



SYNOPTIC STUDY DATA REVIEW:

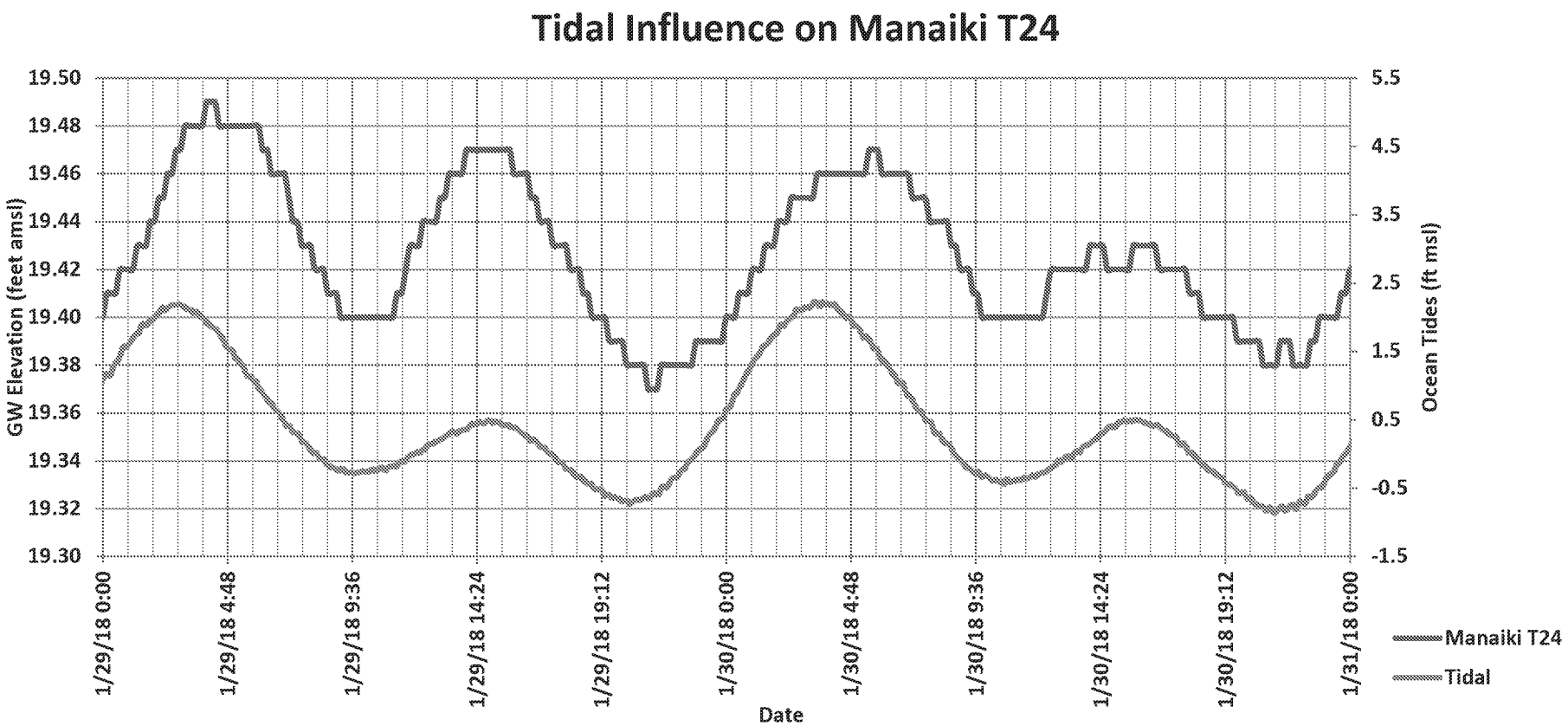
SELECTING BAROMETRIC LAG

		Barometric Response Coefficients			
Lag Number	Lag (days)	a	se(a)	A	se(A)
0	0	0.207544	0.031715	0.207544	0.031715
1	0.006944444	0.098388	0.033273	0.305933	0.052436
2	0.013888889	-0.02193	0.033438	0.284004	0.068461
3	0.020833333	0.005135	0.033661	0.289139	0.079415
4	0.027777778	-0.0252	0.034116	0.263937	0.086193
5	0.034722222	-0.02359	0.034383	0.240343	0.090672
6	0.041666667	-0.05681	0.034624	0.183532	0.093386
7	0.048611111	-0.00435	0.034903	0.179178	0.094786
8	0.055555556	0.003661	0.03		
9	0.0625	-0.04047	0.0		
10	0.069444444	0.034622	0.03		
11	0.076388889	-0.00838	0.03		
12	0.083333333	0.025043	0.03		
13	0.090277778	0.024604	0.03		
14	0.097222222	0.04047	0.03		

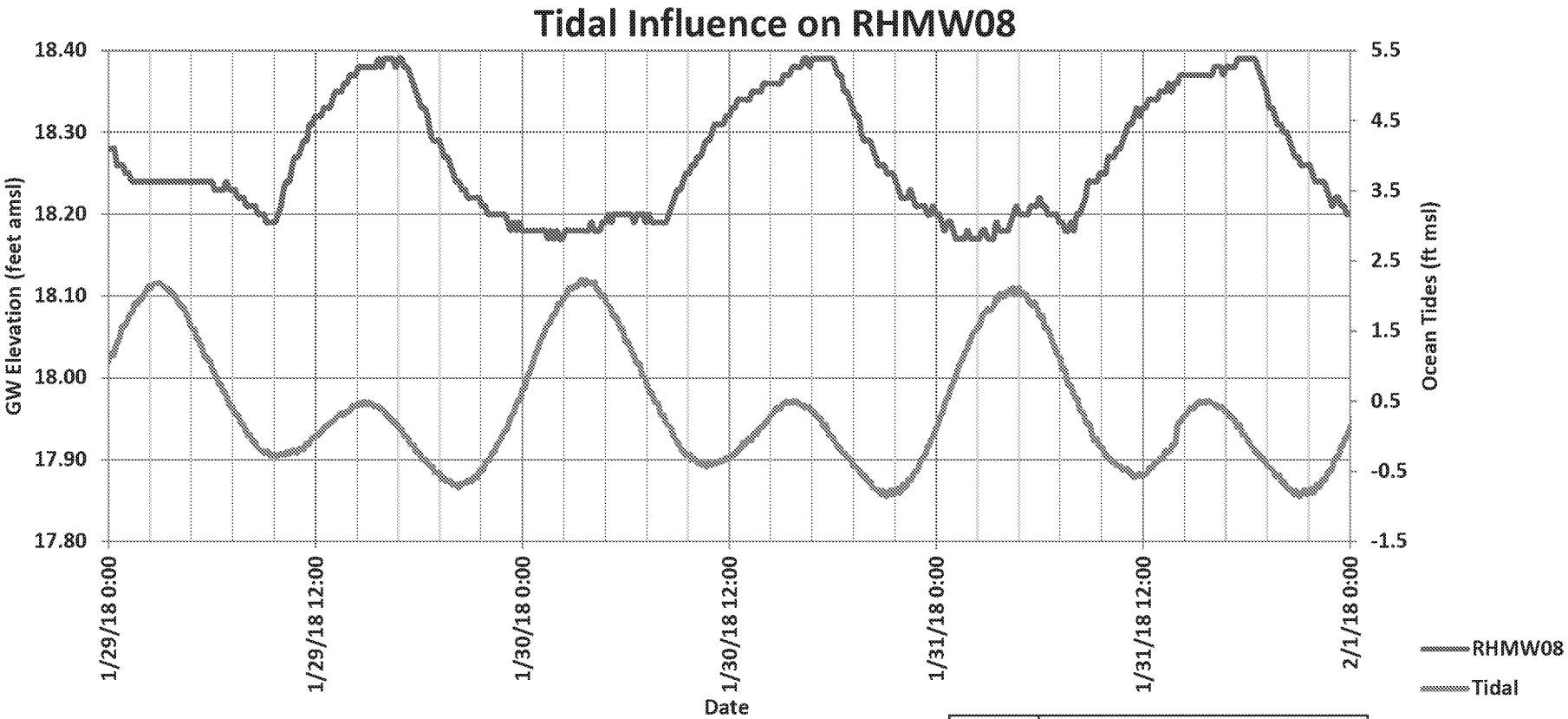


SYNOPTIC STUDY DATA REVIEW:

SELECTING TIDAL LAG



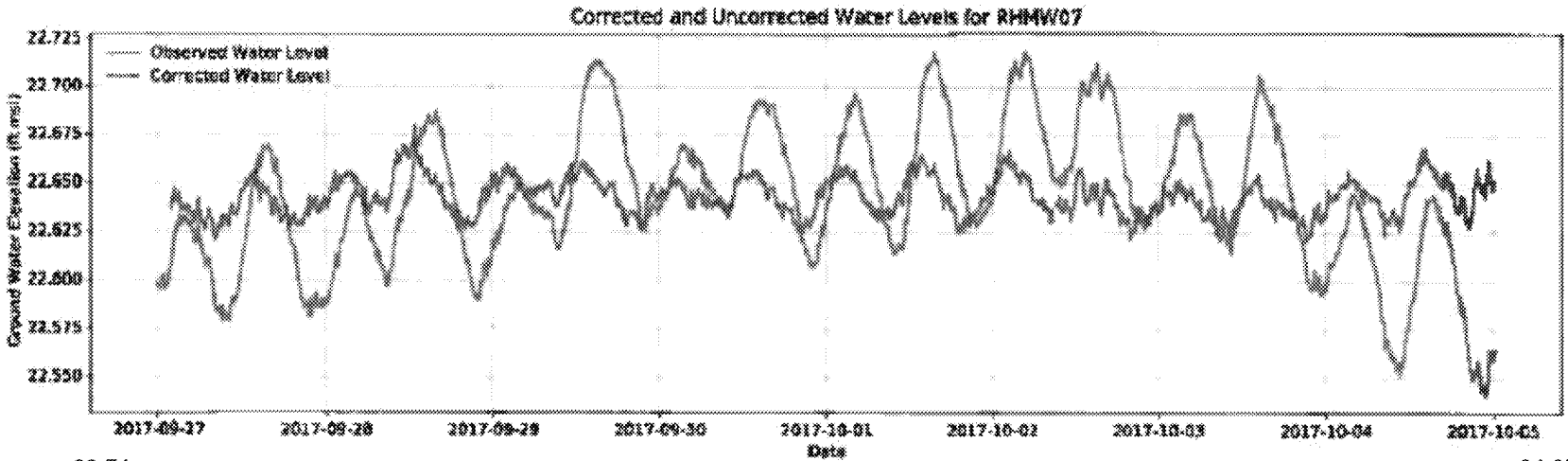
SYNOPTIC STUDY DATA REVIEW:
SELECTING TIDAL LAG

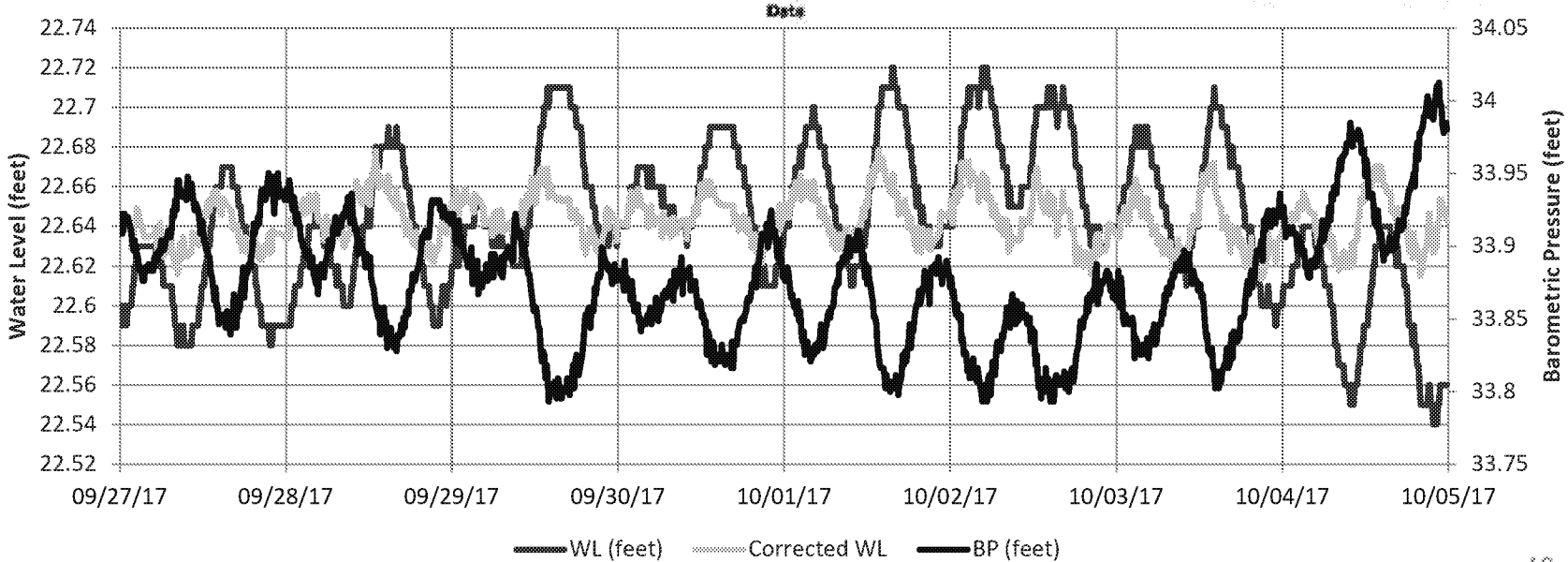


	Δ Minutes	
well	1/29/2018 1600	792
tide	1/29/2018 0248	
well	1/30/2018 0710	826
tide	1/30/2018 0324	
	Average Lag	**809**

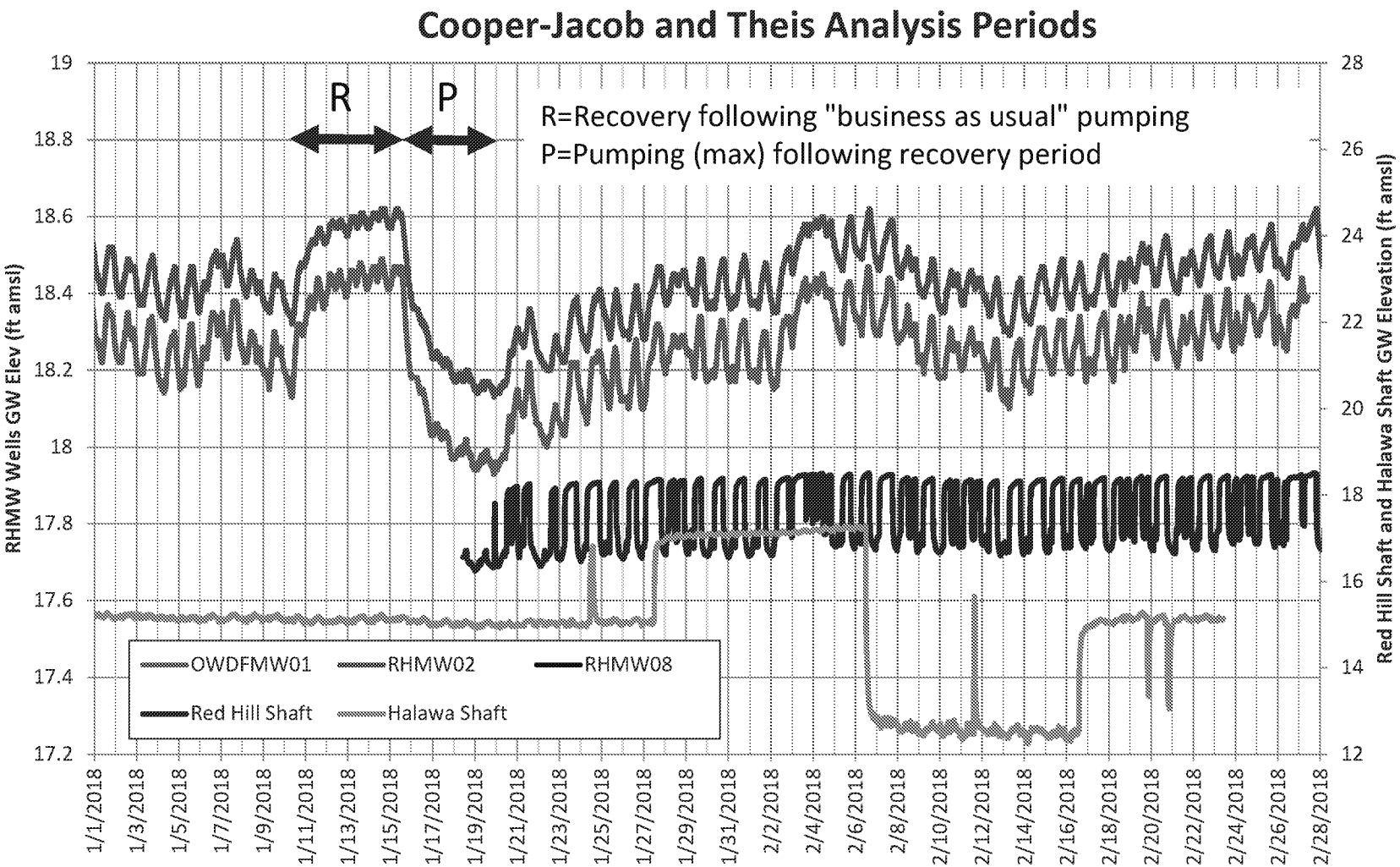
SYNOPTIC STUDY DATA REVIEW:

RHMW07

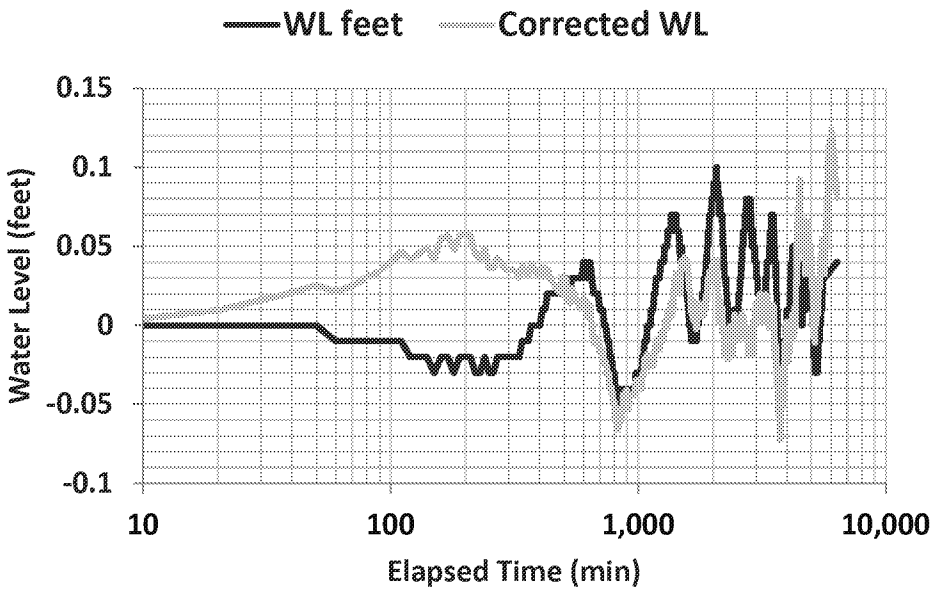


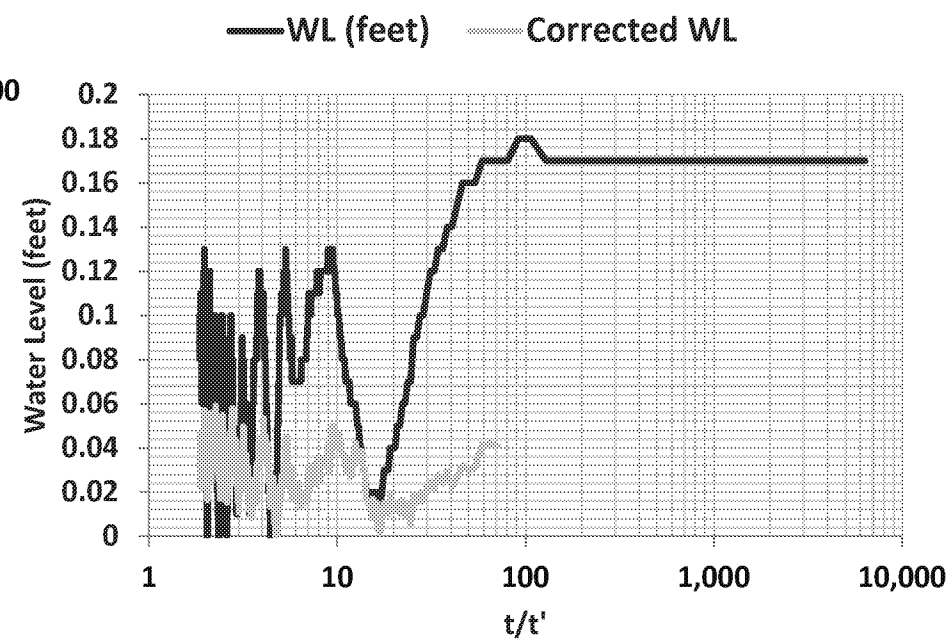


SYNOPTIC STUDY DATA REVIEW:
ANALYSIS PERIODS FOR COOPER-JACOB AND THEIS EVALUATIONS

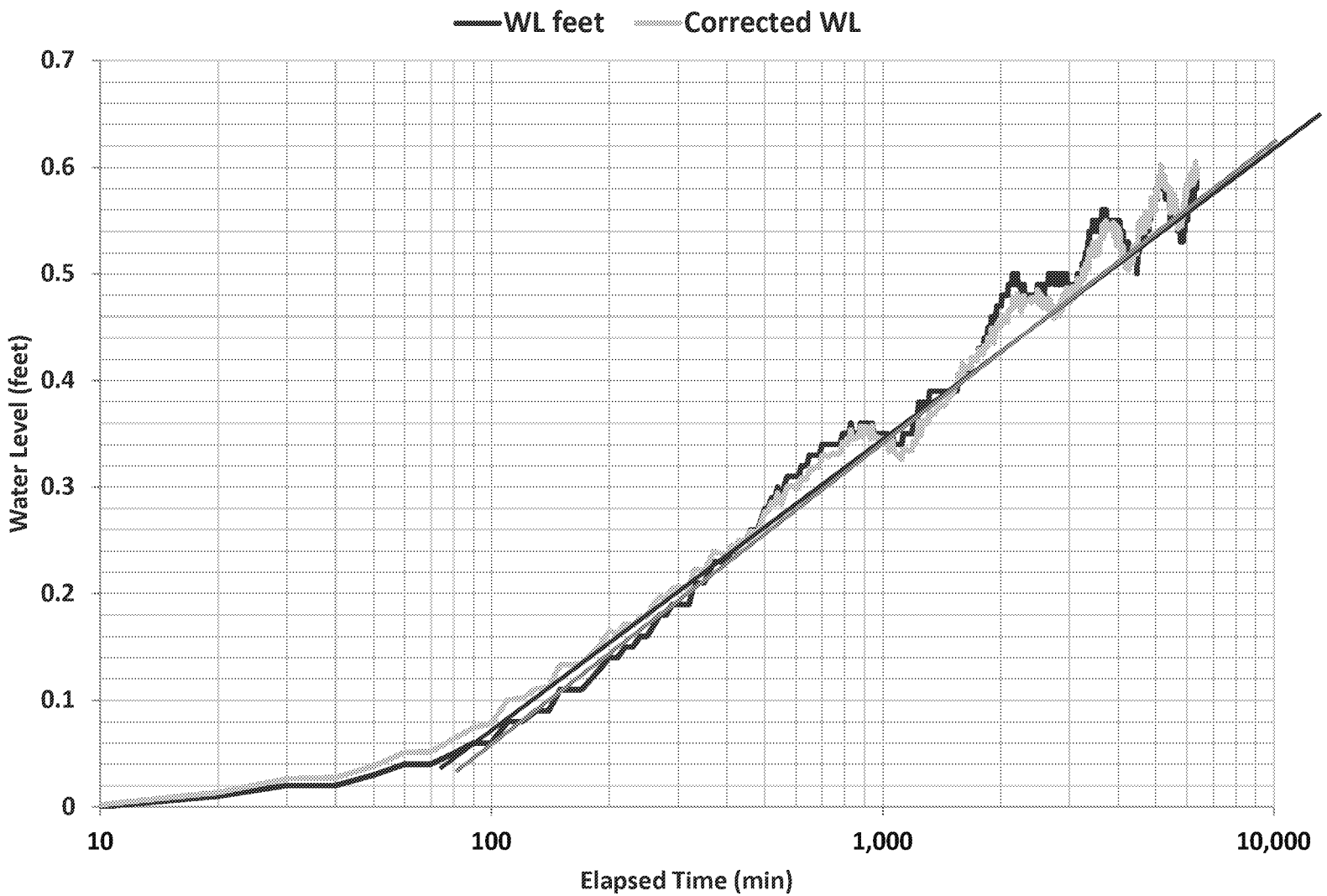


SYNOPTIC STUDY DATA REVIEW:
RHMW07 - SEMI-LOG PLOTS CORRECTED FOR BP

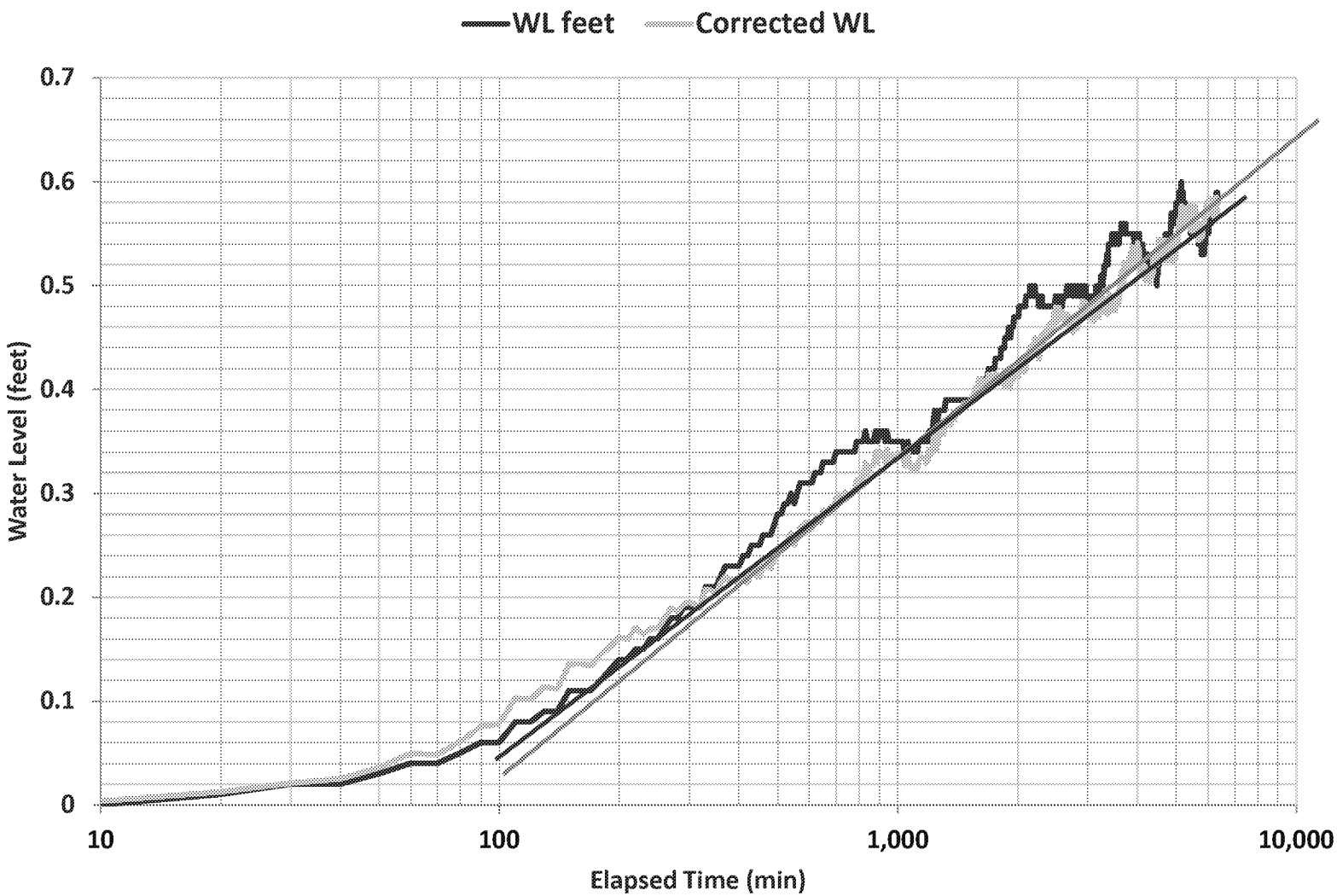




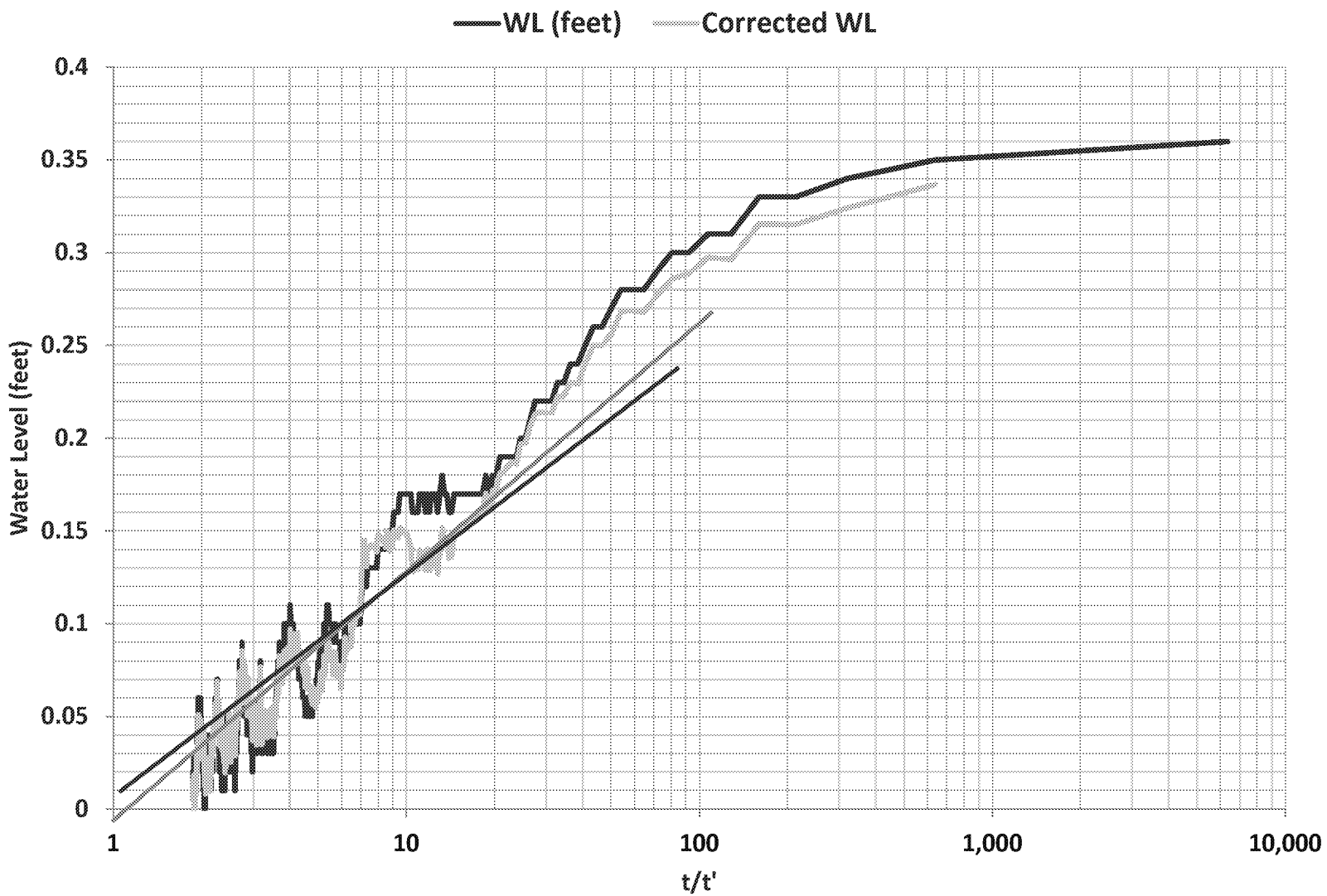
SYNOPTIC STUDY DATA REVIEW:
BP CORRECTIONS – COOPER-JACOB RHMW08 DRAWDOWN



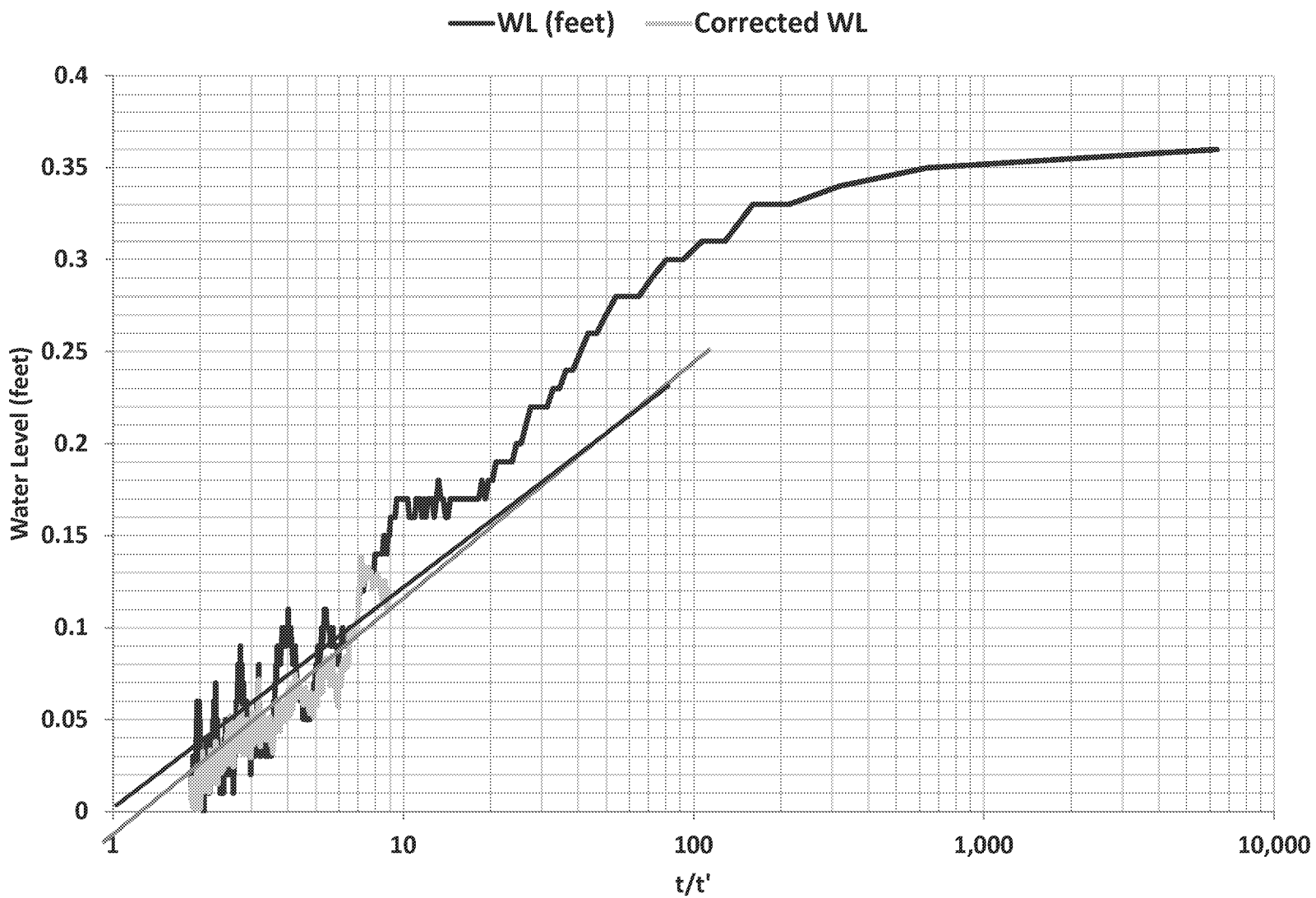
SYNOPTIC STUDY DATA REVIEW:
BP & TIDAL CORRECTIONS – COOPER-JACOB RHMW08 DRAWDOWN



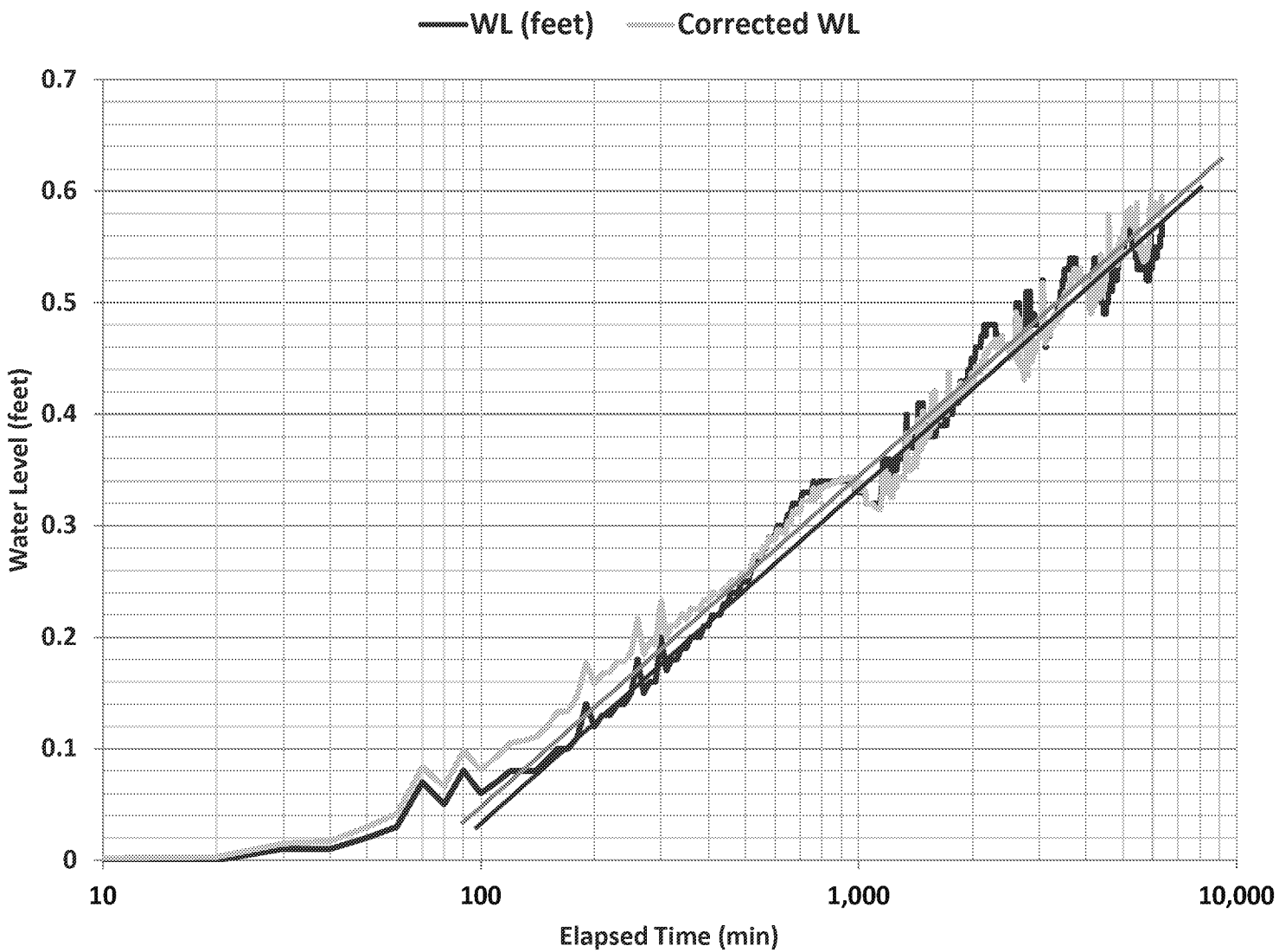
SYNOPTIC STUDY DATA REVIEW:
BP CORRECTIONS – COOPER-JACOB RHMW08 RECOVERY



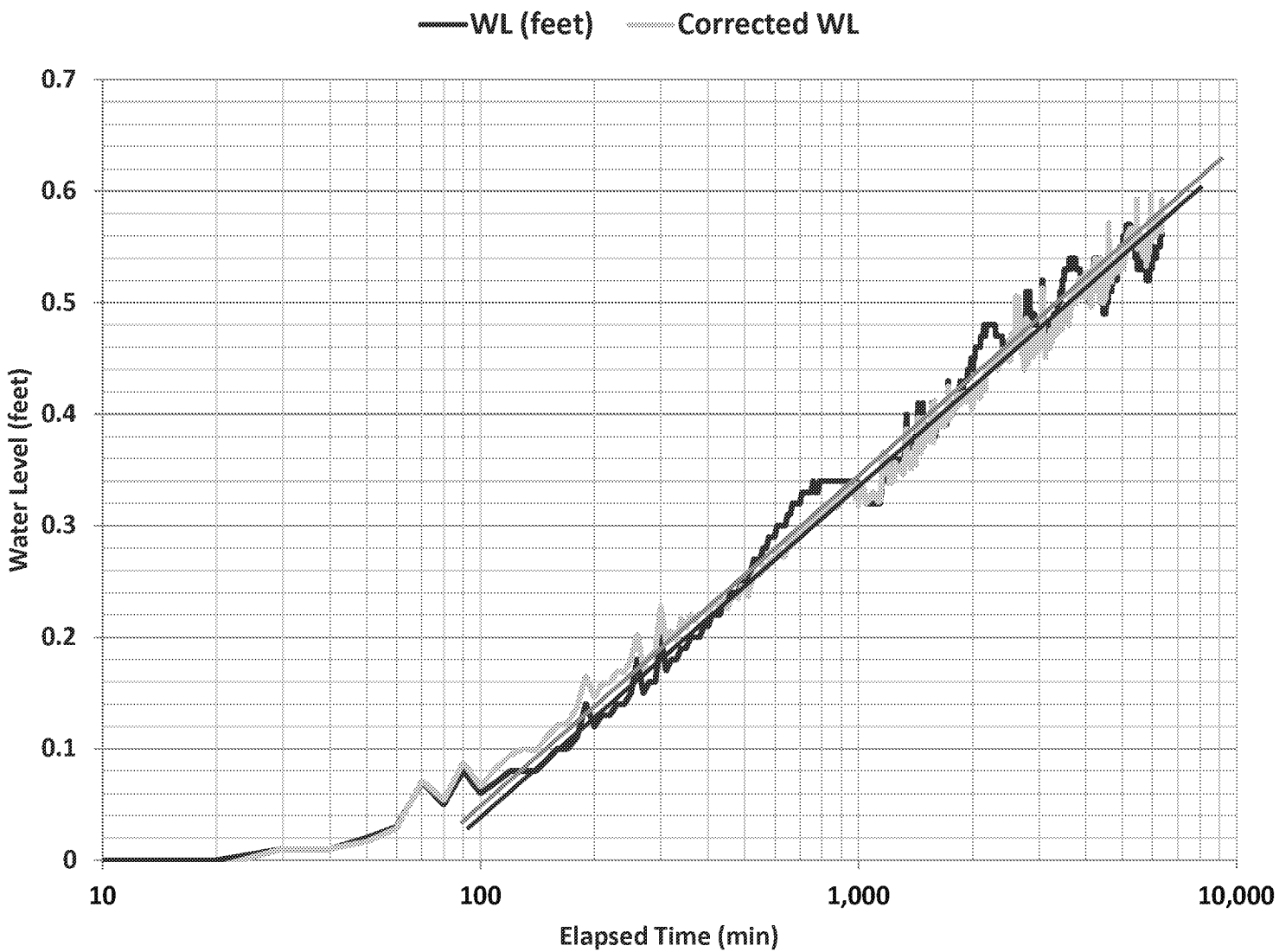
SYNOPTIC STUDY DATA REVIEW:
BP & TIDAL CORRECTIONS – COOPER-JACOB RHMW08 RECOVERY



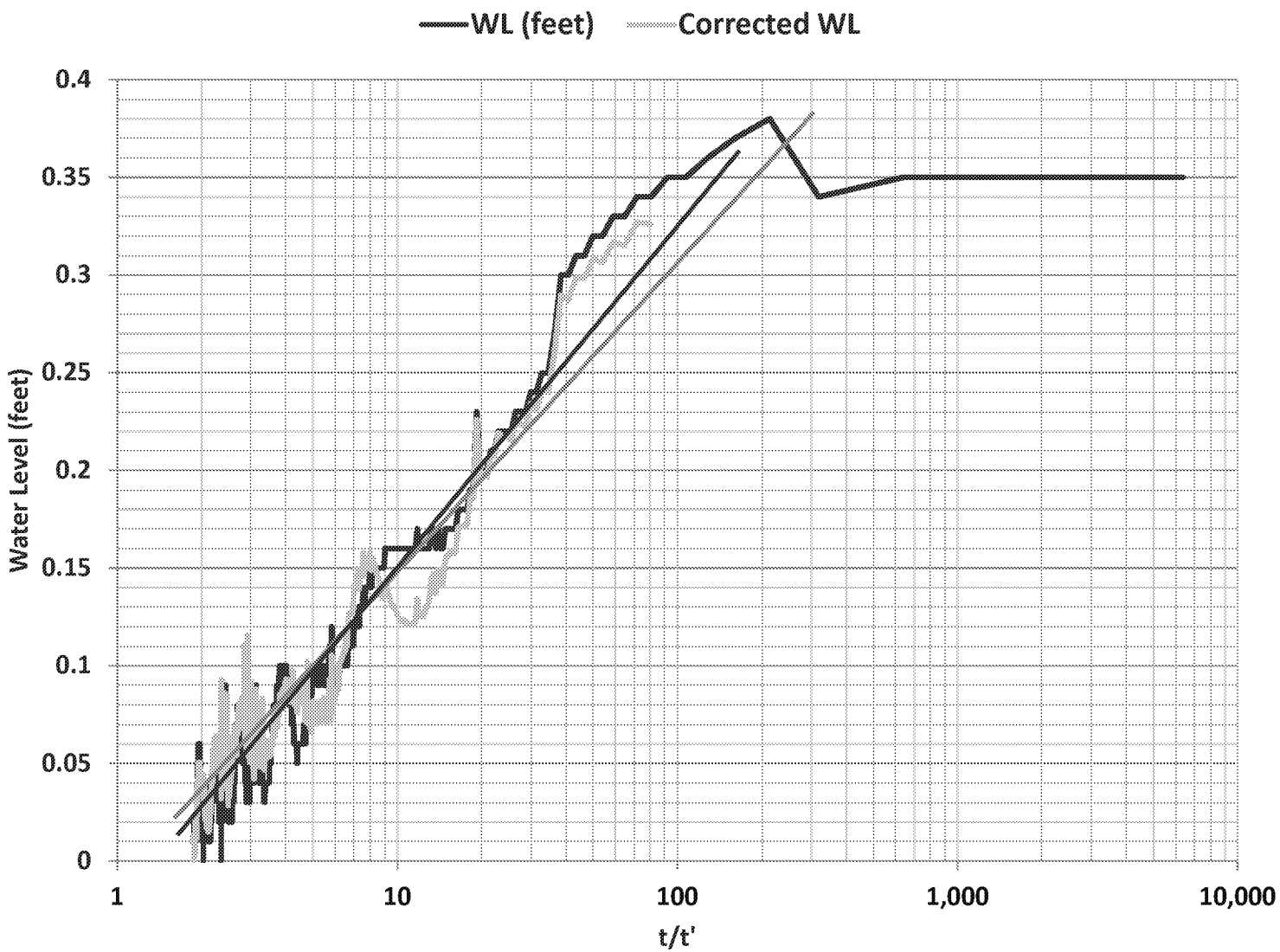
SYNOPTIC STUDY DATA REVIEW:
BP CORRECTIONS – COOPER-JACOB RHMW05 DRAWDOWN



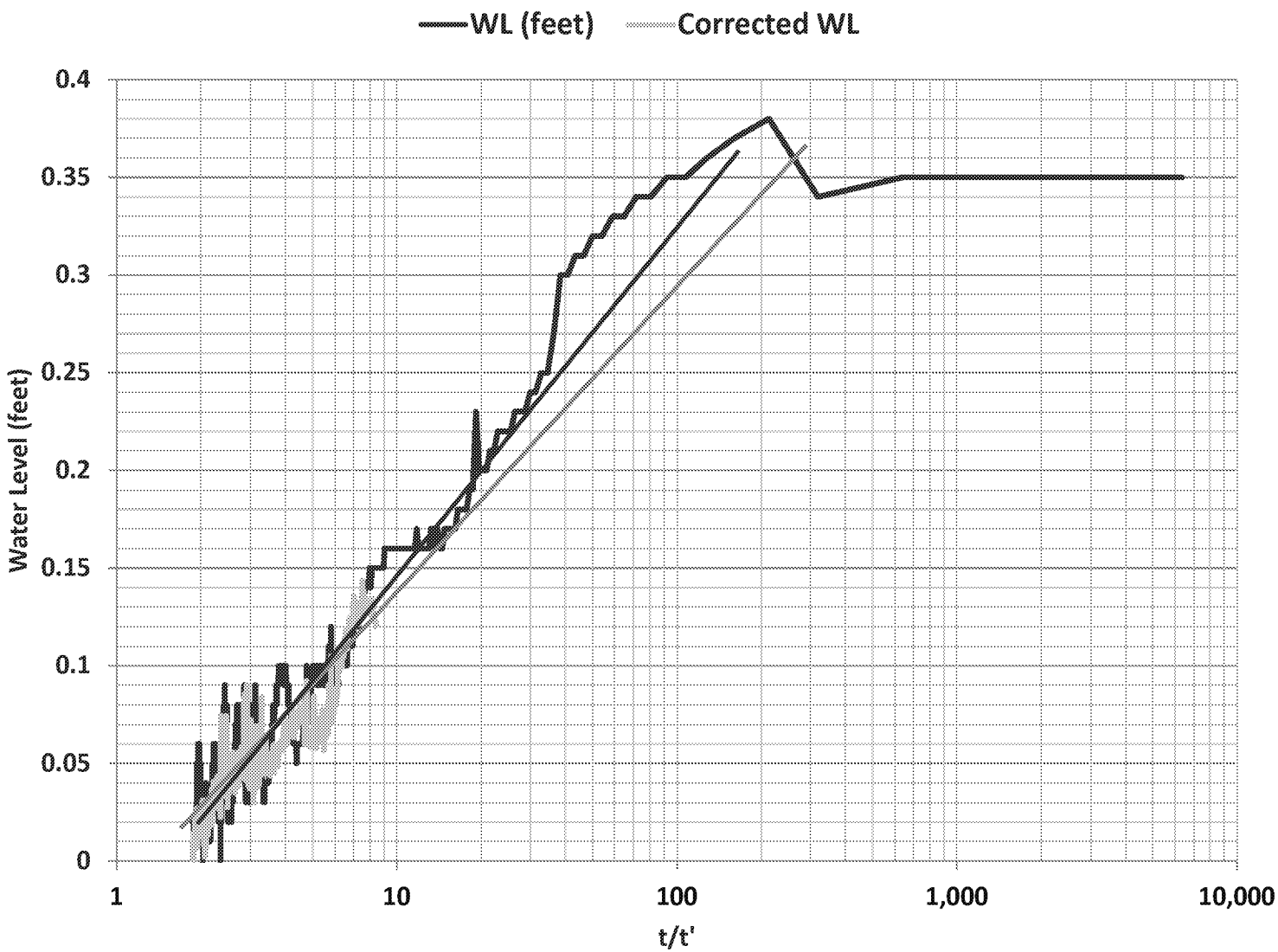
SYNOPTIC STUDY DATA REVIEW:
BP & TIDAL CORRECTIONS – COOPER-JACOB RHMW05 DRAWDOWN



SYNOPTIC STUDY DATA REVIEW:
BP CORRECTIONS – COOPER-JACOB RHMW05 RECOVERY

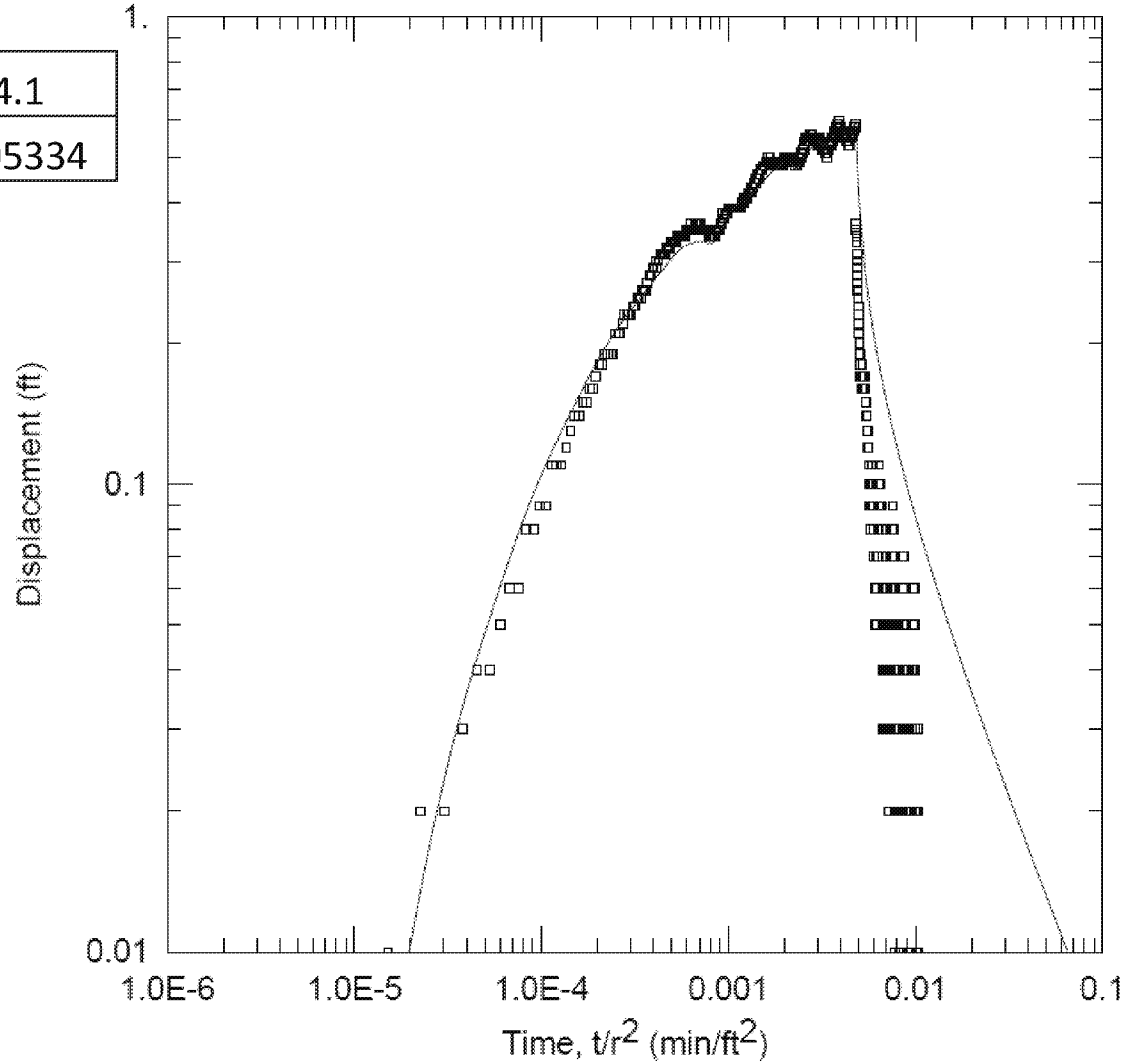


SYNOPTIC STUDY DATA REVIEW:
BP & TIDAL CORRECTIONS – COOPER-JACOB RHMW05 RECOVERY



SYNOPTIC STUDY DATA REVIEW:
UNCORRECTED – THEIS RHMW08

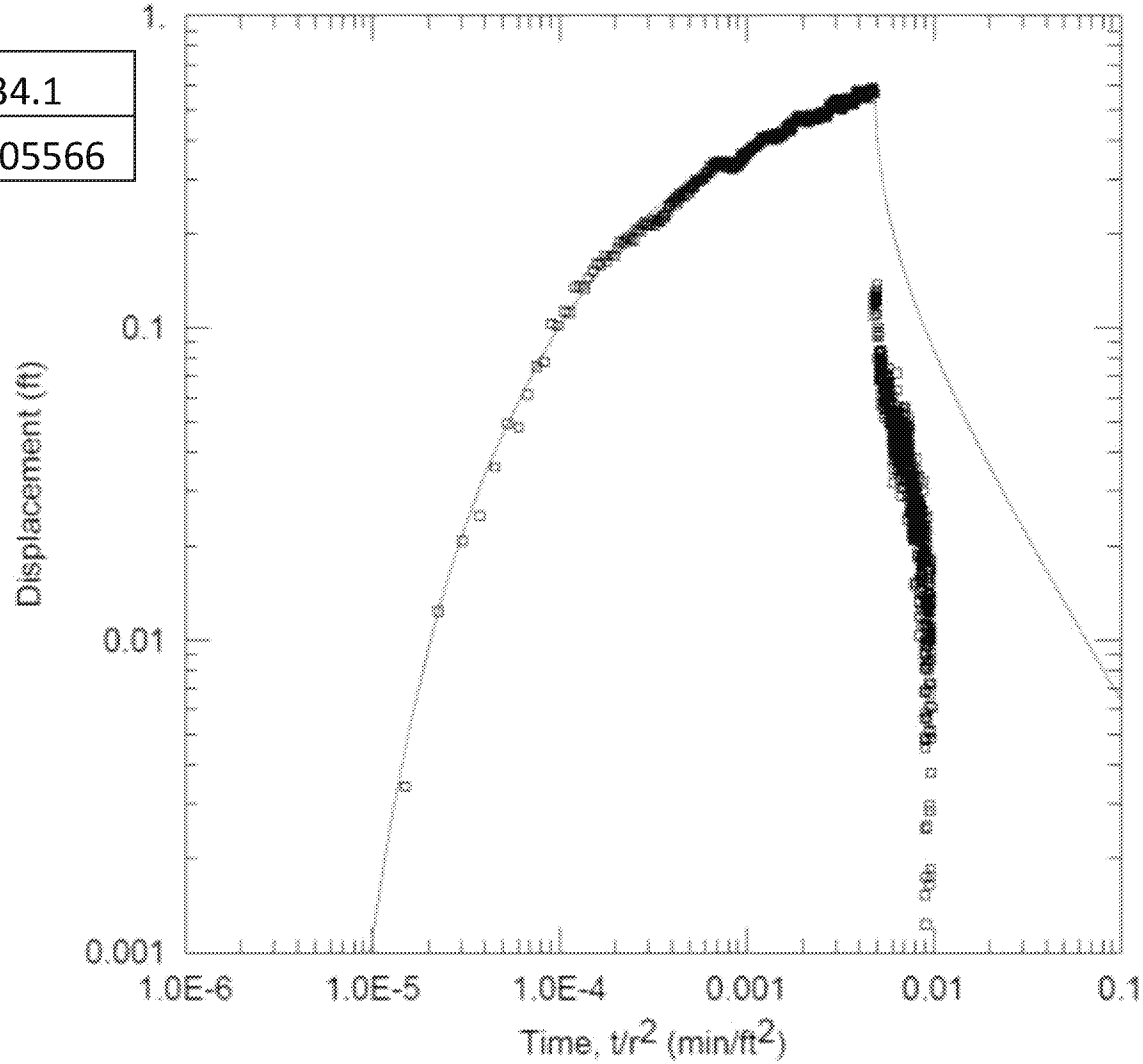
Transmissivity (ft^2/min)	434.1
Storativity	0.05334



SYNOPTIC STUDY DATA REVIEW:

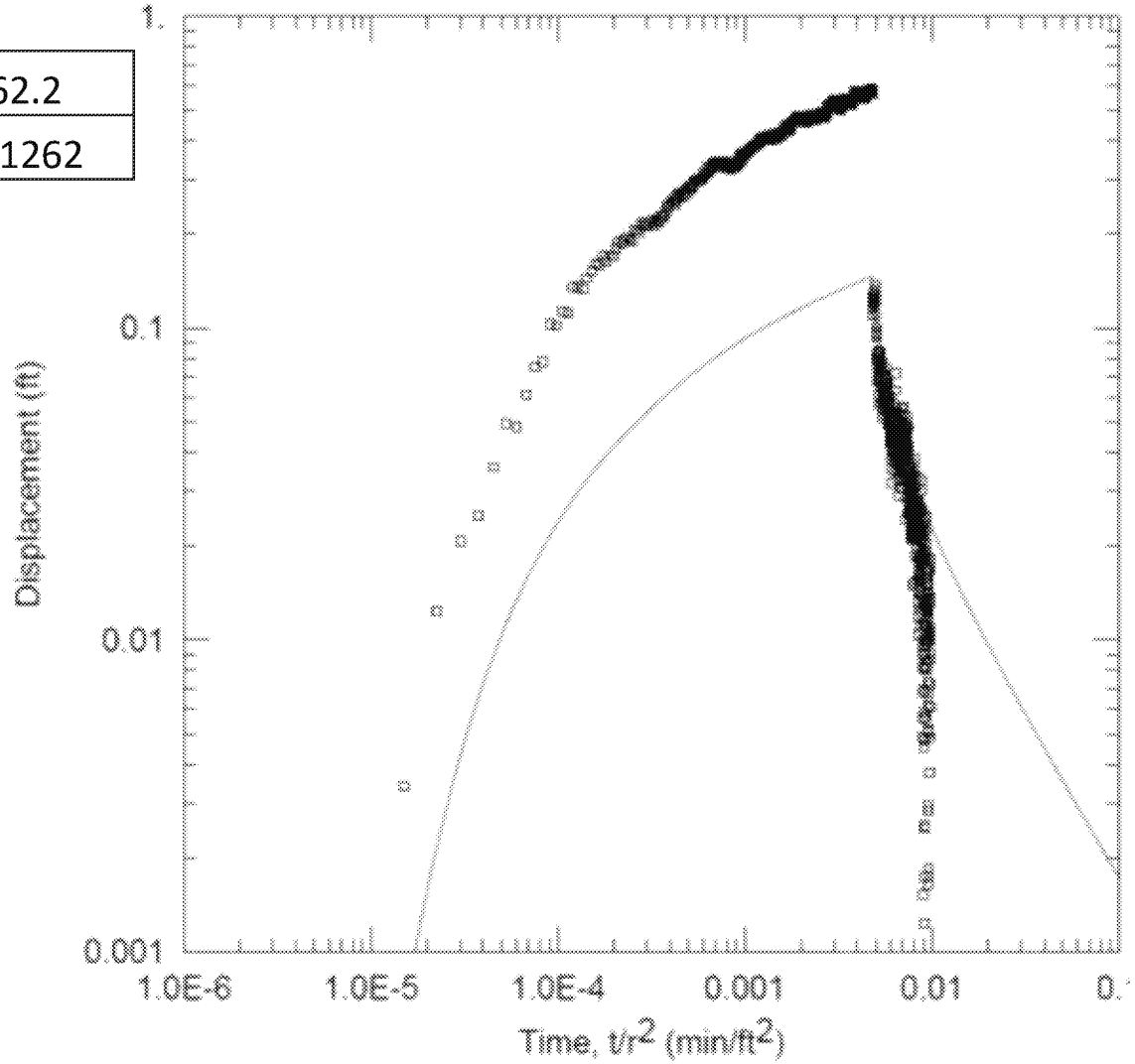
BP & TIDAL CORRECTIONS – THEIS RHMW08 DRAWDOWN

Transmissivity (ft^2/min)	434.1
Storativity	0.05566



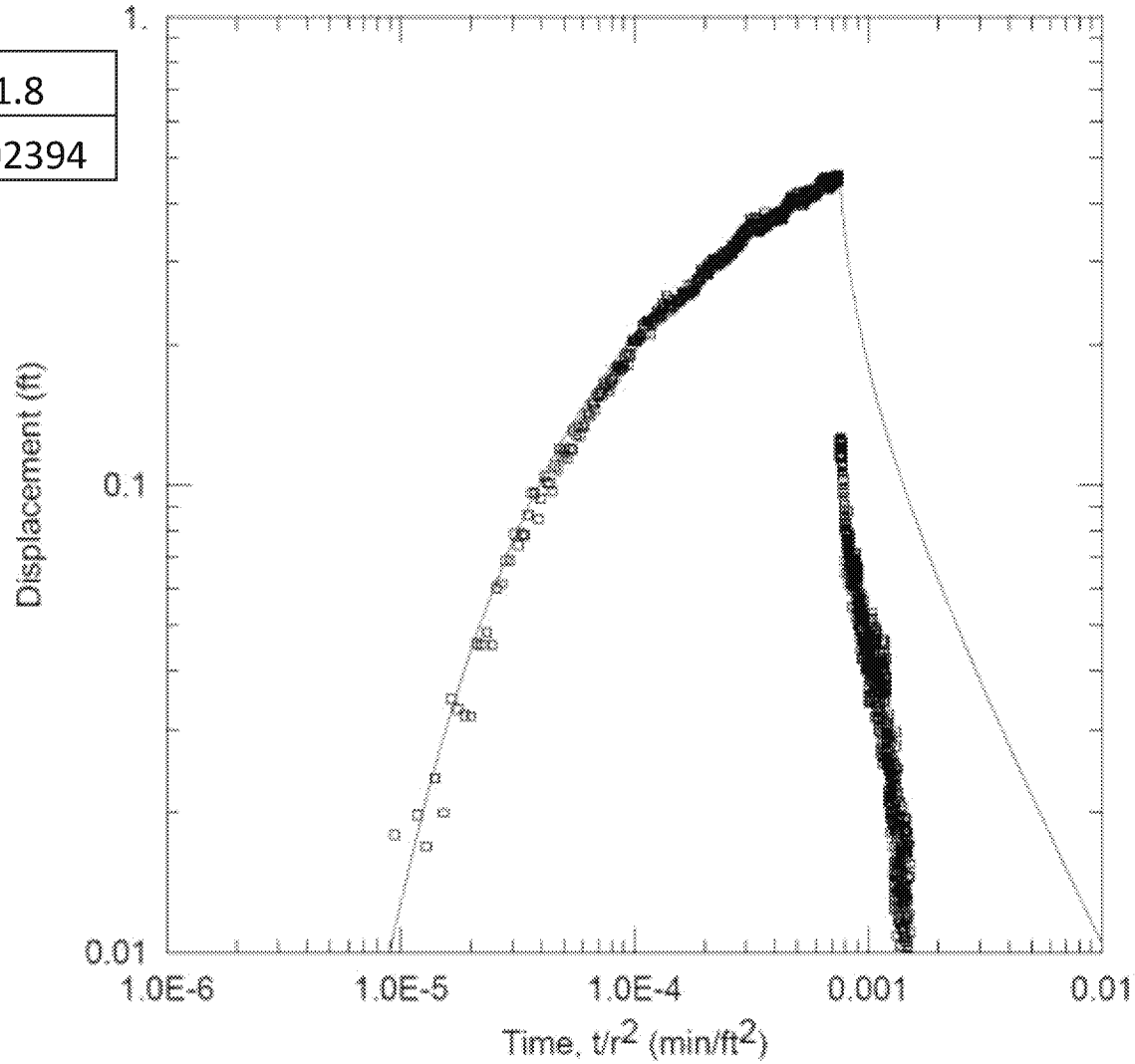
BP & TIDAL CORRECTIONS – THEIS RHMW08 RECOVERY

Transmissivity (ft^2/min)	762.2
Storativity	0.1262



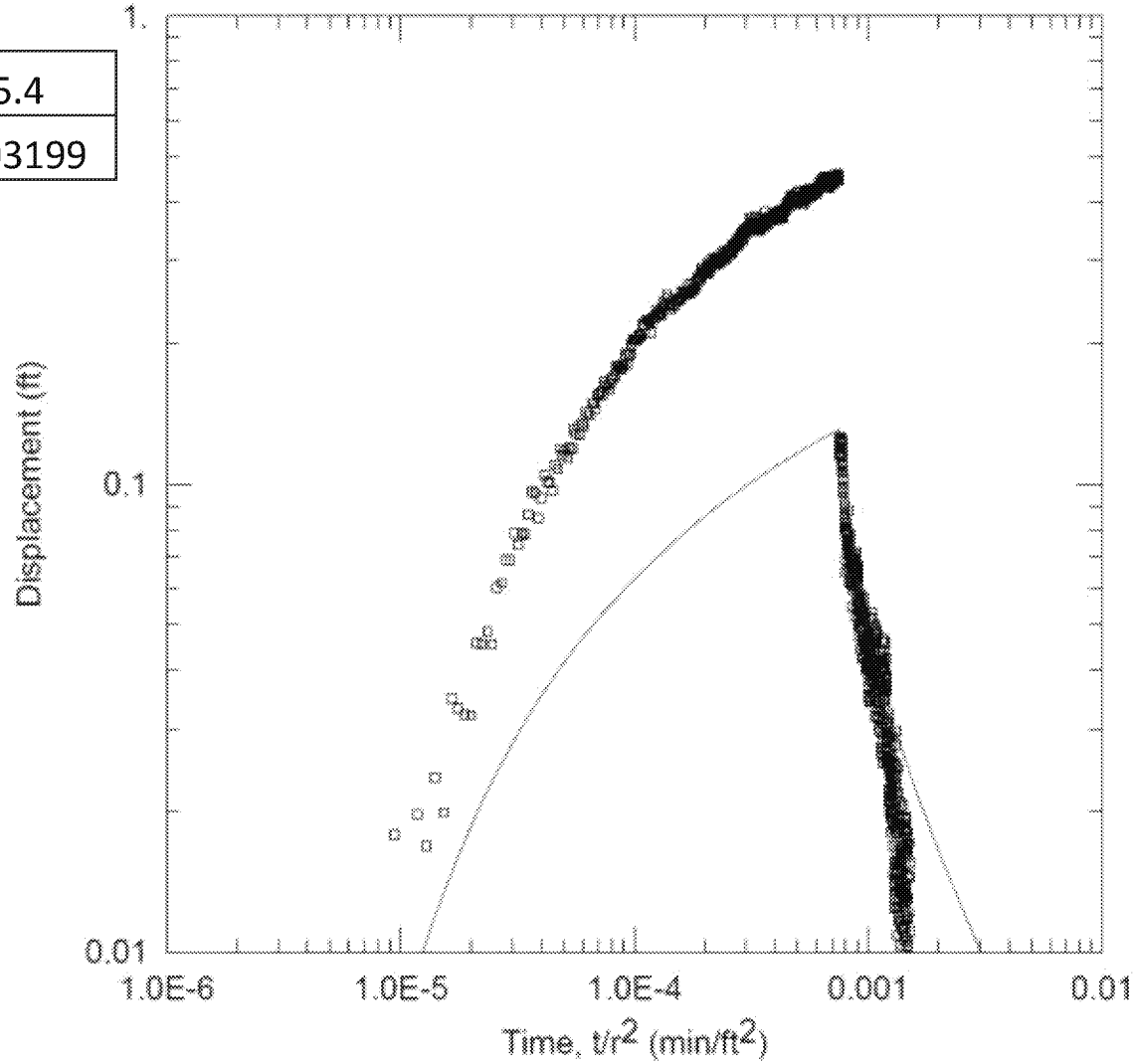
BP & TIDAL CORRECTIONS – THEIS RHMW03 DRAWDOWN

Transmissivity (ft^2/min)	421.8
Storativity	0.02394



SYNOPTIC STUDY DATA REVIEW:
BP & TIDAL CORRECTIONS – THEIS RHMW03 RECOVERY

Transmissivity (ft^2/min)	735.4
Storativity	0.03199



SYNOPTIC STUDY DATA REVIEW:

PREVIOUS ANALYSES

- **The following methods did not improve evaluation of the synoptic data, or allow better resolution of aquifer properties:**
  - Barker (1988)
  - Dougherty-Babu (1984)
  - Moench (1997)
  - Neuman (1974)

SYNOPTIC STUDY DATA REVIEW:

CORRECTION COMPARISONS

	Cooper-Jacob				Theis			
	Drawdown		Recovery		Drawdown		Recovery	
	Effective Transmissivity (ft^2/d)	Apparent Storativity	Effective Transmissivity (ft^2/d)	Apparent Storativity	Effective Transmissivity (ft^2/d)	Apparent Storativity	Effective Transmissivity (ft^2/d)	Apparent Storativity
Uncorrected					**Uncorrected**			
Mean	891,000	0.04	520,000	0.03	725,000	0.04	--	--
Minimum	607,000	0.01	353,000	0.01	657,000	0.02	--	--
Maximum	2,350,000	0.17	631,000	0.13	795,000	0.09	--	--
KGS Corrected - BP					**Corrected**			
Mean	782,000	0.05	655,000	0.05	667,000	0.05	--	--
Minimum	409,000	0.02	402,000	0.01	585,000	0.02	--	--
Maximum	1,450,000	0.15	982,000	0.12	760,000	0.10	--	--
KGS Corrected - BP & Tidal					**Corrected**			
Mean	829,000	0.06	633,000	0.05	651,000	0.06	1,030,000	0.08
Minimum	409,000	0.02	384,000	0.01	589,000	0.02	708,000	0.02
Maximum	1,340,000	0.16	803,000	0.13	750,000	0.19	1,260,000	0.38

* Yellow boxes indicate where Theis was matched once for both drawdown and recovery, instead of two individual analyses.

SYNOPTIC STUDY DATA REVIEW:

SUMMARY AND NEXT STEPS

Summary:

- **Additional evaluation of synoptic data was completed which considered:**
  - Barometric pressure influence on observed water level fluctuations
  - Tidal influence on observed water level fluctuations
- **Refined analyses resulted in only slight changes to derived aquifer properties**

Next Steps:

- **Re-analyze anisotropic solutions with refined synoptic data interpretations**
  - Mutch (2005)
  - Hantush and Thomas (1966)
- **Repeat analysis for Halawa Shaft pumping**

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CSM UPDATE – HYDROGEOLOGY CONSIDERATIONS:

TRANSFER FUNCTION-NOISE (TFN) ANALYSIS

TFN ANALYSIS:
OBJECTIVES

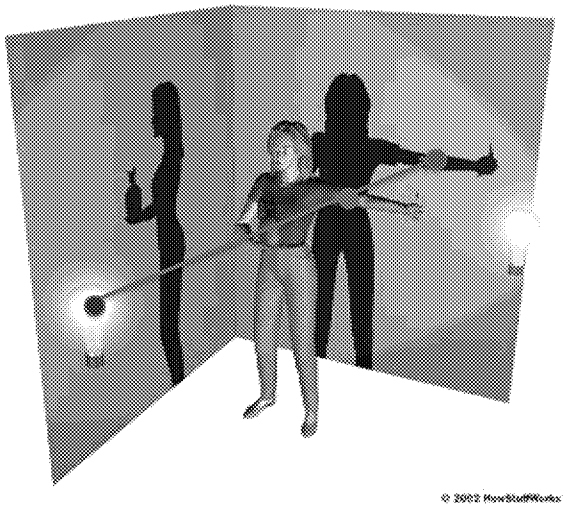
- **Support development of groundwater models by**
  - Developing data for calibration of groundwater model
  - Independent validation of groundwater model predictions
  - Estimation of equivalent aquifer hydraulic properties
  - Evaluation of aquifer anisotropy

VALUE OF TFN ANALYSIS

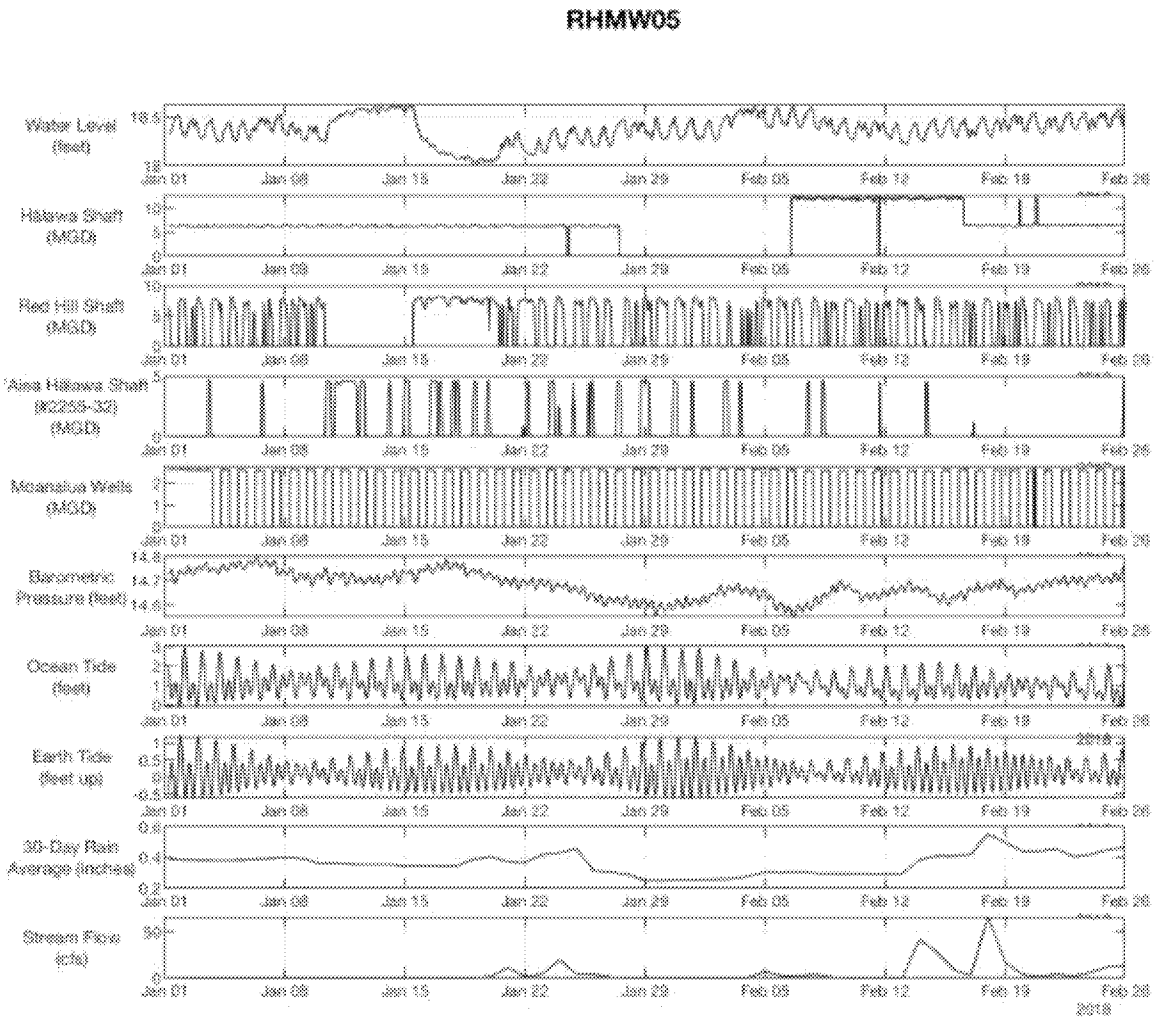
- **The TFN Analysis provides:**
  - Understanding of impacts of individual known stresses (e.g., Red Hill Shaft and Halawa Shaft pumping, barometric, and tidal) on water levels at individual wells
  - Magnitude of the unexplained water level variations
  - Targeted information (water level responses to unit pumping at individual shafts) for calibration and evaluation of the numerical groundwater flow model
  - Estimates of equivalent transmissivity (between each pair of pumping shaft and observation well) indicating heterogeneity, anisotropy and parameter ranges
  - Estimates of equivalent anisotropy ratio and direction (for each pumping shaft)

TFN ANALYSIS:

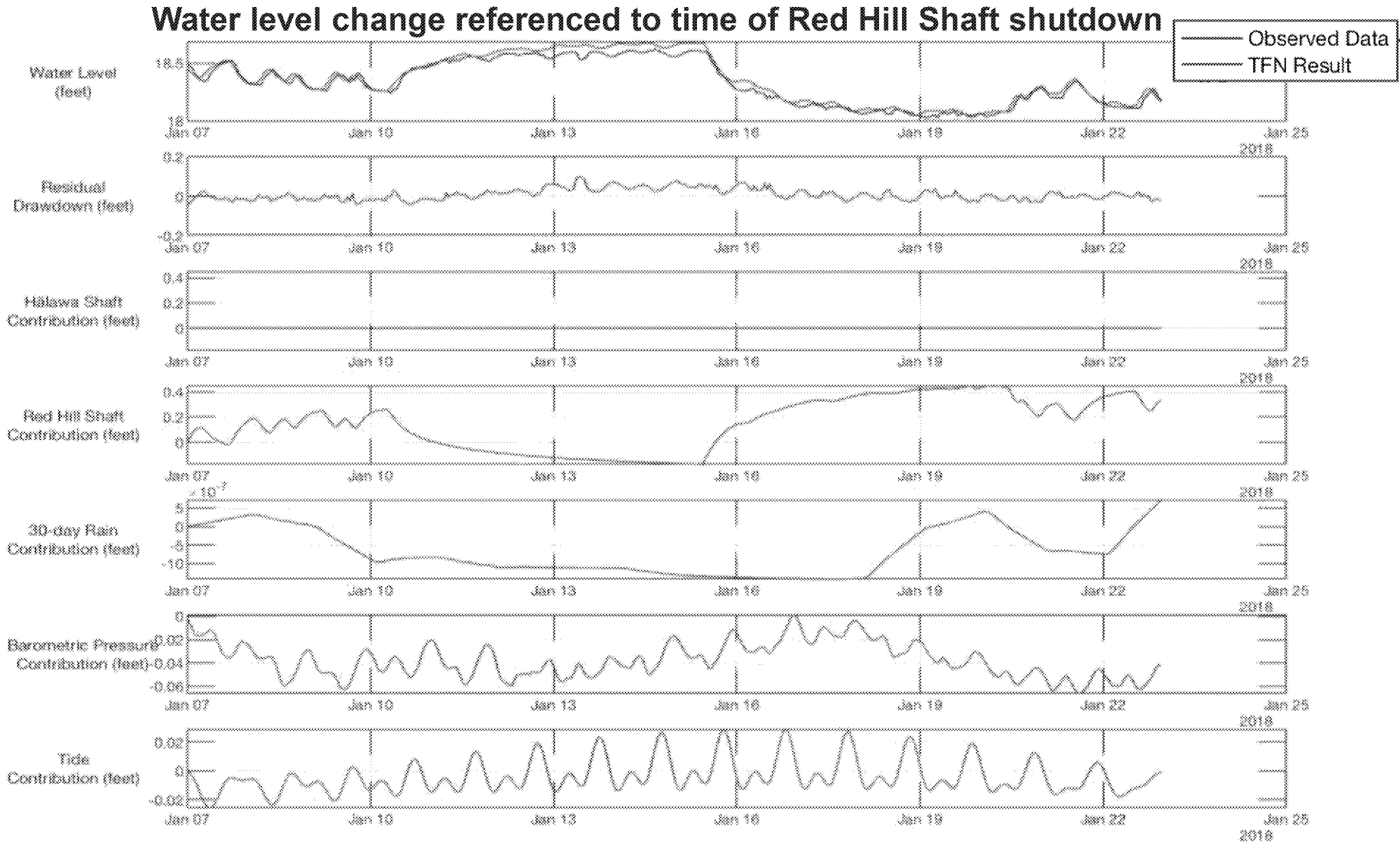
SYNOPTIC WATER LEVEL DATA



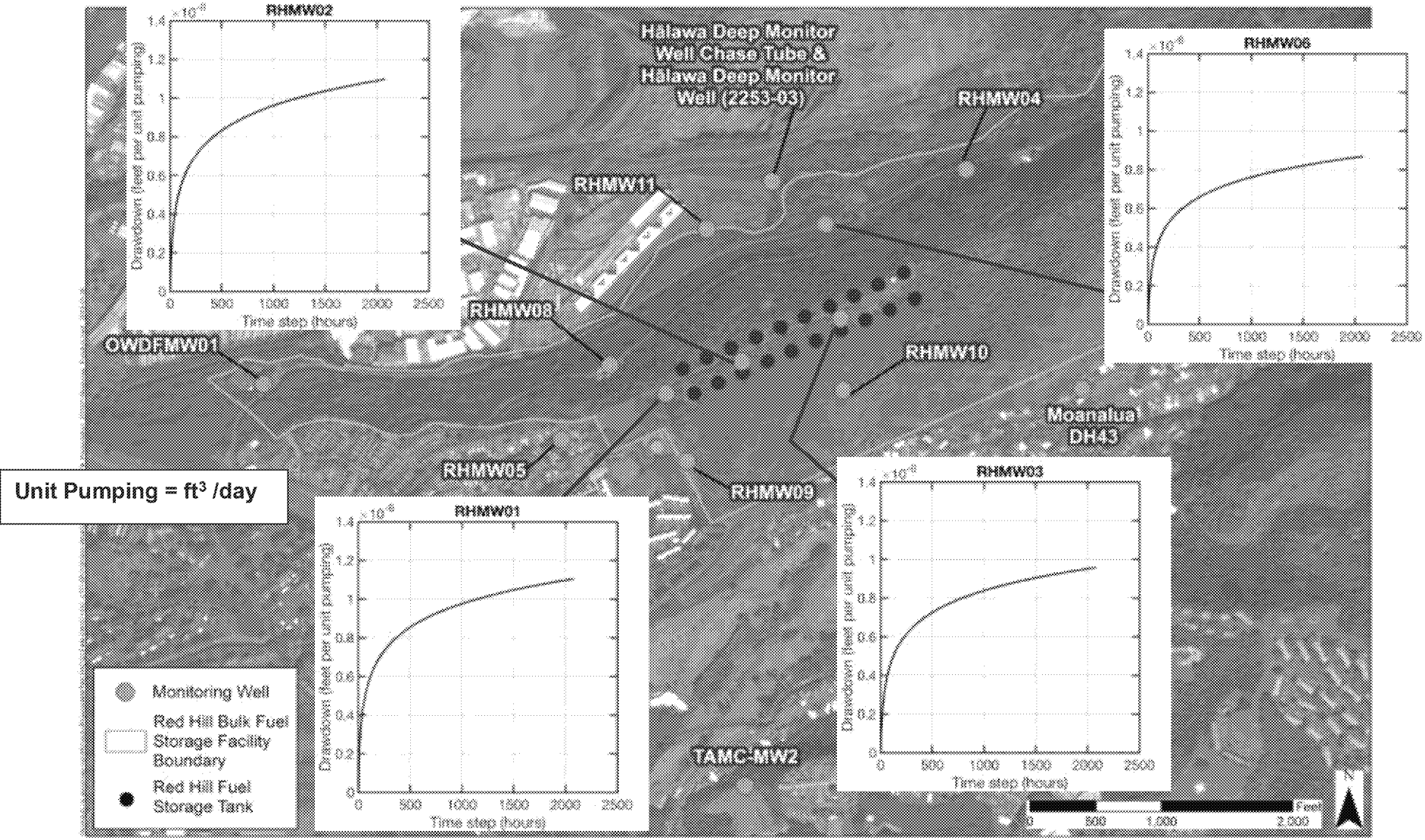
- Multiple sources and multiple observations
- Analogous to recording videos from different angles with known and unknown light sources flickering at different frequencies, durations, and intensities.



