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NAVFAC HAWAII

AOC Parties Technical Working Group Meeting No. 11

Red Hill Bulk Fuel Storage Facility
January 17, 2019

Agenda

- Introductions
- Status of AOC Parties' Data Requests
- Status of Field Work
- General Responses to AOC Parties' Top 10 Comments
- Synoptic Study Data Review
- Transfer Function-Noise Analysis
- Model Update Approach
- Model Update Progress
- AOC Parties' SME Input/Discussion
- February 2019 Face-to-Face Meetings

ED_006532_00002904-00002

Introductions

ED_006532_00002904-00003

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Status of AOC Parties' Data Requests

ED_006532_00002904-00004

Status of AOC Parties' Data Requests

- Strike and Dip (dip azimuth and dip magnitude)
- HART Boring Data
- Isotope and Other Chemistry Data

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Status of Field Work

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Status of Field Work

- **Drilling**
  - **Halawa Correctional Facility**
    - RHTB01 and RHMW12
    - RHMW14
  - **Navy Property**
    - RHMW13
    - RHMW15
- **LTM Sampling**
  - **Scheduled for January 21–29, 2019**

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General Responses to Regulatory Agencies' Top 10 Comments

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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 plans to 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 the current 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.

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 AOC Parties' Top 10 Comments :
Concerns with the Interim GWFM

Comment	Response
4. Representation of caprock, tuffs, and sediments	As part of the geologic studies previously mentioned, the Navy has developed a 3-D geologic model of the Red Hill area that incorporates all available geologic information from ongoing studies as well as past studies. Collaborative feedback from the Regulatory Agencies was considered in development of this 3-D geologic model, which now 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. In addition, HART boring logs used by the Navy as part of their geological evaluation are now available to the Regulatory Agencies for their review. MVS files (.efb format) have been provided to the Regulatory Agencies and will continue to be provided periodically as the model is updated. Finally, marine sediments and tuffs will be modeled as separate layers as part of the ongoing modeling effort.

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Response to AOC Parties' Top 10 Comments:
Concerns with the Interim GWFM (cont.)

Comment	Response
5. Drinking water shaft inflows	As part of the post-interim modeling effort progressing toward the October 2019 model, a sensitivity analysis was conducted related to non-uniform tunnel inflow at Red Hill Shaft. This modeling effort demonstrated that the model was insensitive to this factor. This evaluation was described to the Regulatory Agencies. Additional sensitivity evaluations considering head dependency and the synoptic/transfer function noise (TFN) analysis are being conducted for the current modeling effort as part of a multi-step process. Finally, the Navy is further evaluating the potential effects of pumping conditions on water quality at Red Hill Shaft as part of the ongoing LTM effort.
6. Calibration to groundwater heads and gradients	As part of the interim modeling effort, dozens of models were developed and calibrated. Models that utilized a clinker zone beneath Red Hill (as part of a sensitivity analysis related to preferential pathways) had relatively good calibration to heads. A TFN analysis has been developed, and future modeling efforts will also be calibrated with respect to TFN-based heads in individual monitoring wells under a range of pumping conditions.

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Response to AOC Parties' Top 10 Comments:
Concerns with the Interim GWFM (cont.)

Comment	Response
7. Coastal marine boundary and discharge	The Navy has described how this was addressed in the post-interim model with the Regulatory Agencies. The model is insensitive to this issue when Red Hill Shaft is pumping; however, the model is sensitive to this when Red Hill Shaft is not pumping. The Navy discussed this with the Regulatory Agencies, and this will be further evaluated in the October 2019 model.

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Response to AOC Parties' Top 10 Comments:

Concerns with Interim Work Related to F&T

Comment	Response
8. LNAPL fate and transport	Based on agreements among the AOC Parties in December 2015, the Navy developed a statistical evaluation utilizing a Monte Carlo approach that considered a range of values related to (a) geologic properties of the basalt, and (b) LNAPL properties. The basis of this effort was the Navy's interpretation of chemistry, natural source-zone depletion (NSZD) testing, and groundwater data indicating that the 2014 release did not impact groundwater. Additional geologic data related to petrographic analyses and strike/dip (per the recent alignment on this issue) will be integrated into the ongoing evaluation effort. The Navy concurs with the Regulatory Agencies on the importance of being on the front end of LNAPL transport evaluations and the need to collaborate on source zone evaluation to ensure better alignment in determining if a range of releases can be captured through pumping.

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Response to AOC Parties' Top 10 Comments:

Concerns with Interim Work Related to F&T (cont.)

Comment	Response
9. Groundwater data	The Navy has recently conducted a thorough evaluation of groundwater chemistry related to COPCs, non-COPCs (natural attenuation and groundwater indicator compounds), tentatively identified compounds (TICs), and inorganic chemistry. This analysis forms the basis of the ongoing LNAPL evaluation and is proposed to be discussed during the next face-to-face meeting with the AOC Parties. While there may be multiple interpretations for individual data sets, the Navy is utilizing multiple lines of evidence for each analysis to provide a strong basis for the interpretation of groundwater chemistry.
10. LNAPL and dissolved-phase distribution	Based on agreements among the AOC Parties in December 2015, additional intrusive investigation within the tank farm would not be conducted due to the potential to create a conduit (preferential pathway) to the underlying aquifer. As described in the Navy's response to Comment #9, a holistic evaluation of groundwater chemistry data (considering COPCs, non-COPCs (natural attenuation and groundwater indicator compounds), TICs, and inorganic chemistry) along with the results of various NSZD studies provide multiple lines of evidence that support the Navy's current interpretation of LNAPL and dissolved chemical distribution. While different interpretations of single data sets may be possible, the use of multiple lines of evidence provides a very strong basis for the Navy's interpretation.

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Synoptic Study Data Review

ED_006532_00002904-00017

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

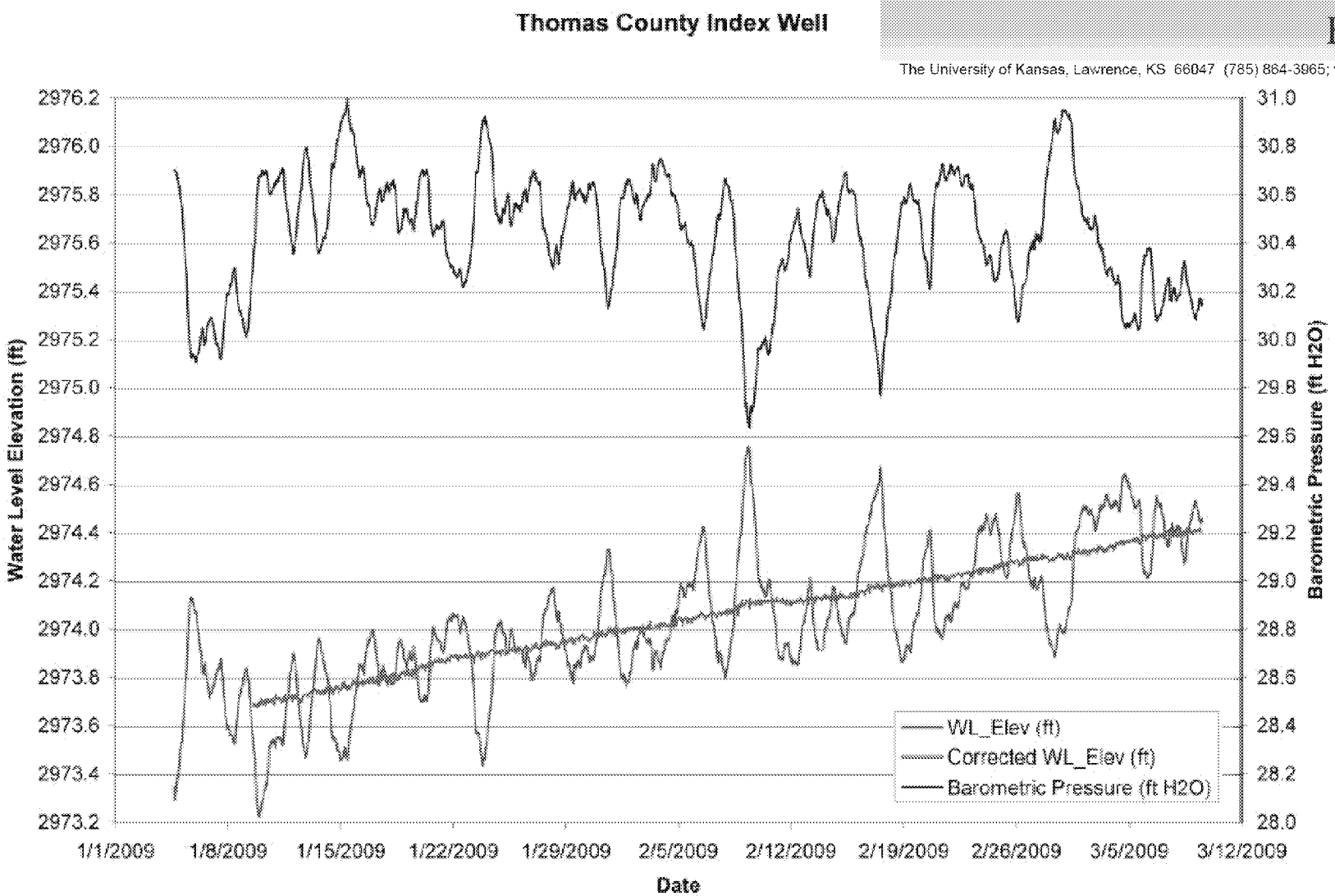
ED_006532_00002904-00018

Synoptic Study Data Review:

Kansas Geological Survey Barometric Response Function Software

GEOHYDROLOGY

The University of Kansas, Lawrence, KS 66047 (785) 864-3965; www.kgs.ku.edu



Kansas Geological Survey
Barometric Response Function Software

NAVFAC

Copy your data into this template then press Compute BRF or Correct WL button. Use Fill Gaps button to interpolate across gaps in data.

Update the yellow cells appropriately. This information will be passed on to output BRF worksheet.

Comment:	A note to yourself		
Well:	RHMW10		
Water Level Units:	feet		
Barometric Pressure Units:	feet		
Earth Tide Units:		(Not used if Number of ET Lags = -1)	
Sample Interval:	0.00694		
Sample Interval Units:	days		
Number of BP Lags:	11	Max BP lag:	0.076388889 days
Number of ET Lags:	89	Max ET lag:	0.618055556 days
BRF Data Start:	1/11/18 12:00 AM		
BRF Data End:	1/15/18 9:50 AM	☑ Detrend	
Correction Data Start:	1/10/18 9:00 AM		
Correction Data End:	1/19/18 10:00 PM		

Fill Gaps

Compute BRF (and correct W L)

Correct W L (with selected BRF)

Selected BRF: BRF 3

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

Time	WL (ft)	BP (feet)	ET
1/10/2018 9:00	18.3	34.00551	0.334
1/10/2018 9:10	18.3	34.0032	0.368
1/10/2018 9:20	18.3	34.01937	0.402
1/10/2018 9:30	18.3	34.00551	0.436
1/10/2018 9:40	18.3	34.01013	0.443666667
1/10/2018 9:50	18.3	34.0032	0.451333333
1/10/2018 10:00	18.3	34.00089	0.459
1/10/2018 10:10	18.31	33.99627	0.485333333
1/10/2018 10:20	18.31	34.01244	0.511666667
1/10/2018 10:30	18.31	33.99858	0.538
1/10/2018 10:40	18.31	34.00089	0.541
1/10/2018 10:50	18.31	33.99396	0.544
1/10/2018 11:00	18.32	34.0032	0.547
1/10/2018 11:10	18.32	34.01013	0.557
1/10/2018 11:20	18.32	33.98472	0.567
1/10/2018 11:30	18.33	33.99627	0.577
1/10/2018 11:40	18.33	33.99165	0.556333333

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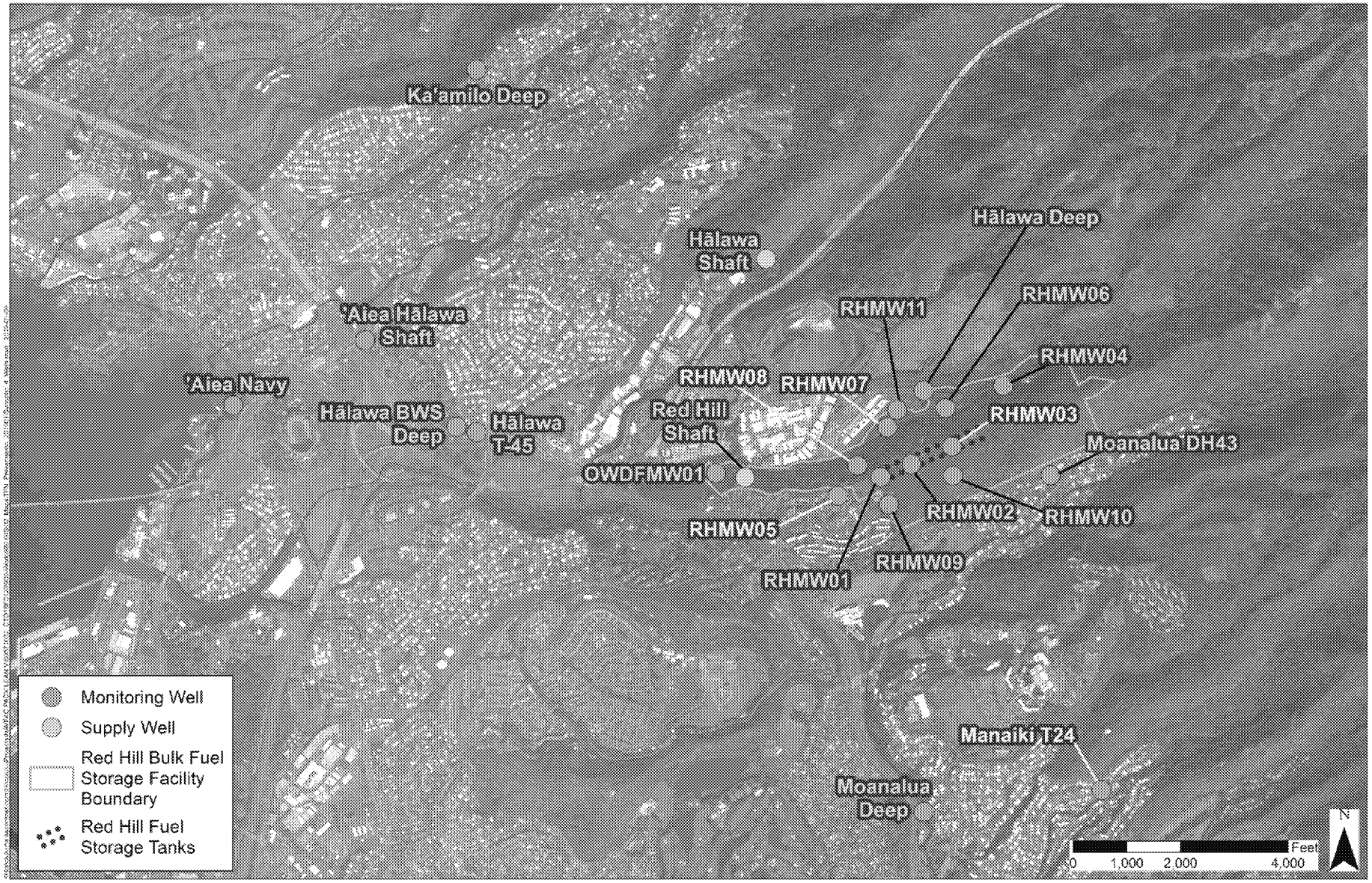
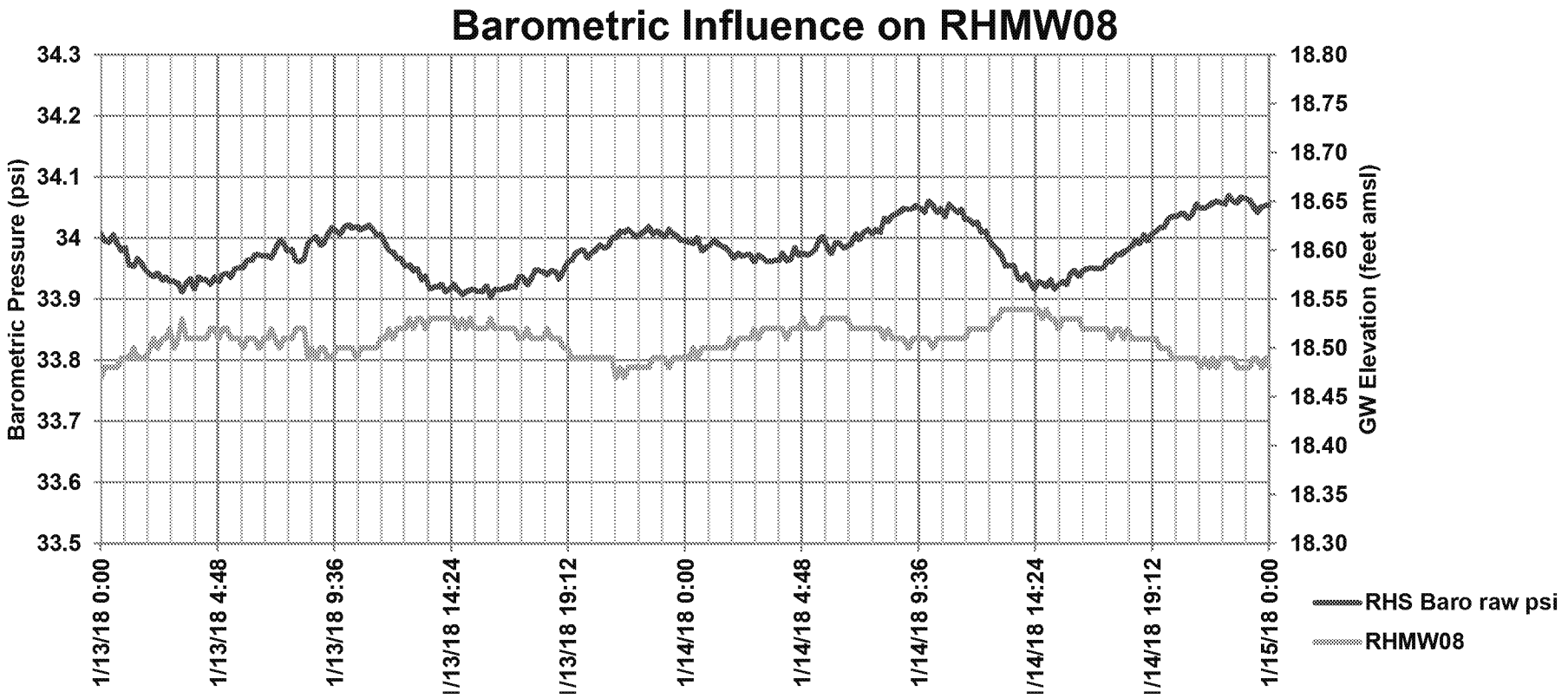
Synoptic Study Data Review:

Location of RHMW03, RHMW05, RHMW07, RHMW08, and Manaiki T24



Synoptic Study Data Review:

Barometric Response During Non-pumping at Red Hill Shaft



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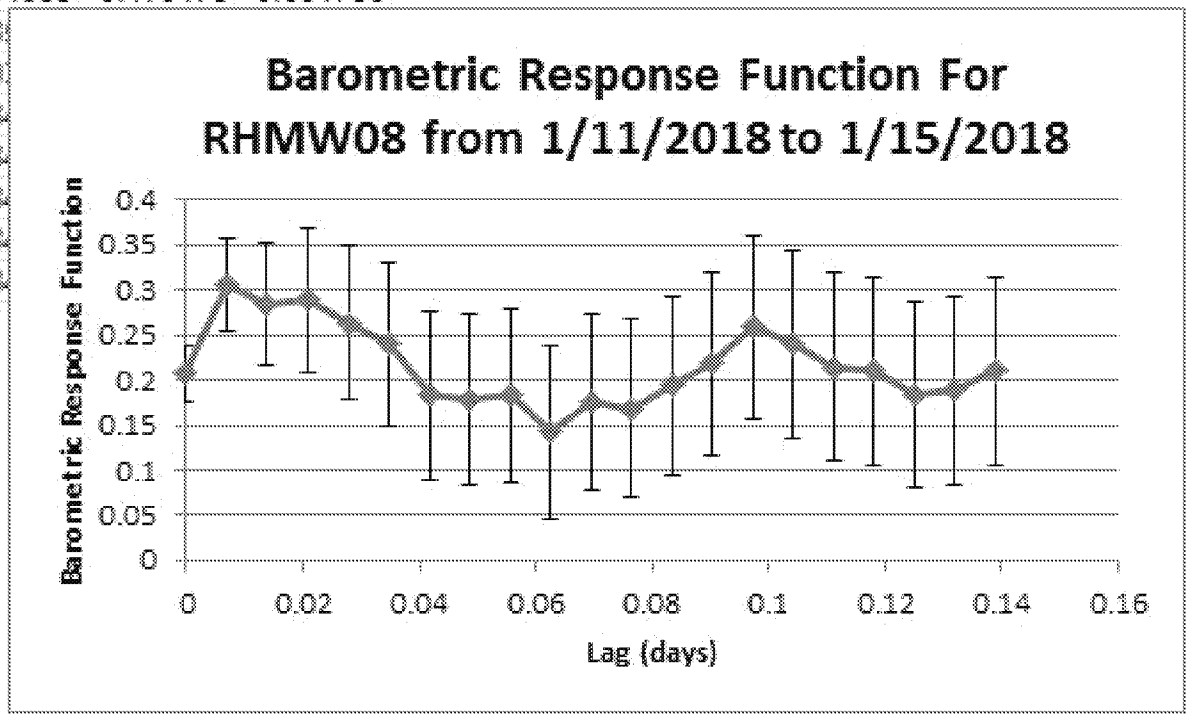
Synoptic Study Data Review:
Selecting Barometric Lag

		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		



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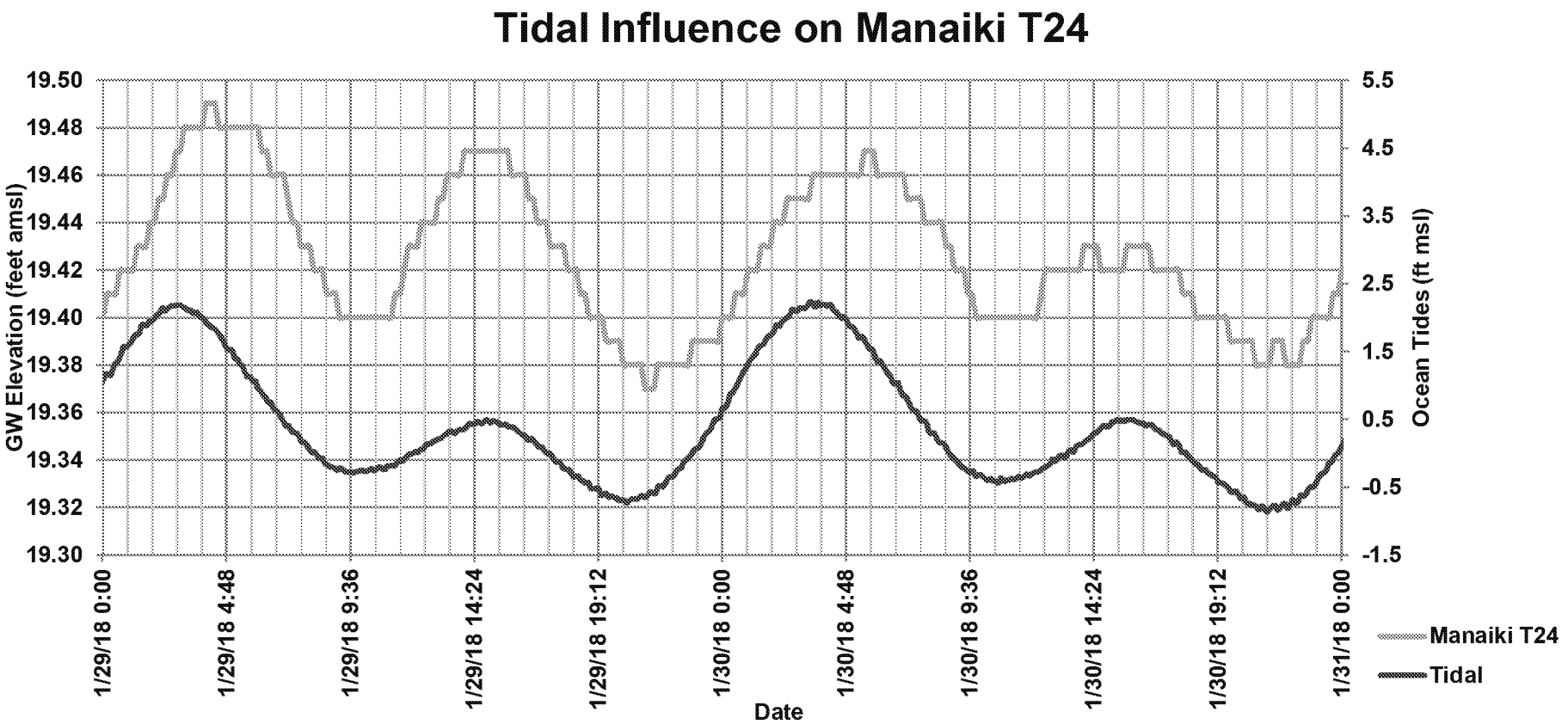
Selecting Tidal Lag



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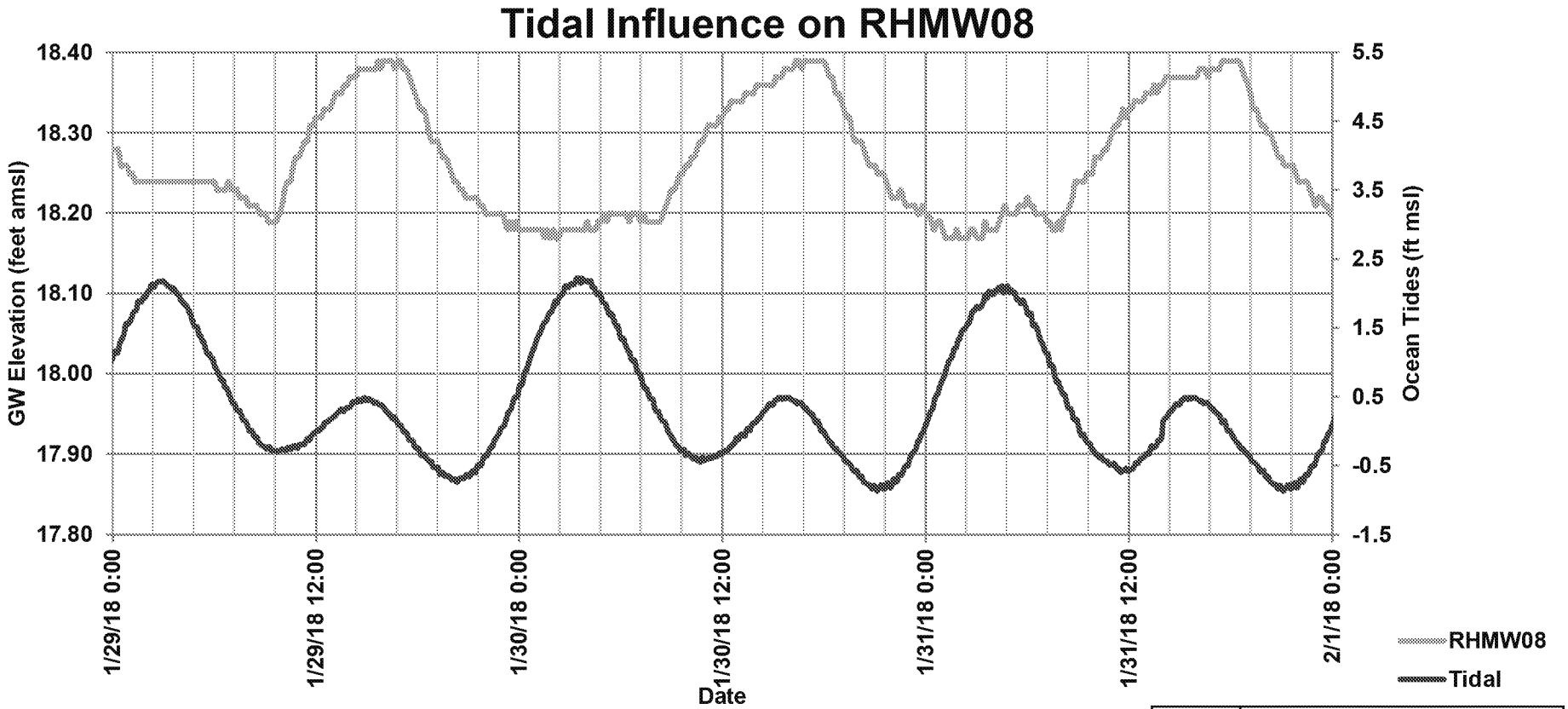
Synoptic Study Data Review:
Selecting Tidal Lag