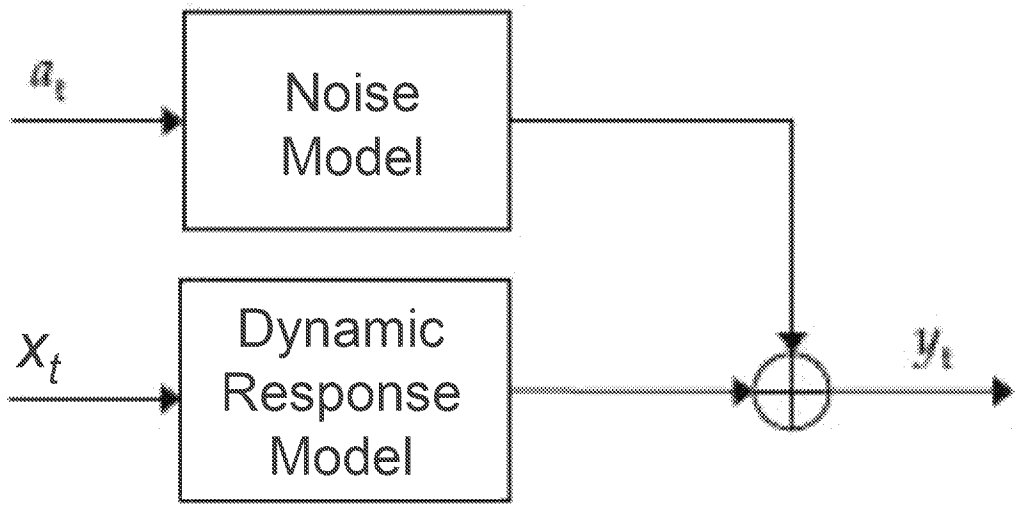
TFN ANALYSIS:
ESTIMATION OF CONTRIBUTIONS FROM INDIVIDUAL SOURCES TO WATER LEVEL CHANGE – RHMW05



TFN ANALYSIS:
ESTIMATION OF STEP RESPONSE FUNCTIONS FOR GROUNDWATER MODEL CALIBRATION (RED HILL SHAFT PUMPING)



TFN MODEL WITH SINGLE INPUT SOURCE



Output = dynamic component + noise

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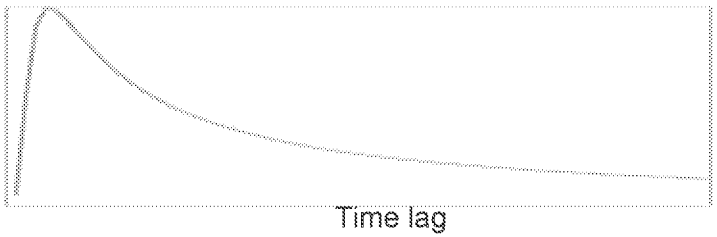
TFN ANALYSIS:
DISCRETE TRANSFER FUNCTION

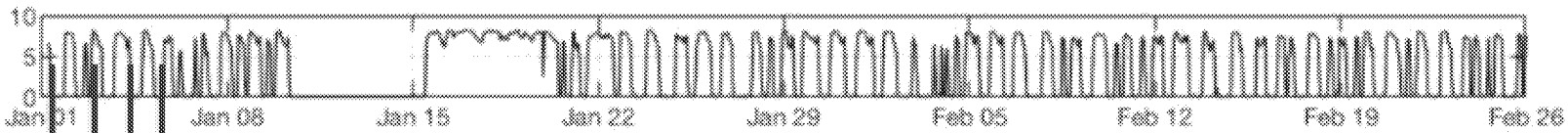
Unit impulse response function as transfer function

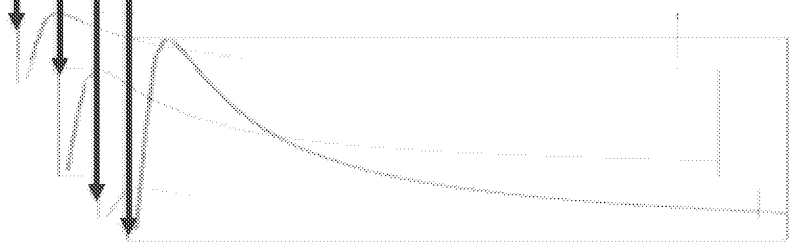
$$y_t = v_0 x_t + v_1 x_{t-1} + v_2 x_{t-2} + \cdots$$
$$= v(B) x_t$$
$$where\ v(B) = v_0 + v_1 B + v_2 B^2$$

Unit impulse response function



Source



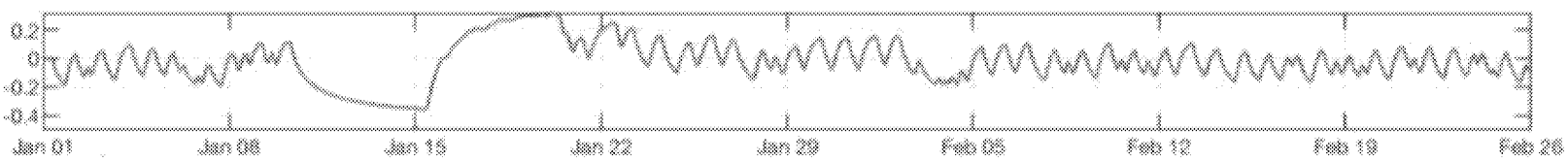


Responses to individual impulses

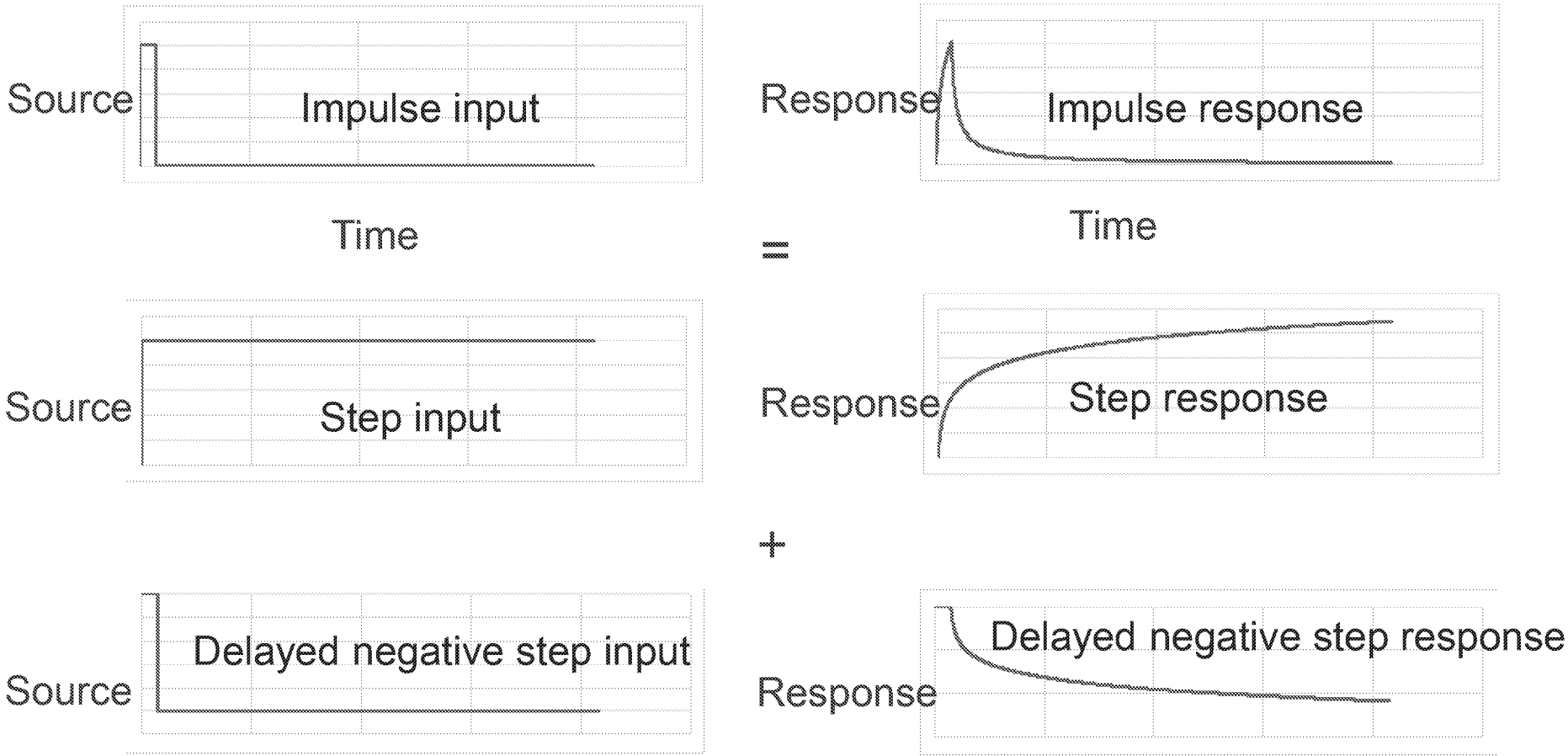
CONVOLUTION

Summing all responses to impulses

Response



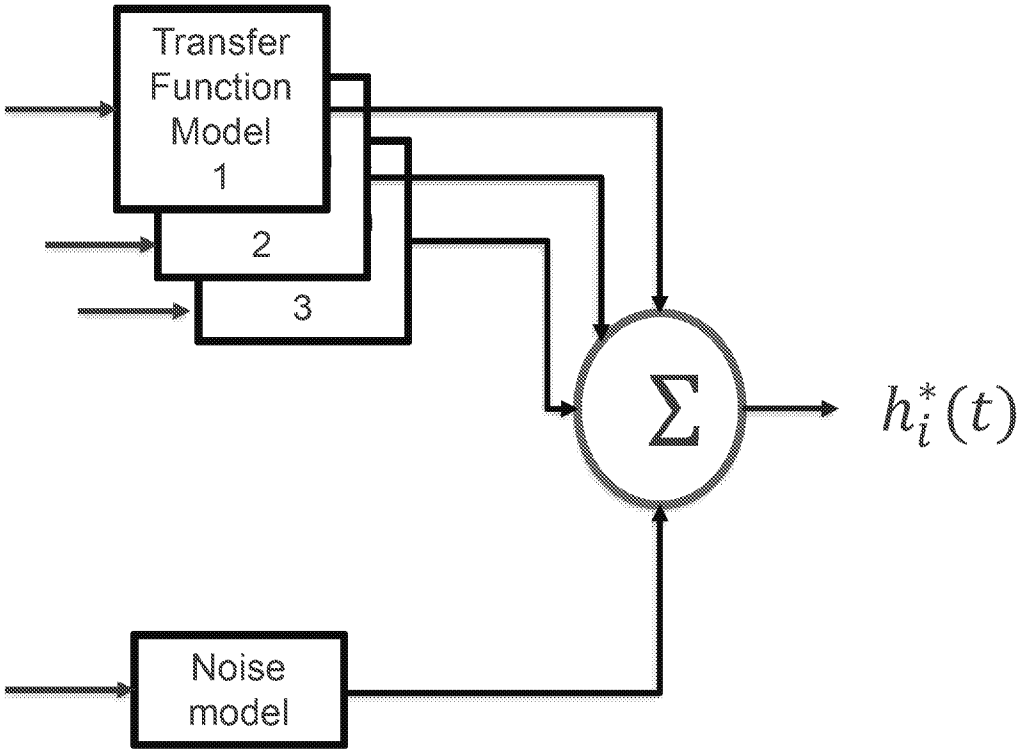
TFN ANALYSIS:
RELATIONSHIP BETWEEN IMPULSE RESPONSE AND STEP RESPONSE FUNCTIONS



TFN ANALYSIS:

TFN MODEL WITH MULTIPLE INPUT SOURCES

- Red Hill Shaft
- Halawa Shaft
- Barometric
- Earth tide
- 30-day averaged rainfall



$$(y - \mu_y) = f(\boldsymbol{k}, \boldsymbol{x}, t) + N_t$$

$$f(\boldsymbol{k}, \boldsymbol{x}, t) = \sum_{i=1}^{l} v_i(B)(x_{ti} - \mu_{ti})$$

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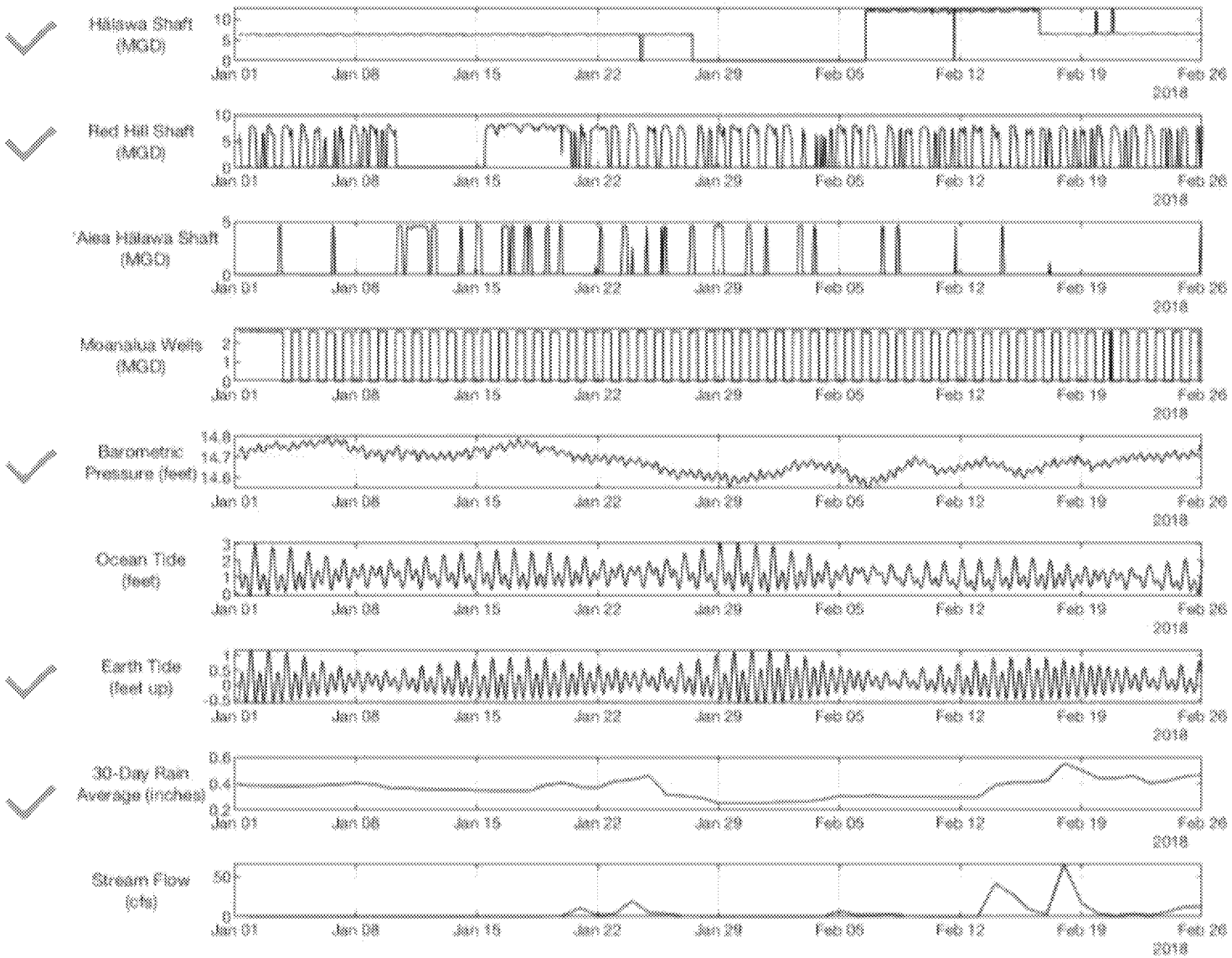
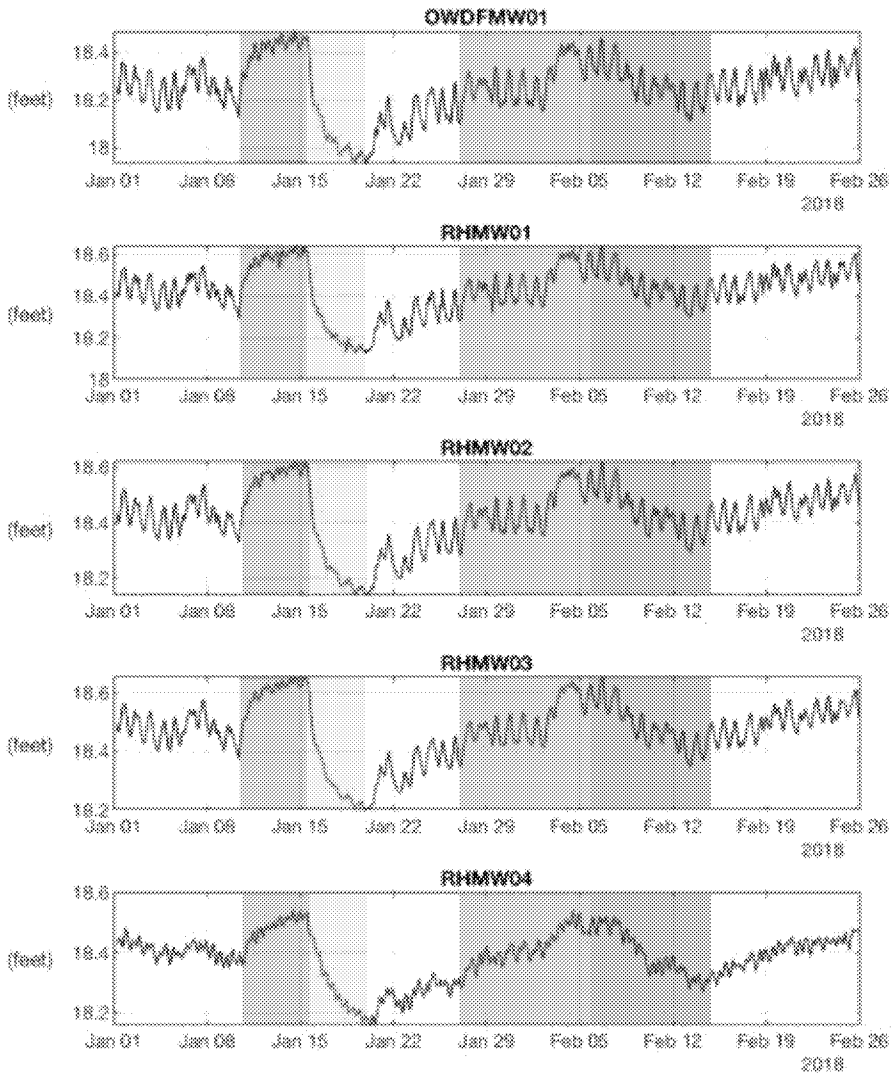
TFN ANALYSIS:

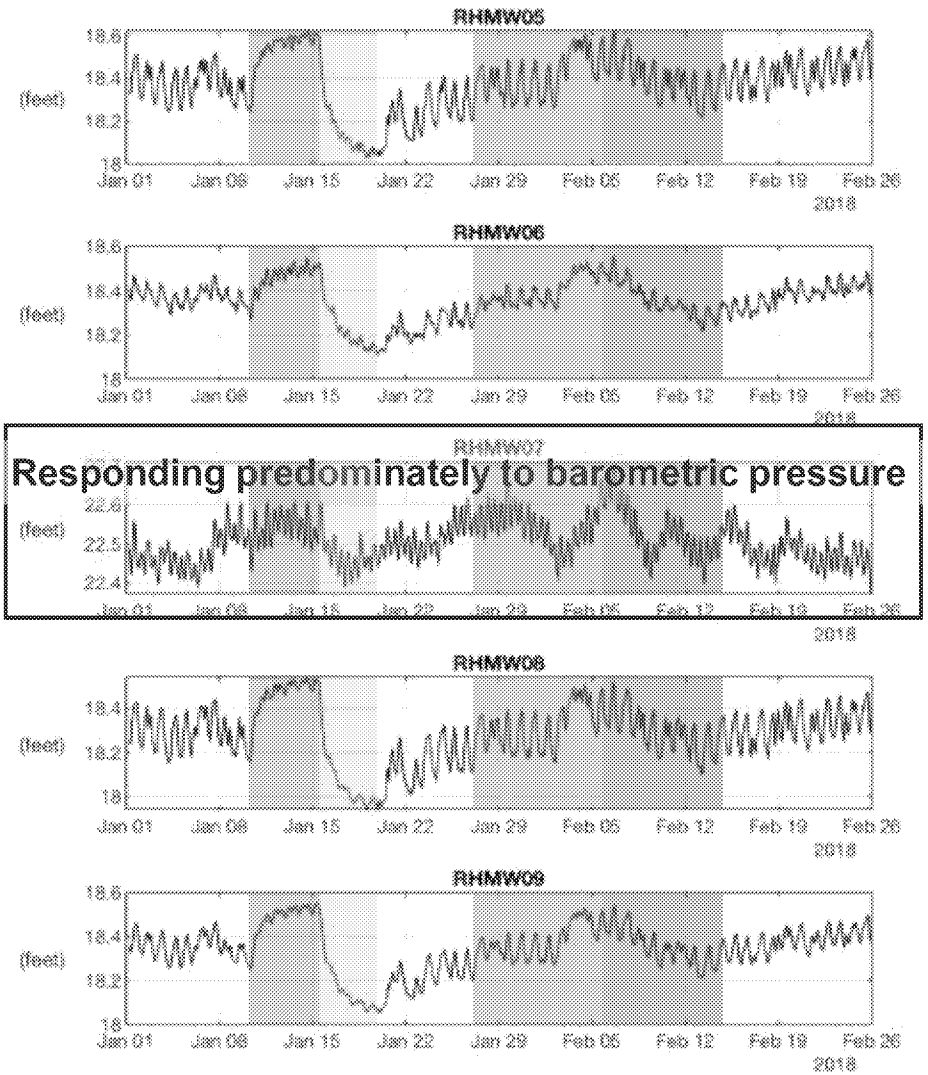
SOURCES INCLUDED IN TFN ANALYSIS



TFN ANALYSIS:

WELLS RESPONDING TO RED HILL SHAFT SHUTDOWN





Responding predominately to barometric pressure

Red Hill Shaft Off

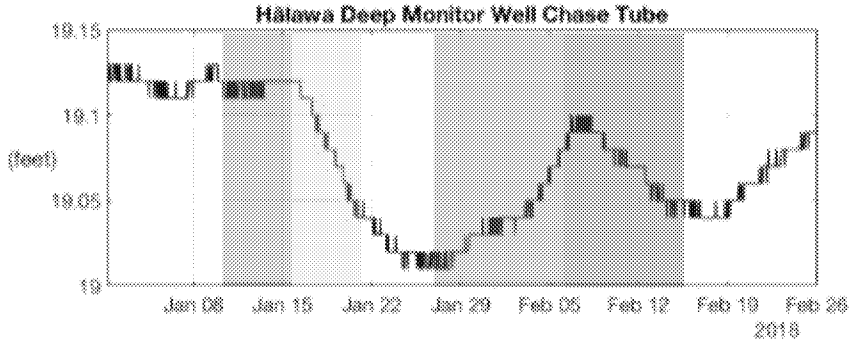
Red Hill Shaft On, Max Pumping

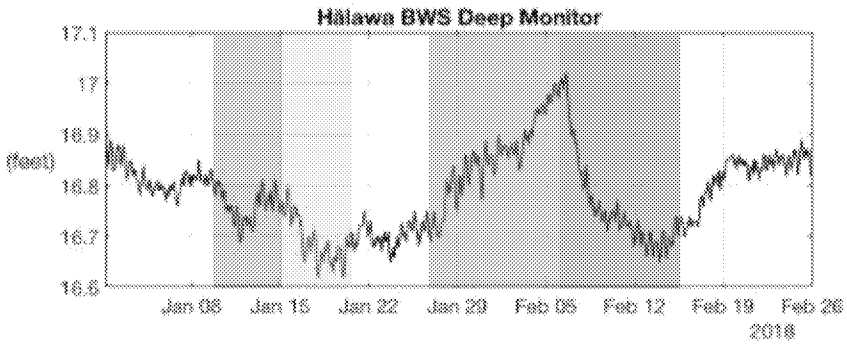
Halawa Shaft Off

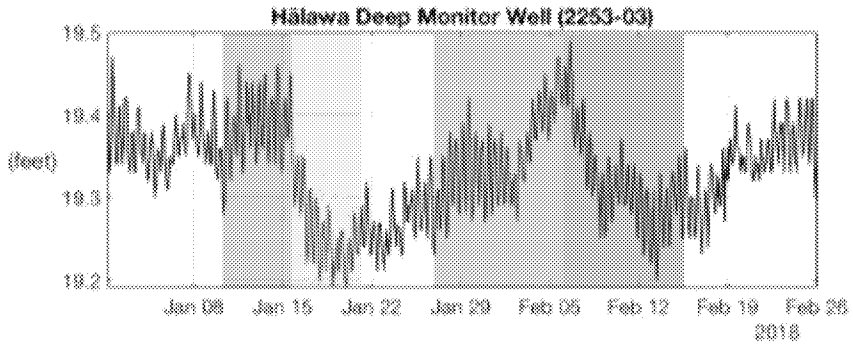
Halawa Shaft On, Max Pumping

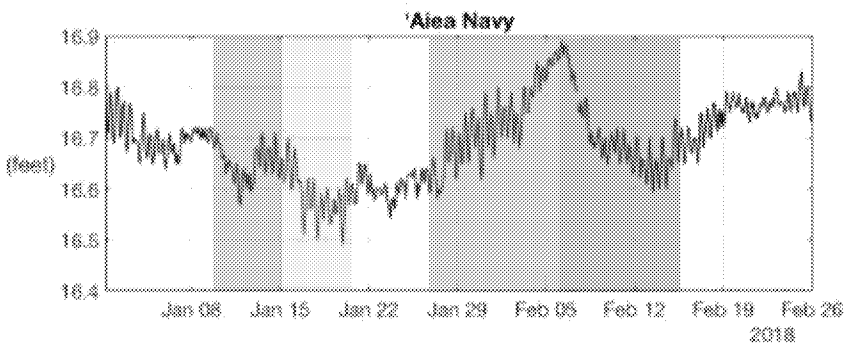
TFN ANALYSIS:

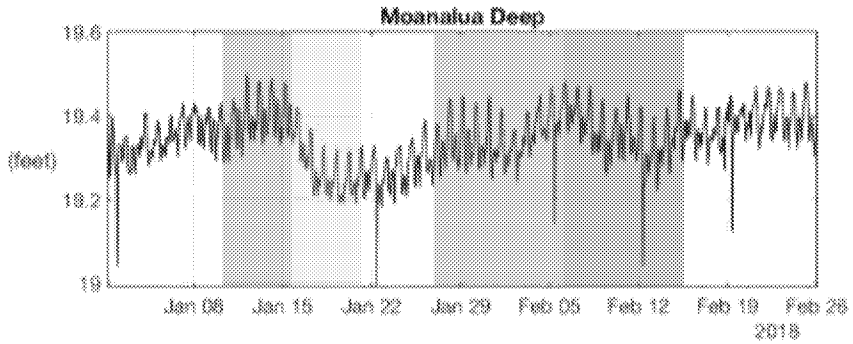
WELLS NOT RESPONDING TO RED HILL SHAFT SHUTDOWN

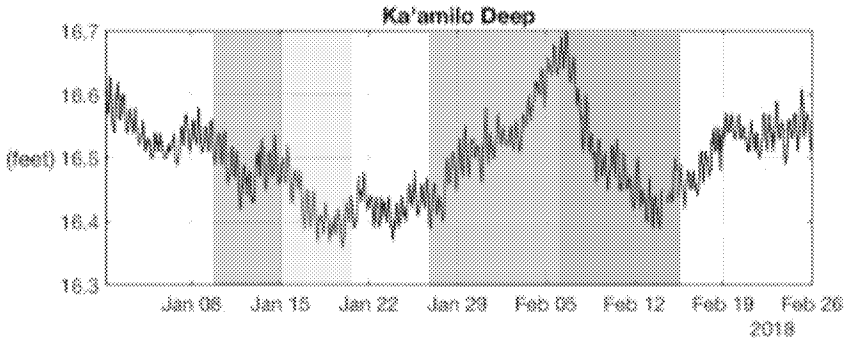












Red Hill Shaft Off

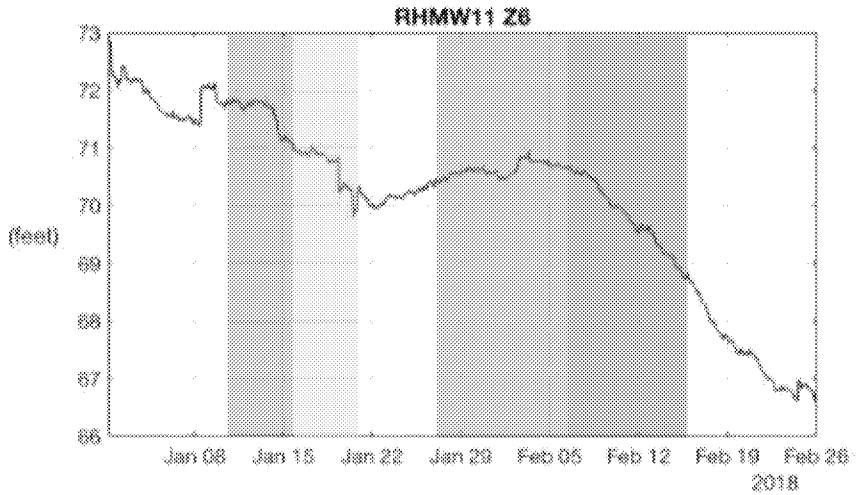
Red Hill Shaft On, Max Pumping

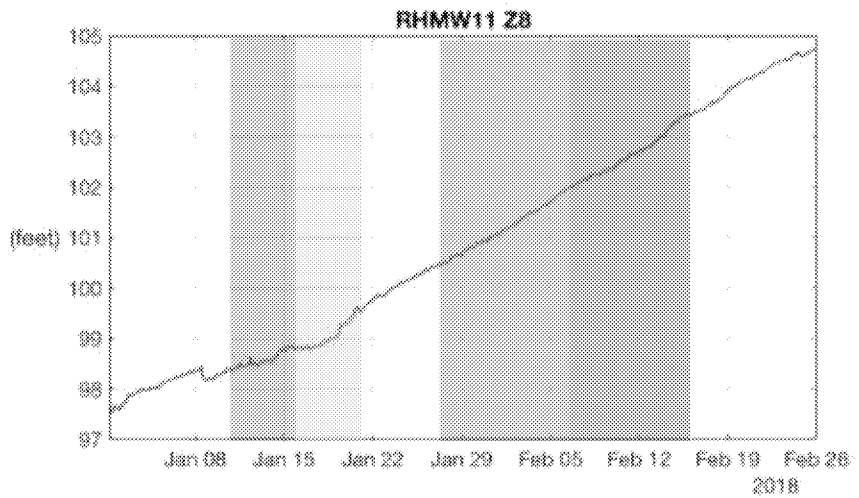
Halawa Shaft Off

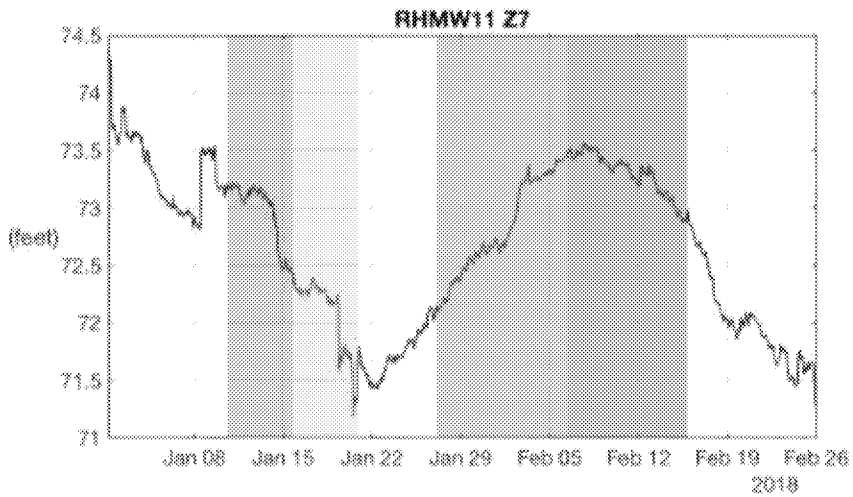
Halawa Shaft On, Max Pumping

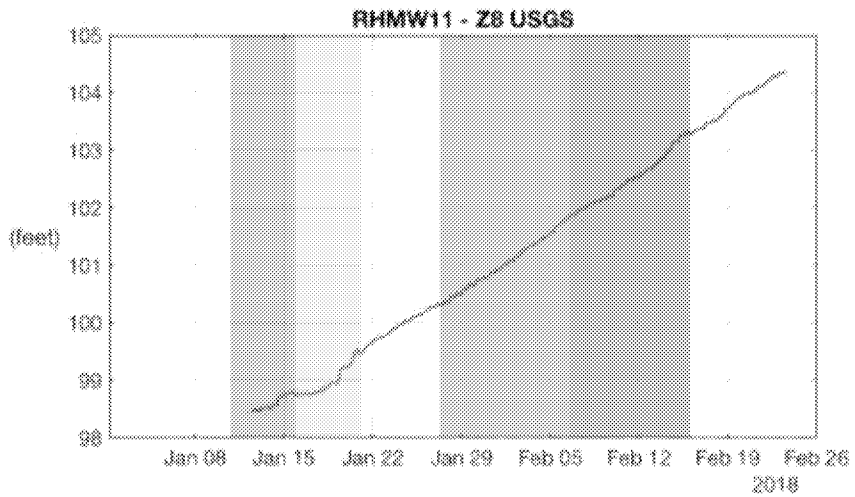
TFN ANALYSIS:

WELLS NOT RESPONDING TO RED HILL SHAFT SHUTDOWN









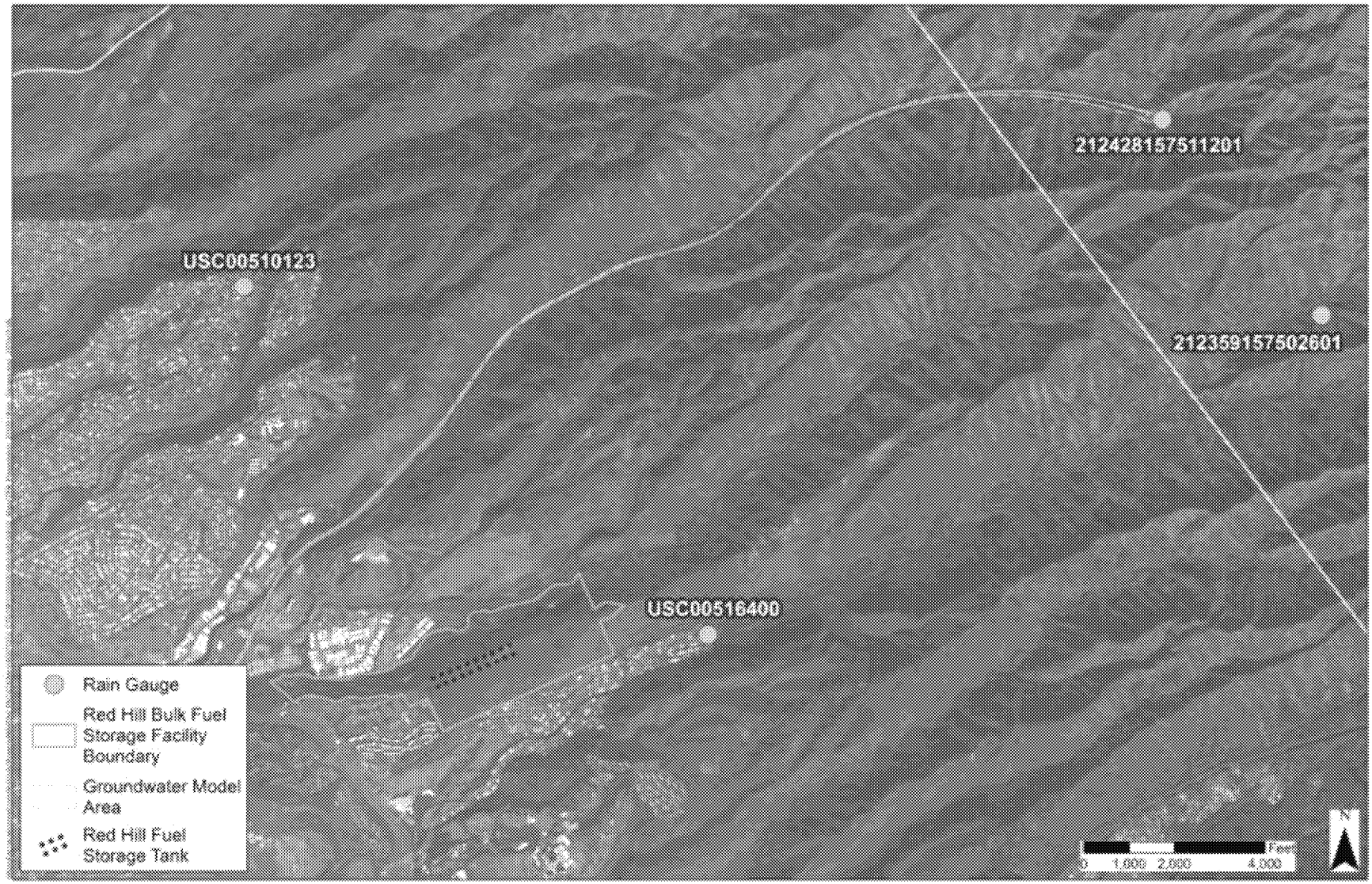
Red Hill Shaft Off

Red Hill Shaft On, Max Pumping

Halawa Shaft Off

Halawa Shaft On, Max Pumping

TFN ANALYSIS:
LOCATION OF RAIN GAUGES

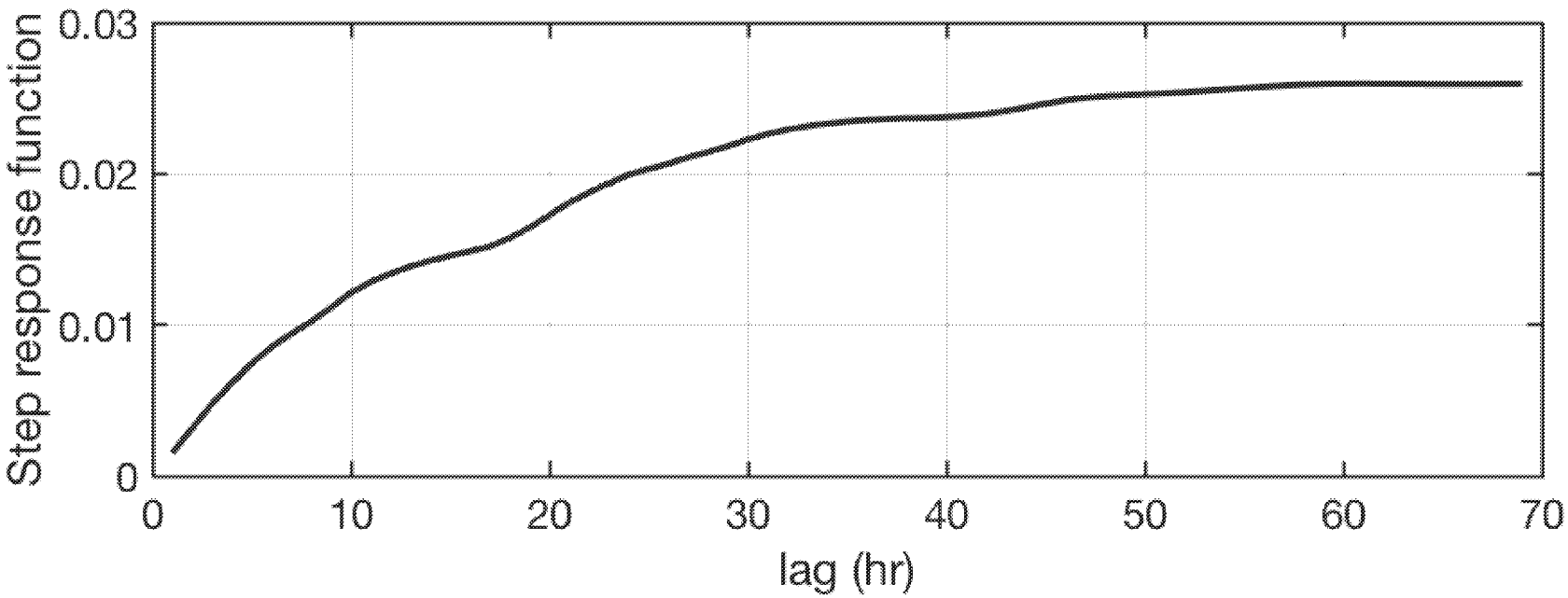


IMPLEMENTATION OF TFN ANALYSIS

- **Implementation variations:**
  - TF due to barometric, tidal, and rainfall – different empirical forms
  - Inclusion of various non-pumping sources
  - Optimization period – total versus sequential
  - TF due to pumping – empirical, Hantush, Theis, Ttim
  - Residual noise vs. white noise

TFN ANALYSIS:

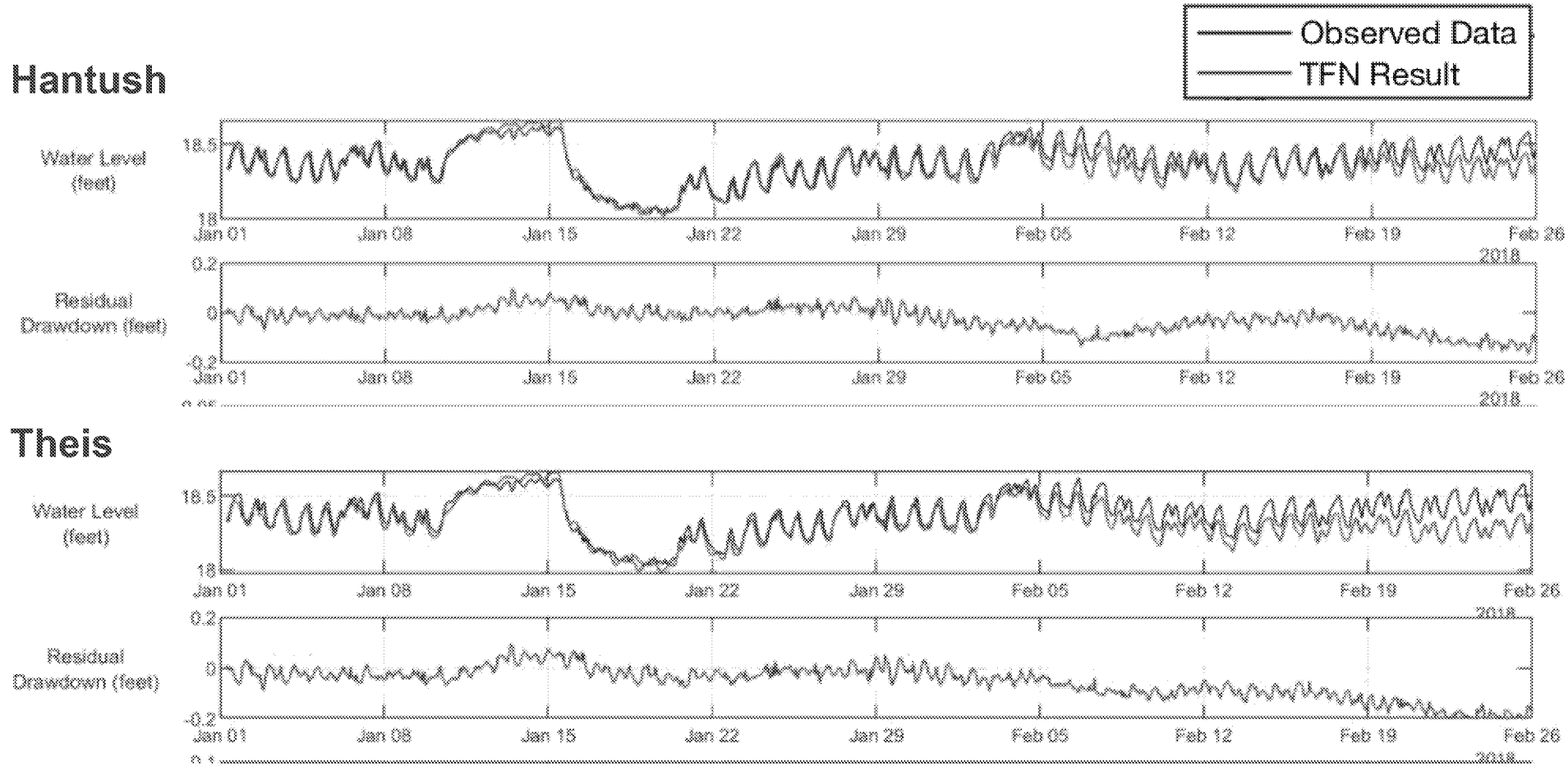
EXAMPLE EMPIRICAL STEP FUNCTION RESPONSE



Resembles Hantush leaky aquifer solution

TFN ANALYSIS:

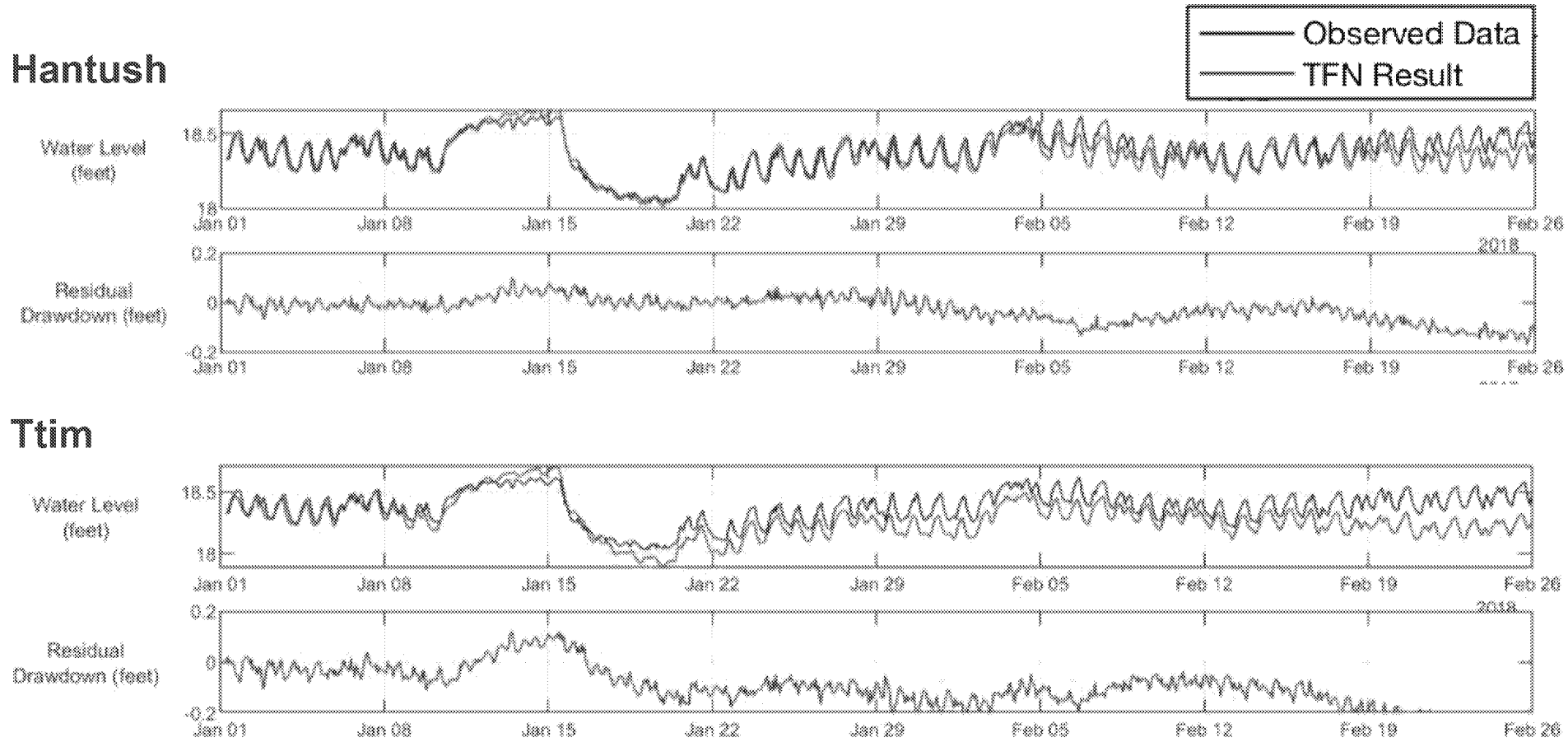
HANTUSH VS. THEIS STEP RESPONSE FUNCTIONS



Using Hantush step response function results in slightly better matching than Theis

TFN ANALYSIS:

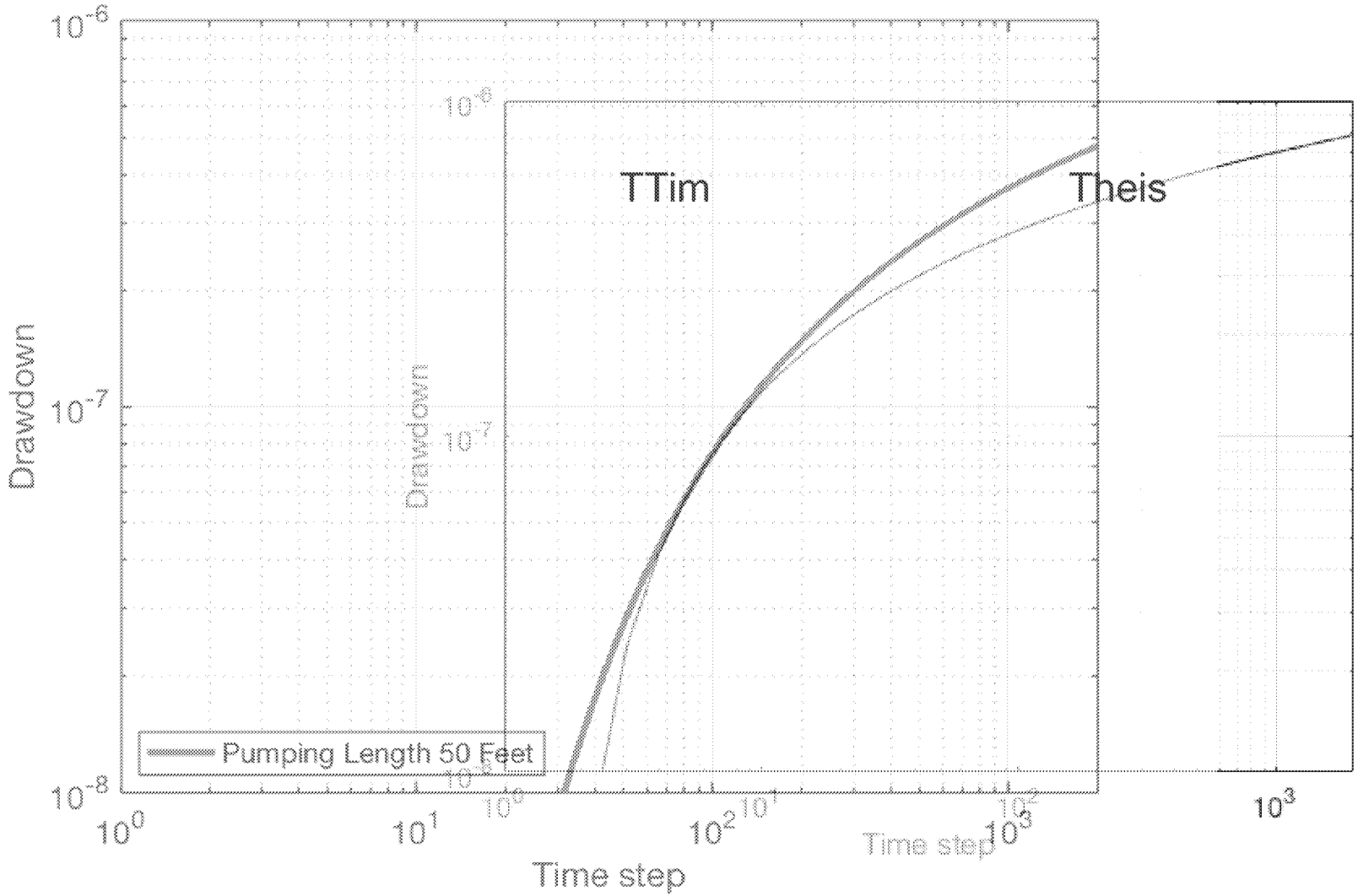
HANTUSH VS. TTIM STEP RESPONSE FUNCTIONS



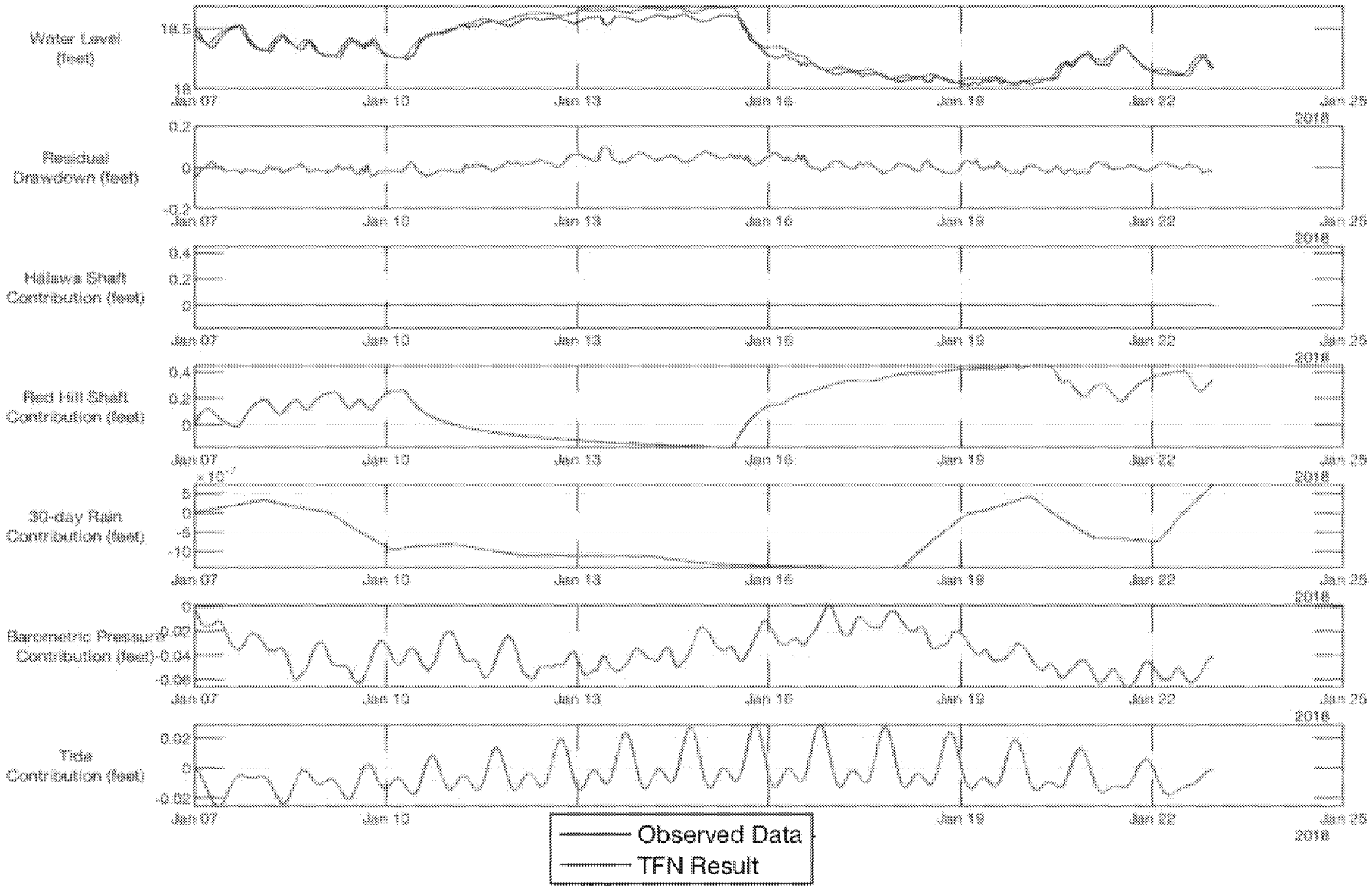
Using Hantush step response function results in better matching than Ttim

TFN ANALYSIS:
COMPARISON OF TTIM AND THEIS STEP RESPONSE FUNCTIONS

Ttim step response function shows less abrupt curvature than Theis

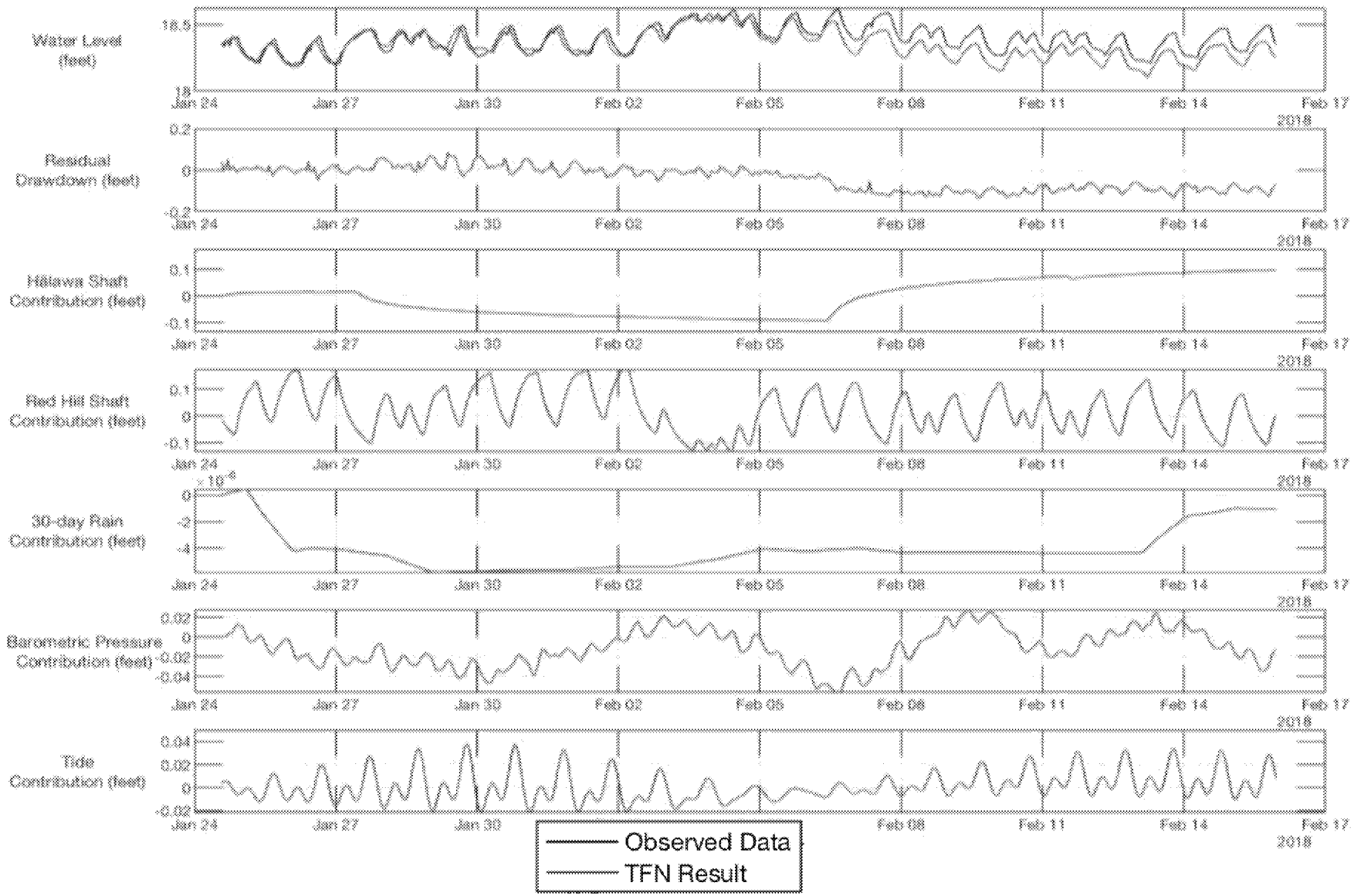


TFN ANALYSIS:
RESULTS FOR RHMW05 – RED HILL SHAFT SHUTDOWN & RESTART

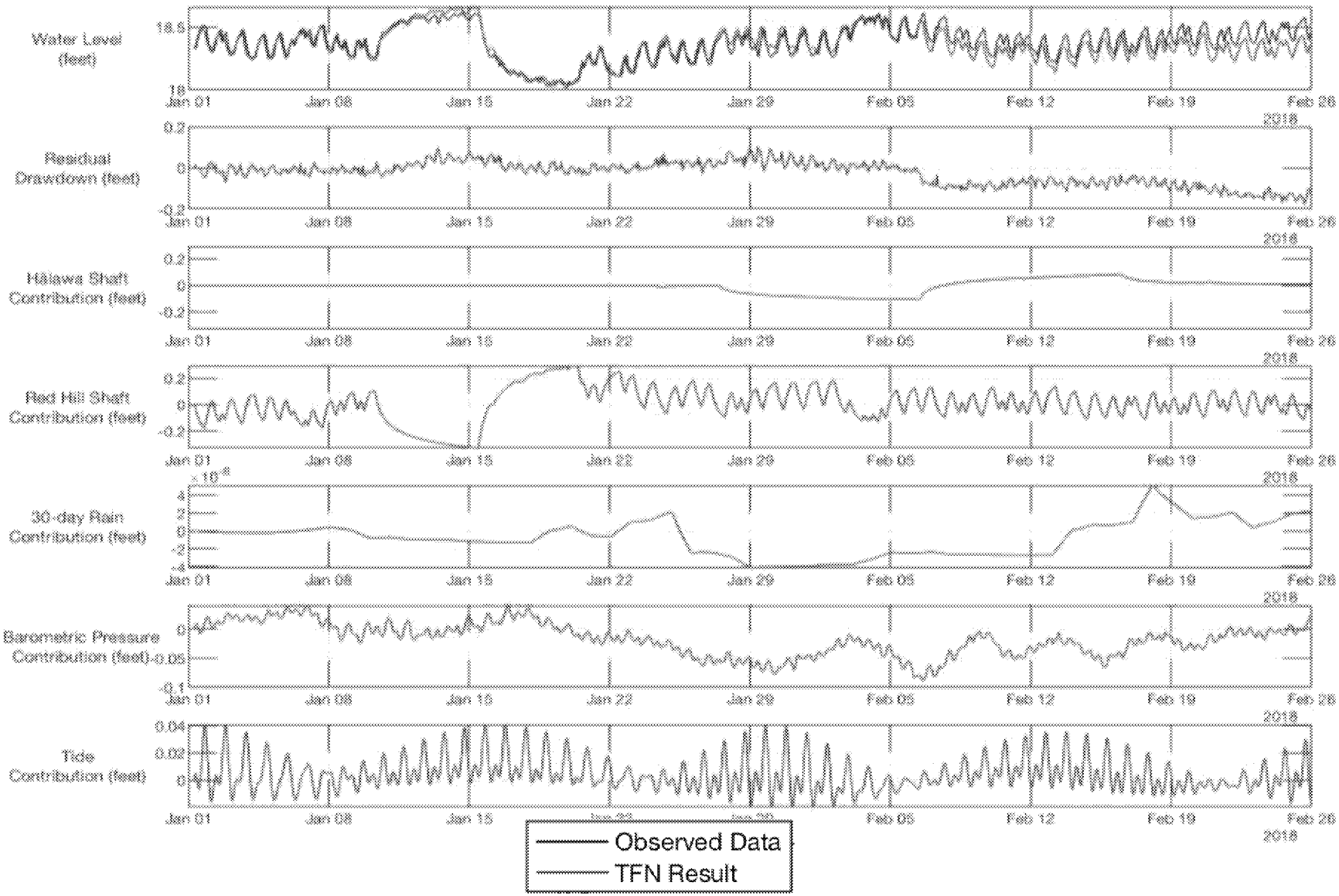


TFN ANALYSIS:

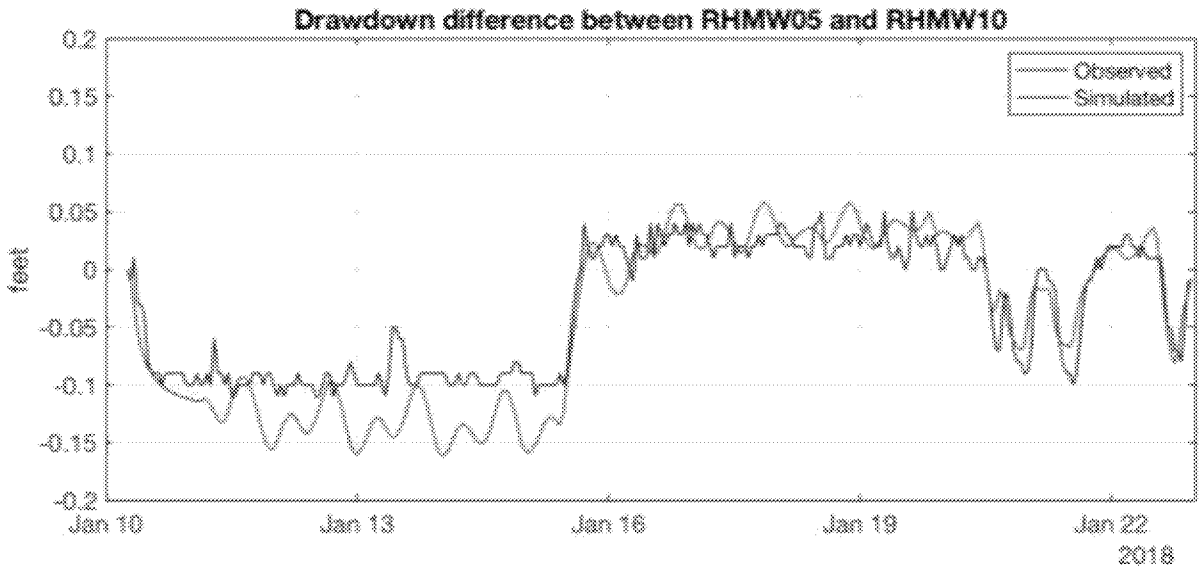
RESULTS FOR RHMW05 – HALAWA SHAFT SHUTDOWN & RESTART

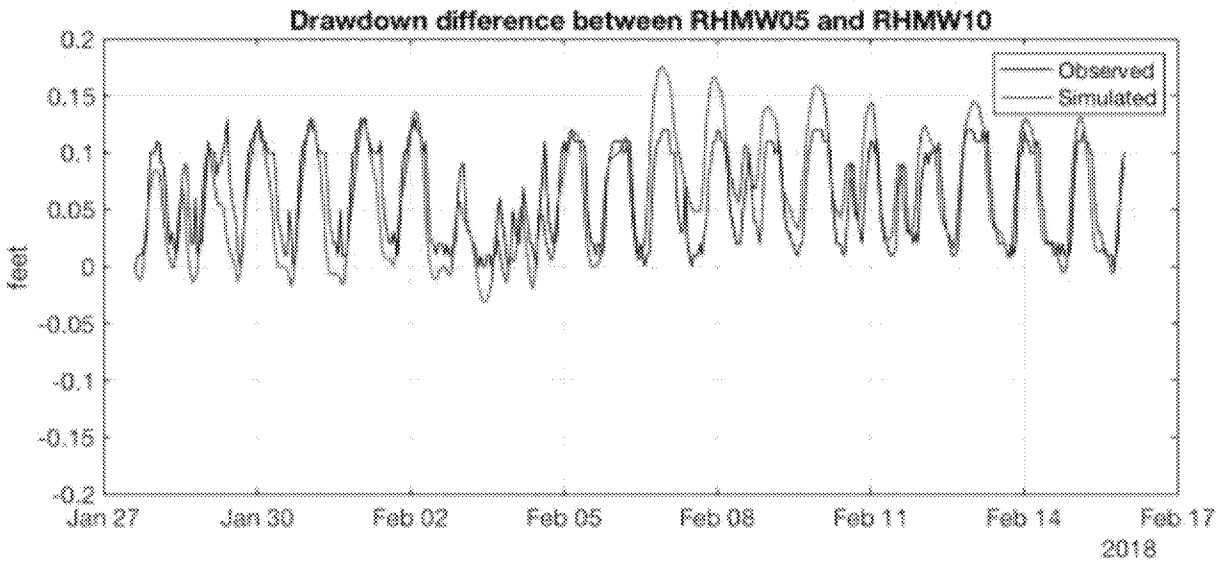


TFN ANALYSIS:
RESULTS FOR RHMW05 – SYNOPTIC DATA PERIOD



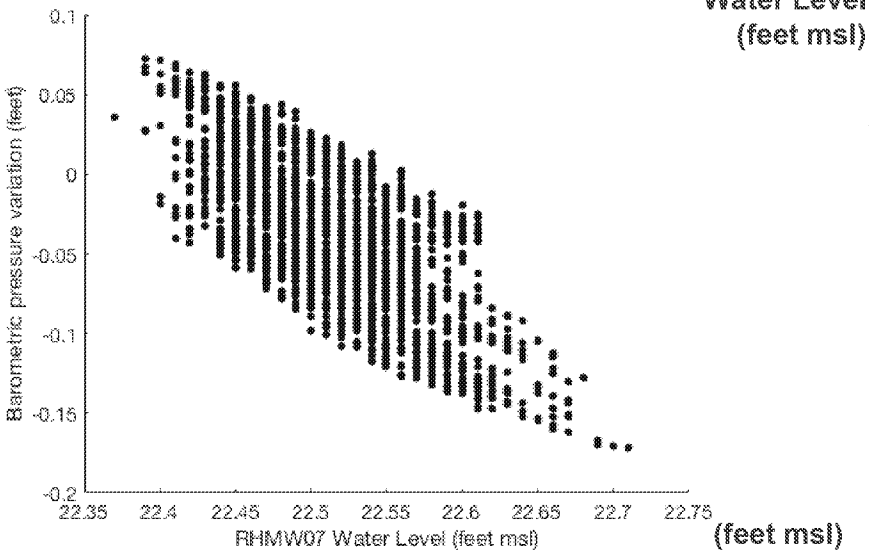
TFN ANALYSIS:
DIFFERENTIAL HEAD TIME SERIES BETWEEN RHMW05 AND RHMW10

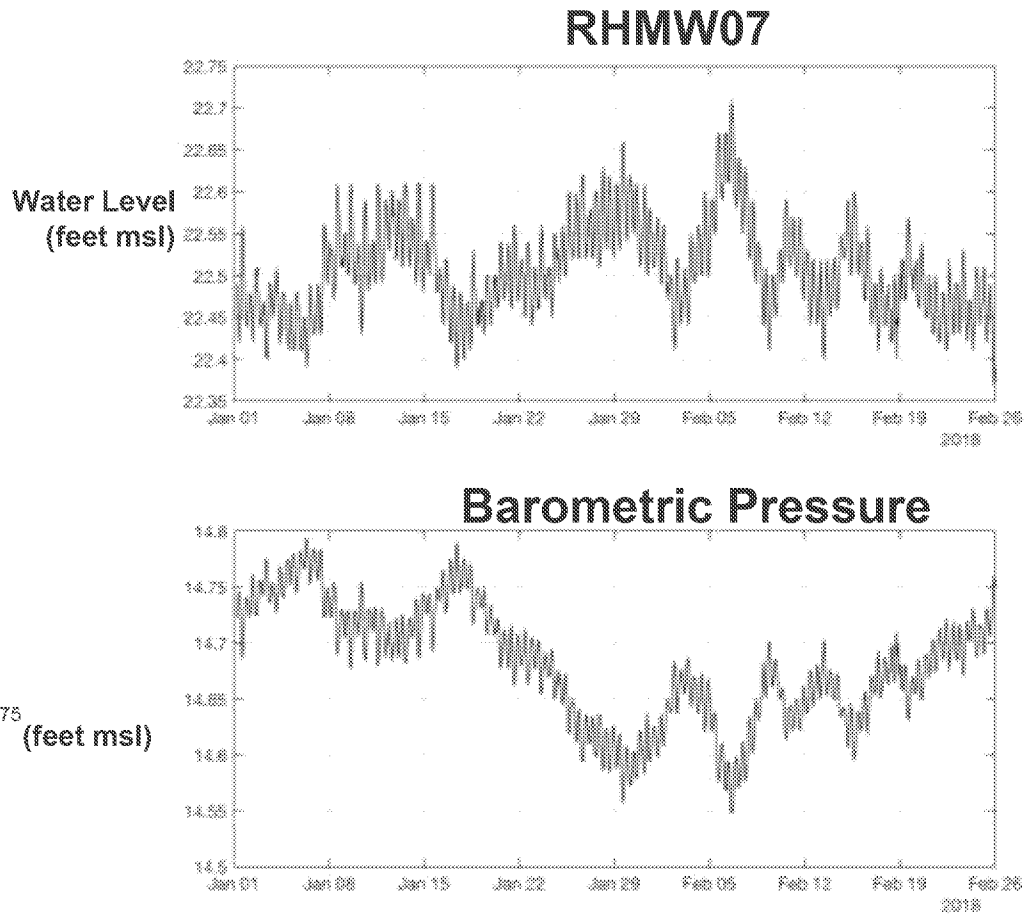




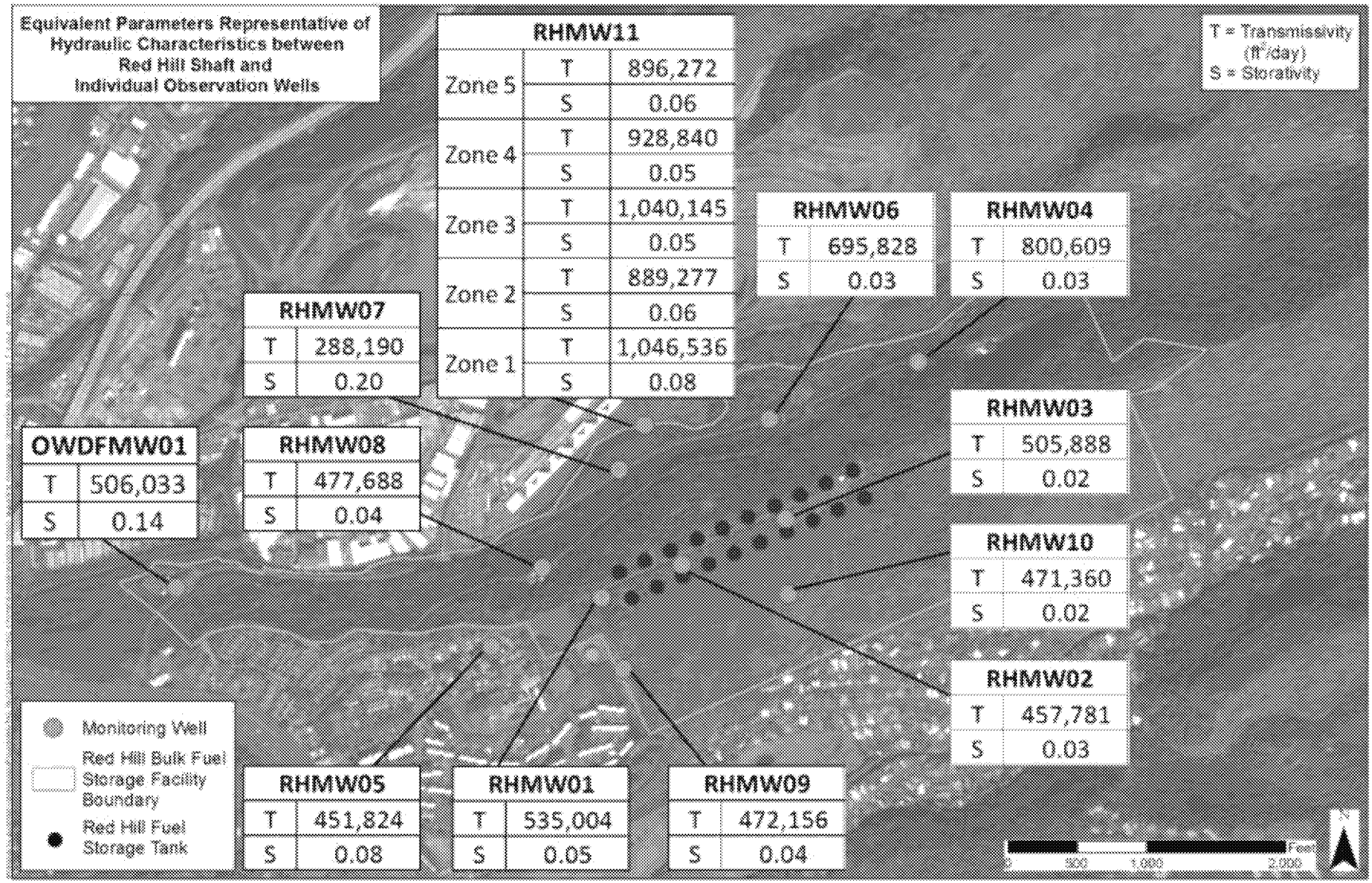
TFN ANALYSIS:

STRONG CORRELATION OF RHMW07 AND BAROMETRIC PRESSURE VARIATION



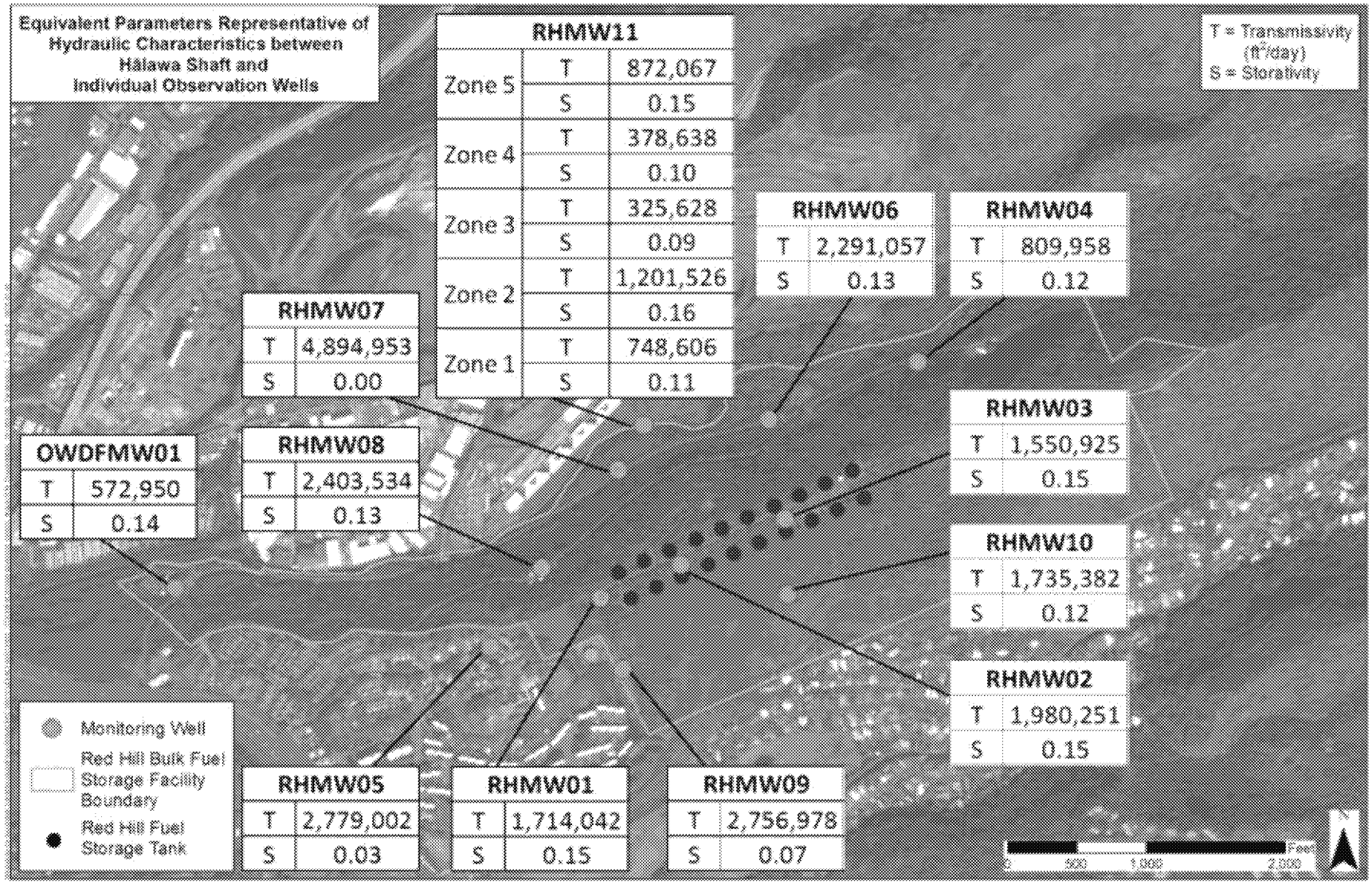


TFN ANALYSIS:
EQUIVALENT AQUIFER HYDRAULIC PARAMETER MAP – RED HILL SHAFT SHUTDOWN & RESTART



TFN ANALYSIS:

EQUIVALENT AQUIFER HYDRAULIC PARAMETER MAP – HALAWA SHAFT SHUTDOWN & RESTART



TFN ANALYSIS:

HYDRAULIC PARAMETER COMPARISONS

	Cooper-Jacob				Theis				TFN	
	Drawdown		Recovery		Drawdown		Recovery			
	Effective Transmissivity (ft^2/d)	Apparent Storativity	Effective Transmissivity (ft^2/d)	Apparent Storativity	Effective Transmissivity (ft^2/d)	Apparent Storativity	Effective Transmissivity (ft^2/d)	Apparent Storativity	Effective Transmissivity (ft^2/d)	Apparent Storativity
Mean	754,000	0.05	684,000	0.05	651,000	0.06	1,030,000	0.08	678,000	0.05
Min.	588,000	0.02	384,000	0.01	559,000	0.02	708,000	0.02	452,000	0.02
Max.	1,110,000	0.15	982,000	0.13	750,000	0.19	1,260,000	0.38	1,047,000	0.14

* Only includes the Red Hill monitoring well network

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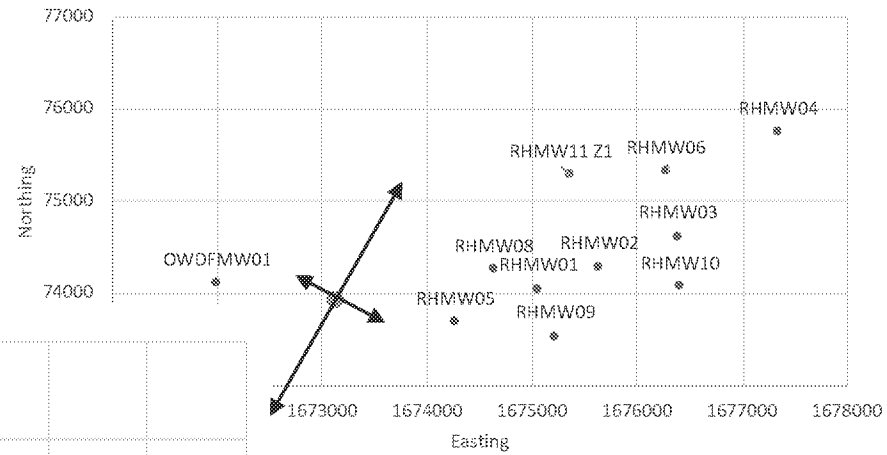
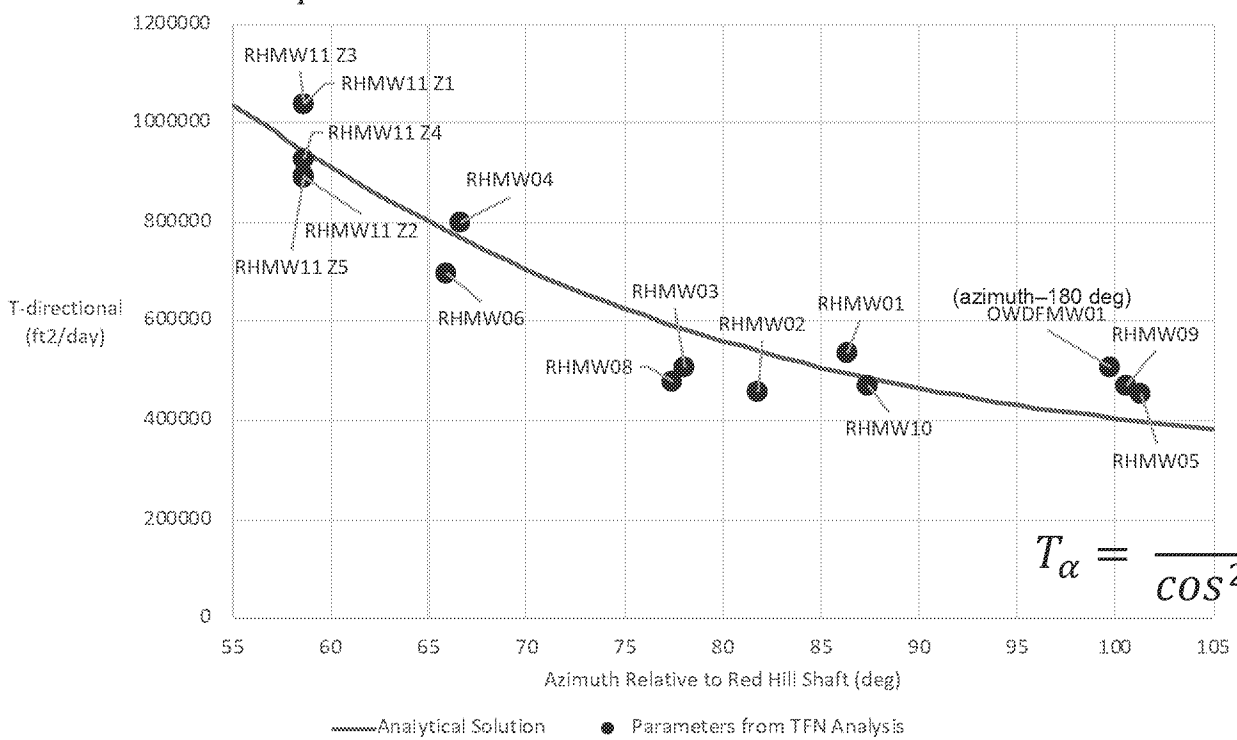
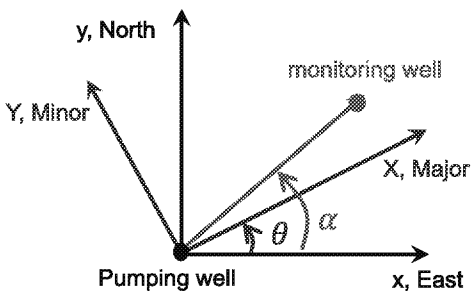
TFN ANALYSIS:
ANALYSIS OF AQUIFER ANISOTROPY – RED HILL SHAFT SHUTDOWN AND RESTART

θ = Azimuth of major principal direction
= 35 degrees (215 degrees)
Azimuth of minor principal direction
= 125 degrees (305 degrees)

$$m = \frac{T_X}{T_Y} = 4$$







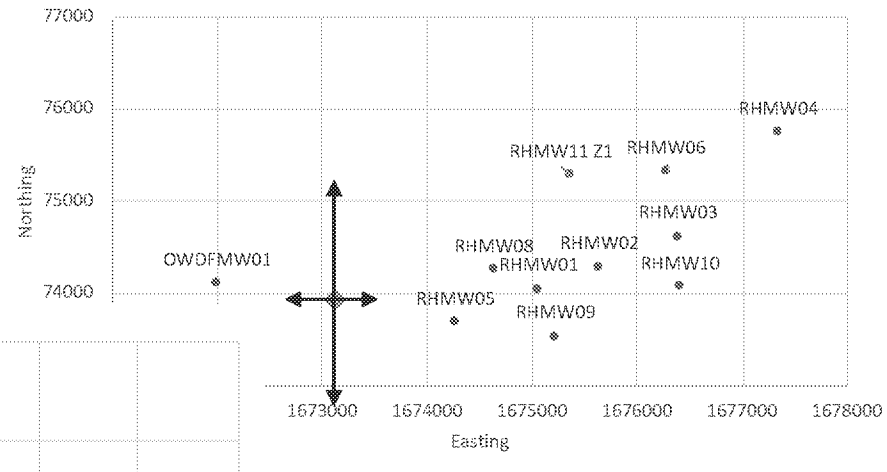
$$T_\alpha = \frac{T_{major}}{cos^2(\alpha - \theta) + m \cdot sin^2(\alpha - \theta)}$$

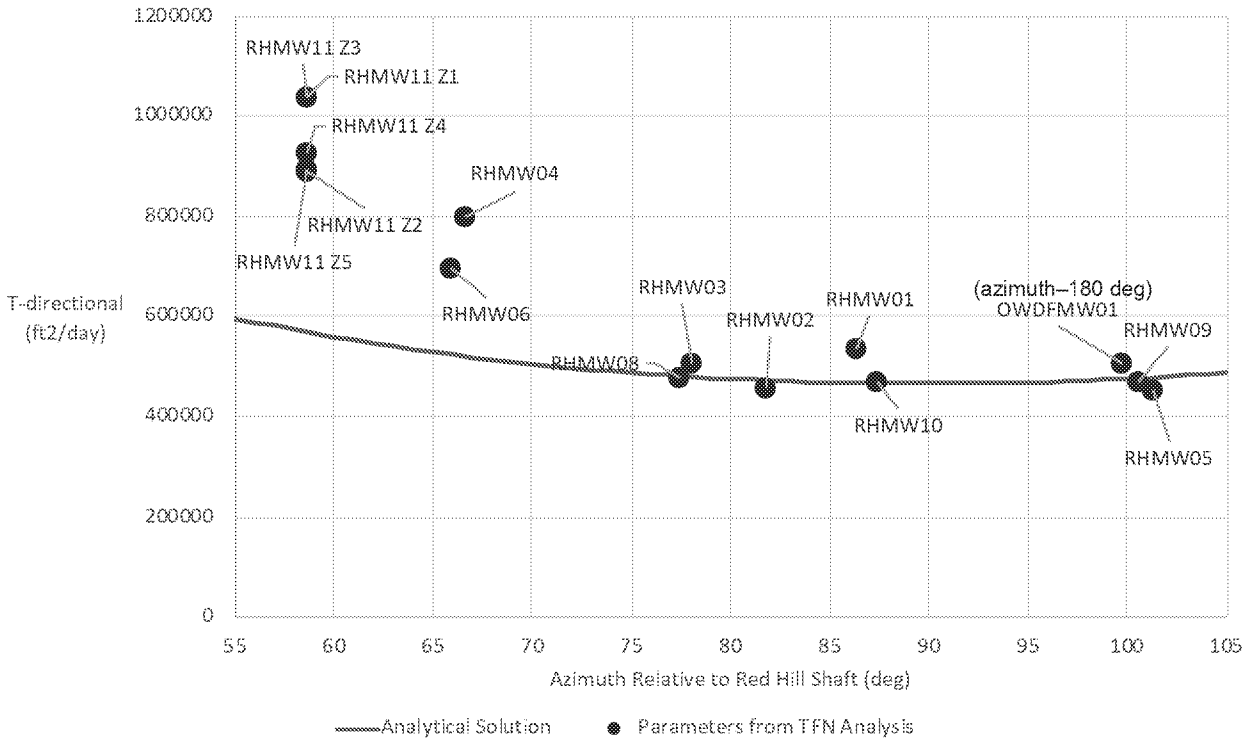
Analytical solution matches data reasonably well

TFN ANALYSIS:
ANALYSIS OF AQUIFER ANISOTROPY – RED HILL SHAFT SHUTDOWN AND RESTART (CONT.)

Azimuth of major principal direction = 0 degrees (180 degrees)
Azimuth of minor principal direction = 90 degrees (270 degrees)

$$\frac{T_X}{T_Y} = 3$$



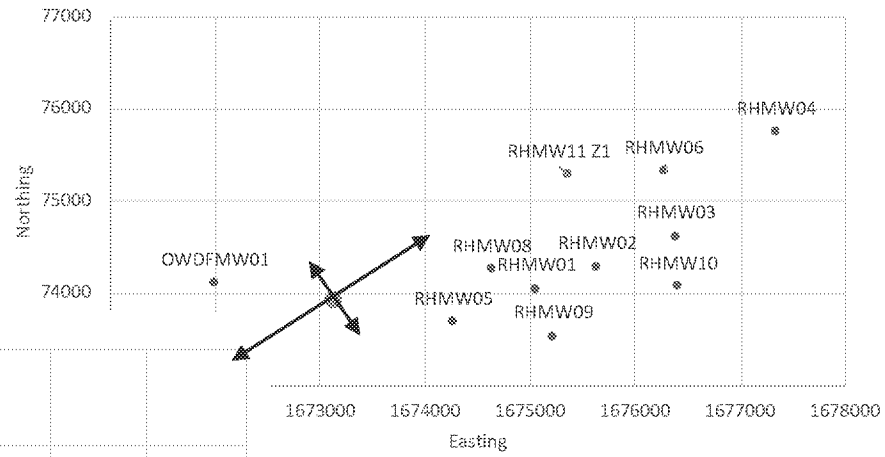


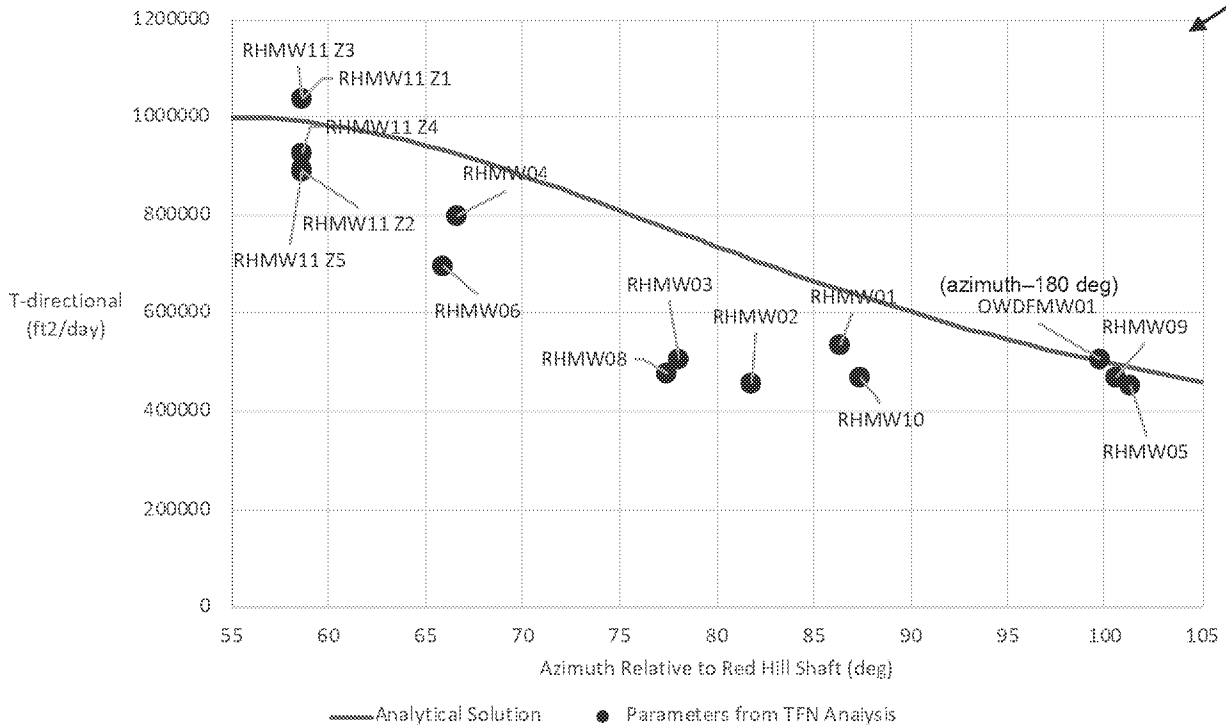
Analytical curve is too flat for azimuth between 55 deg and 75 deg

TFN ANALYSIS:
ANALYSIS OF AQUIFER ANISOTROPY – RED HILL SHAFT SHUTDOWN AND RESTART (CONT.)

Azimuth of major principal direction = 55 degrees (235 degrees)
Azimuth of minor principal direction = 145 degrees (325 degrees)

$$\frac{T_X}{T_Y} = 3$$





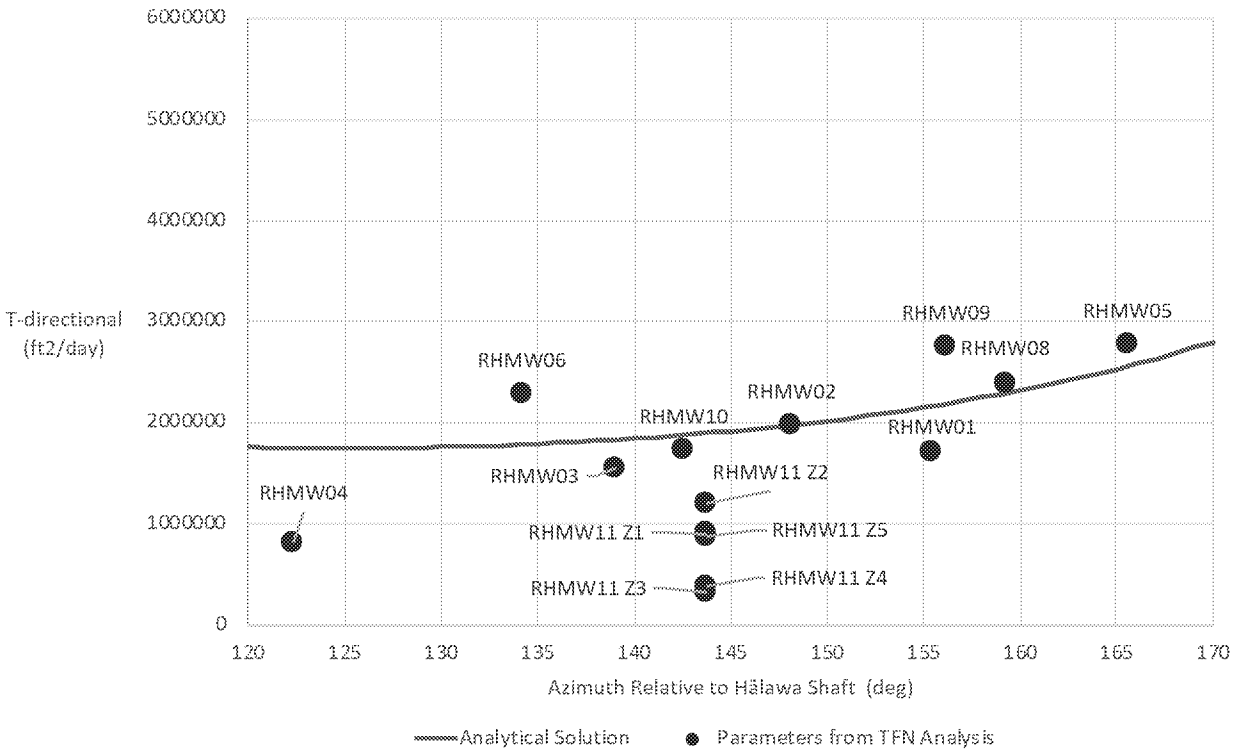
Slope of analytical curve is too uniform

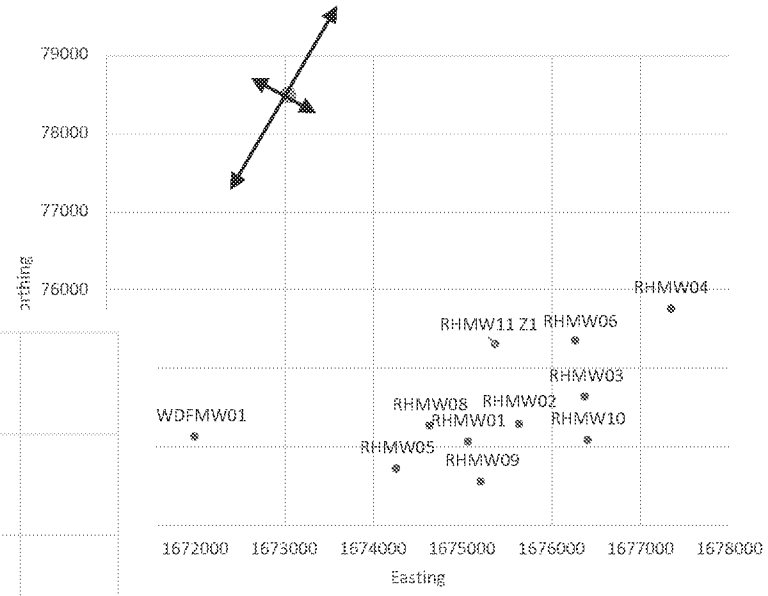
TFN ANALYSIS:
ANALYSIS OF AQUIFER ANISOTROPY – HALAWA SHAFT SHUTDOWN AND RESTART

Azimuth of major principal direction = 35 degrees (215 degrees)

Azimuth of minor principal direction = 125 degrees (305 degrees)

$$\frac{T_X}{T_Y} = 4$$



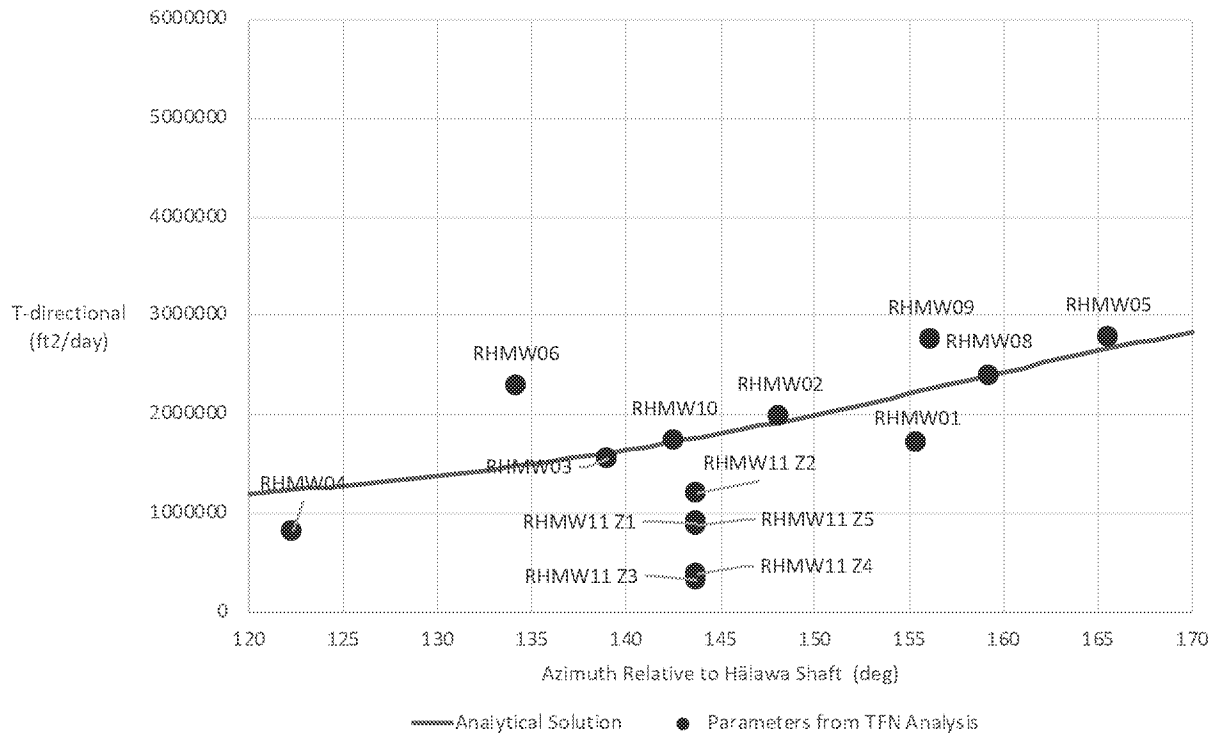


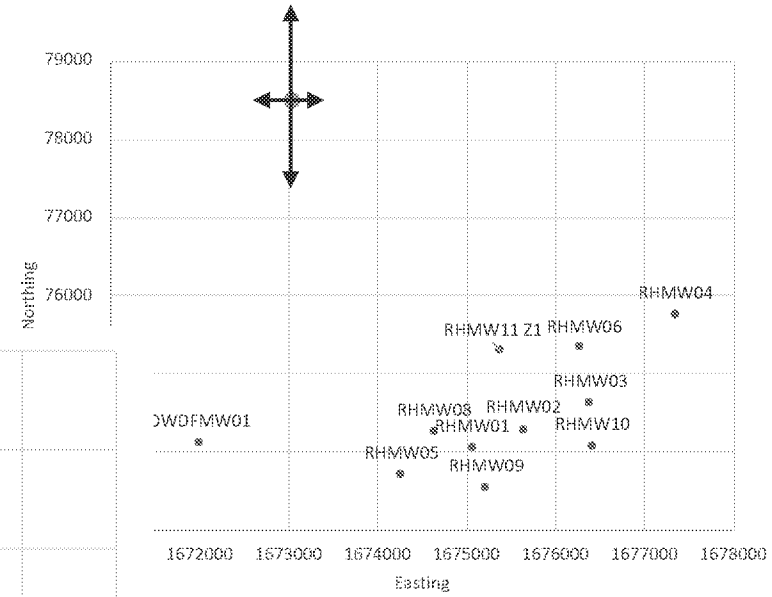
Analytical solution matches data reasonably well

TFN ANALYSIS:
ANALYSIS OF AQUIFER ANISOTROPY – HALAWA SHAFT SHUTDOWN AND RESTART (CONT.)

Azimuth of major principal direction
= 0 degrees (180 degrees)
Azimuth of minor principal direction
= 90 degrees (270 degrees)

$$\frac{T_X}{T_Y} = 3$$





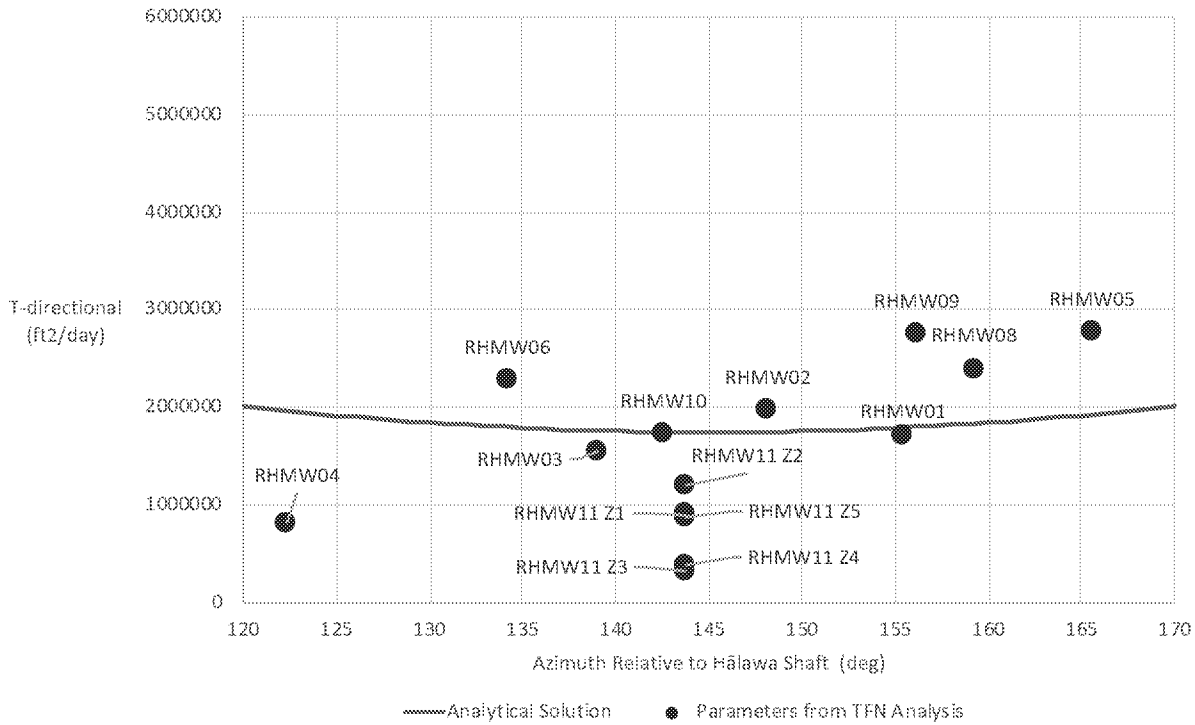
Analytical solution matches data reasonably well

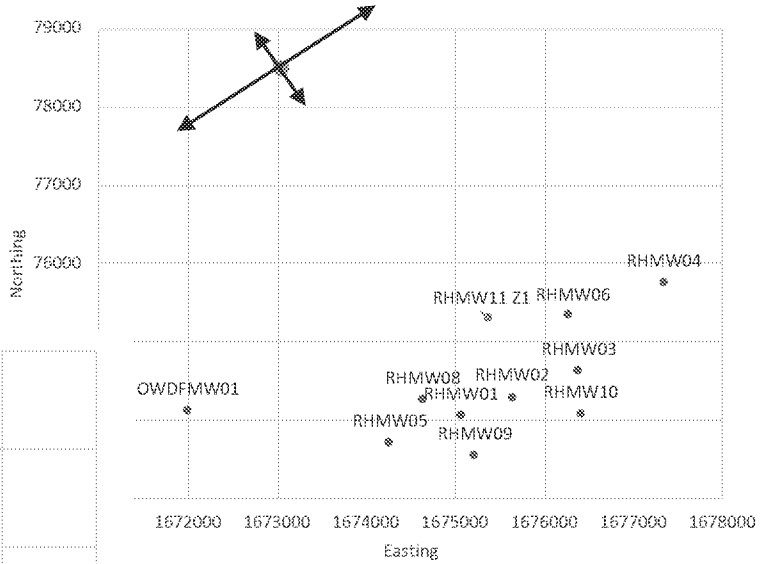
TFN ANALYSIS:
ANALYSIS OF AQUIFER ANISOTROPY – HALAWA SHAFT SHUTDOWN AND RESTART (CONT.)

Azimuth of major principal direction = 55 degrees (235 degrees)

Azimuth of minor principal direction = 145 degrees (325 degrees)

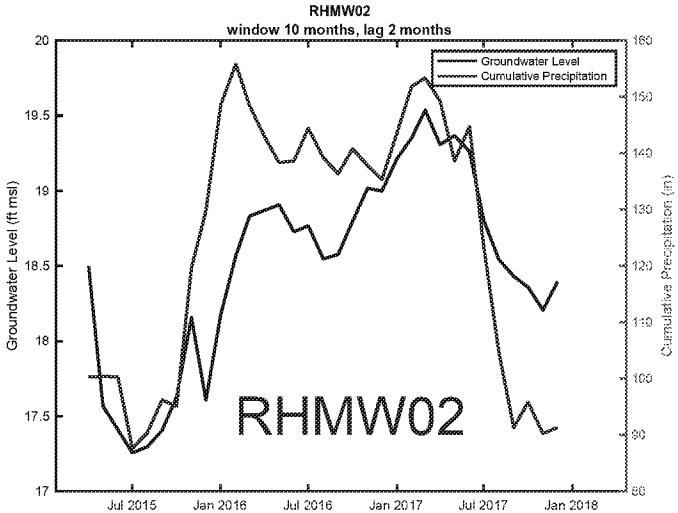
$$\frac{T_X}{T_Y} = 4$$

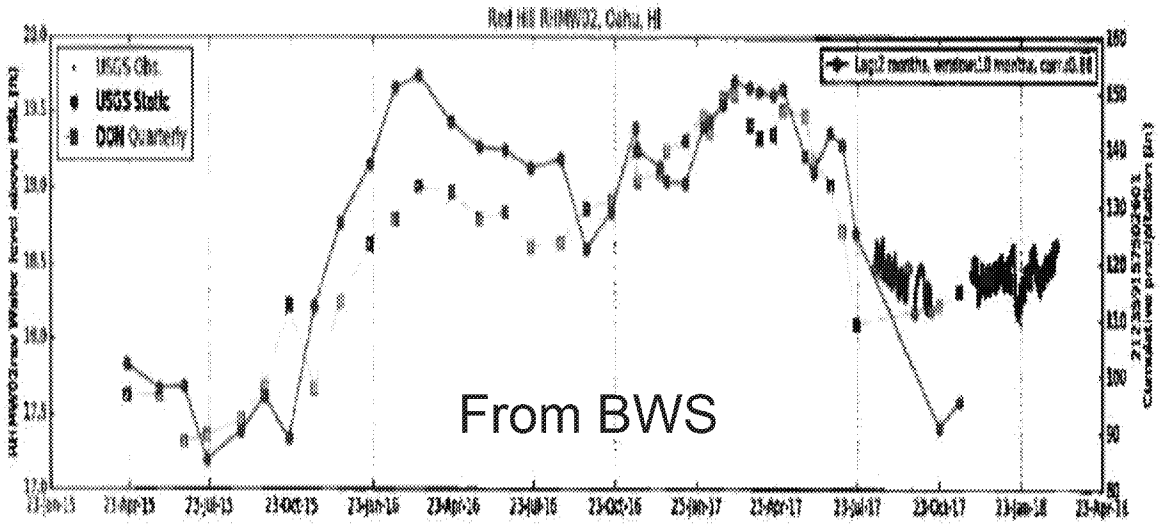


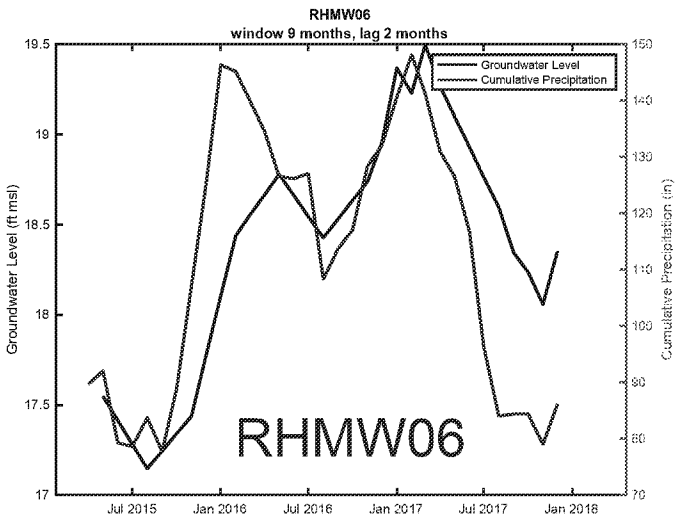


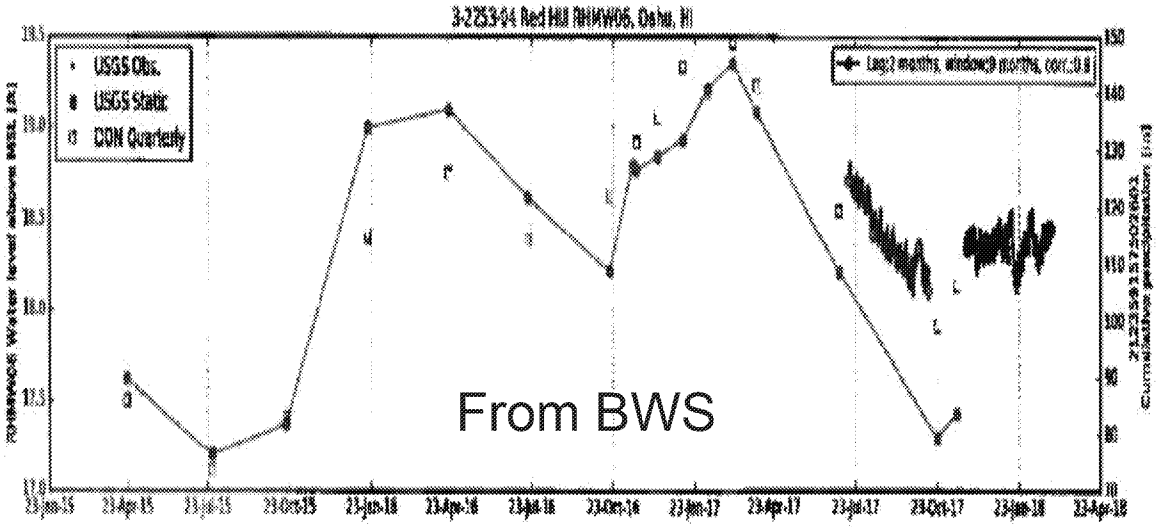
Analytical curve is too flat

TFN ANALYSIS:
MULTI-YEAR RAINFALL AND WATER LEVEL RELATIONSHIP:
RHMW02 AND RHMW06 FROM 2015 – 2018

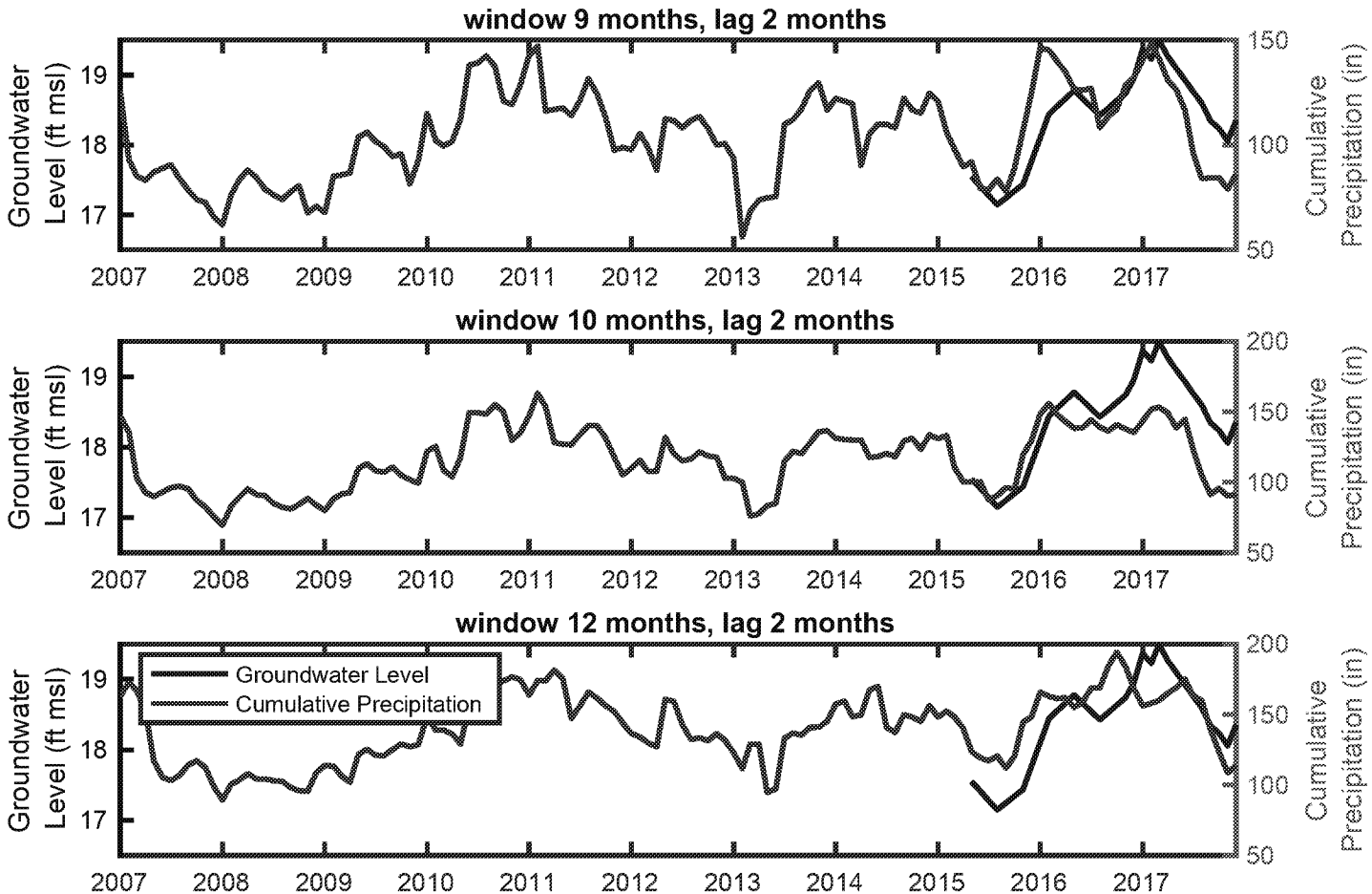






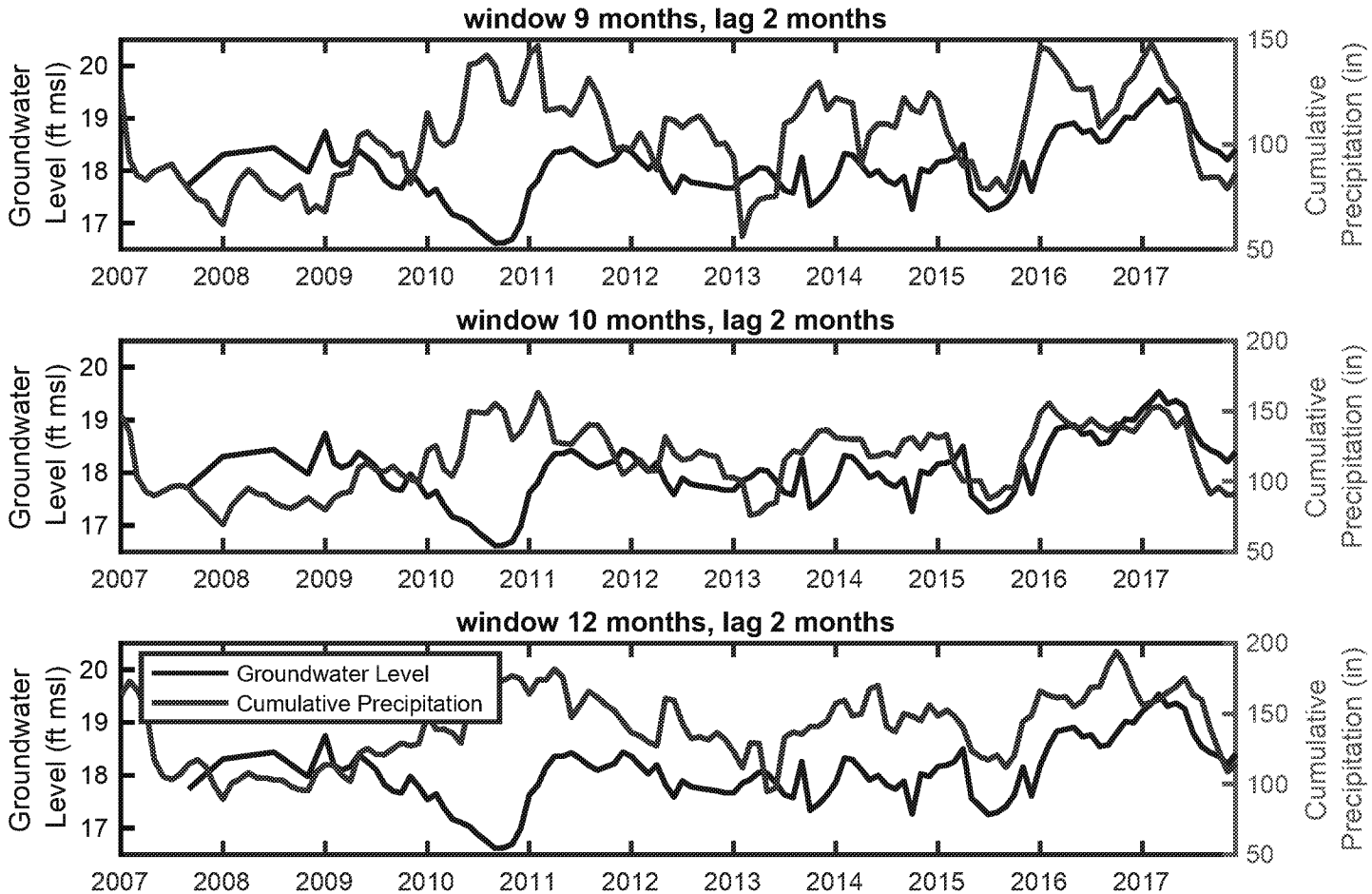


TFN ANALYSIS:
MULTI-YEAR RAINFALL AND WATER LEVEL RELATIONSHIP:
RHMW06 FROM 2007 – 2018



Water level is short for characterizing reliable relationship

TFN ANALYSIS:
MULTI-YEAR RAINFALL AND WATER LEVEL RELATIONSHIP:
RHMW02 FROM 2007 – 2018



2015–2018 observations cannot be generalized to long-term behavior

TFN ANALYSIS:
SUMMARY

- Red Hill Shaft pumping has a significant effect on monitoring wells near Red Hill and is more influential than effects related to pumping at Halawa Shaft (and other pumping wells in the area).
- Precipitation/streamflow did not show an influence on water levels on a daily or weekly basis, indicating that localized recharge is insignificant.
- TFN-based step response function in individual monitoring wells will be used to support model calibration.
- TFN-based hydraulic analyses support very high permeabilities in shallow groundwater beneath Red Hill, which is also demonstrated in the synoptic data review.
- The TFN analysis supports a major principal direction of around 215° azimuth.