		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**

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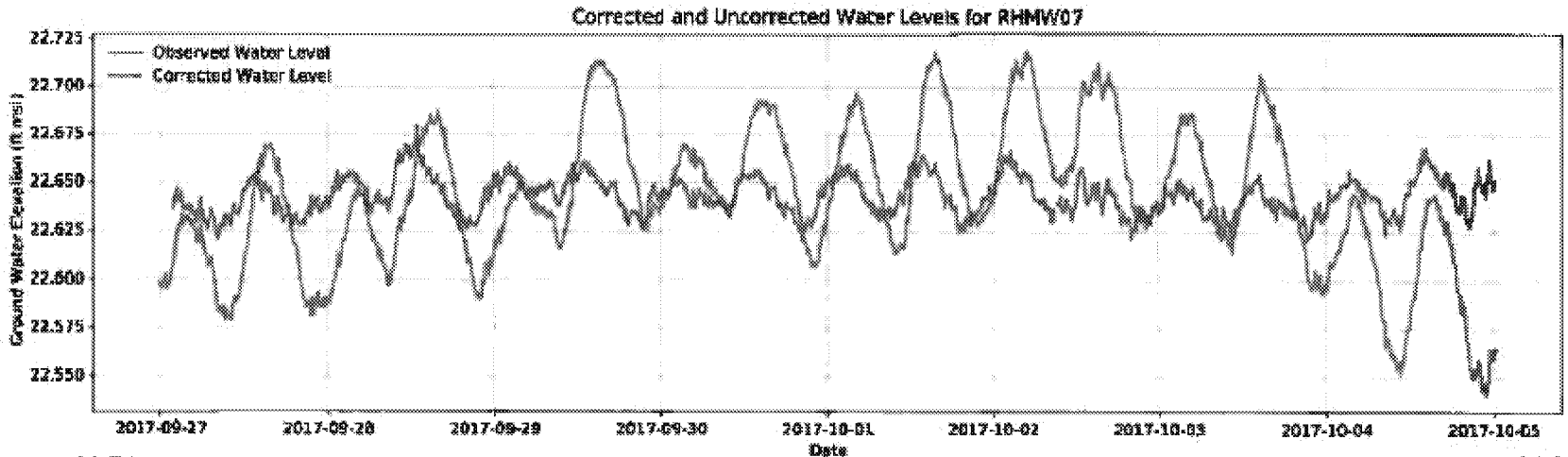
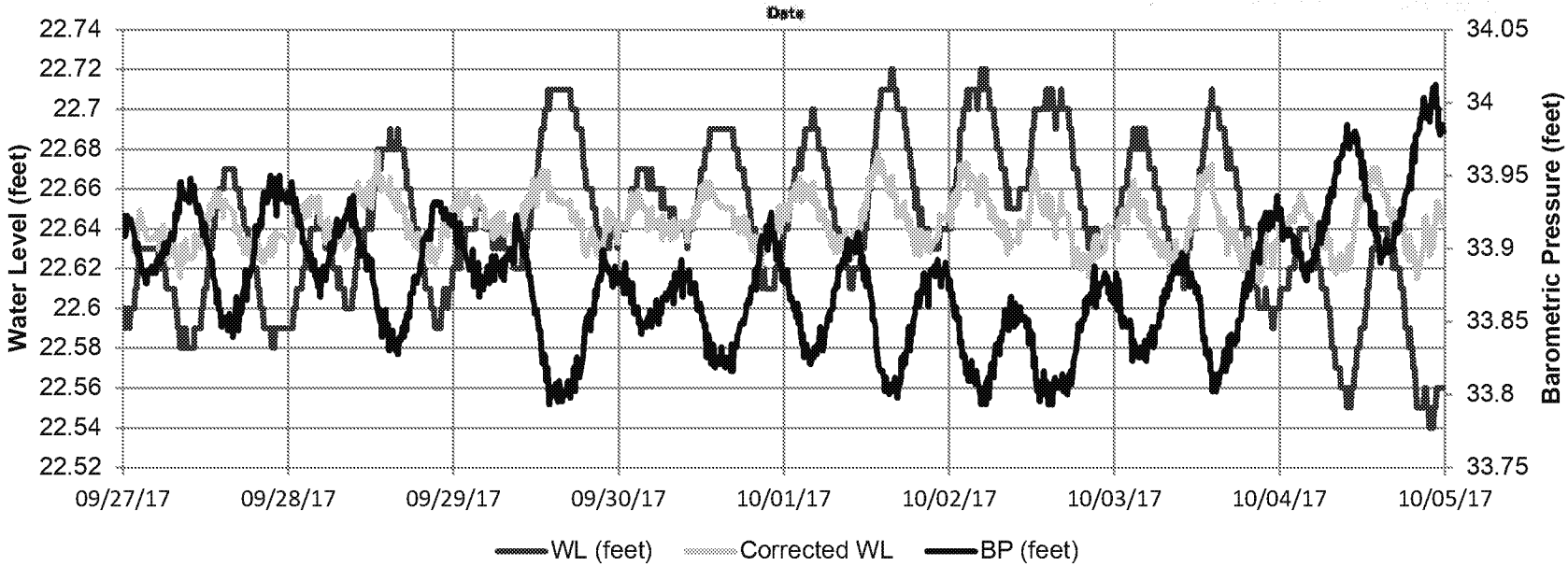
Synoptic Study Data Review:
RHMW07





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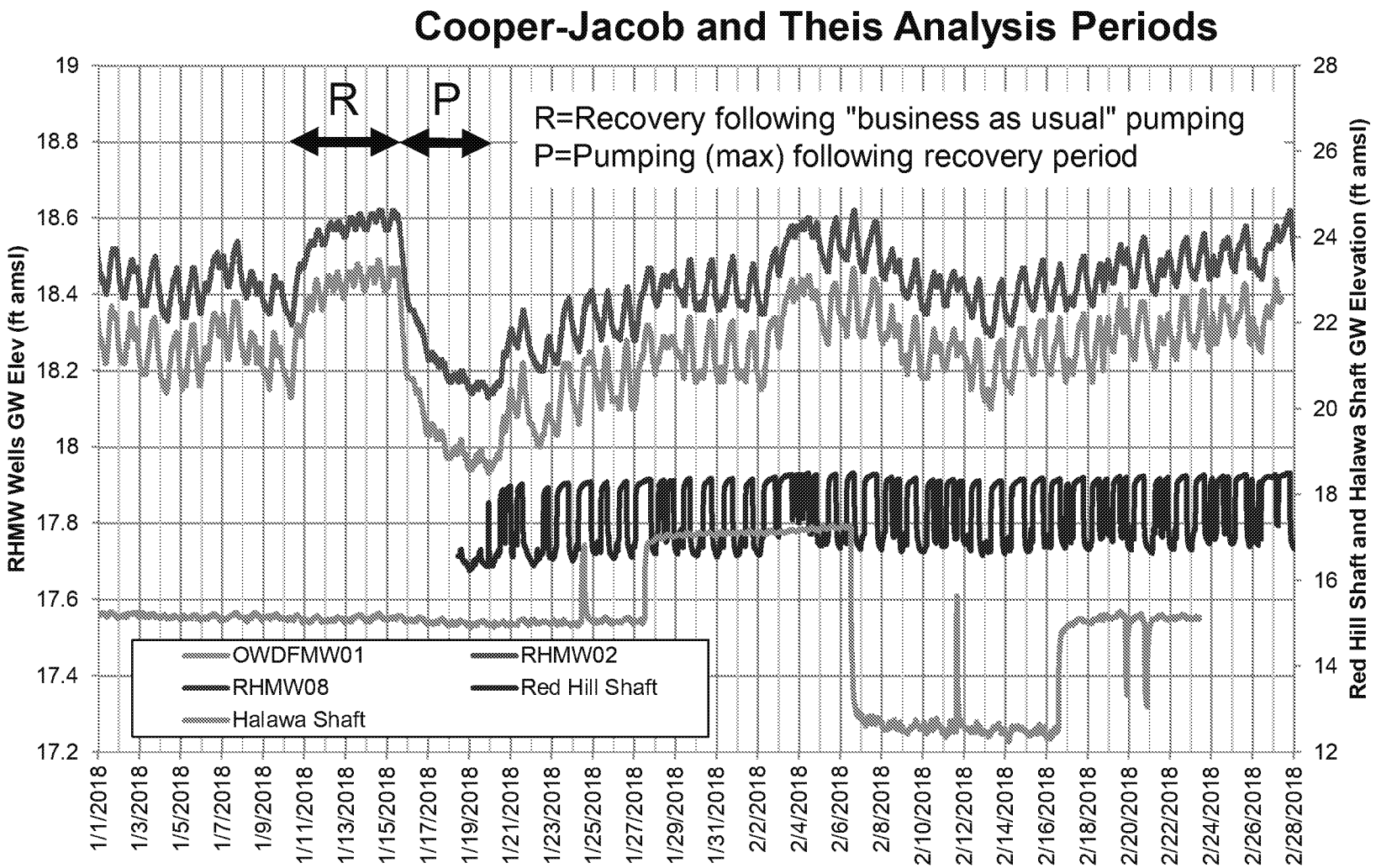
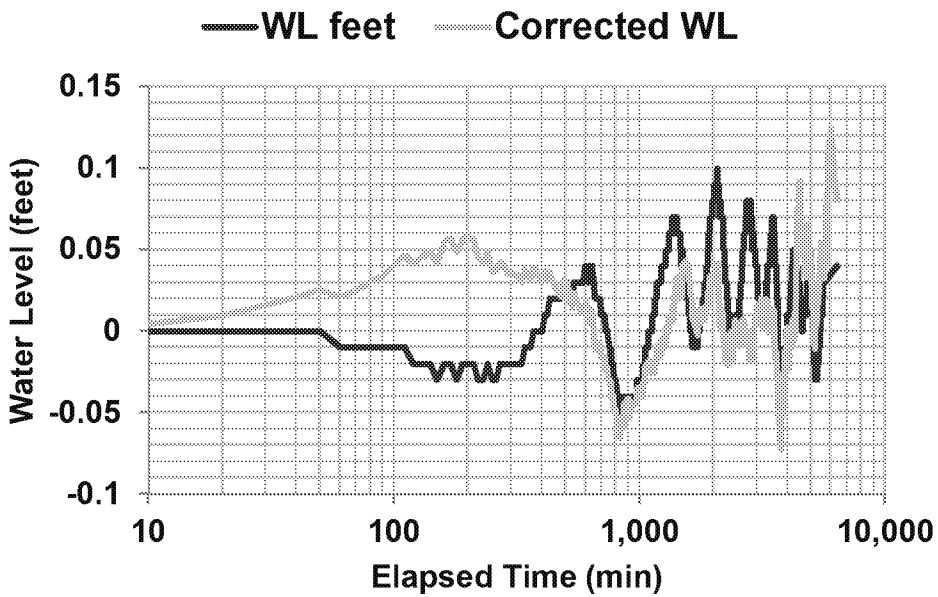
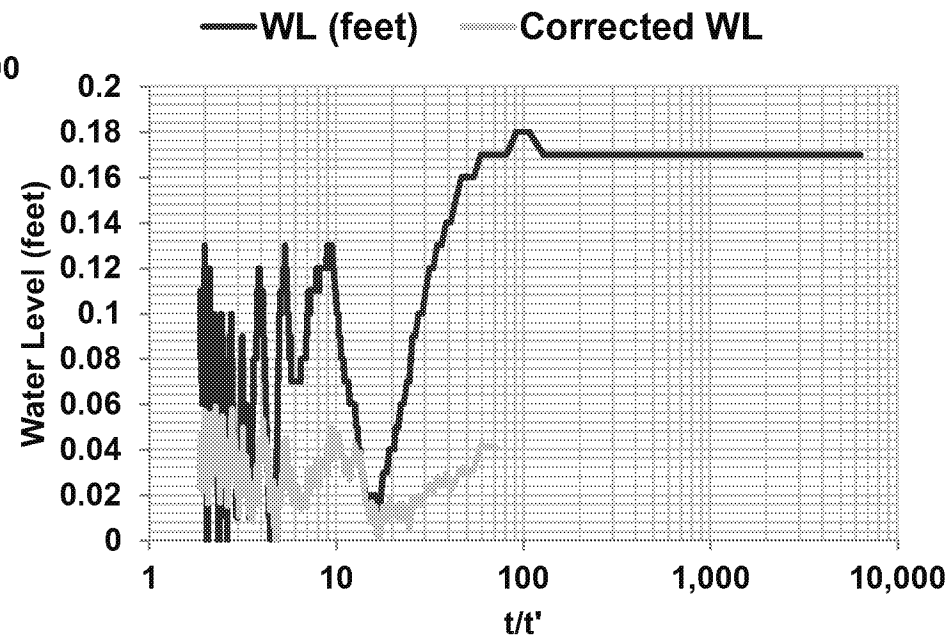
Analysis Periods for Cooper-Jacob and Theis Evaluations



Synoptic Study Data Review:

RHMW07 - Semi-log Plots Corrected for BP





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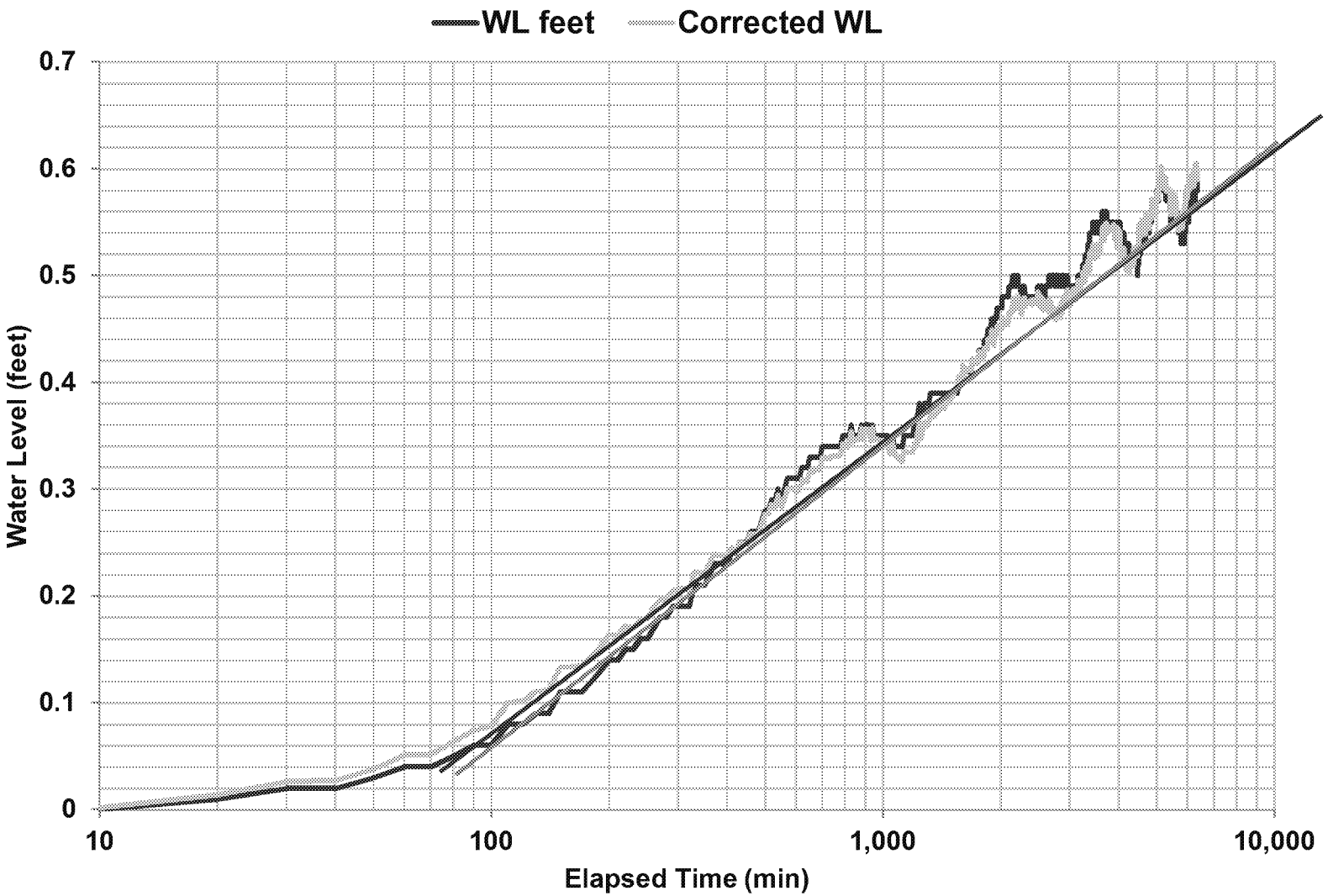
Synoptic Study Data Review:

BP Corrections – Cooper-Jacob RHMW08 Drawdown



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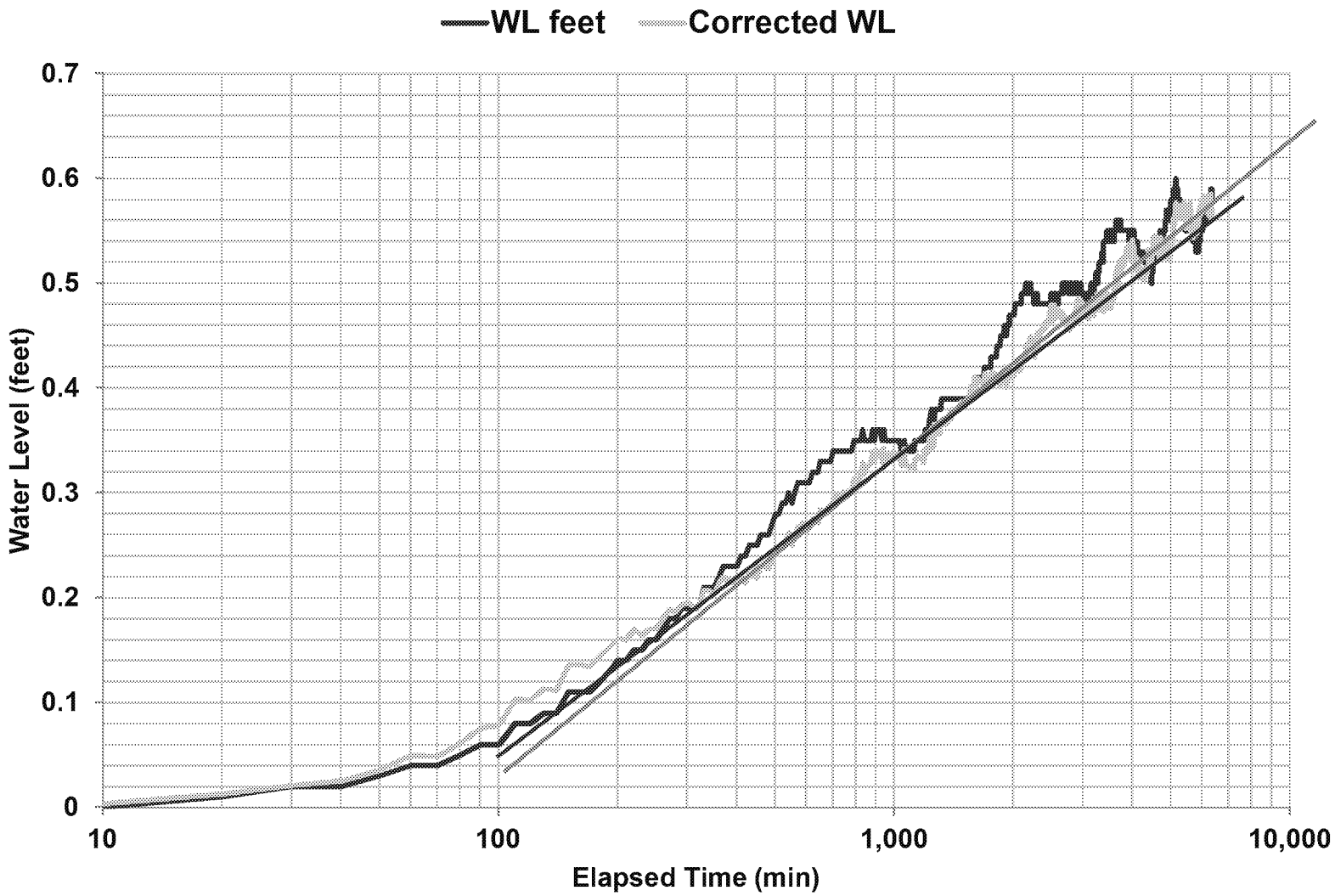
Synoptic Study Data Review:

BP & Tidal Corrections – Cooper-Jacob RHMW08 Drawdown



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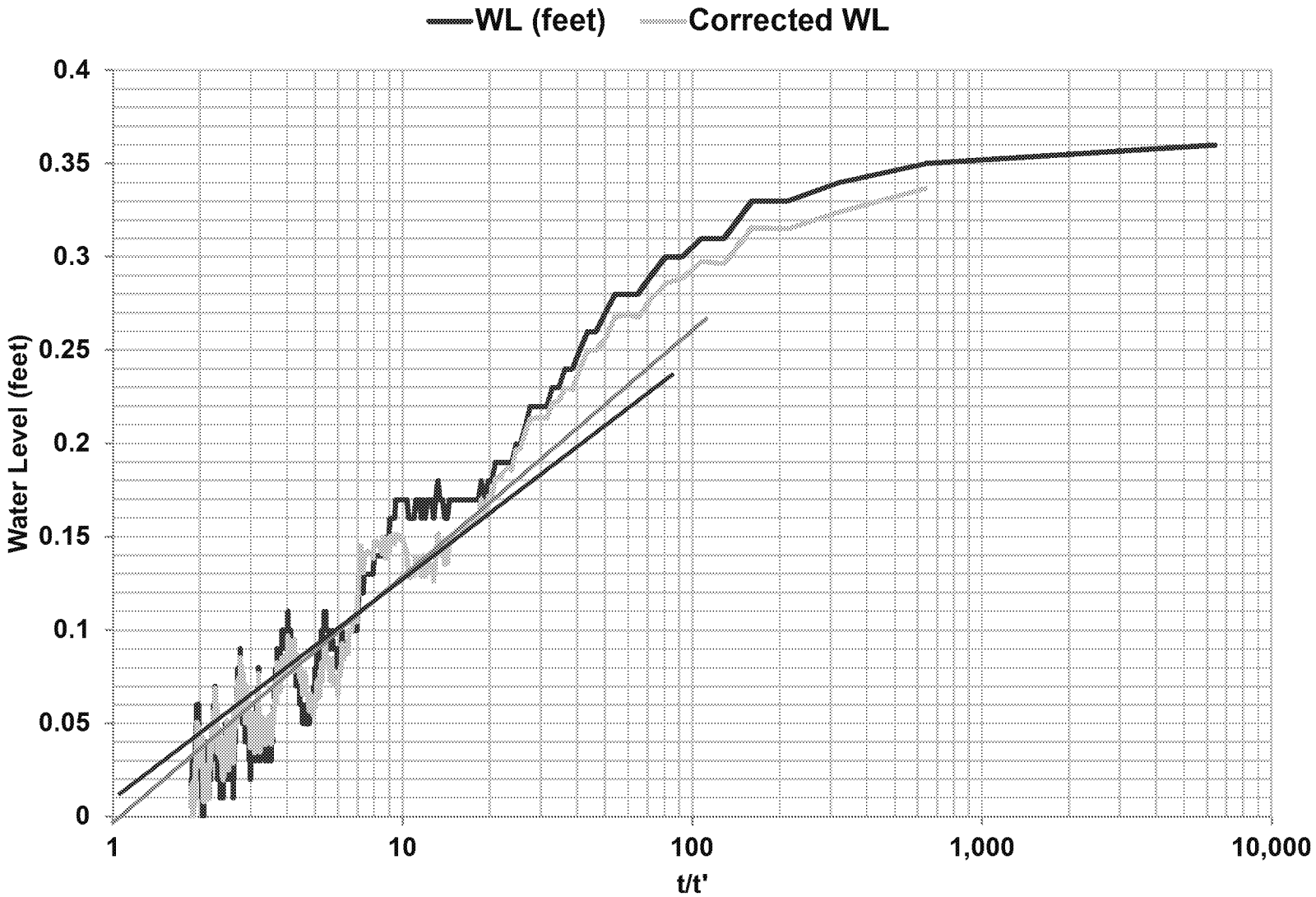
Synoptic Study Data Review:

BP Corrections – Cooper-Jacob RHMW08 Recovery



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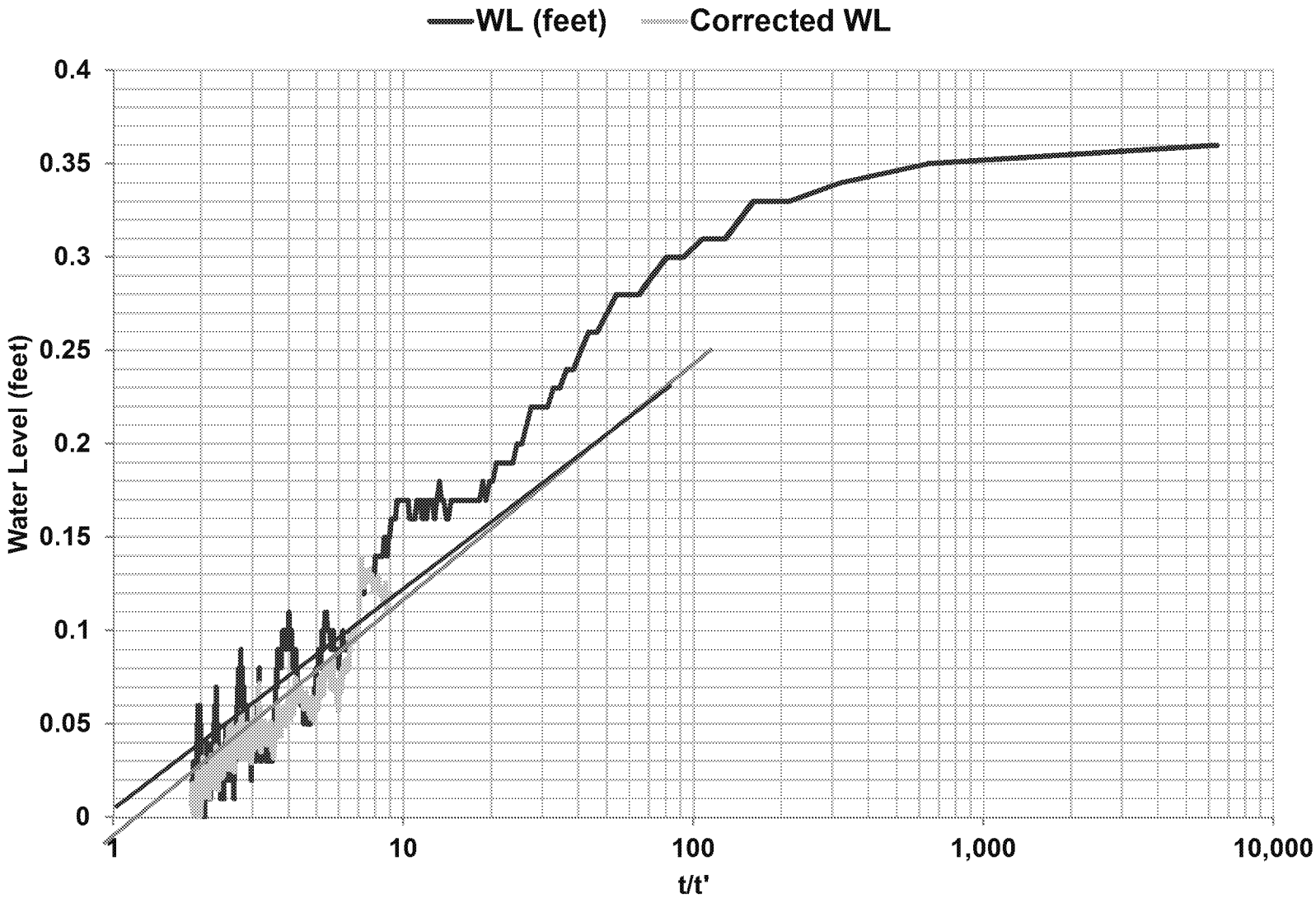
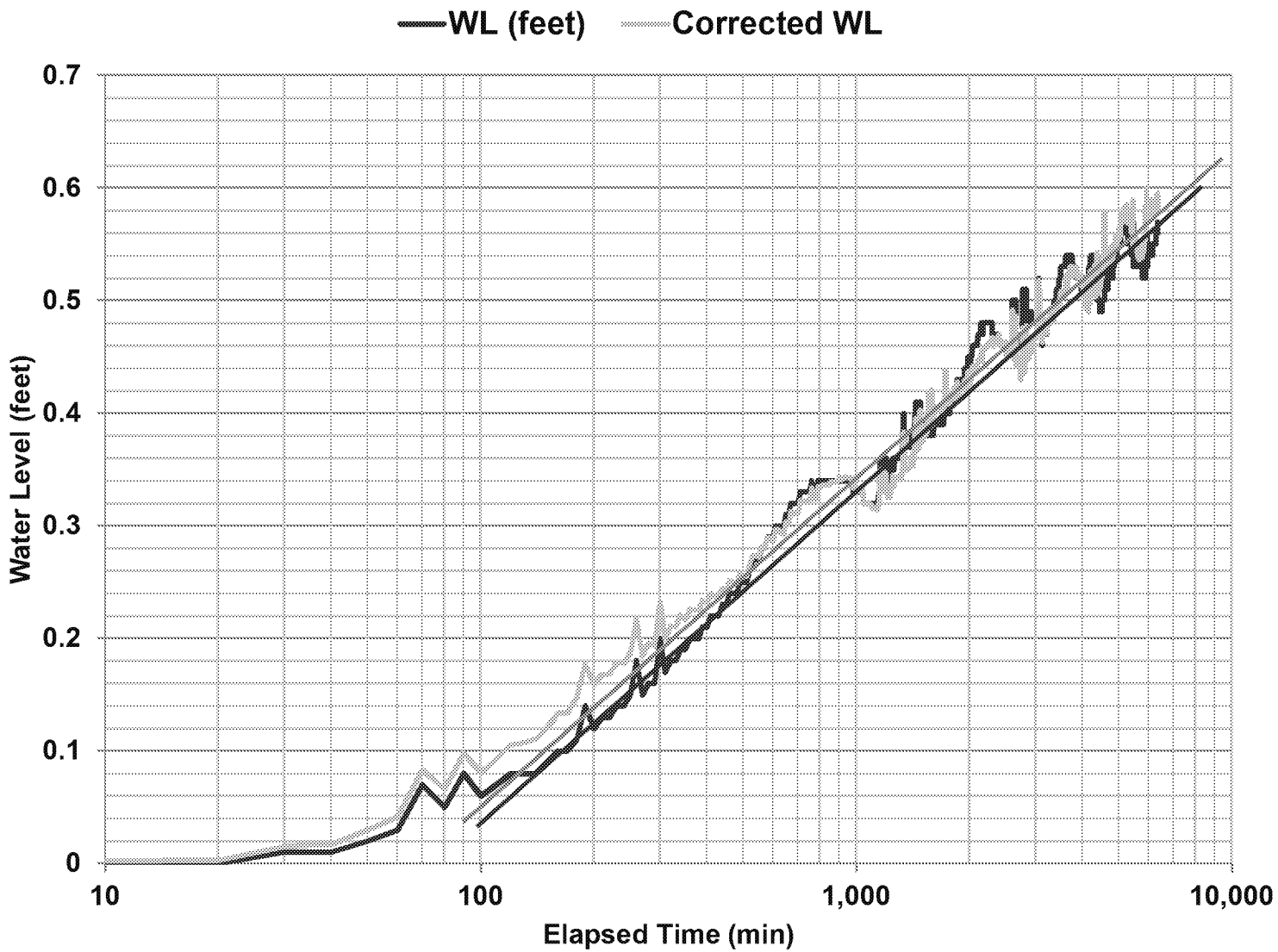
Synoptic Study Data Review:

BP & Tidal Corrections – Cooper-Jacob RHMW08 Recovery



Synoptic Study Data Review:

BP Corrections – Cooper-Jacob RHMW05 Drawdown



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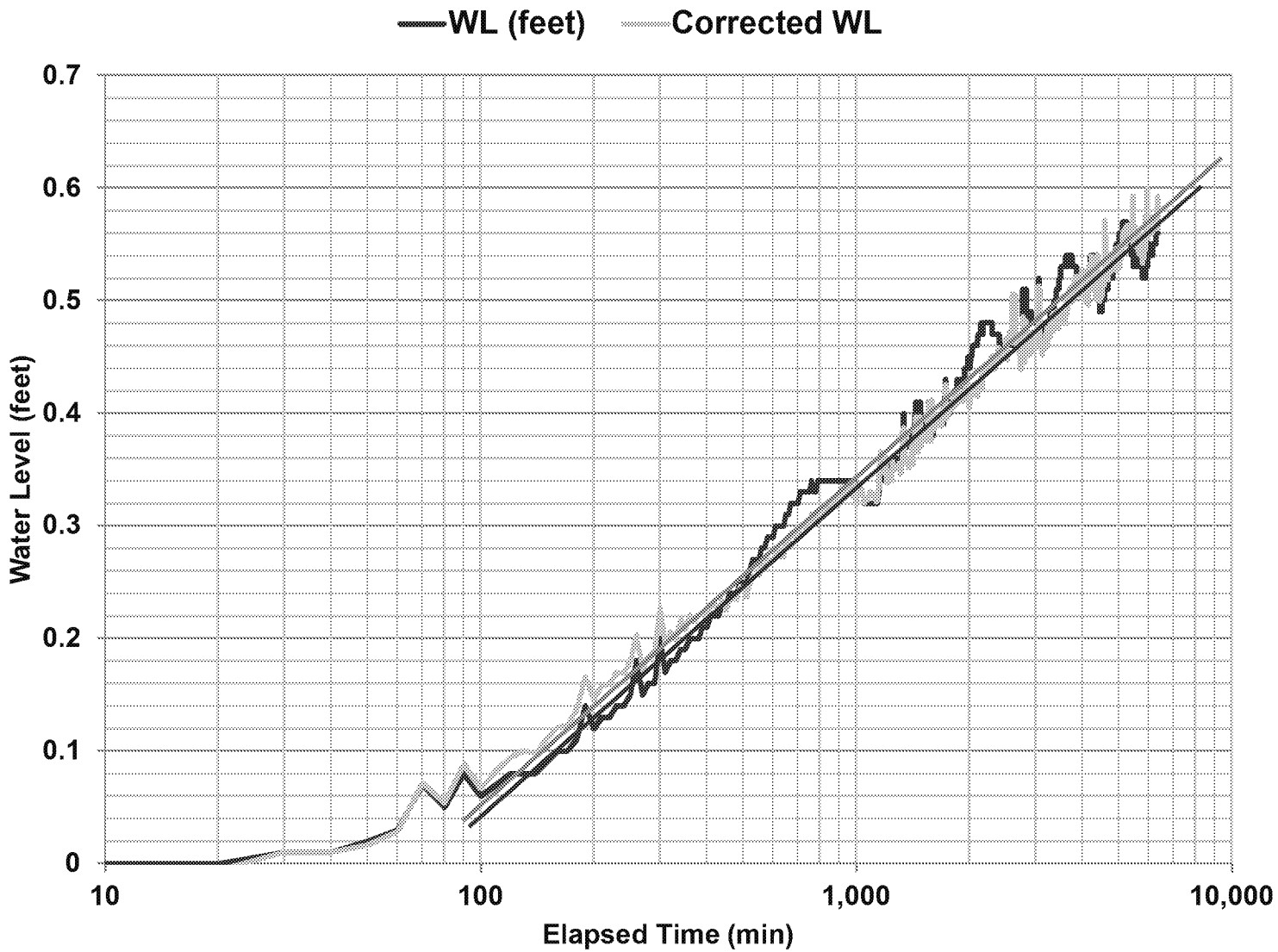
Synoptic Study Data Review:

BP & Tidal Corrections – Cooper-Jacob RHMW05 Drawdown



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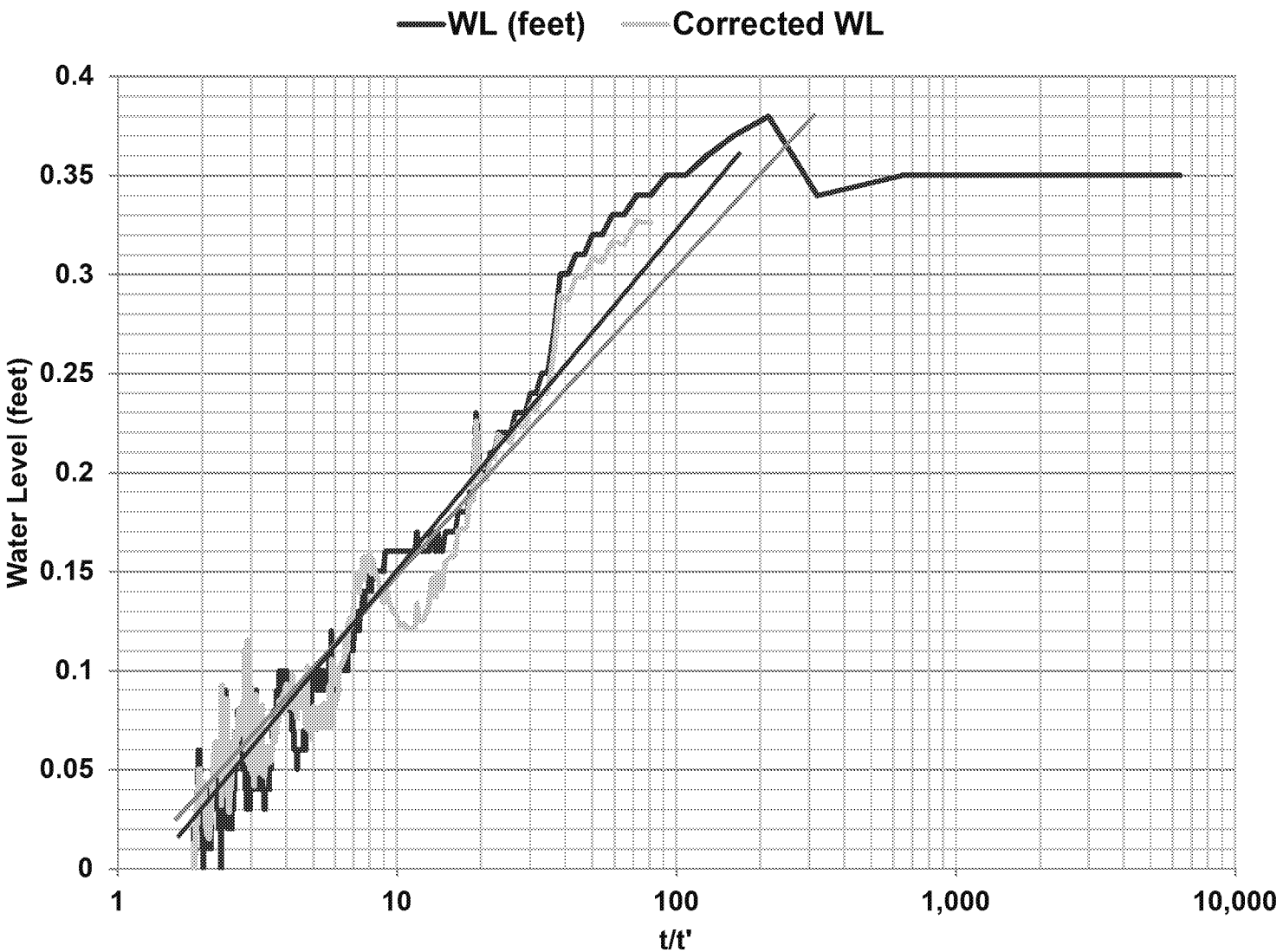
Synoptic Study Data Review:

BP Corrections – Cooper-Jacob RHMW05 Recovery



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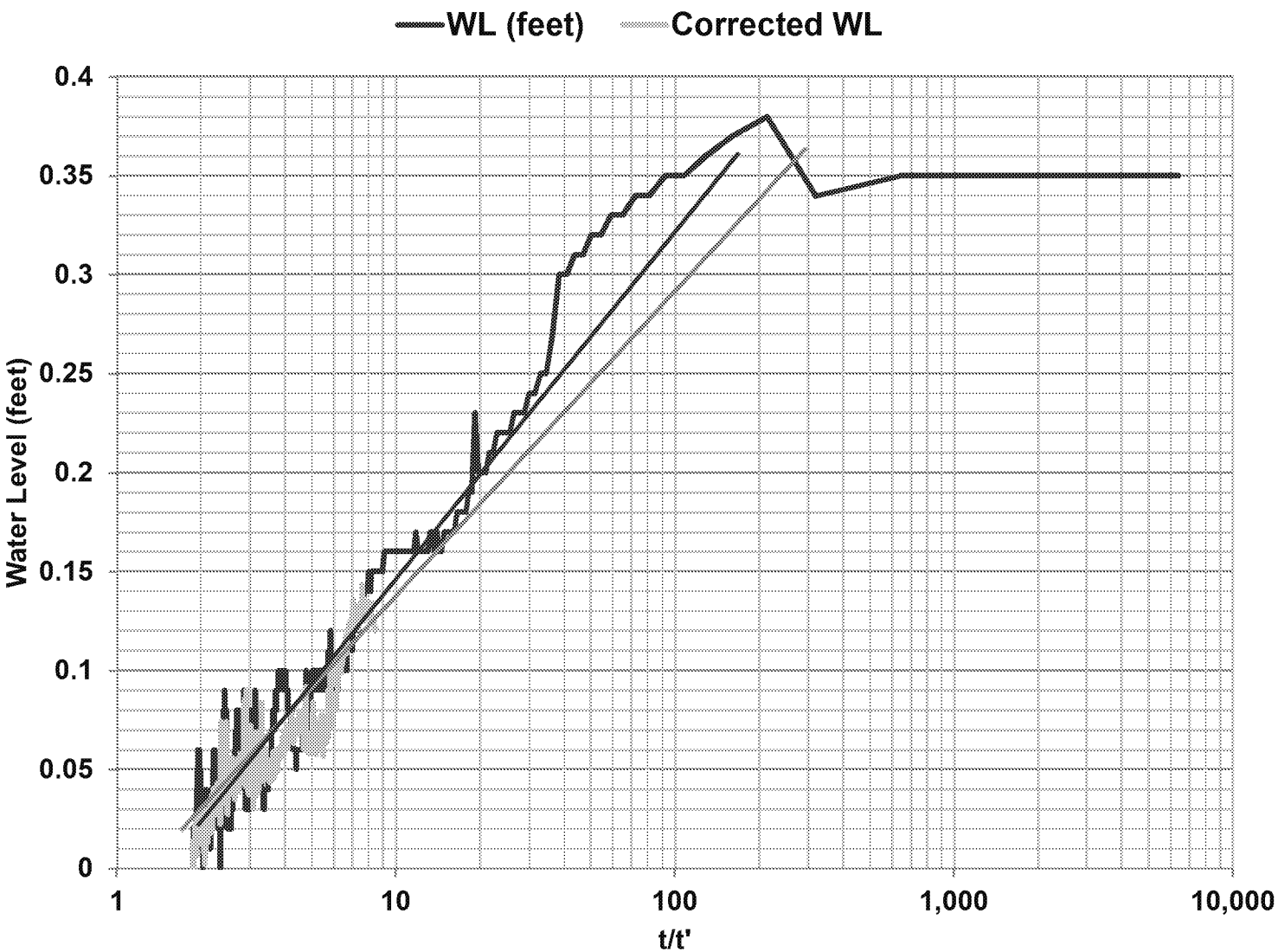
Synoptic Study Data Review:

BP & Tidal Corrections – Cooper-Jacob RHMW05 Recovery



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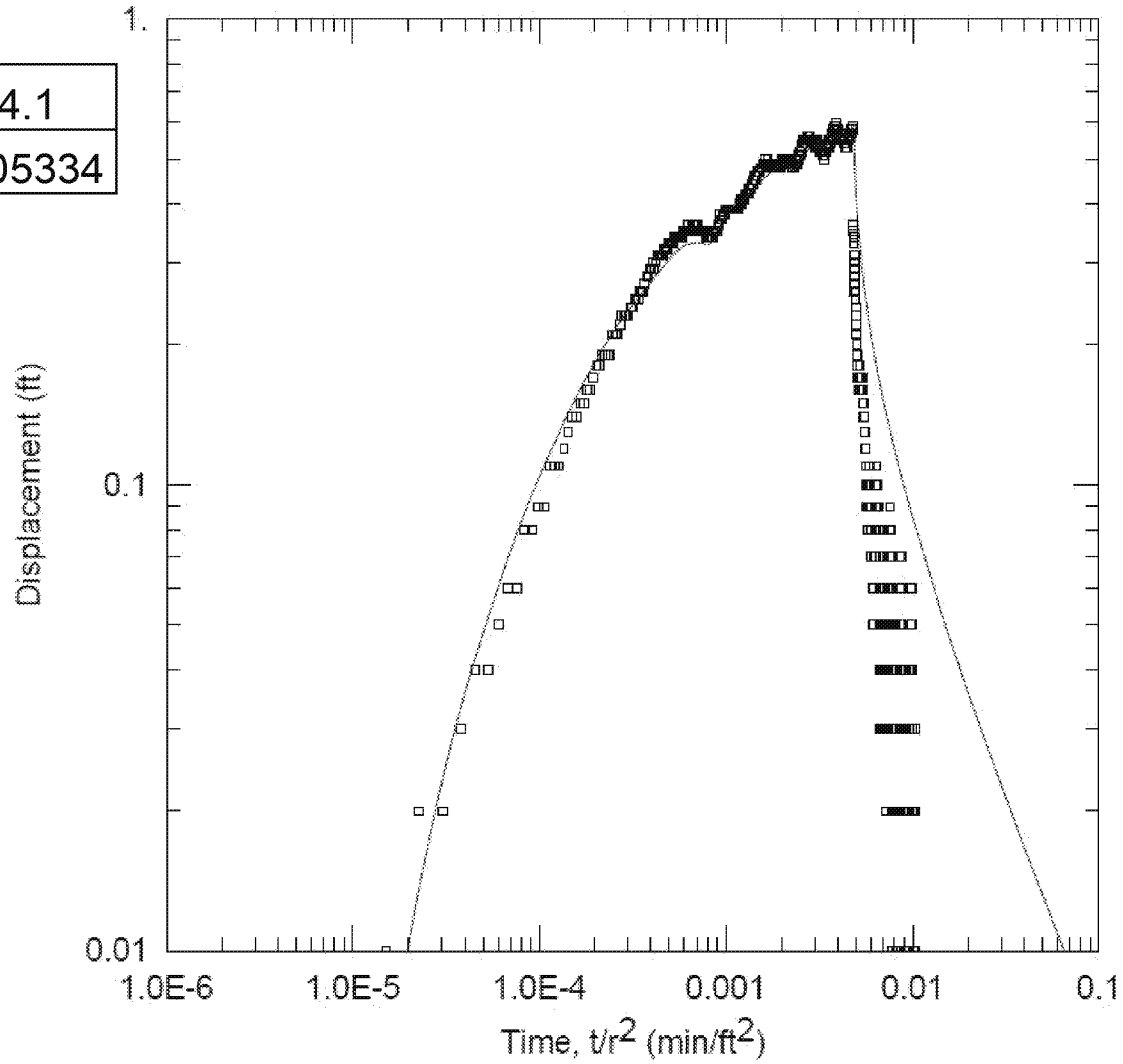
Uncorrected – Theis RHMW08

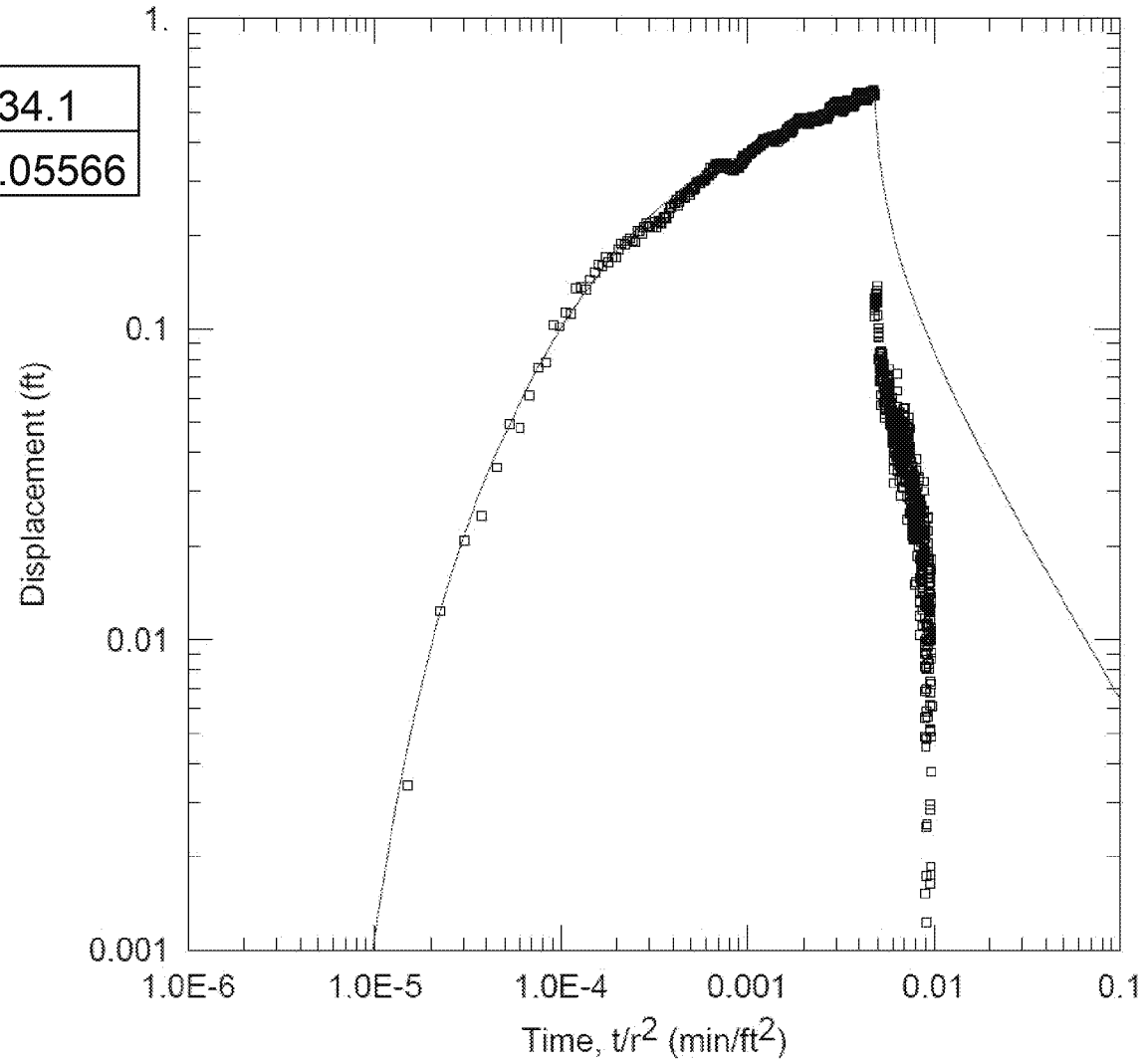
Transmissivity (ft^2/min)	434.1
Storativity	0.05334



Synoptic Study Data Review:

BP & Tidal Corrections – Theis RHMW08 Drawdown

Transmissivity (ft^2/min)	434.1
Storativity	0.05566



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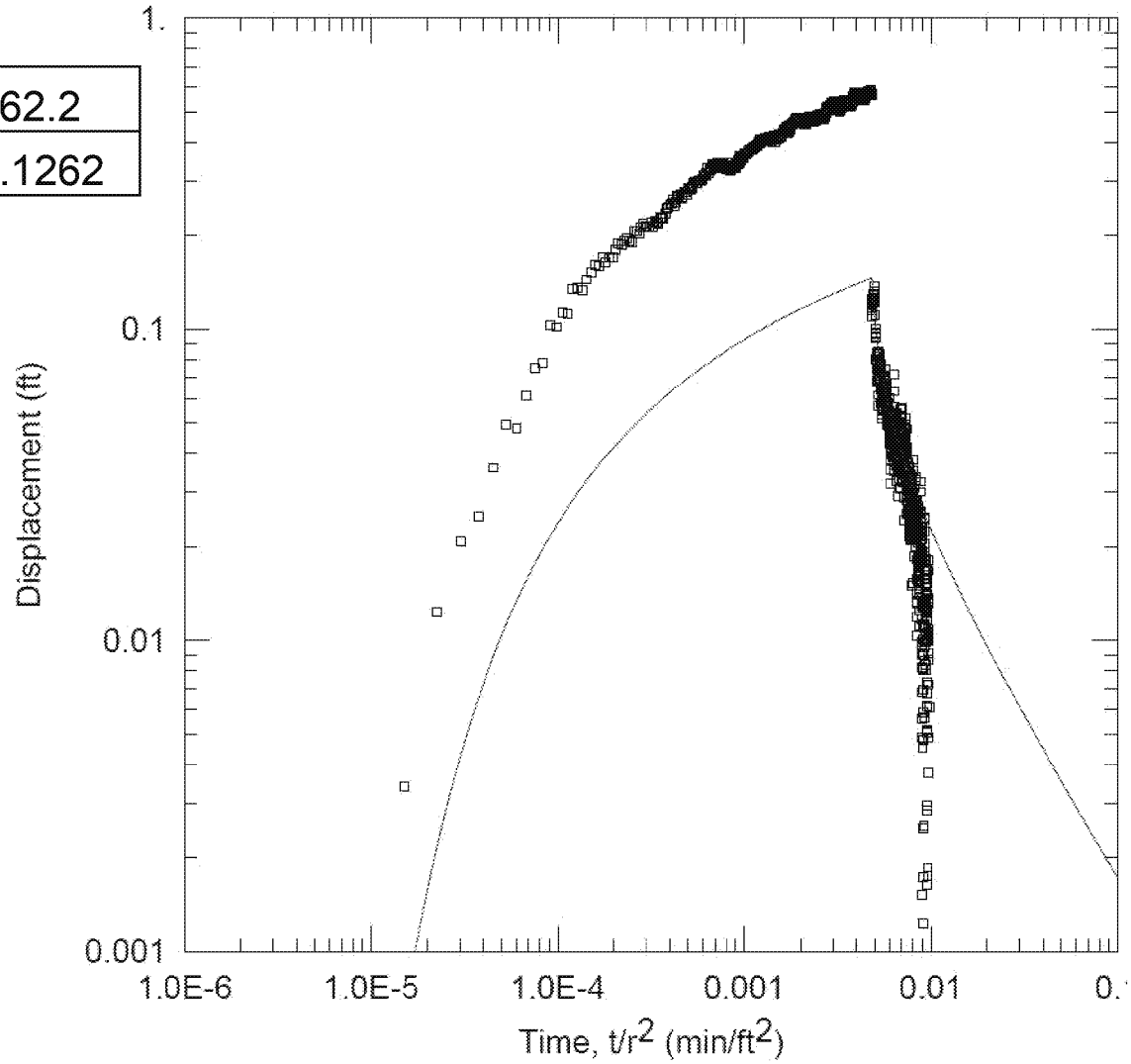
Synoptic Study Data Review:

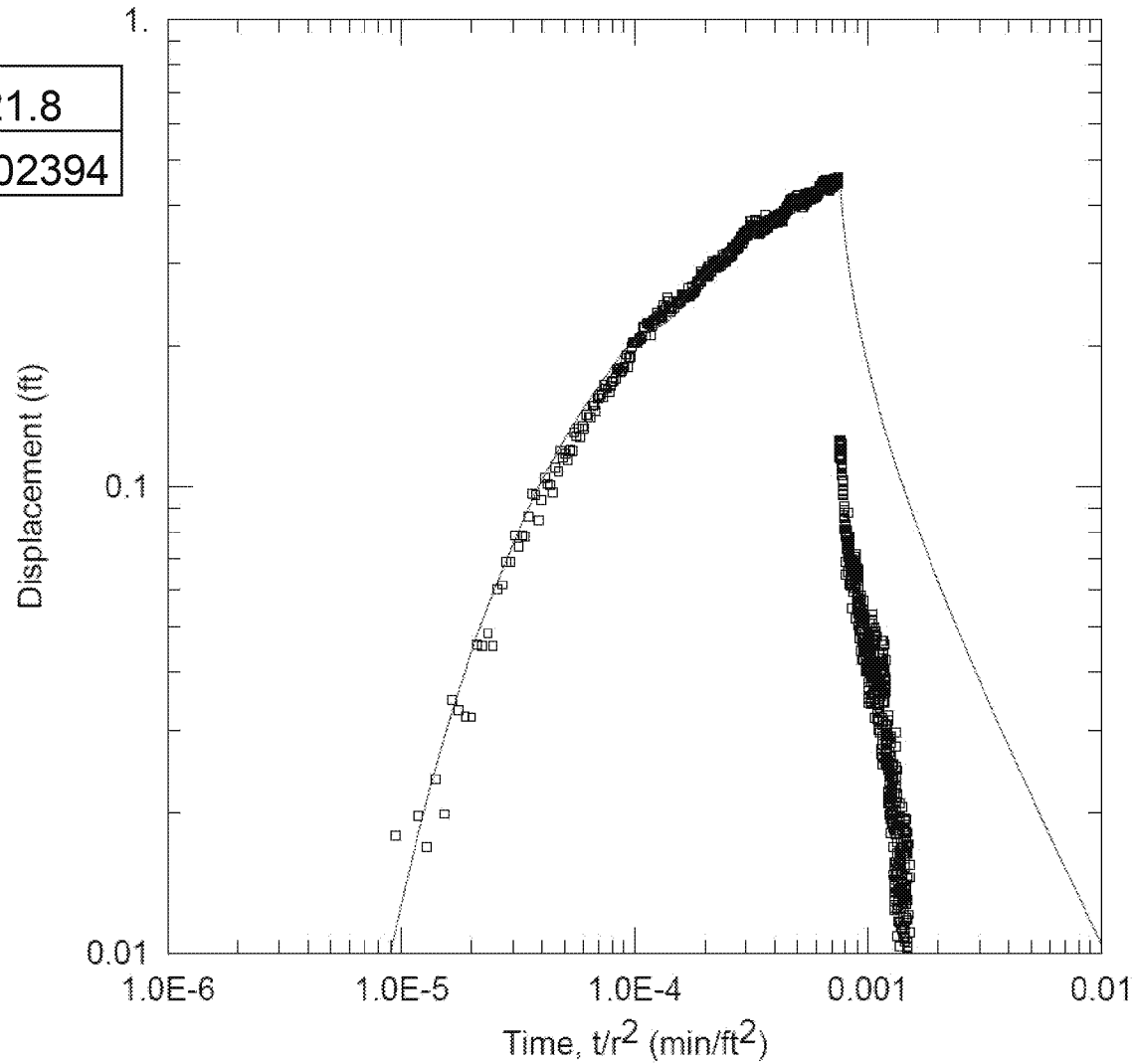
BP & Tidal Corrections – Theis RHMW08 Recovery

Transmissivity (ft^2/min)	762.2
Storativity	0.1262



BP & Tidal Corrections – Theis RHMW03 Drawdown

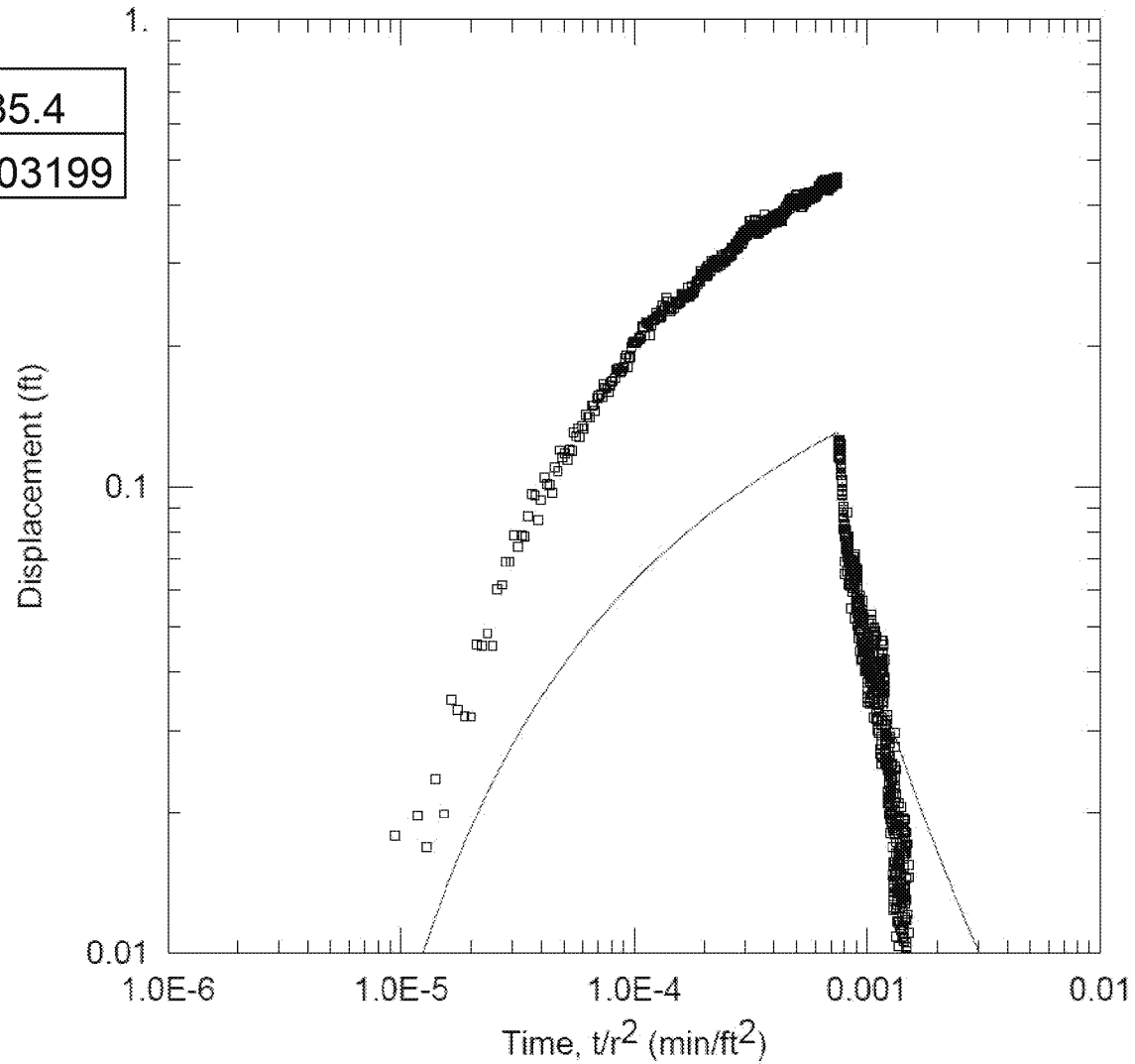
Transmissivity (ft^2/min)	421.8
Storativity	0.02394



Synoptic Study Data Review:

BP & Tidal Corrections – Theis RHMW03 Recovery

Transmissivity (ft^2/min)	735.4
Storativity	0.03199



ED_006532_00002904-00041

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.