GROUNDWATER FLOW MODEL UPDATE: GRIDS, LAYERS, AND BOUNDARIES

MODELING UPDATE PROGRESS:
SUMMARY

- Evaluated data needs for updated model
- Developed 3-D geologic block model to include saprolite, tuff, alluvial sediments, and marine limestone
- Obtained concurrence on grid orientation from Regulatory Agencies
- Developing model grid
- Developing other datasets for 2017–2018 Synoptic Study
  - Recharge
  - NE Inflow
  - Estimated spring flows from Navy Aiea (Navy Boat Harbor) well water levels
  - Synoptic Study pumping and water level response datasets
  - Preliminary material property estimates from literature
  - TFN analysis

MODEL GRID UPDATE SUMMARY

- Quadtree grid aligned with 213.6-degree dip azimuth
- Grid Levels:
  - Parent grid = 500 ft
  - Level 1 = 250 ft
  - Level 2 = 125 ft
    - NW and SE boundaries
    - Tuff cone perimeter
    - Red Hill ridge
    - Adjacent ridges
    - Area of interest
    - Saprolite extent based on two different depths as interpreted at Halawa Deep Monitoring Well (2253-03)
    - Marine caprock limestone extent
  - Level 3 = 62.5 ft
    - Pumping wells
  - Level 4 = 31.25 ft
    - Red Hill Shaft
    - Halawa Shaft

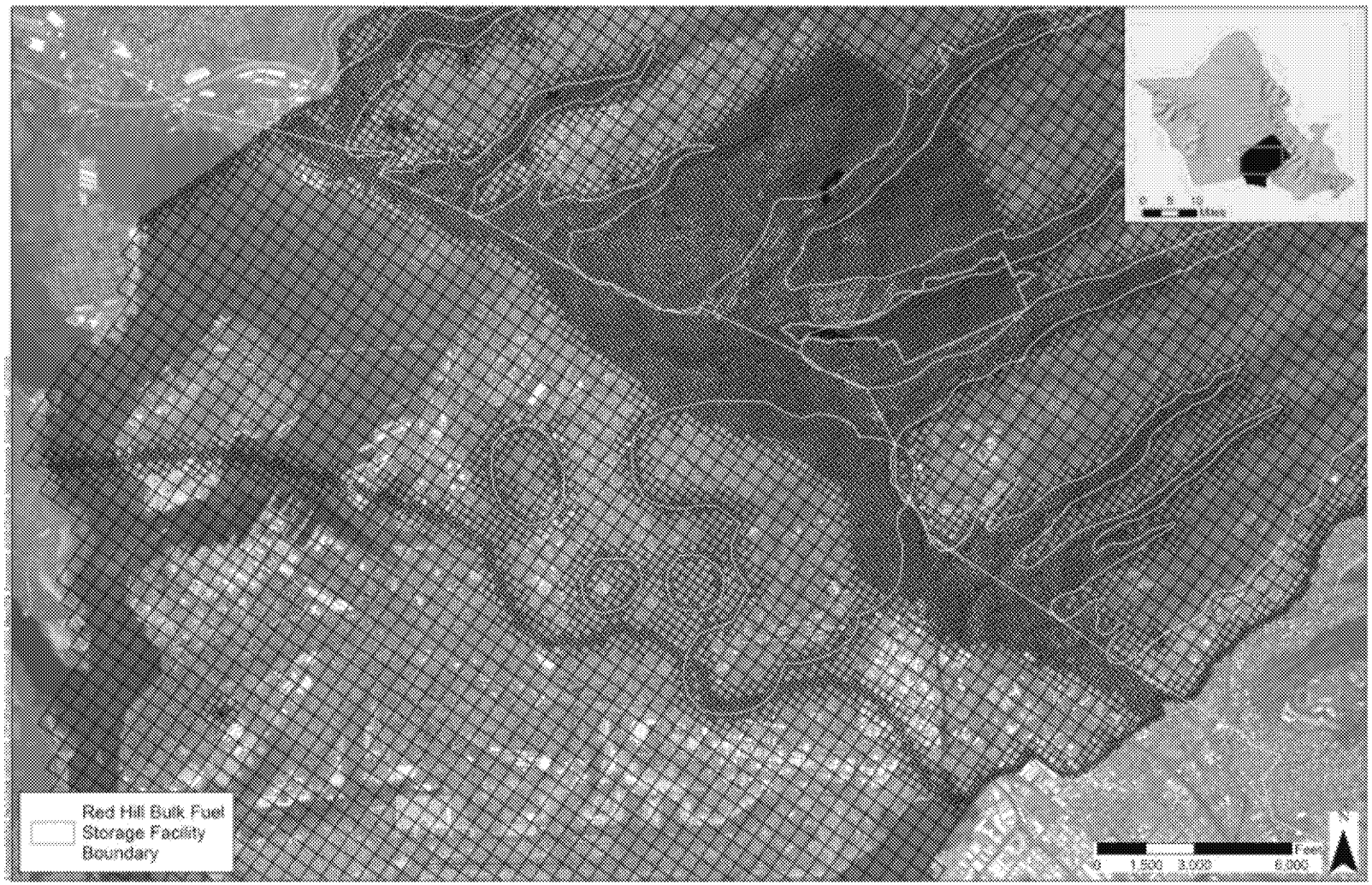
MODELING UPDATE PROGRESS:

MODEL GRID AERIAL VIEW

The grid refinement is the same for all layers, with Azimuth = 213.6

MODELING UPDATE PROGRESS:

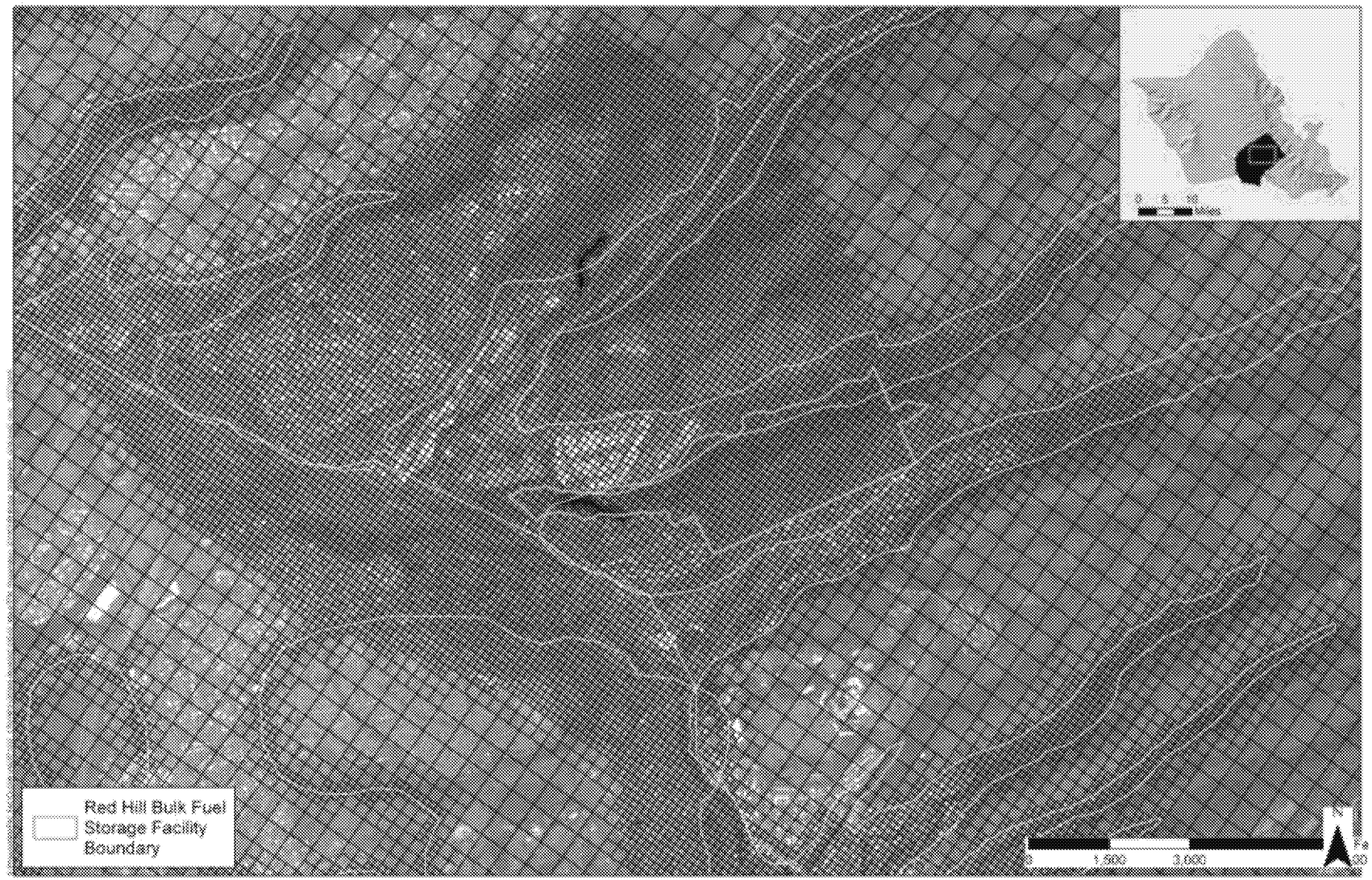
TUFF CONE AND MARINE DEPOSITS EXTENT (GRID LEVEL 2)



Marine deposits perimeter extent connects both NW and SE boundaries.

MODELING UPDATE PROGRESS:

RED HILL RIDGE, ADJACENT RIDGES, AND AREA OF INTEREST (GRID LEVEL 2)



MODELING UPDATE PROGRESS:

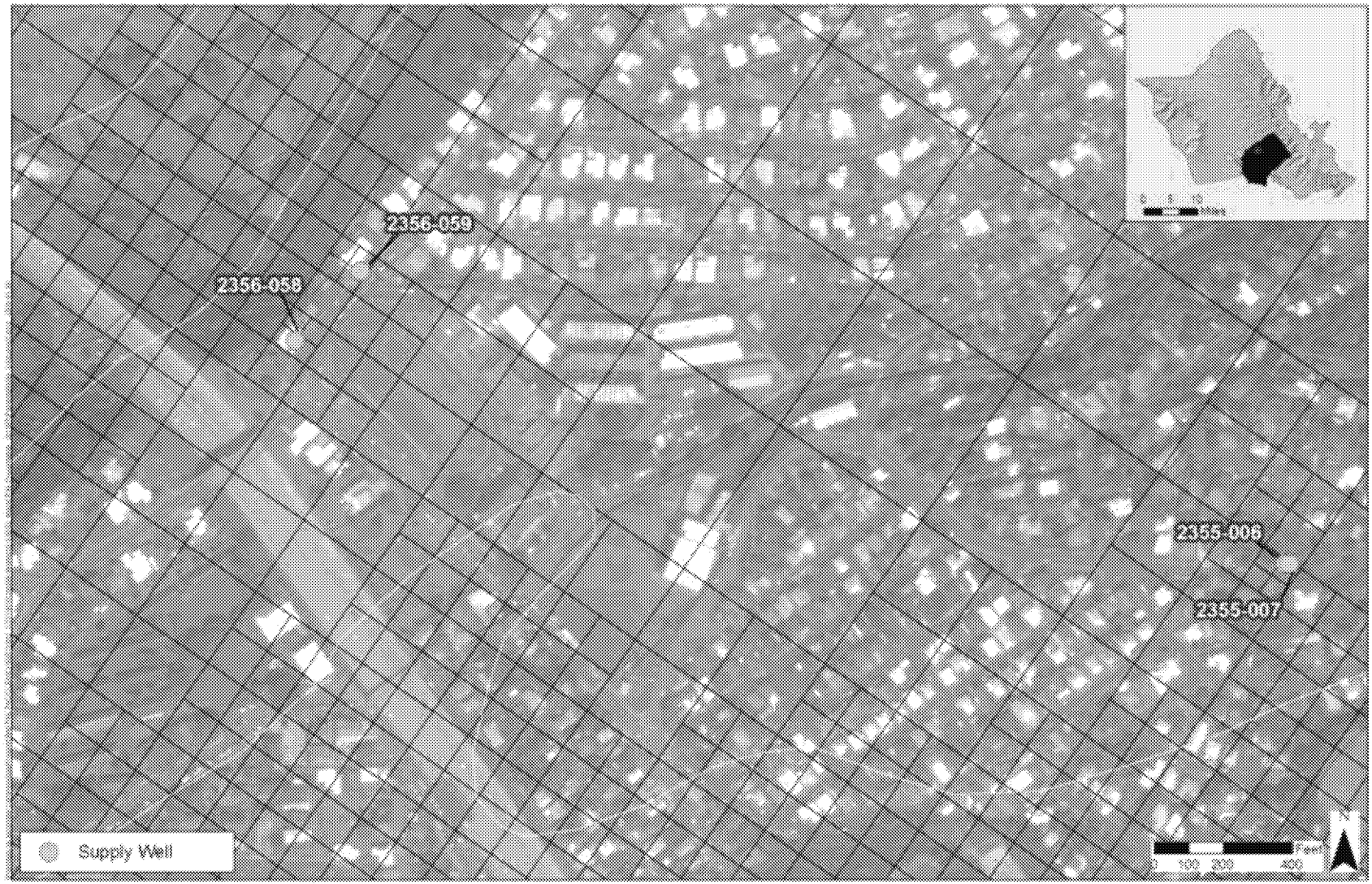
NW BOUNDARY (GRID LEVEL 2)

MODELING UPDATE PROGRESS:

SE BOUNDARY (GRID LEVEL 2)

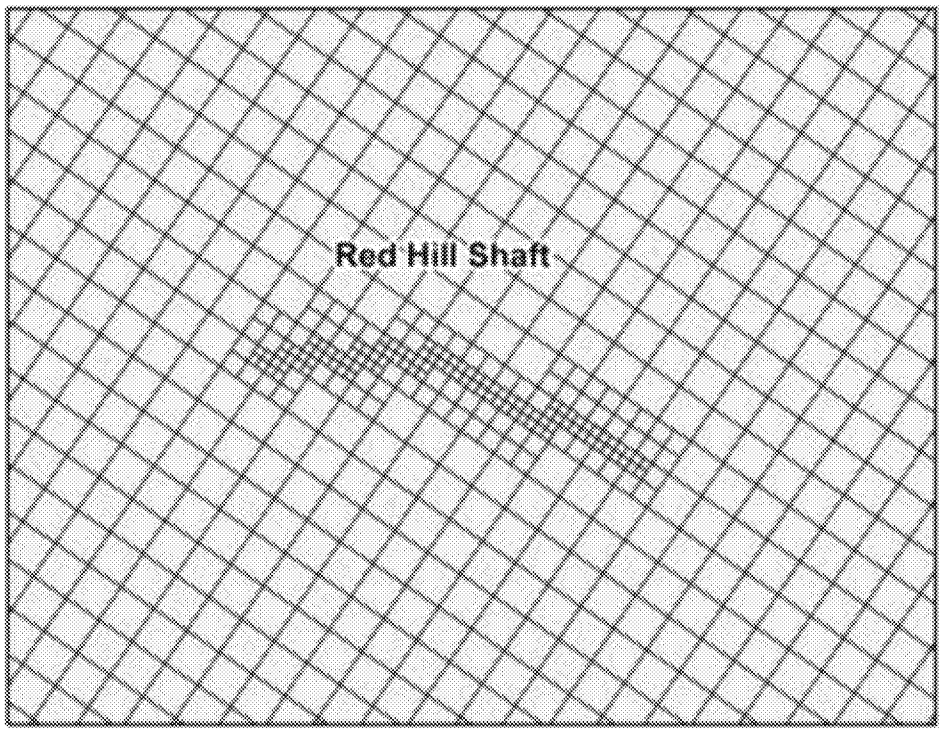
MODELING UPDATE PROGRESS:

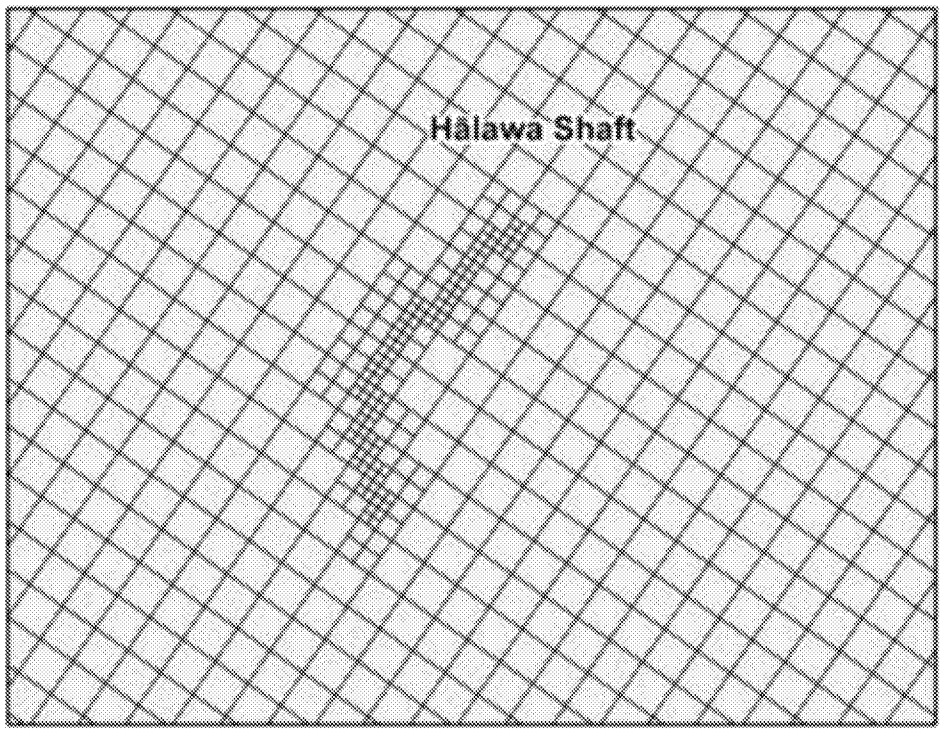
PUMPING WELLS (GRID LEVEL 3)



MODELING UPDATE PROGRESS:

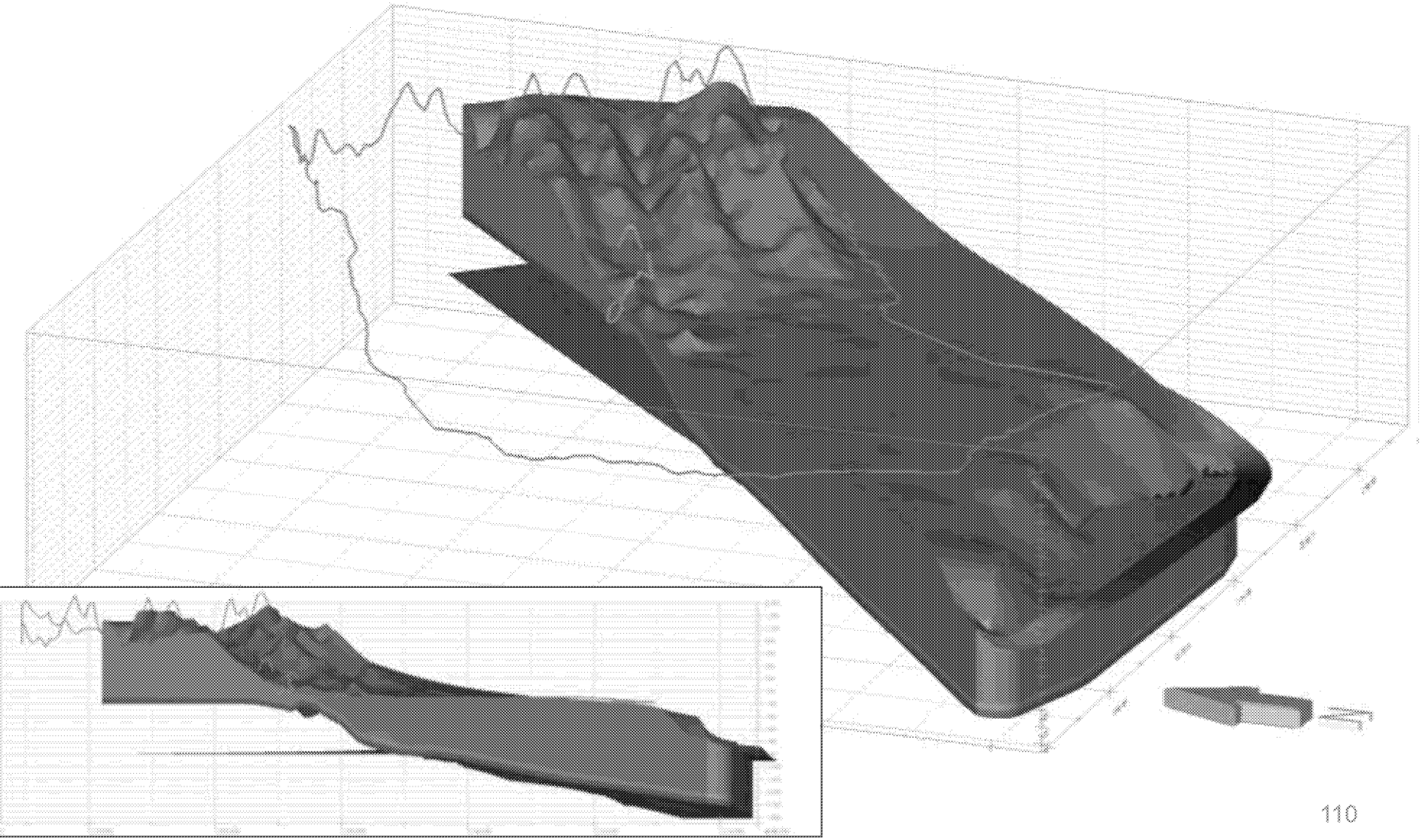
RED HILL SHAFT AND HALAWA SHAFT (GRID LEVEL 4)





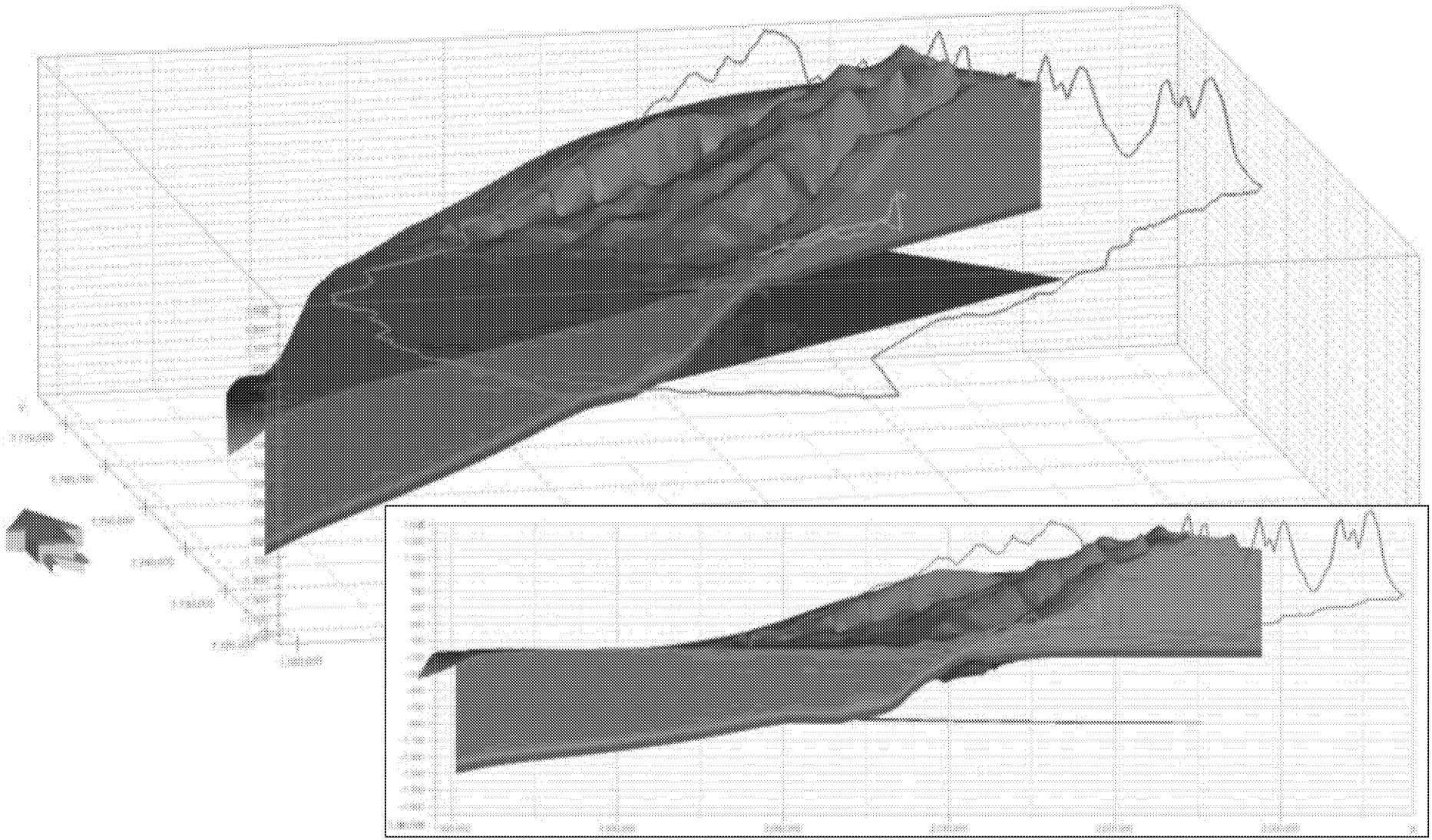
MODELING UPDATE PROGRESS:

CROSS SECTION THROUGH MODEL DOMAIN: NE–SW



MODELING UPDATE PROGRESS:

CROSS SECTION THROUGH MODEL DOMAIN: SE–NW



MODELING UPDATE PROGRESS:

UPDATED CALIBRATION TARGETS FOR REVISED MODEL

Synoptic Data Processed through TFN

- Using 2017/2018 synoptic data
- Shallow gradients and small head differences between wells create unique calibration challenges
- We will calibrate to signal, not noise
- TFN analysis isolates signal, removes noise and results in a cleaner calibration data set

MODELING UPDATE PROGRESS:

UPDATED CALIBRATION TARGETS FOR REVISED MODEL

Head-Difference Targets

- **Calibrating to head differences also enhances signal, compared to absolute heads**
- **We are simulating flow behavior**
- **A head mismatch of 0.1 ft can be inconsequential to flow, while a head-difference mismatch always affects flow**
  - Spatial differences (well pairs)
  - Temporal differences (drawdown/buildup)
  - Focus is on behavior between wells and between times
- **2017–2018 synoptic dataset will be used to develop absolute head and head-difference targets for calibration**

GROUNDWATER FLOW MODEL CALIBRATION: TRANSFER FUNCTION-NOISE ANALYSIS

MODELING UPDATE APPROACH

- Geologic Mapping and Modeling Grid Orientation
- Address issues identified by Regulatory Agencies
  - Geophysical surveys
  - Additional well drilling
  - 2017–2018 Synoptic Water Level Study
  - Interim modeling evaluation
- Calibrate updated model to information from 2017–2018 Synoptic Water Level Study
- Evaluate particle migration and solute transport to refine model

MODELING UPDATE APPROACH:

GEOLOGIC MAPPING AND MODELING GRID ORIENTATION

- The AOC Parties have agreed with a primary lava flow orientation dip azimuth of 213.6 degrees and a dip magnitude of 2.9 degrees.
- The Navy is proceeding with modeling accordingly, constructing the model with a grid orientation of 213.6 degrees.
- The Navy is also performing limited sensitivity runs/analyses with a second model orientation using a dip azimuth of 184.6 degrees and dip angle of 5.9 degrees (based on the bimodal Gaussian distribution).
- Note that all of the data acquired and evaluated for the orientations described above are from the vadose zone.
- The Navy plans to use these same grid orientations for the vadose zone evaluation.

SENSITIVITY ANALYSES: ALTERNATIVE MODELS

SENSITIVITY ANALYSIS: ALTERNATIVE MODELS

- Average basalt
- Clinker model
- Heterogeneous model
- Pearl Harbor v. Offshore GHB conductance sensitivity
- Honolulu Volcanics properties sensitivity
- Lateral boundary GHB sensitivity
- Sensitivity on anisotropy direction (strike)

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REGULATORY AGENCIES' LOOKING FORWARD/FUTURE CONSIDERATIONS

STATUS UPDATES:
NAVY'S CURRENT/PROJECTED FIELD ACTIVITIES

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- 2nd Quarter 2019 GW LTM event - April
- Drilling and well/test borehole installation update:
  - RHMW14 Westbay install scheduled for the week of March 18
  - RHTB01 drilling scheduled following RHMW14
  - RHMW13 drilling scheduled following RHTB01
  - RHMW12 drilling and RHMW15 completion - TBD
- Synoptic water level data collection ongoing

SUMMARY AND NEXT STEPS

- Overview of technical feedback, decisions, and action items
- Around the table and takeaways
- Next modeling working group meeting: TBD
- Proposed topics for next modeling working group meeting

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