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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)

ED_006532_00002904-00044

Transfer Function-Noise Analysis

ED_006532_00002904-00045

TFN Analysis:

Objectives

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

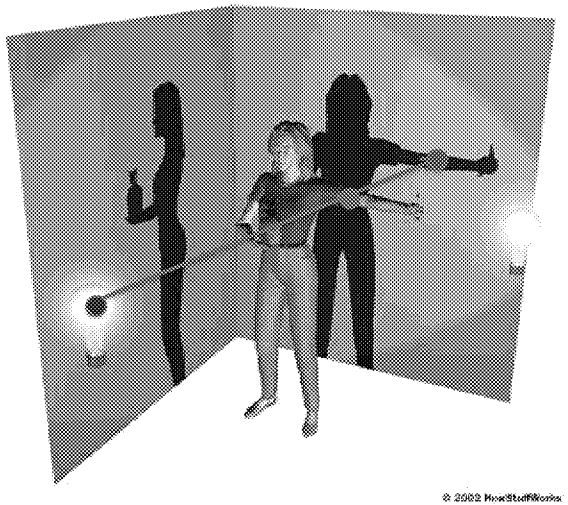
ED_006532_00002904-00046

Value of TFN Analysis

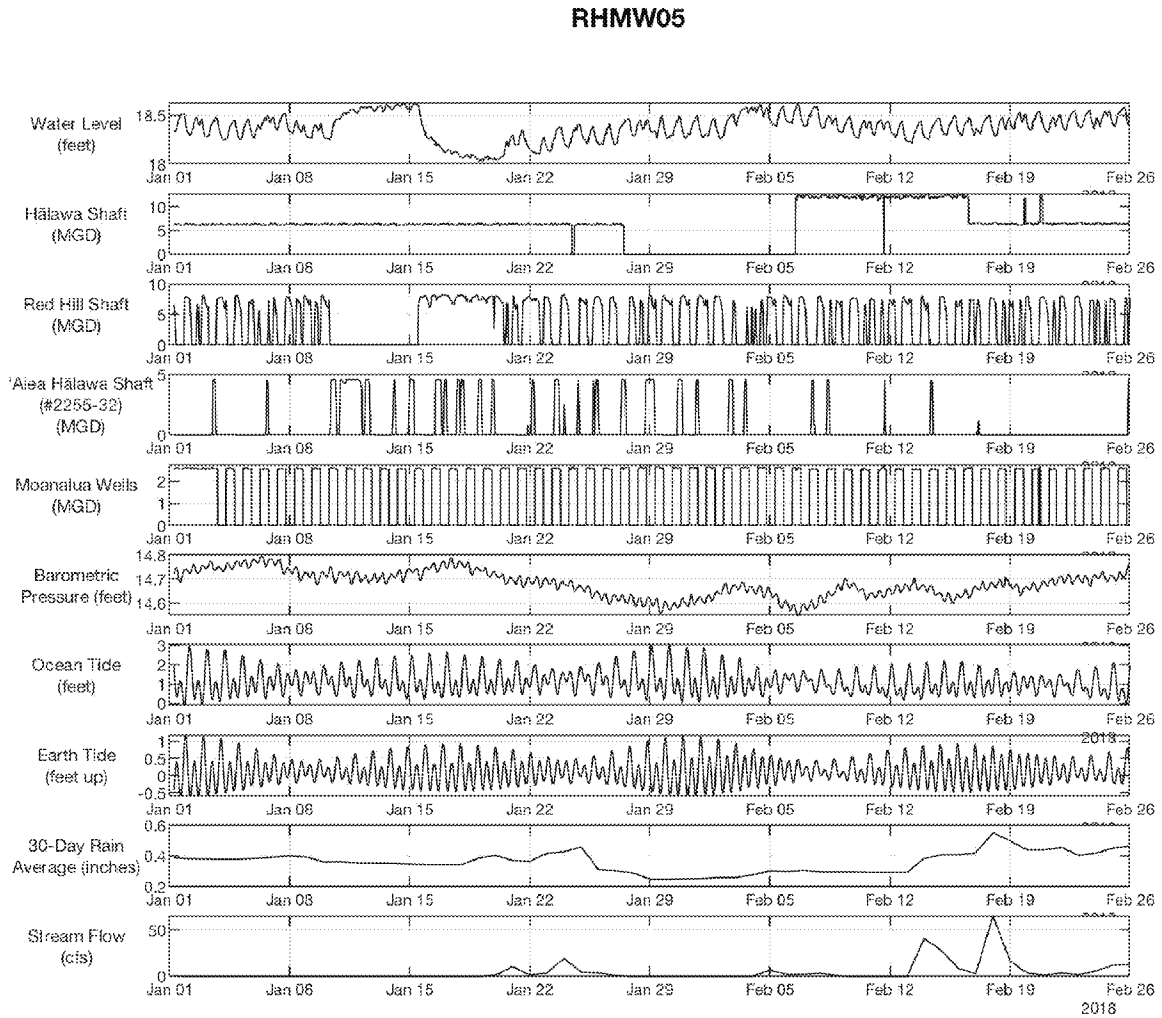
- **The TFN Analysis provides:**
  - An **understanding of the individual impact of known stresses** (e.g., pumping at Halawa Shaft and at Red Hill Shaft; barometric pressure, earth tides) at various time scales, on the synoptic water level data at the various monitoring wells (receptors)
  - Quantification of the **magnitude of the unexplained water level variations**
  - **Dataset for calibration and evaluation of the numerical groundwater flow model** – calibrate to individual stresses and signals; evaluate against combined signal of all synoptic pumping.
  - **Signal strength of a particular stress to a particular receptor** (e.g., RHMW07 response is similar to barometric fluctuations and does not resemble the pumping signatures at Red Hill Shaft and Halawa Shaft)
  - **Estimates of equivalent transmissivity** between different stress (pumping well) locations and observation wells indicating heterogeneity, anisotropy, and parameter ranges

ED_006532_00002904-00047

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.

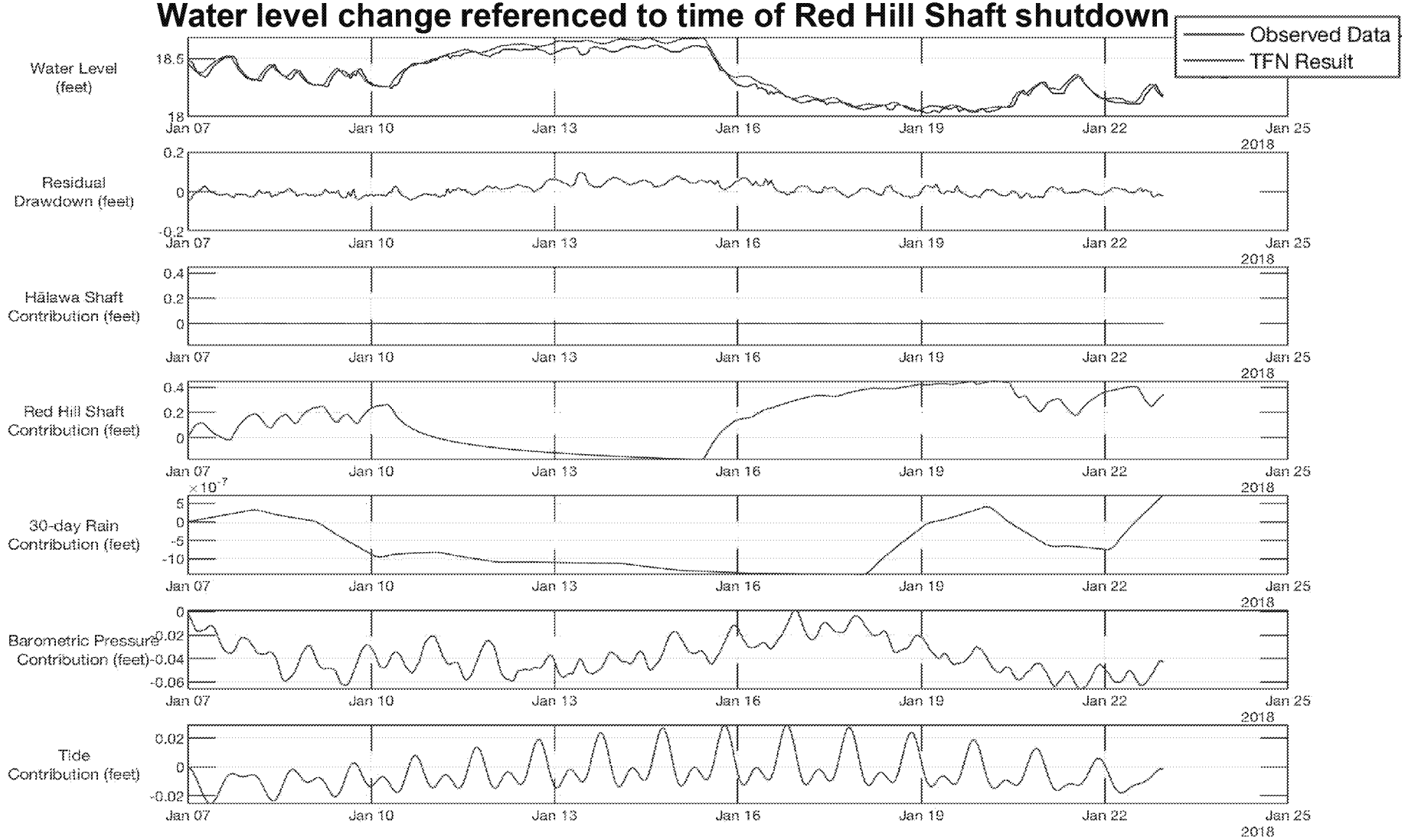


ED_006532_00002904-00048

TFN Analysis:

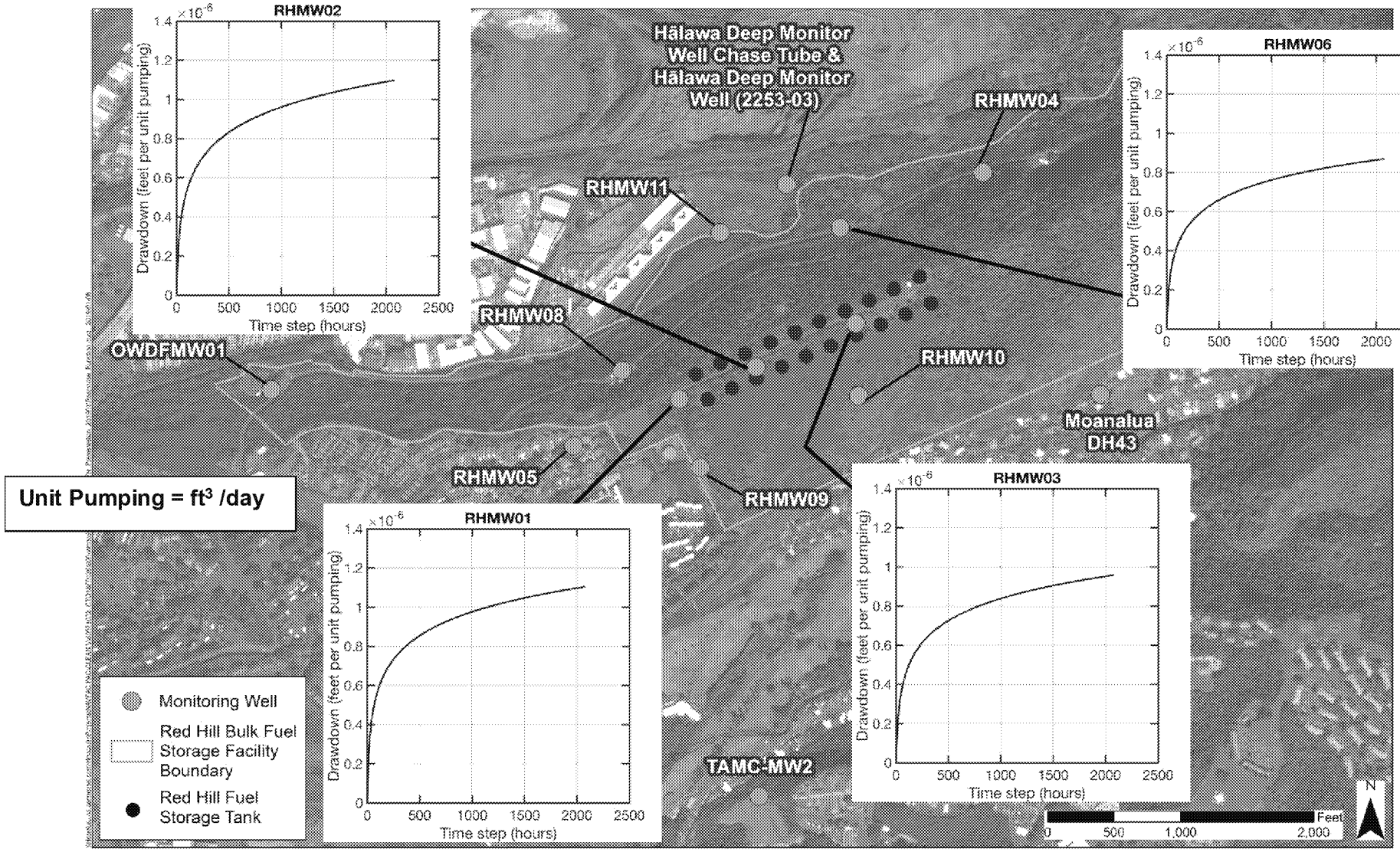
Estimation of Contributions from Individual Sources to Water Level Change – RHMW05

Water level change referenced to time of Red Hill Shaft shutdown

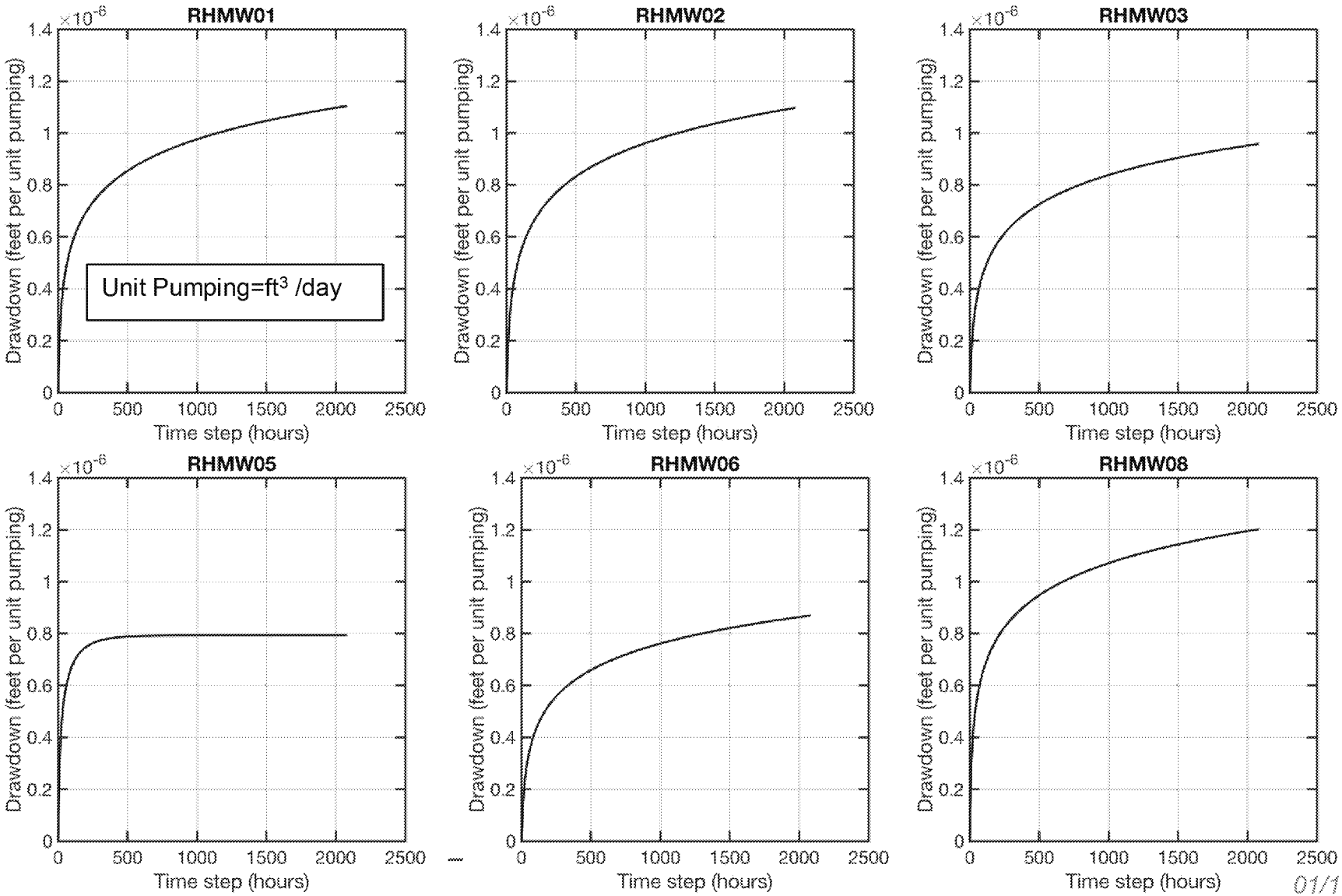


ED_006532_00002904-00049

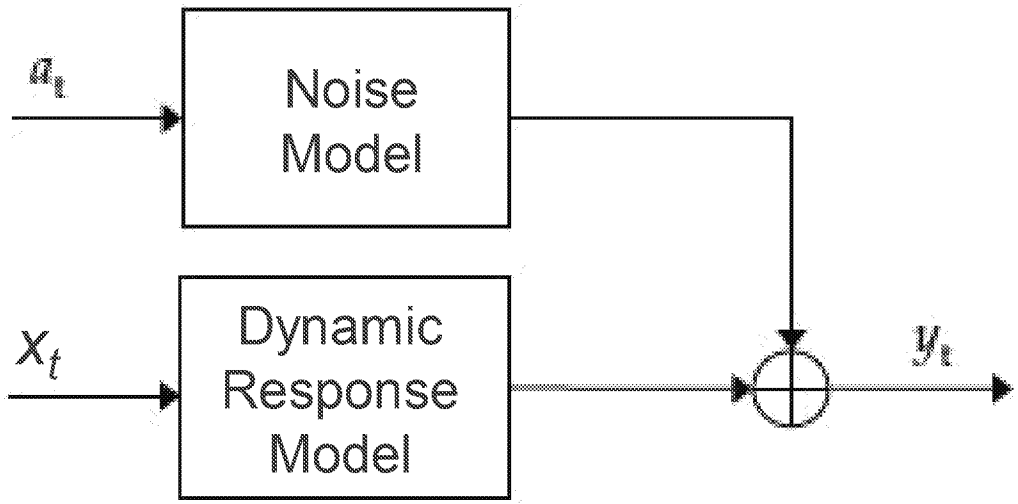
TFN Analysis:
Estimation of Step Response Functions for Groundwater Model Calibration (Red Hill Shaft Pumping)



TFN Analysis:
Estimation of Step Response Functions for Groundwater Model Calibration (Red Hill Shaft Pumping) (cont.)



TFN Model with Single Input Source



Output = dynamic component + noise

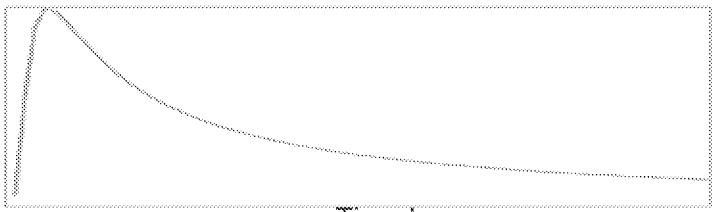
ED_006532_00002904-00052

Discrete Transfer Function

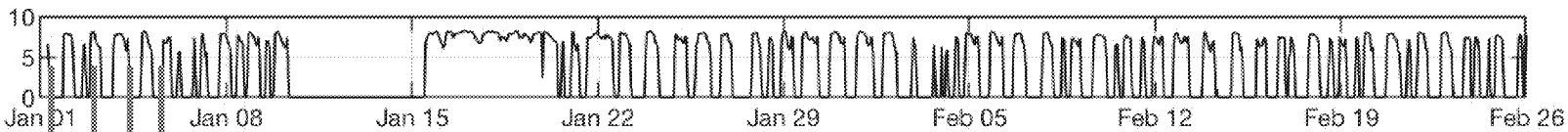
Unit impulse response function as transfer function

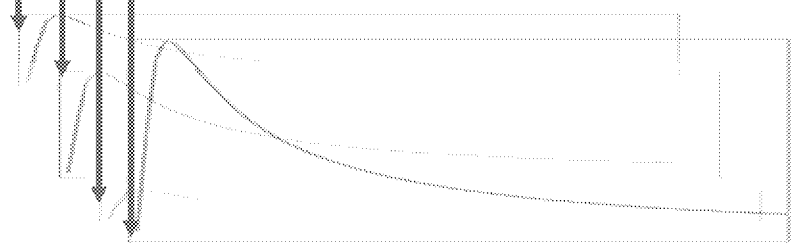
$$y_t = v_0 x_t + v_1 x_{t-1} + v_2 x_{t-2} + \cdots$$
$$= v(B) x_t$$
$$where\ v(B) = v_0 + v_1 B + v_2 B^2$$

Unit impulse response function



Source



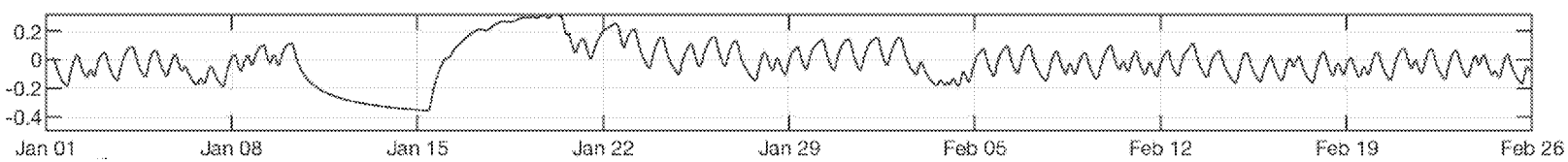


Responses to individual impulses

CONVOLUTION

Summing all responses to impulses

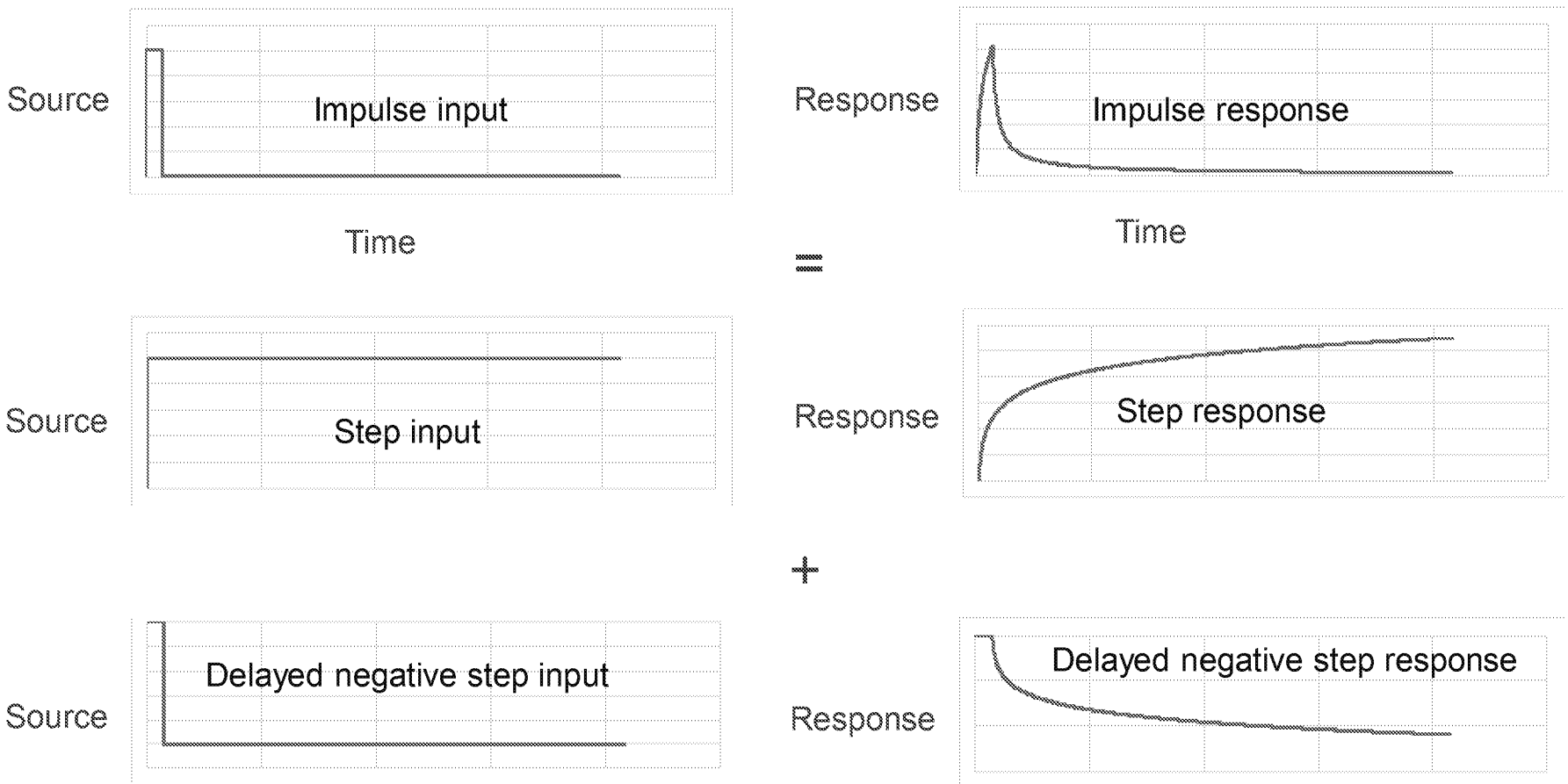
Response



ED_006532_00002904-00053

TFN Analysis:

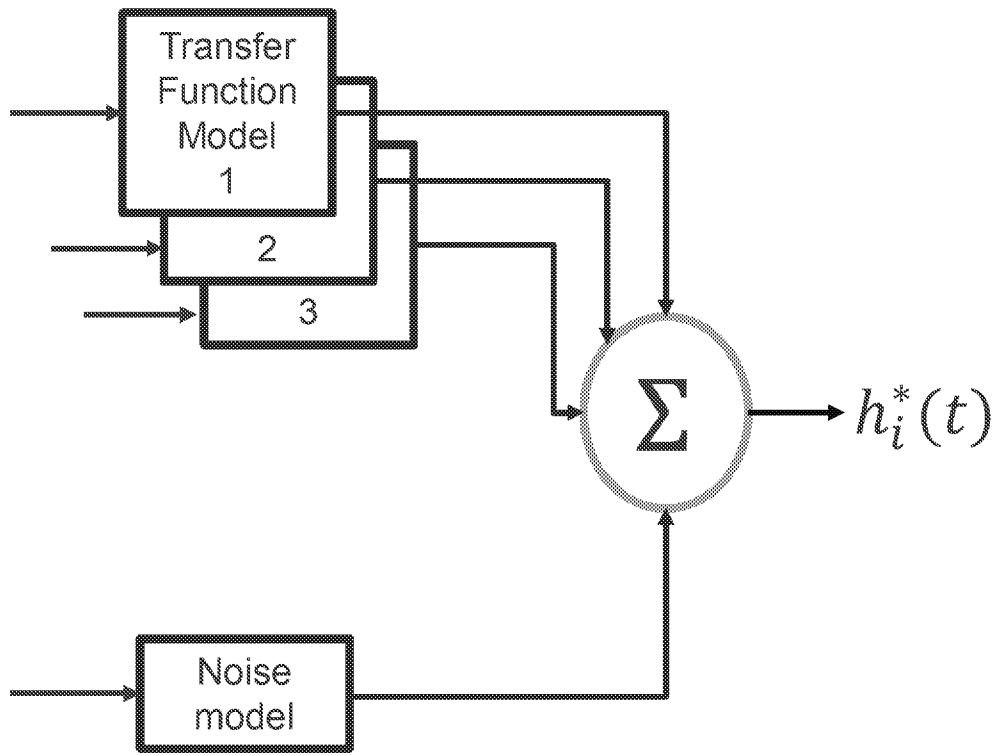
Relationship Between Impulse Response and Step Response Functions



ED_006532_00002904-00054

TFN Model with Multiple Input Sources

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

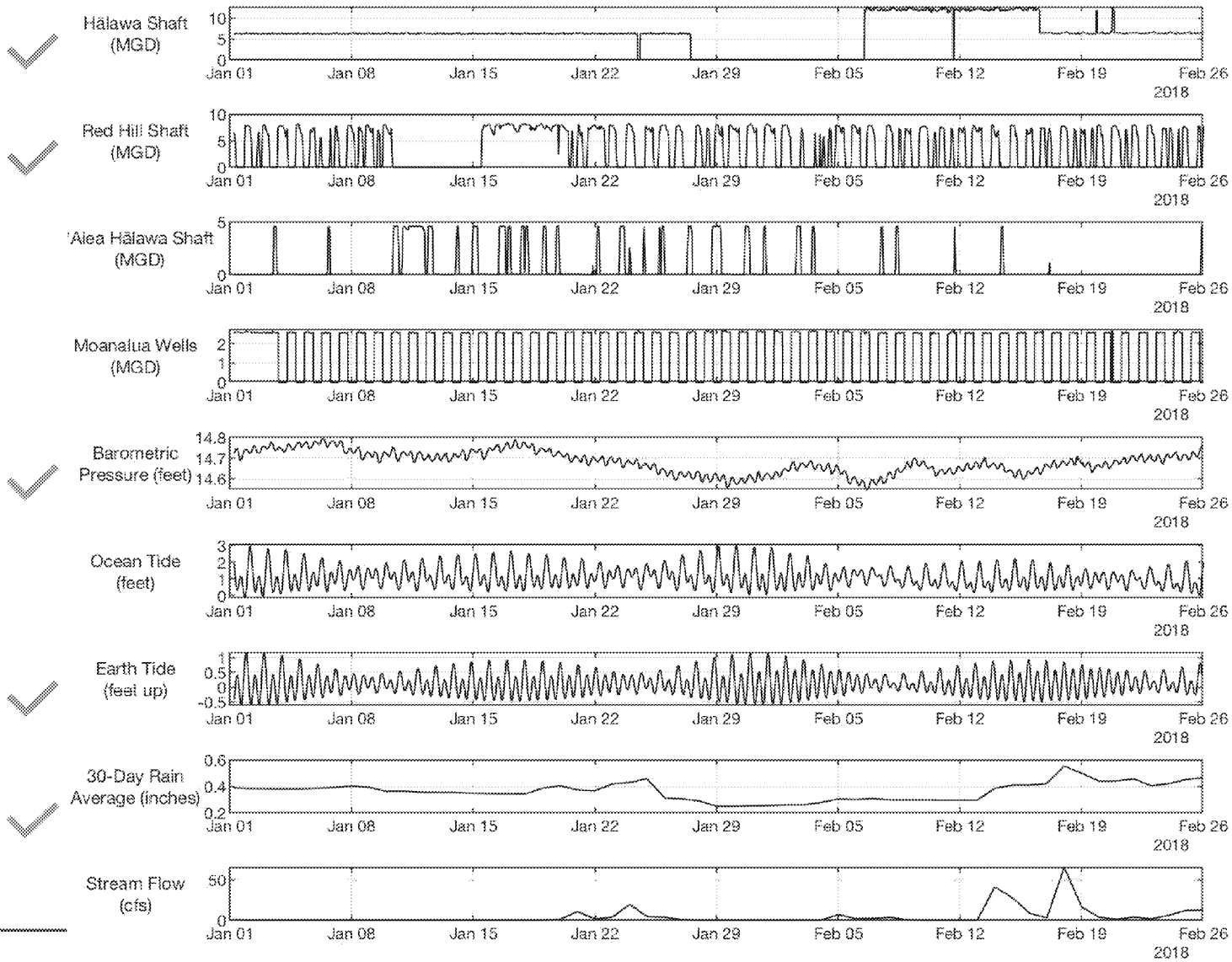


$$(y - \mu_y) = f(\boldsymbol{k}, \boldsymbol{x}, t) + N_t$$

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

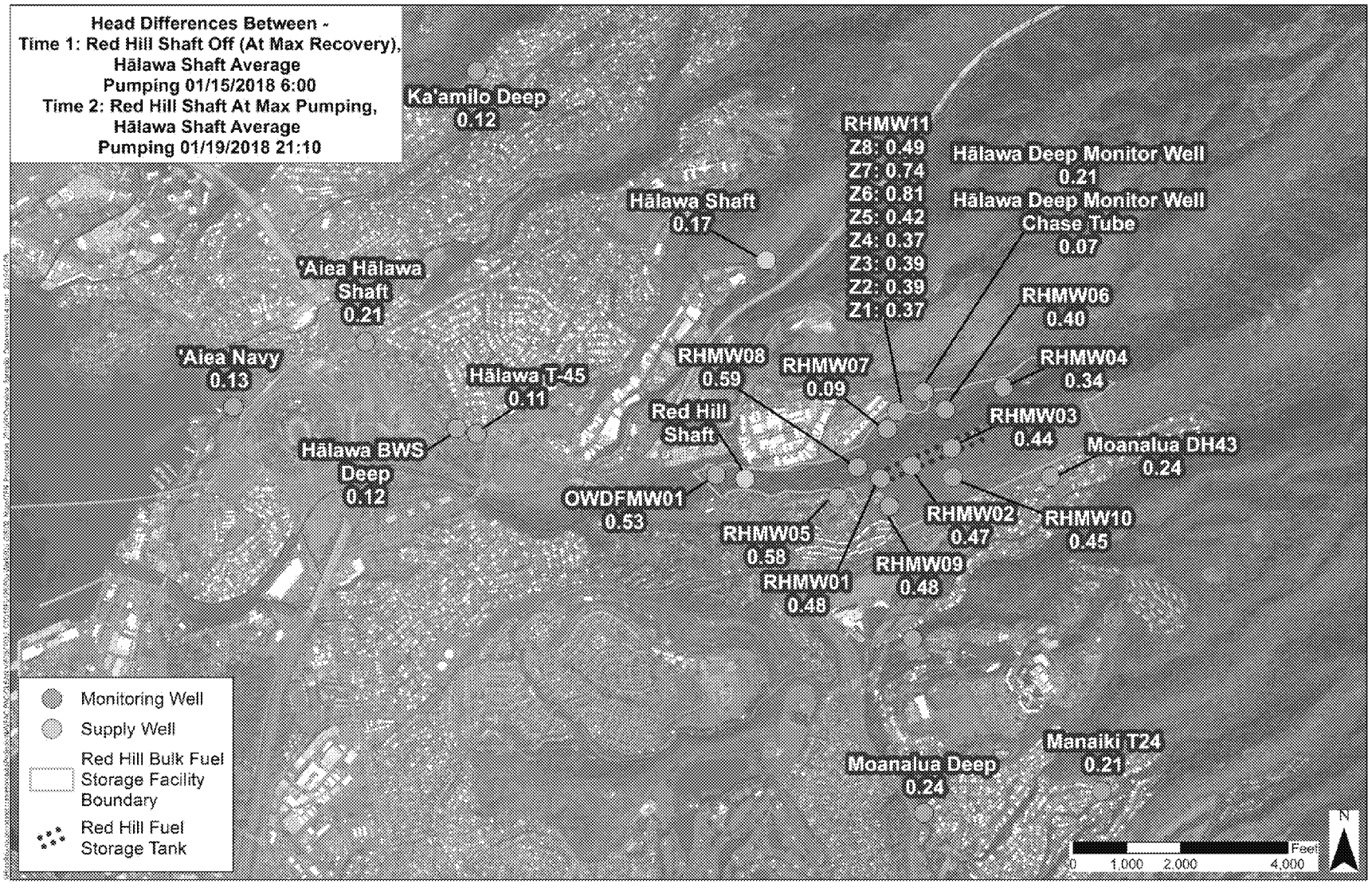
TFN Analysis:

Sources Included in TFN Analysis

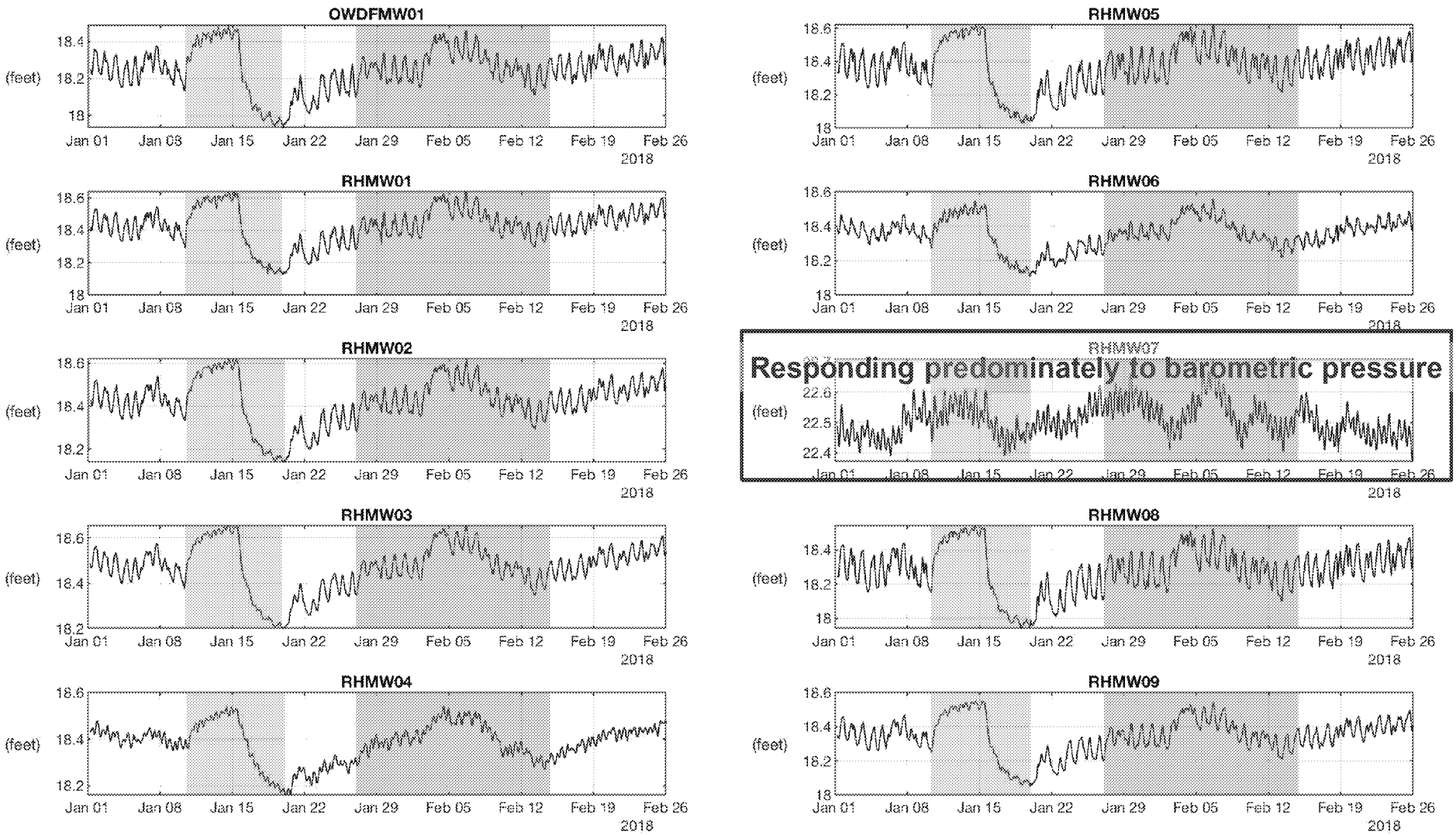


TFN Analysis:

Overview of Synoptic Data – Head Differences at Select Wells for Two Red Hill Shaft Stress Conditions



TFN Analysis:
Wells Responding to Red Hill Shaft Shutdown



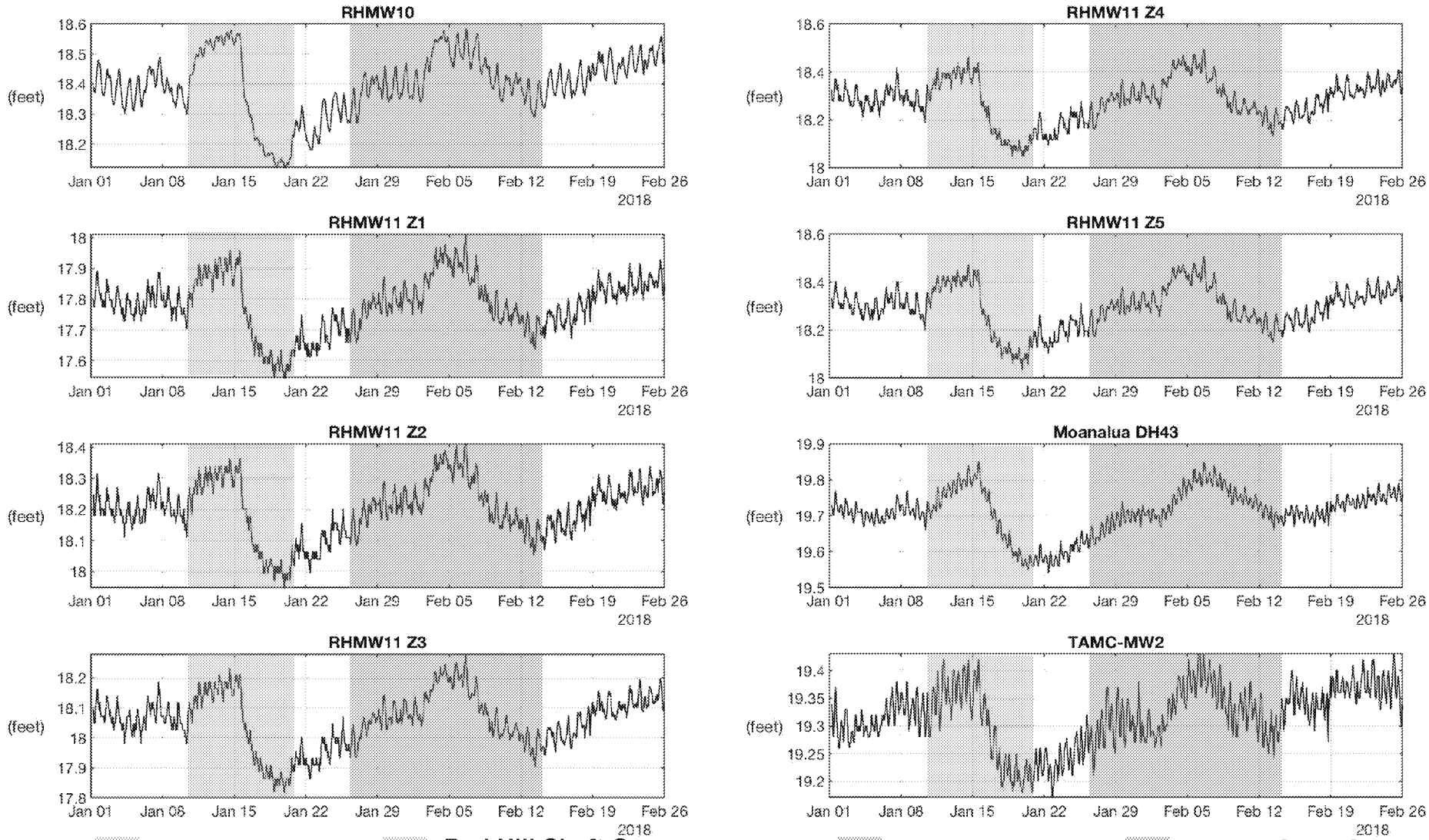
Red Hill Shaft Off

Red Hill Shaft On, Max Pumping

Halawa Shaft Off

Halawa Shaft On, Max Pumping

TFN Analysis:
Wells Responding to Red Hill Shaft Shutdown (cont.)



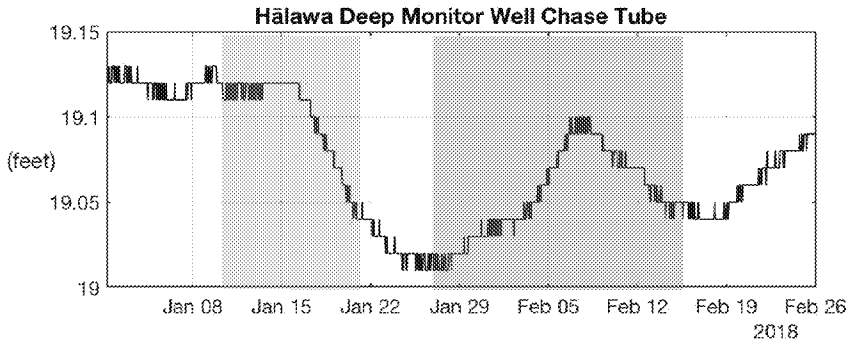
Red Hill Shaft Off

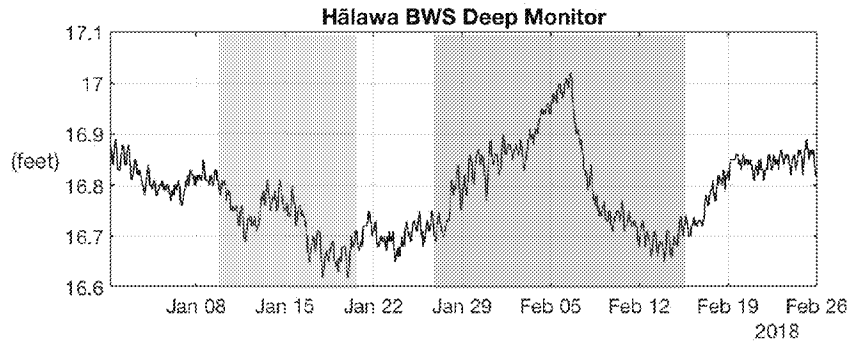
Red Hill Shaft On, Max Pumping

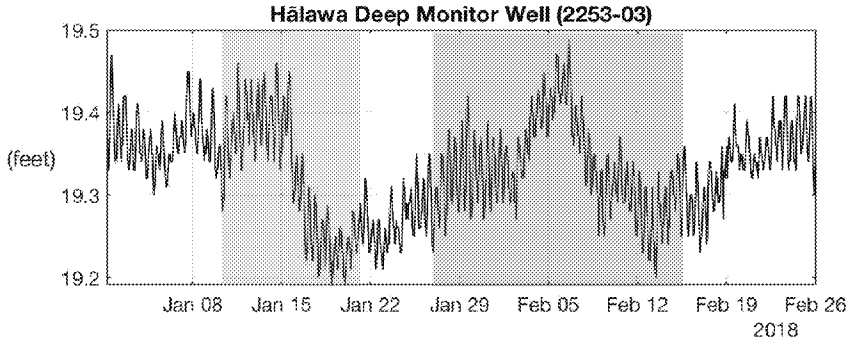
Halawa Shaft Off

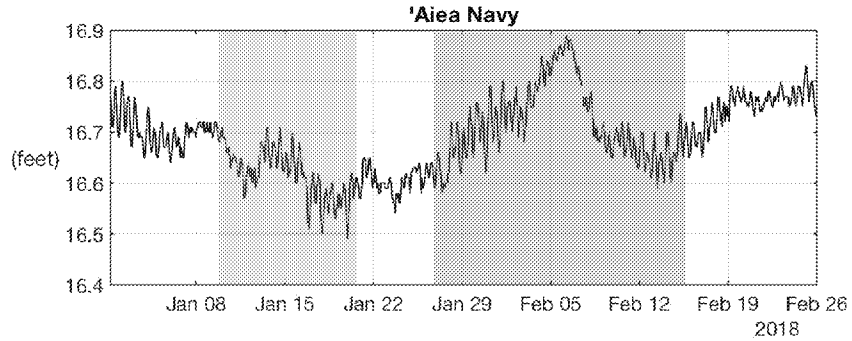
Halawa Shaft On, Max Pumping

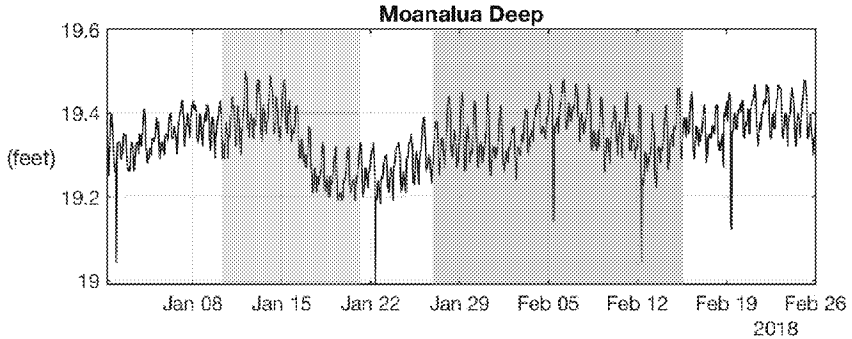
TFN Analysis:
Wells Not Responding to Red Hill Shaft Shutdown

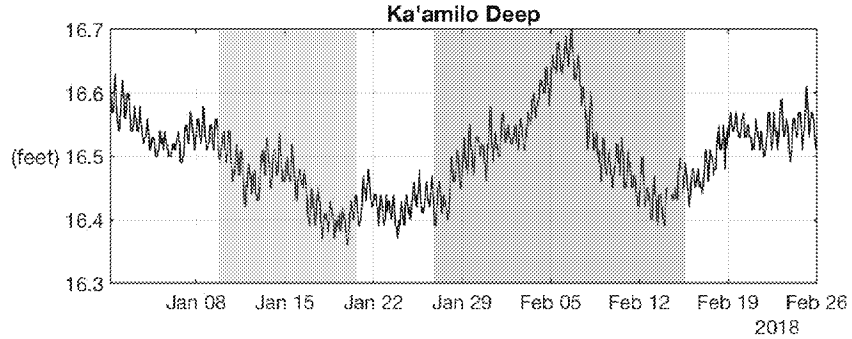








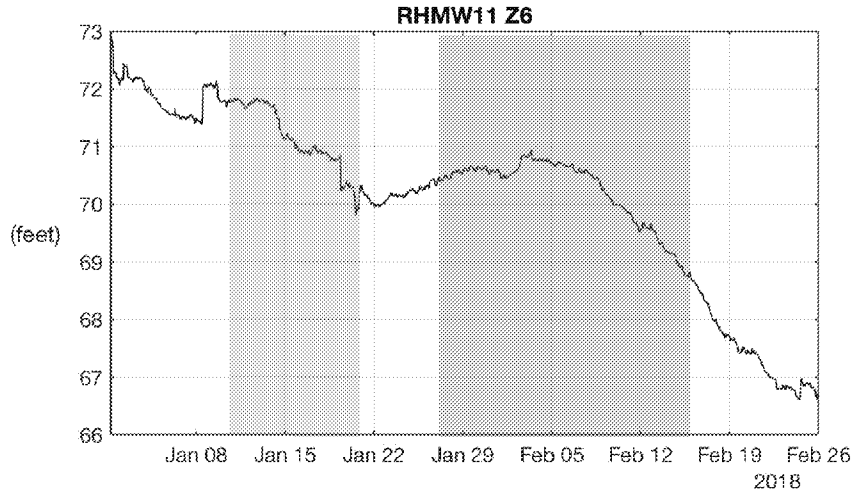


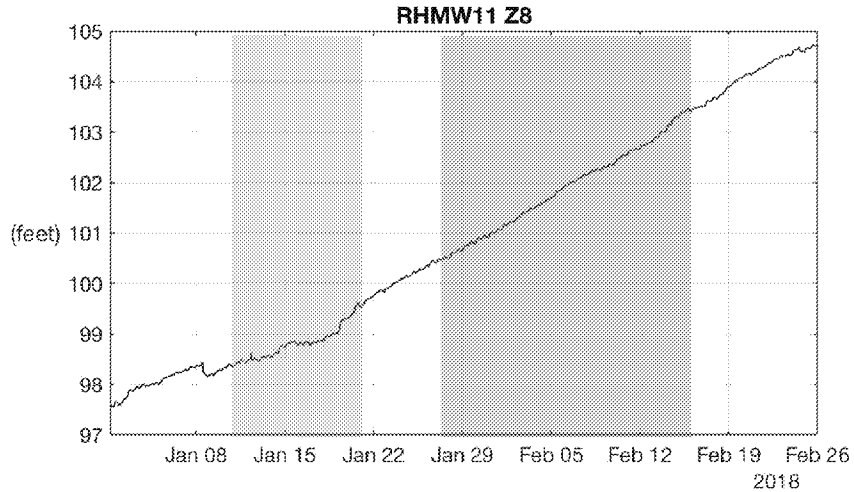


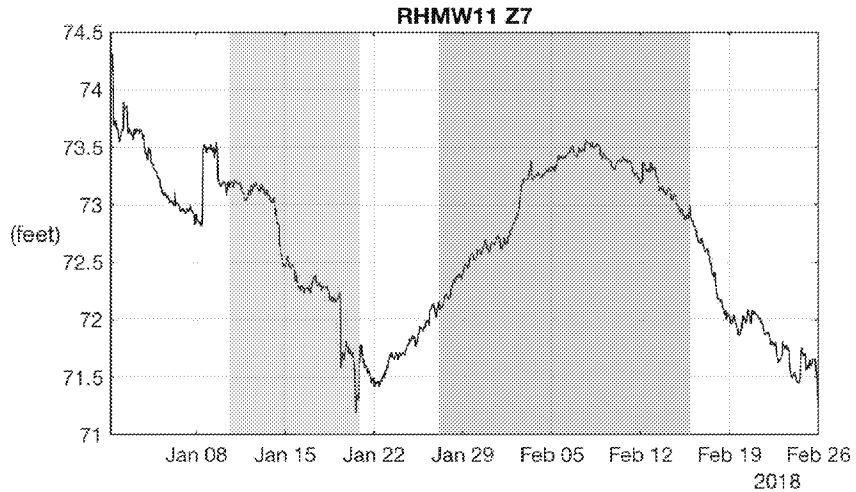
Red Hill Shaft Off | **Red Hill Shaft On, Max Pumping** | **Halawa Shaft Off** | **Halawa Shaft On, Max Pumping**

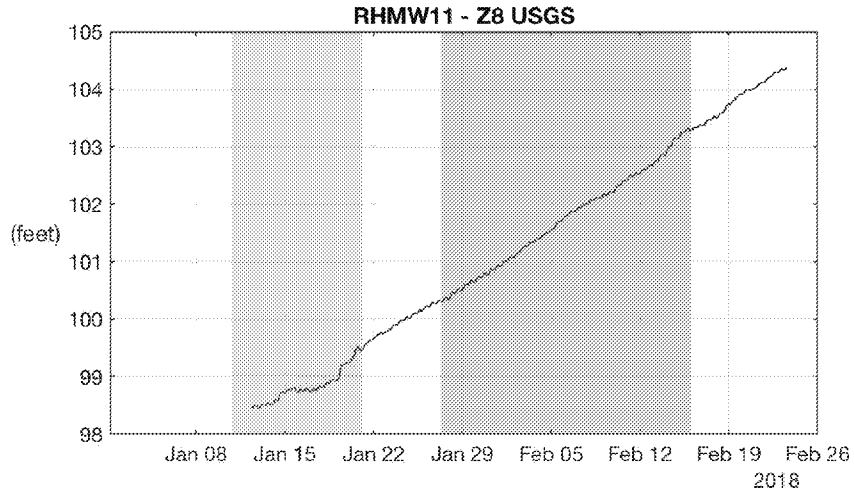
TFN Analysis:

Wells Not Responding to Red Hill Shaft Shutdown (cont.)



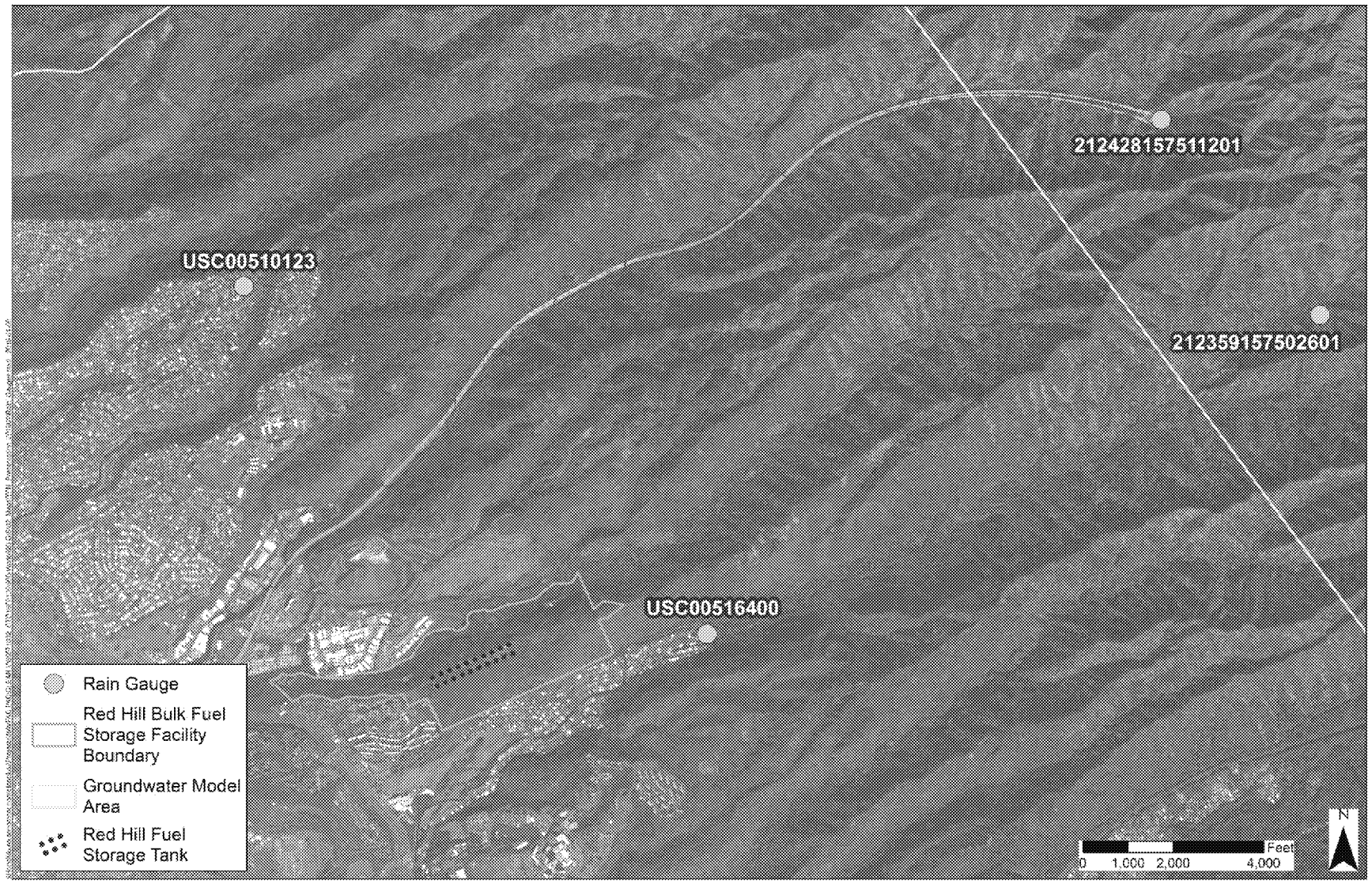




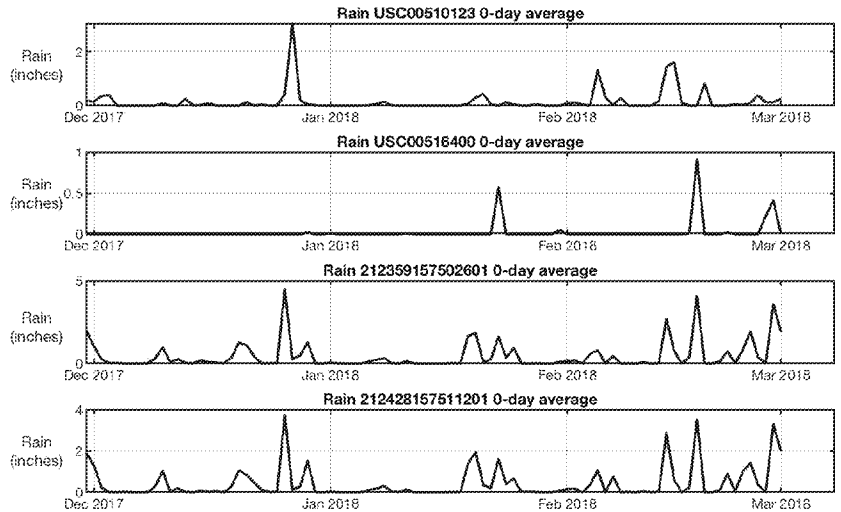


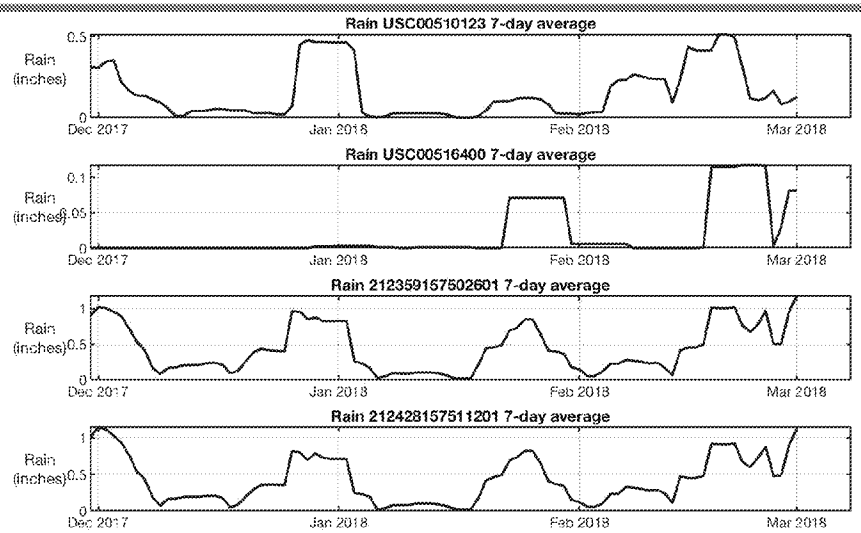
Red Hill Shaft Off | **Red Hill Shaft On, Max Pumping** | **Halawa Shaft Off** | **Halawa Shaft On, Max Pumping**

TFN Analysis:
Location of Rain Gauges

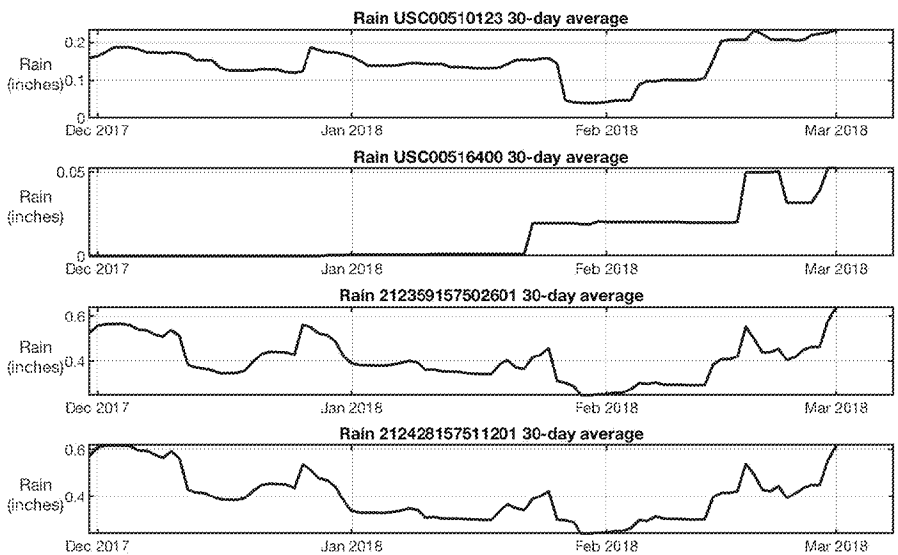


TFN Analysis:
Rainfall Data Coherency





- **Water level does not respond to daily and 7-day-average rainfall**
- **30-day averaging shows higher coherency**



ED_006532_00002904-00063

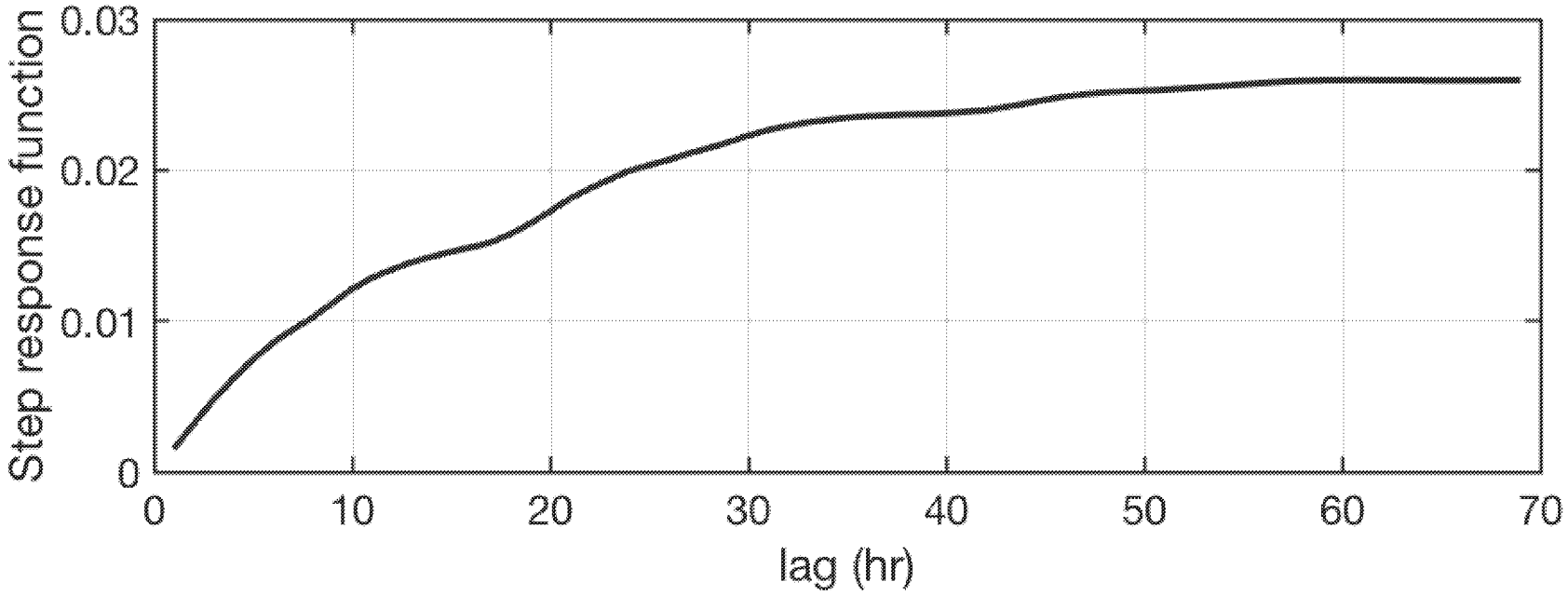
Implementation of TFN Analysis

- 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

ED_006532_00002904-00064

TFN Analysis:

Example Empirical Step Function Response

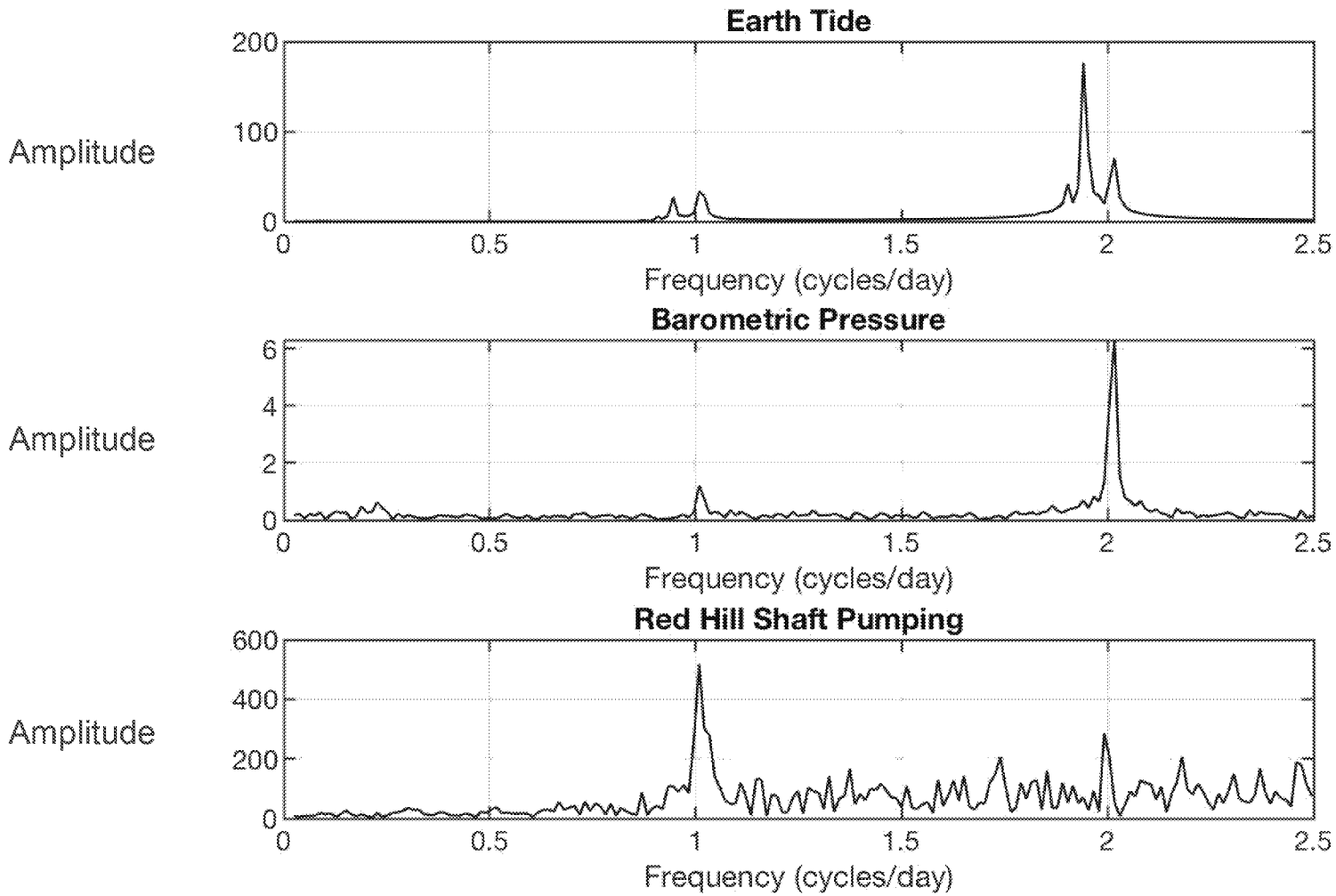


Resembles Hantush leaky aquifer solution

ED_006532_00002904-00065

TFN Analysis:

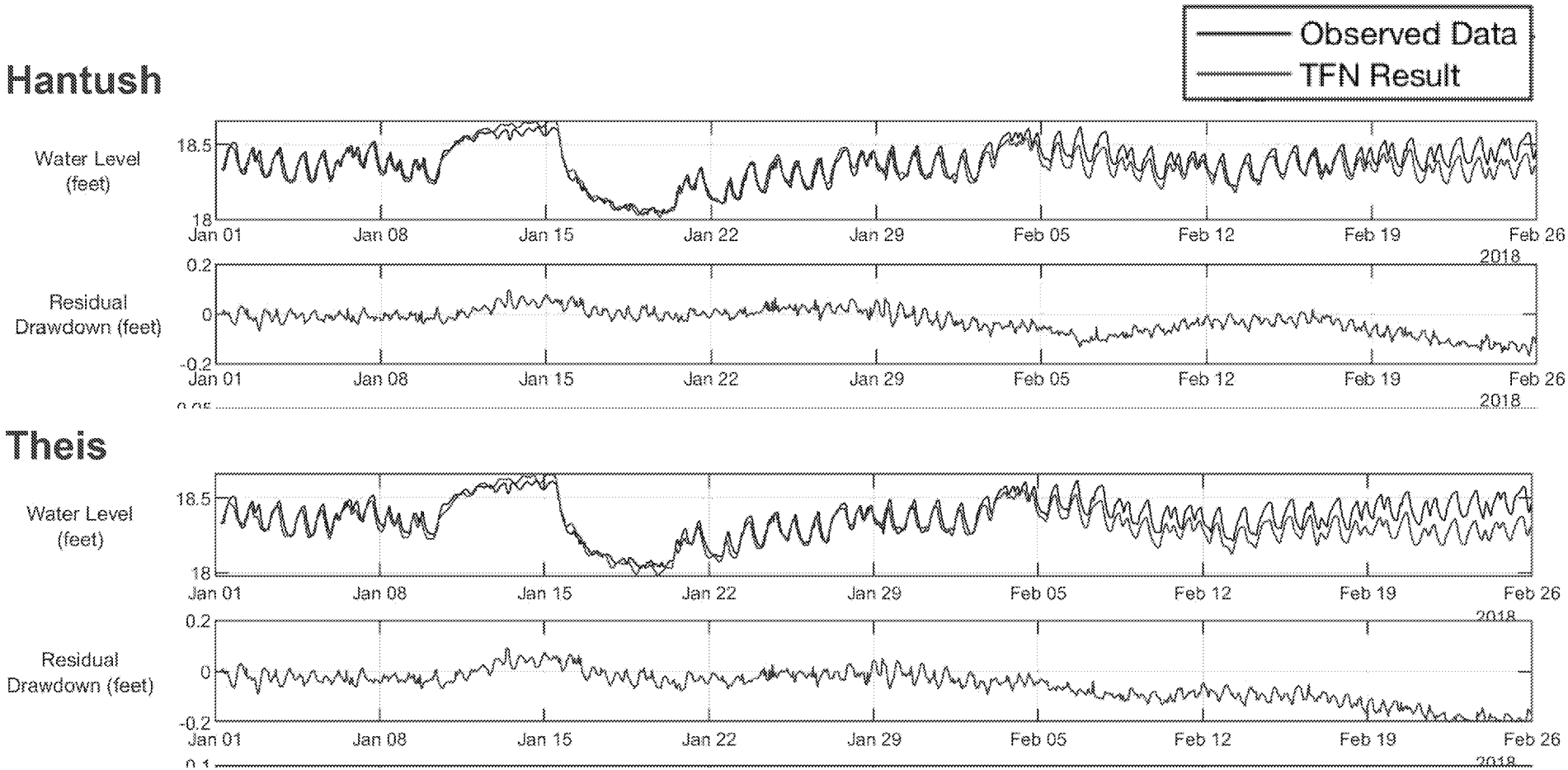
Spectral Characteristics of Earth Tide, Barometric Pressure, and Red Hill Shaft Pumping Rate



ED_006532_00002904-00066

TFN Analysis:

Hantush vs. Theis Step Response Functions



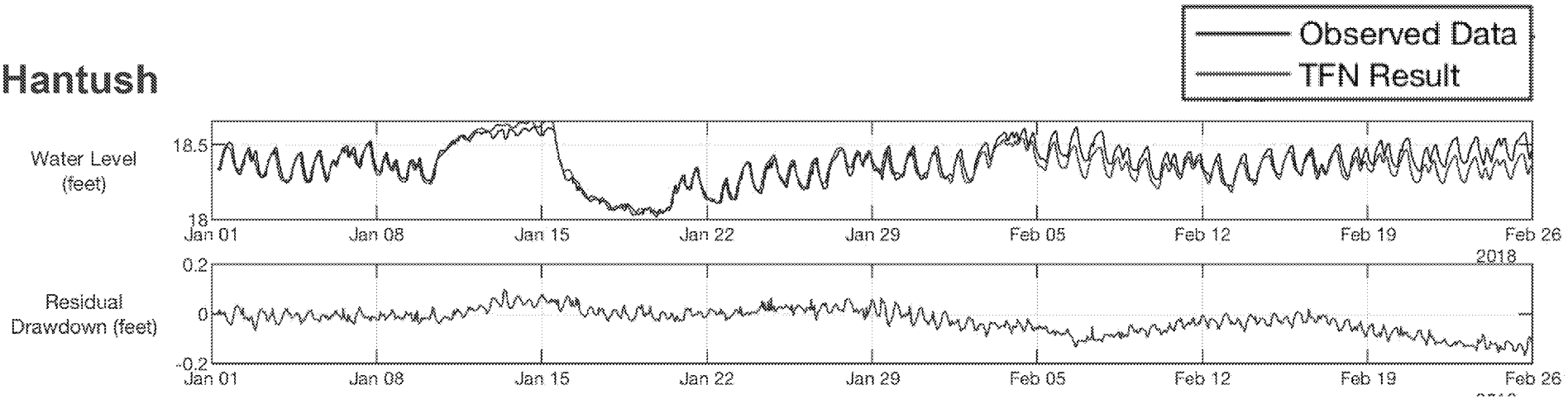
Using Hantush step response function results in slightly better matching than Theis

ED_006532_00002904-00067

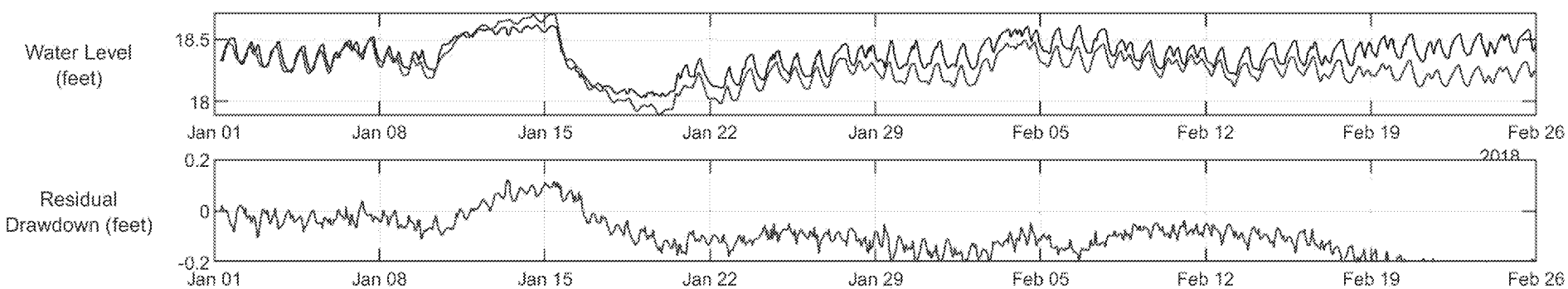
TFN Analysis:

Hantush vs.Ttim Step Response Functions

Hantush



Ttim



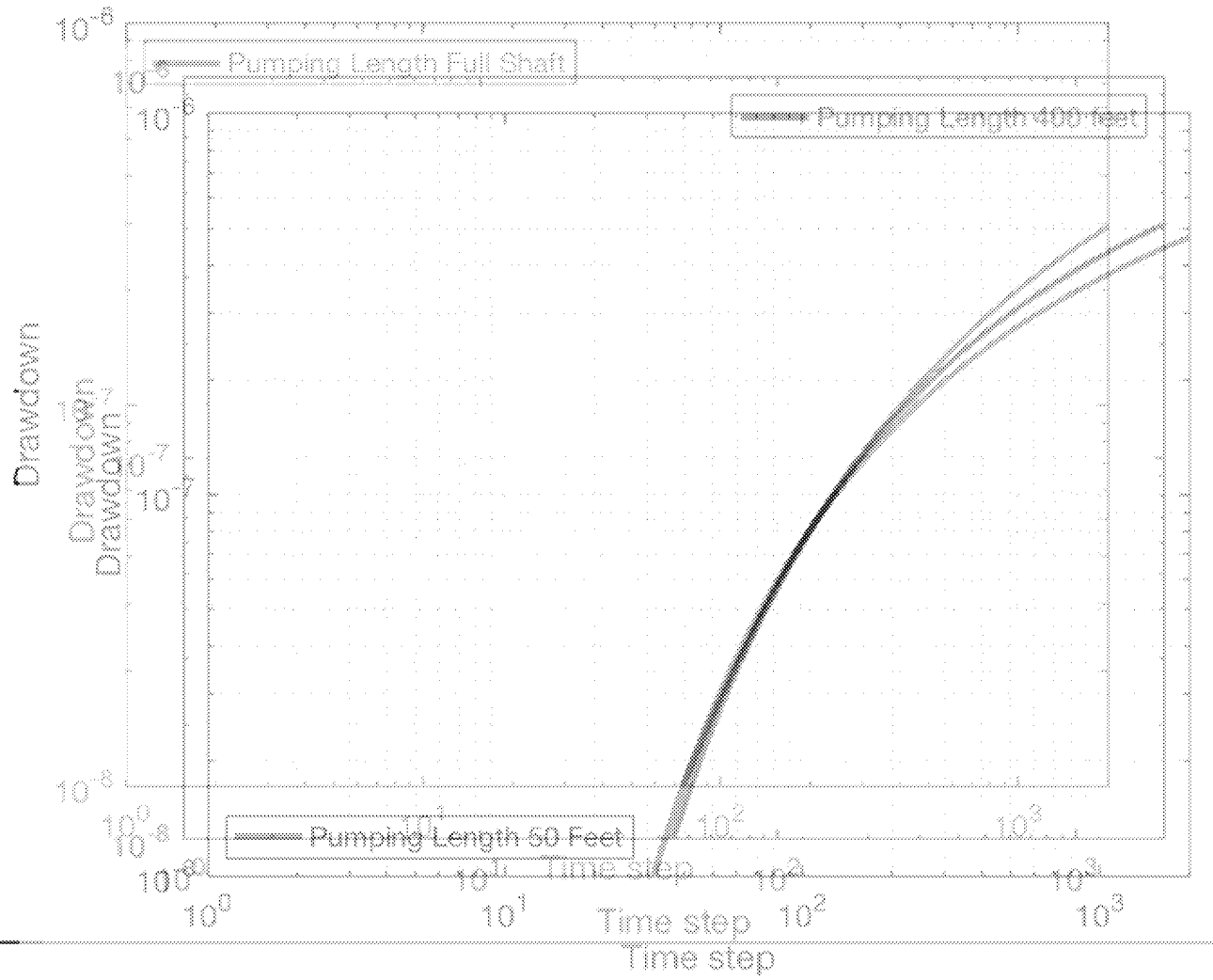
Using Hantush step response function results in better matching than Ttim

ED_006532_00002904-00068

TFN Analysis:

Variation of Ttim Step Response Functions

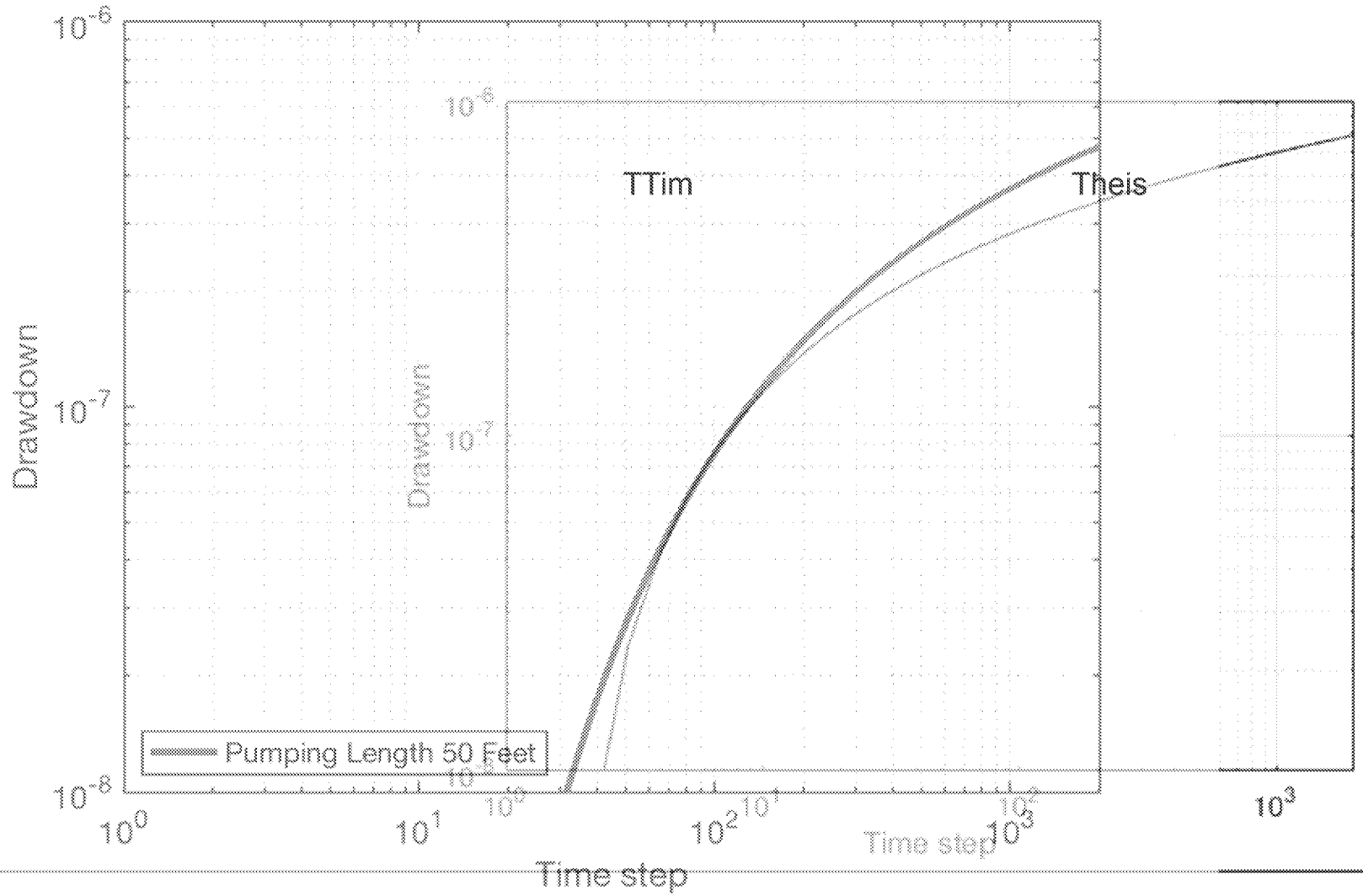
Drawdown curvature as a function of shaft pumping length



TFN Analysis:

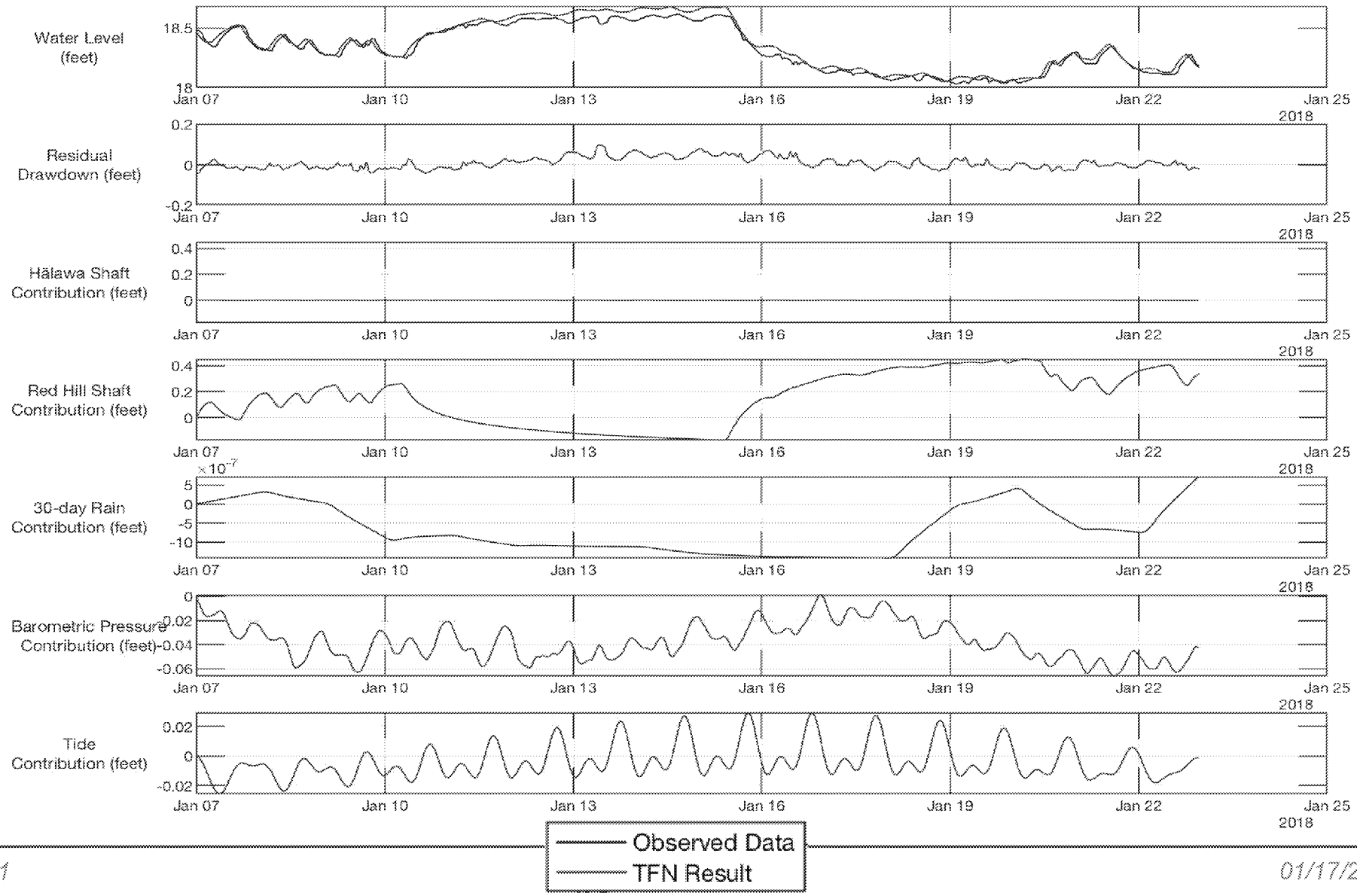
Comparison of Ttim and Theis Step Response Functions

Ttim step response function shows less abrupt curvature than Theis



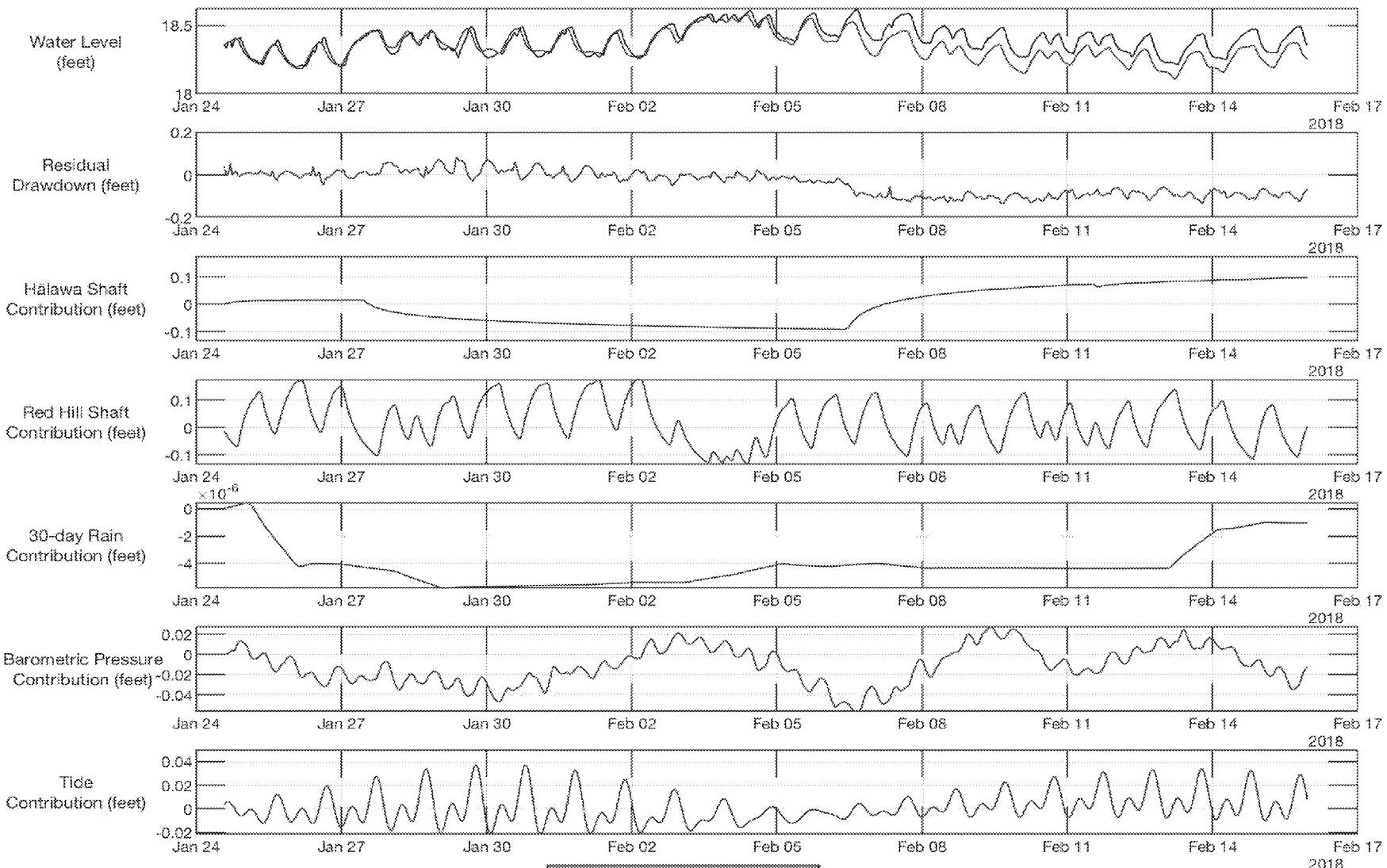
TFN Analysis:

Results for RHMW05 – Red Hill Shaft Shutdown & Restart



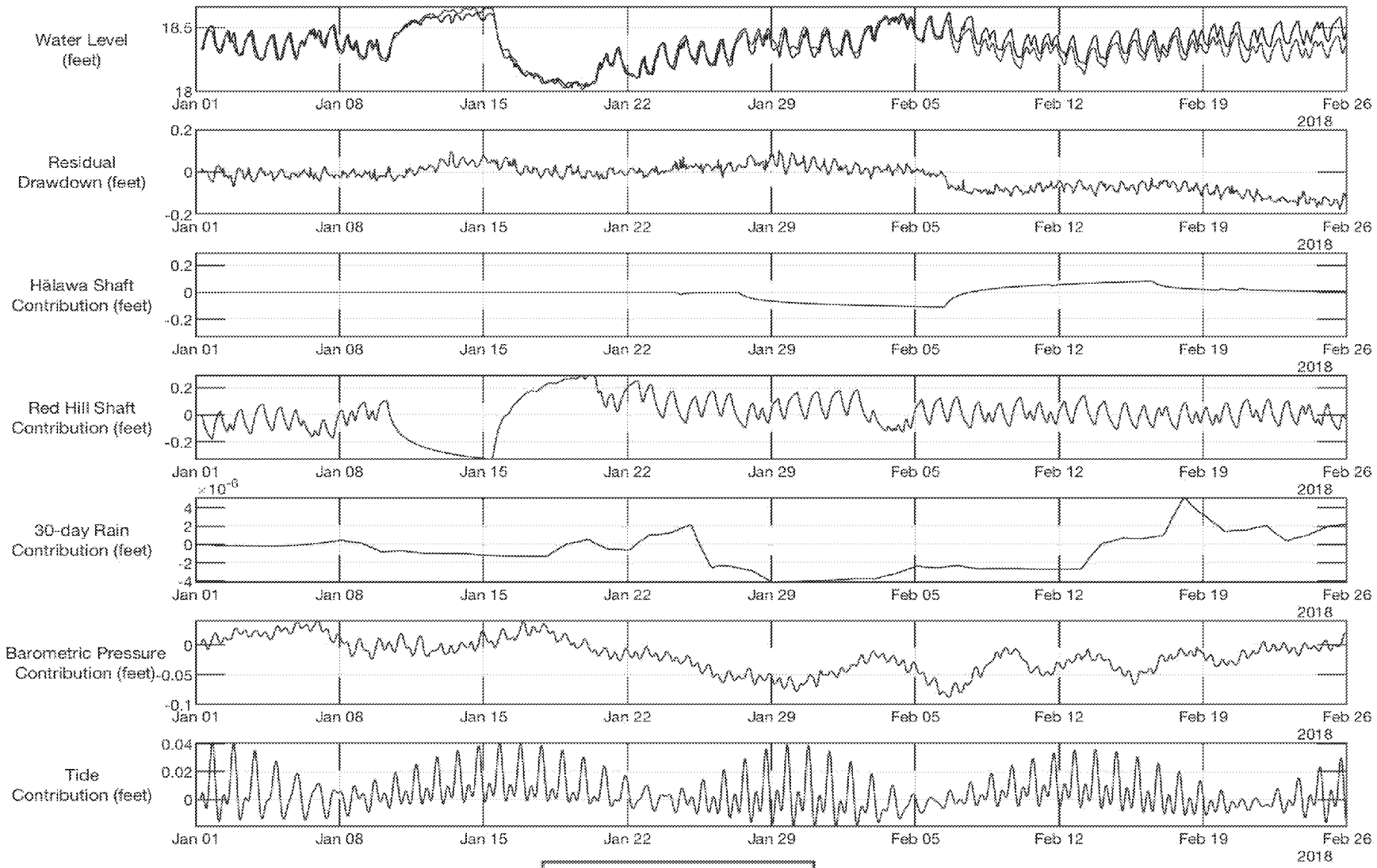
TFN Analysis:

Results for RHMW05 – Halawa Shaft Shutdown & Restart



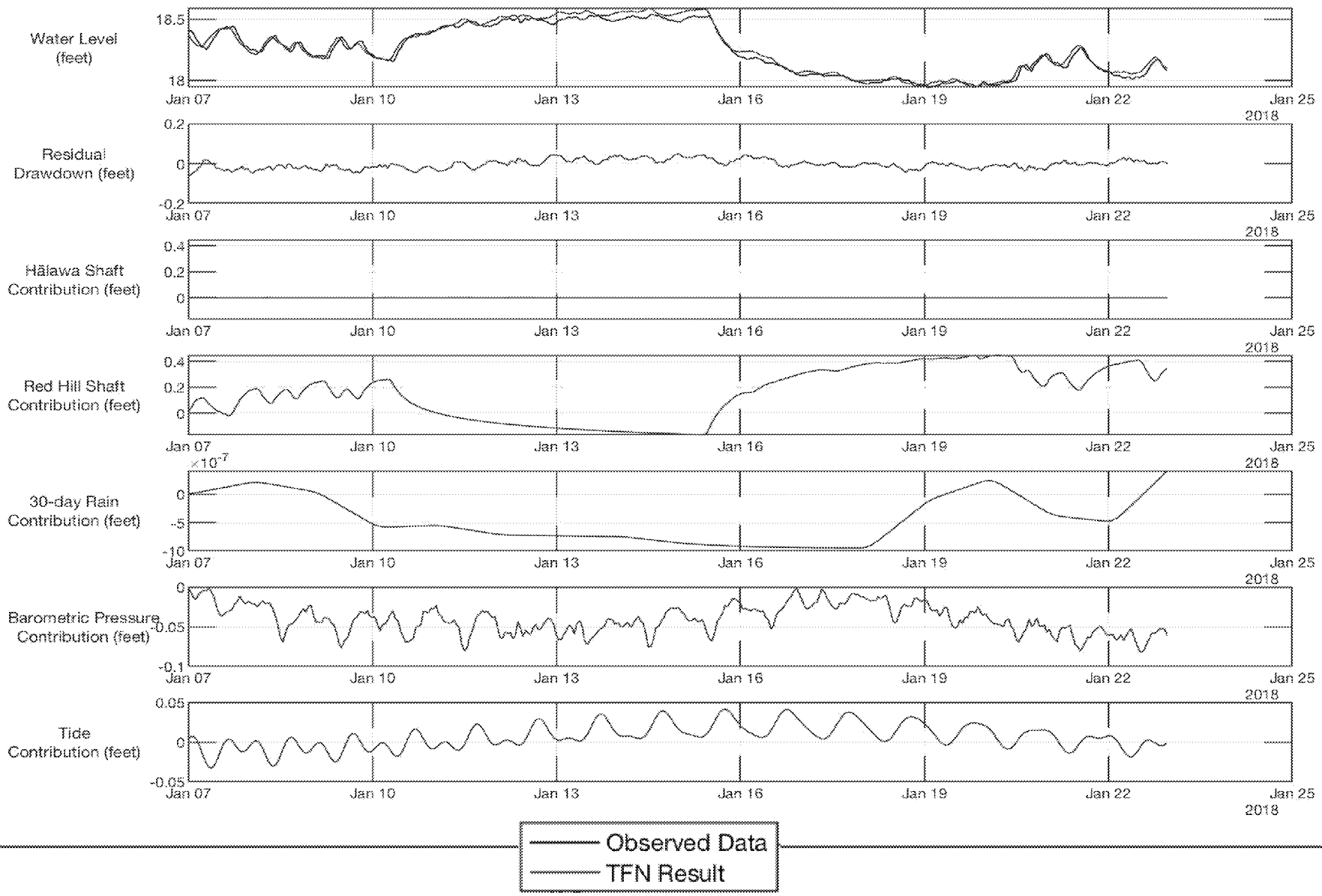
TFN Analysis:

Results for RHMW05 – Synoptic Data Period



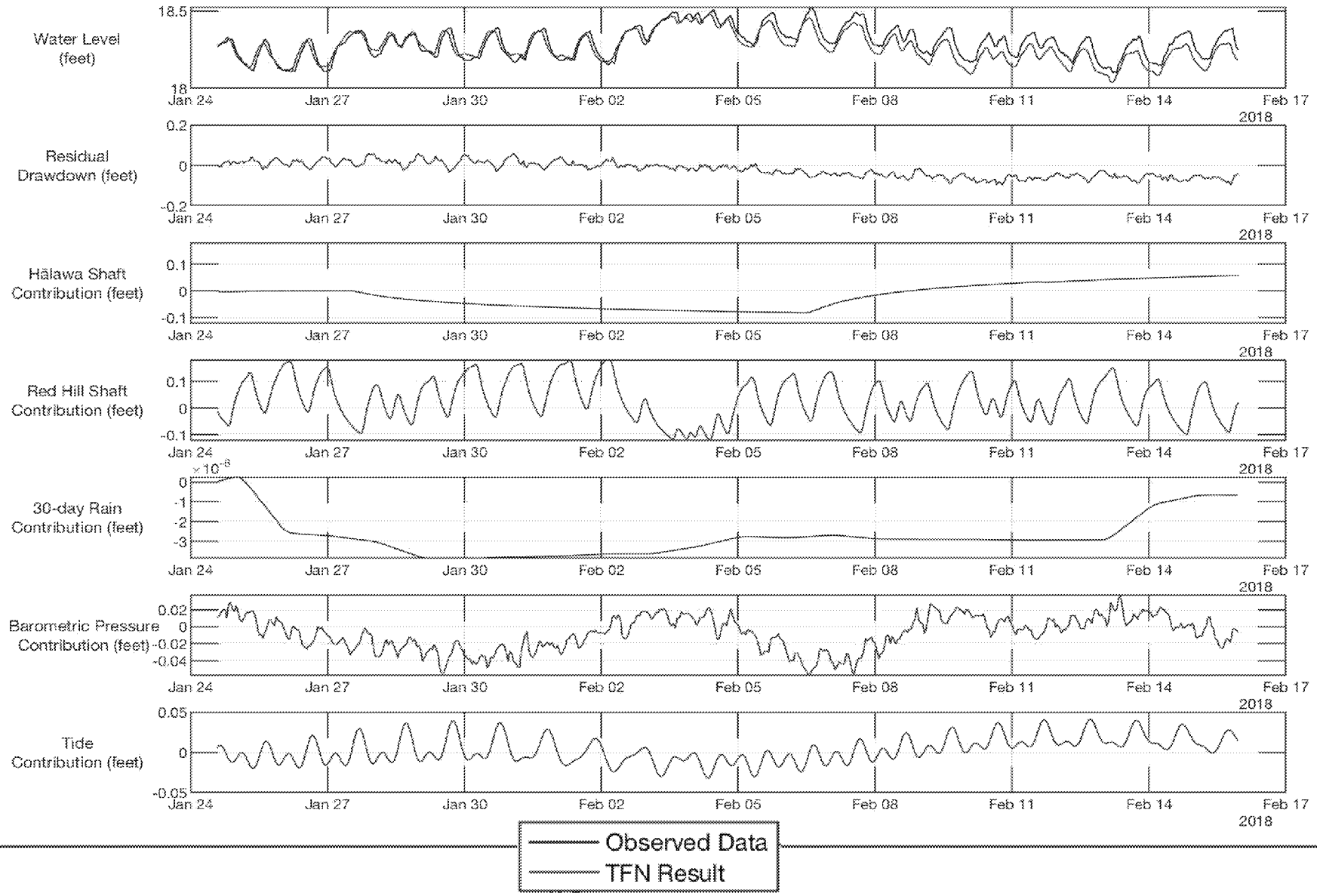
TFN Analysis:

Results for RHMW08 – Red Hill Shaft Shutdown & Restart



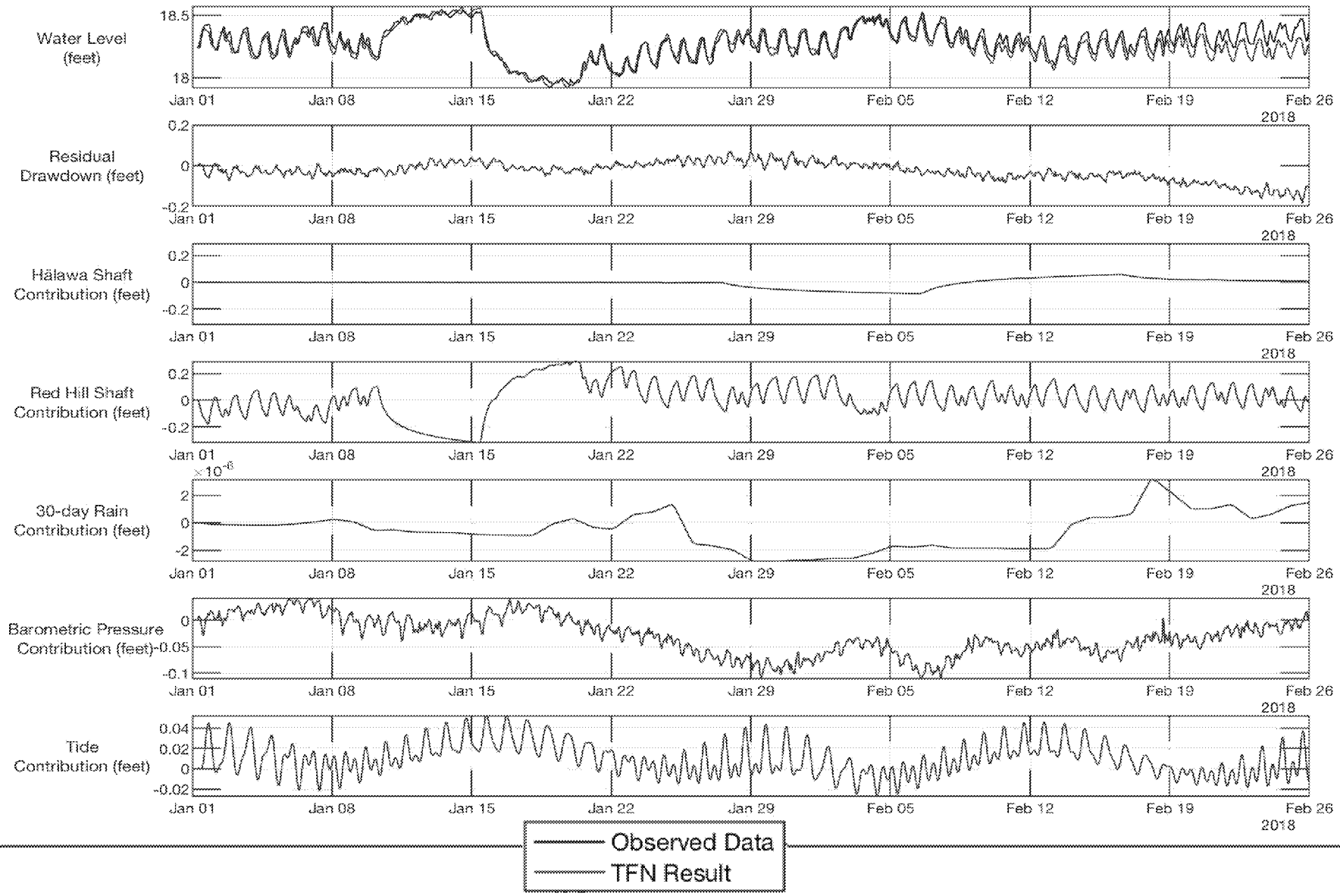
TFN Analysis:

Results for RHMW08 – Halawa Shaft Shutdown & Restart



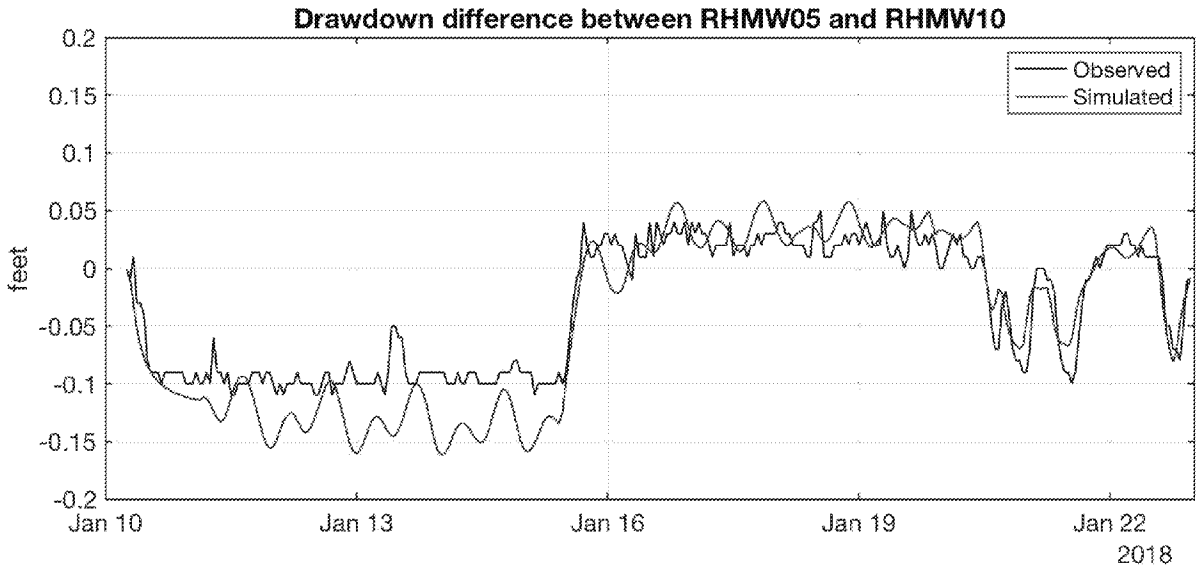
TFN Analysis:

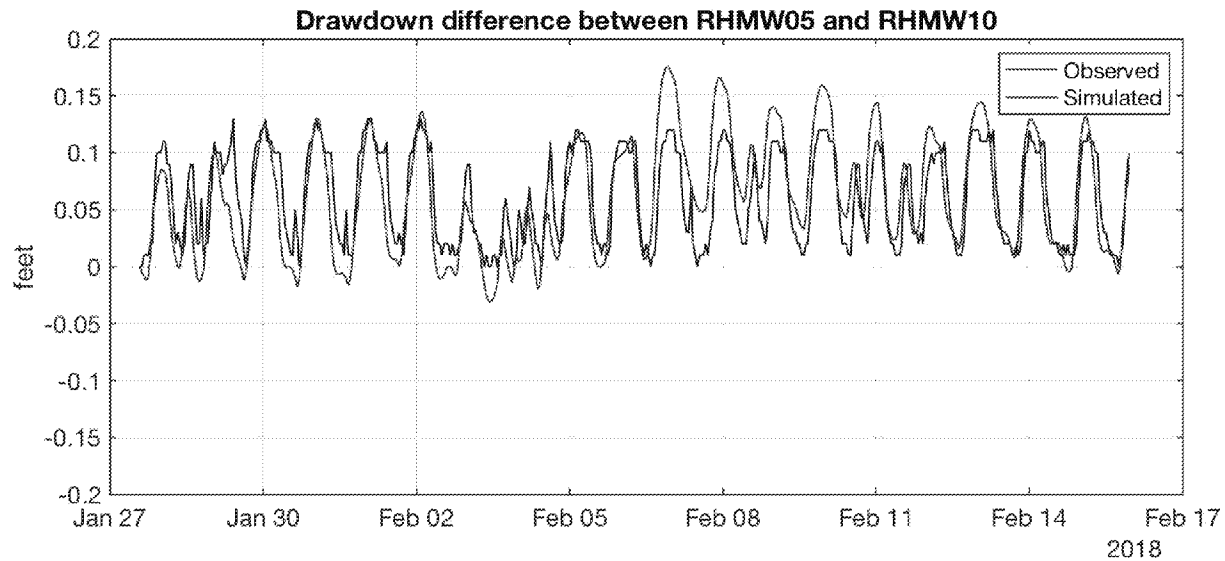
Results for RHMW08 – Synoptic Data Period



TFN Analysis:

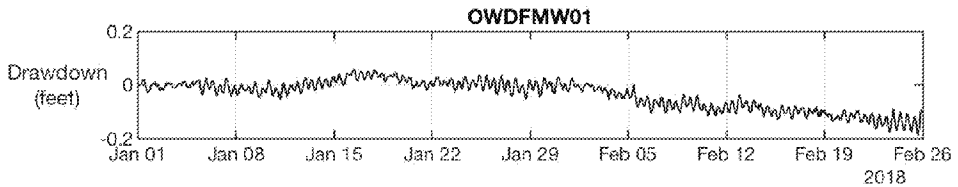
Differential Head Time Series between RHMW05 and RHMW10

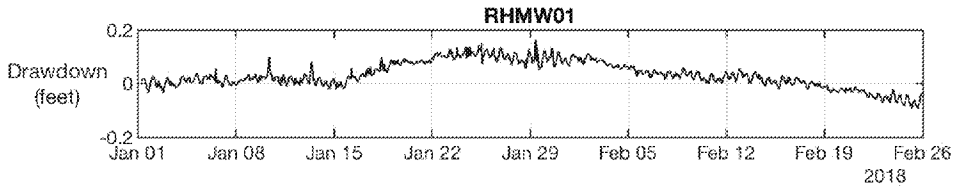


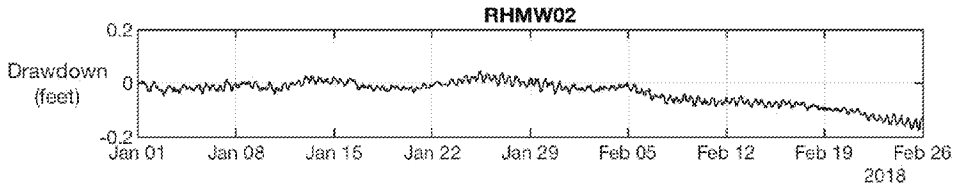


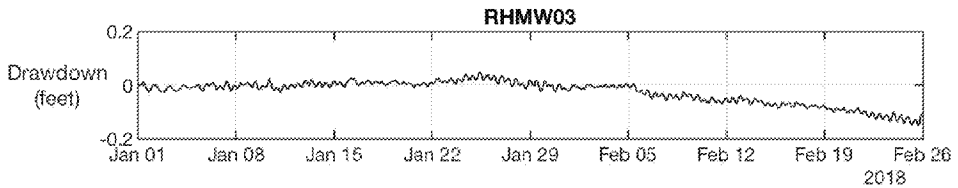
ED_006532_00002904-00077

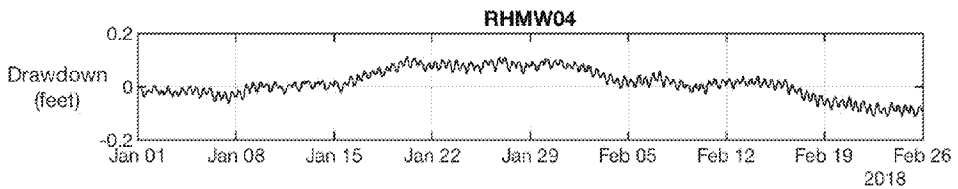
TFN Analysis:
Residuals

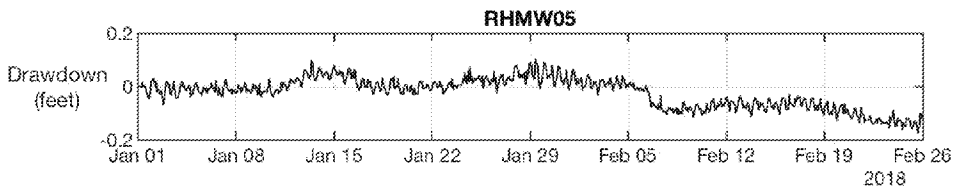


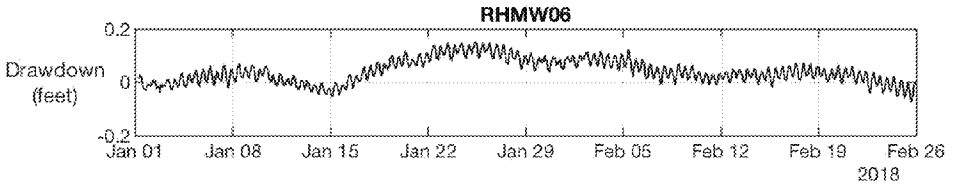


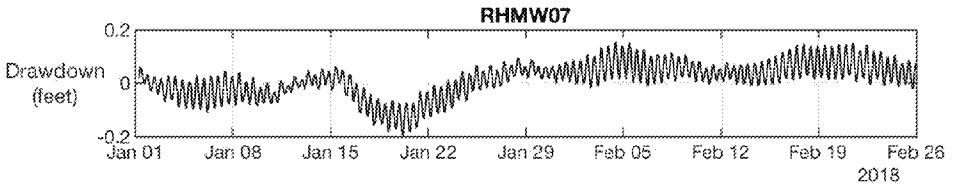


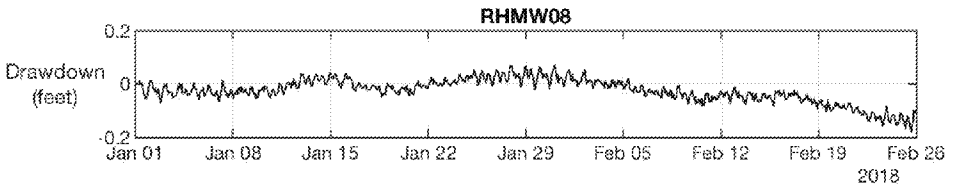


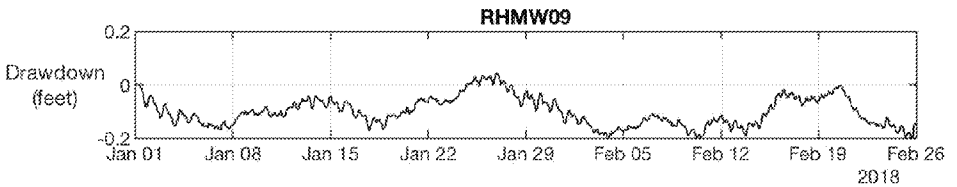


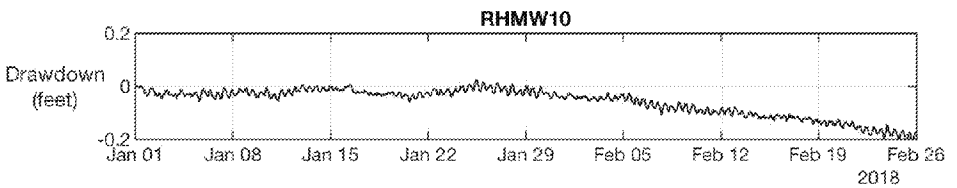


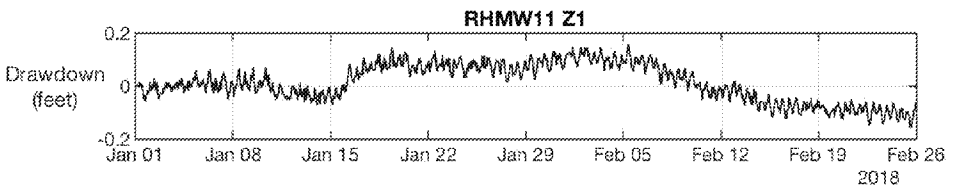




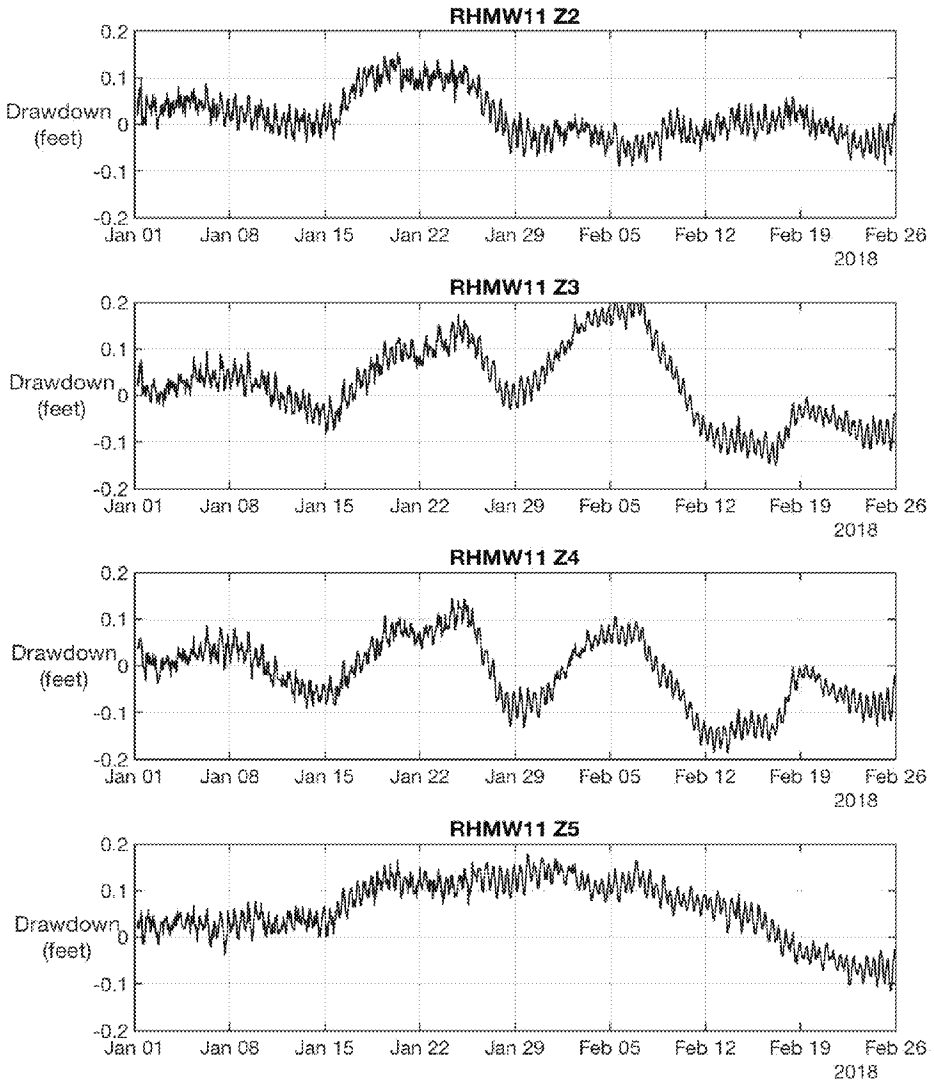








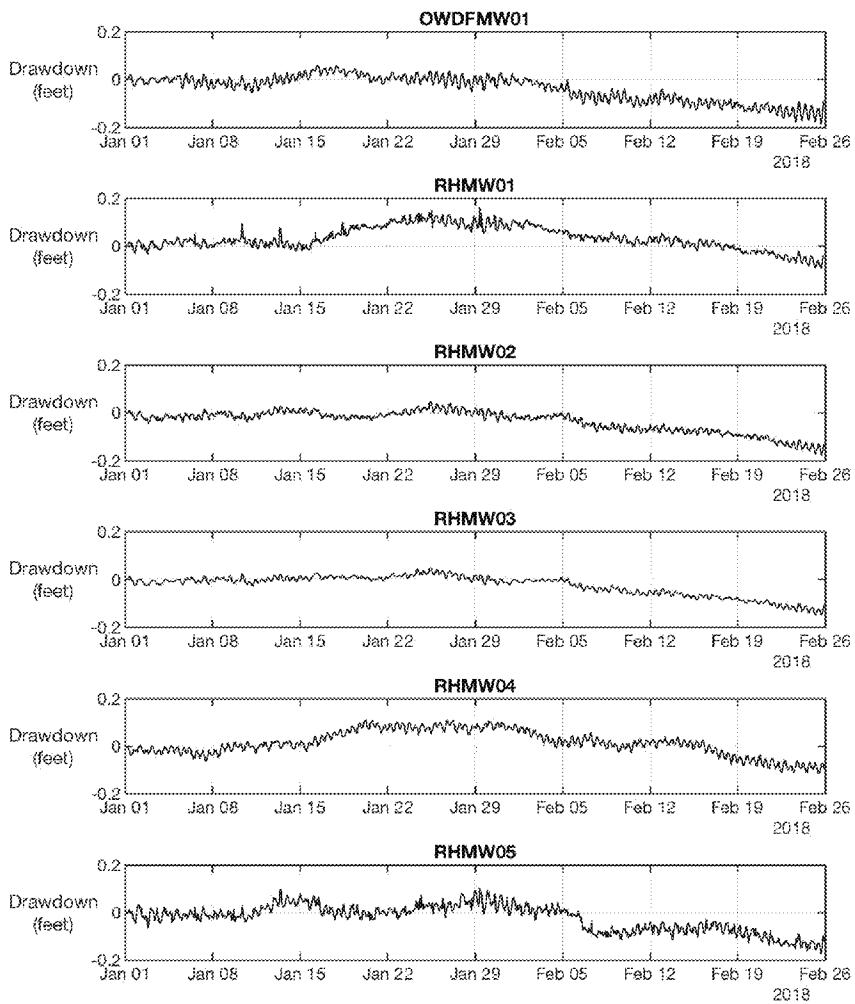
TFN Analysis:
Residuals (cont.)

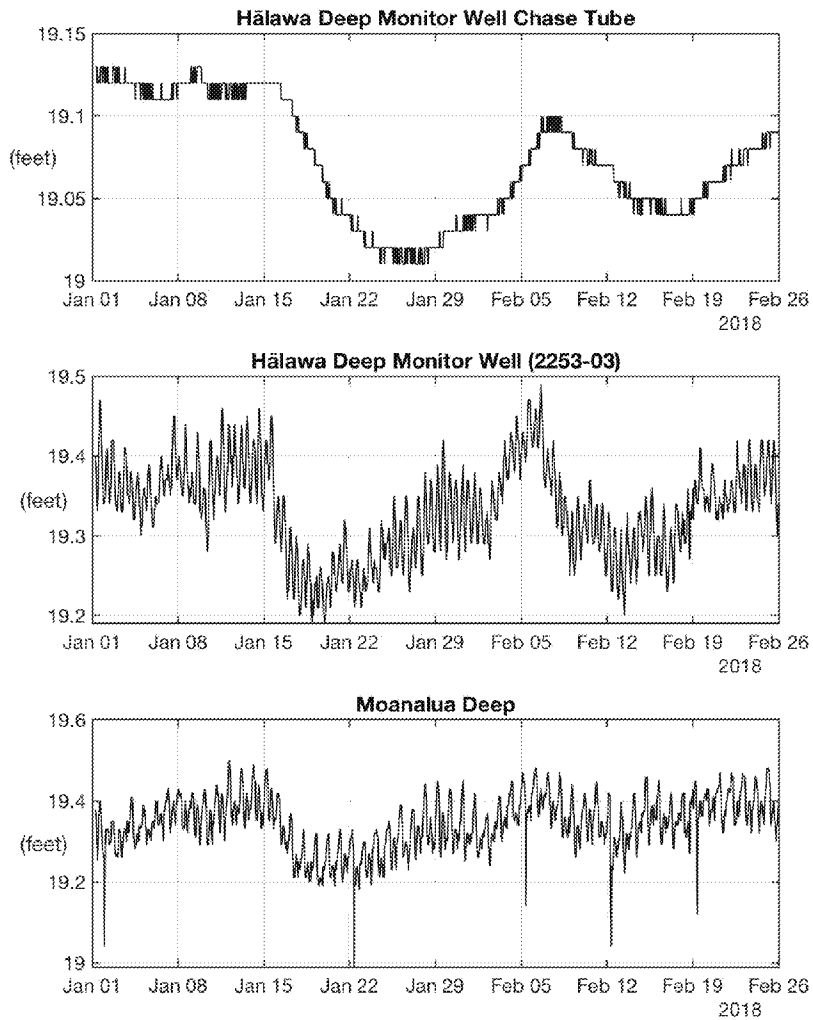


ED_006532_00002904-00079

TFN Analysis:

Slight Resemblance of Residuals with Deep Well Time Series





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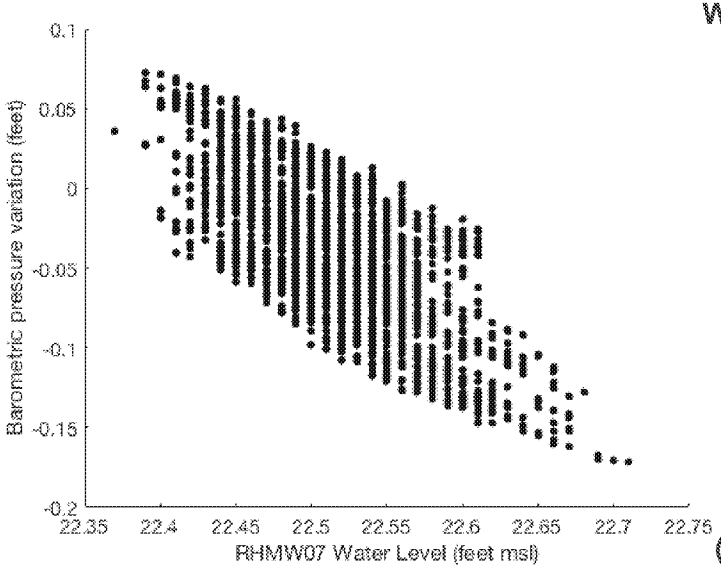
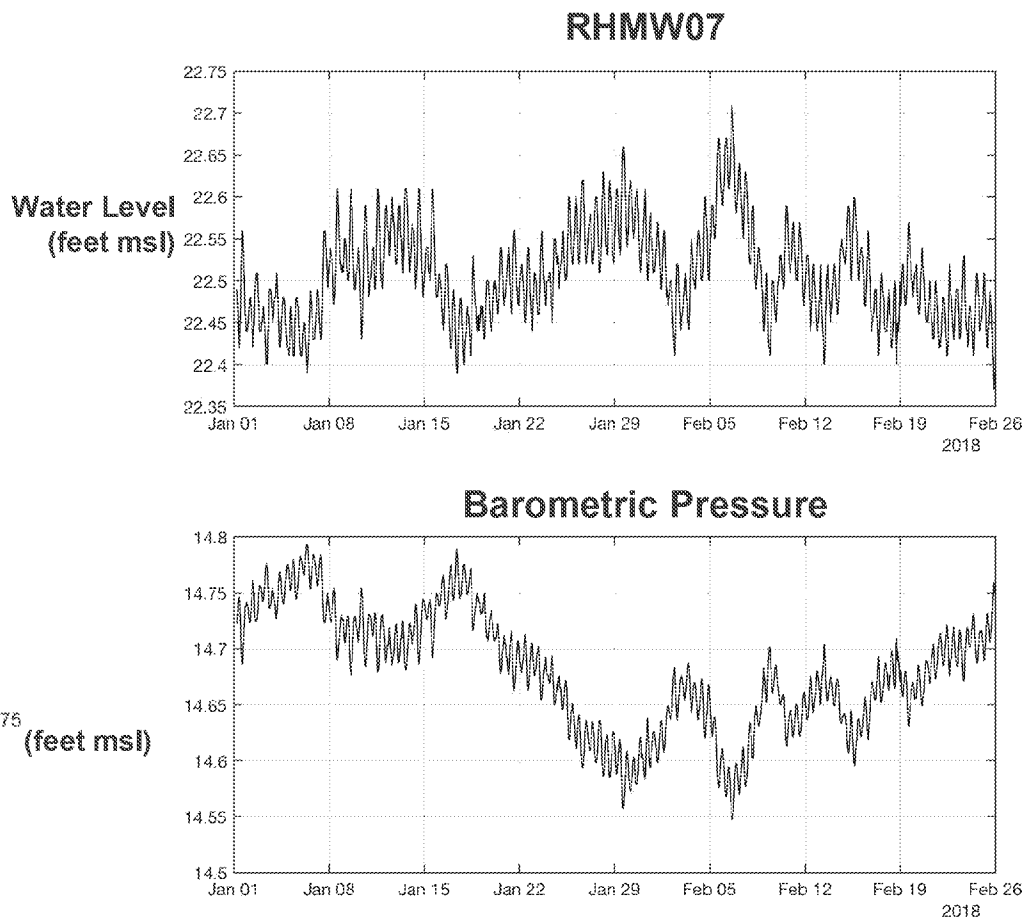
TFN Analysis:

Strong Correlation of RHMW07 and Barometric Pressure Variation





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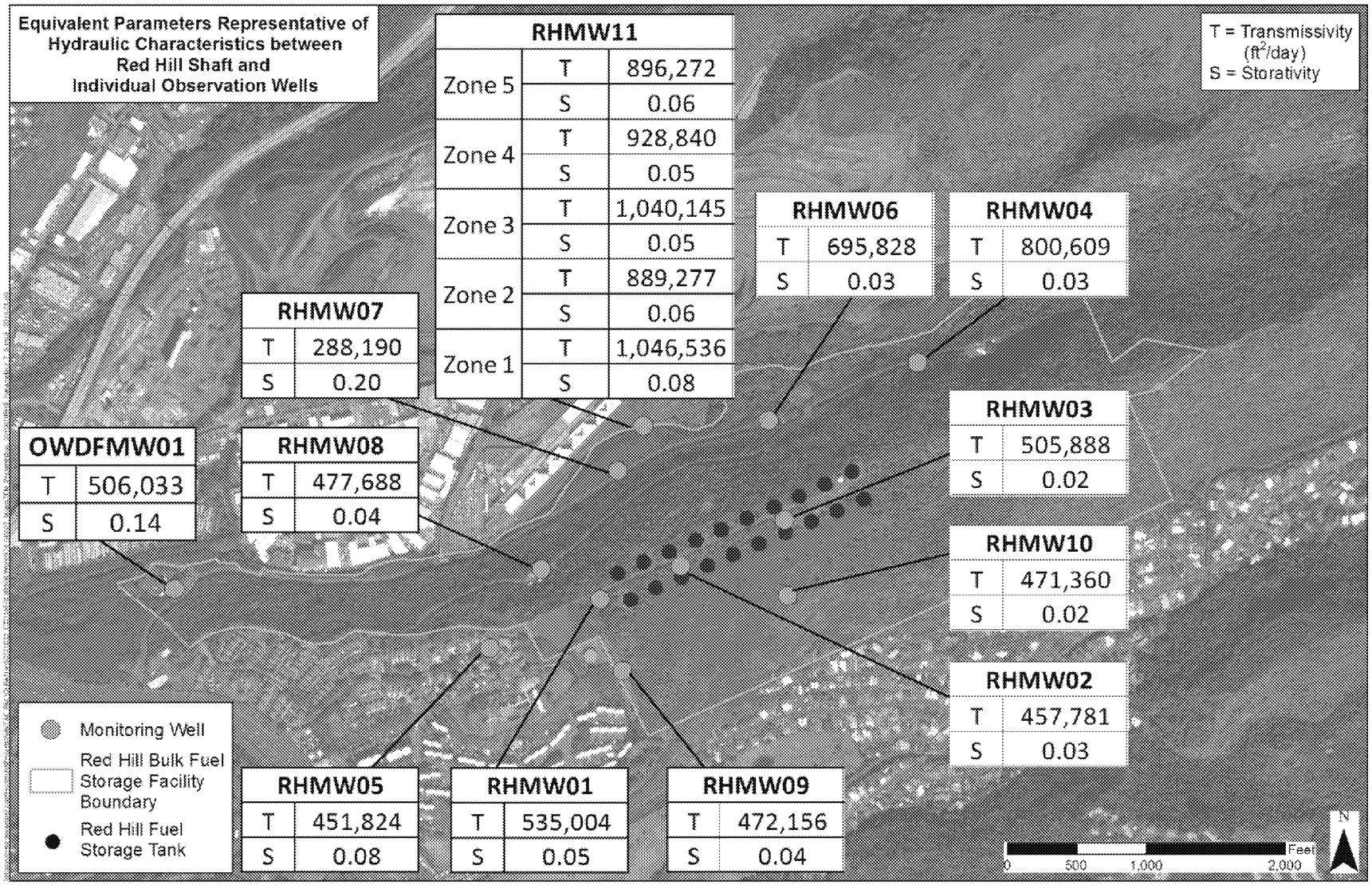
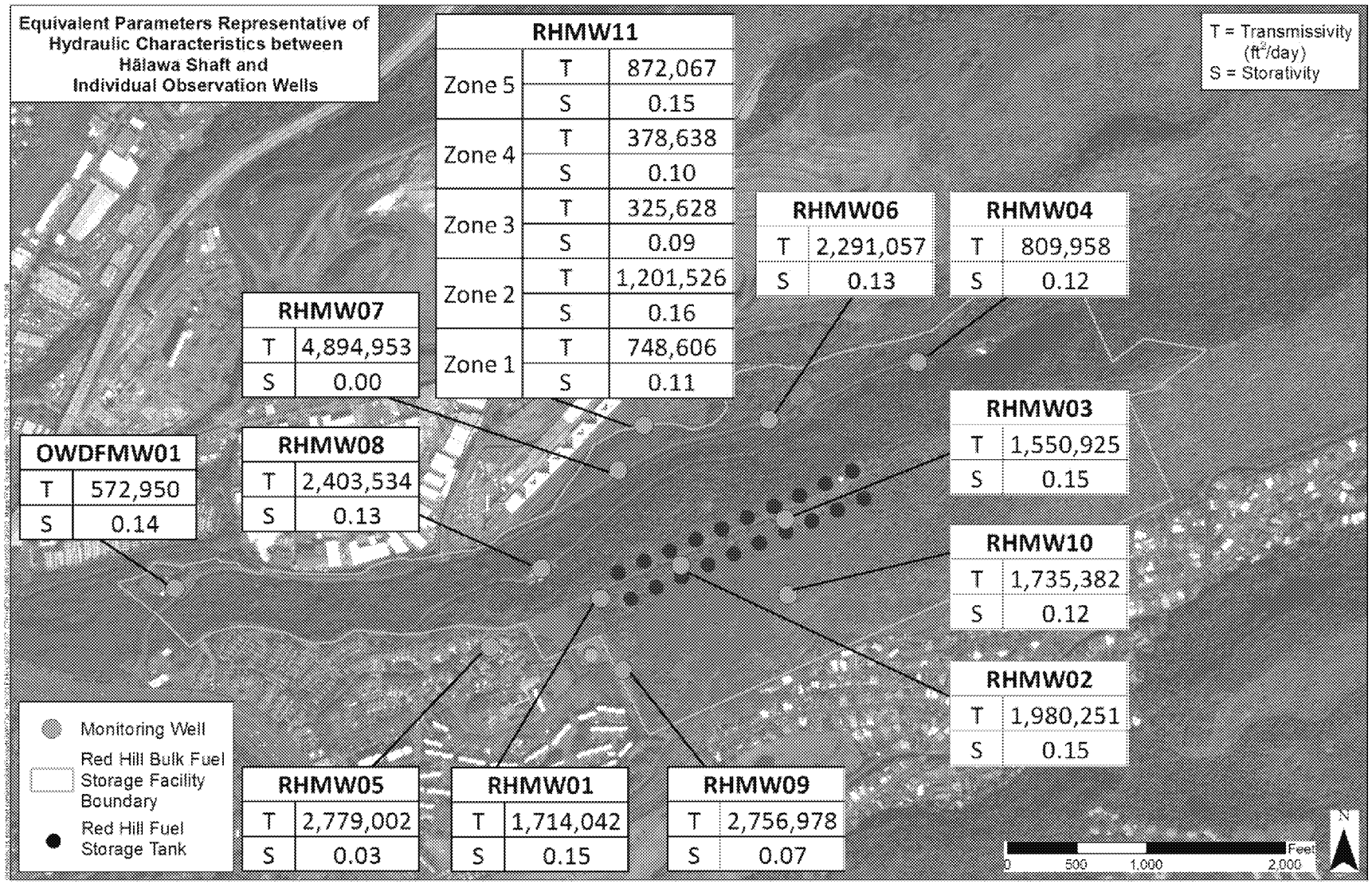
TFN Analysis:

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

ED_006532_00002904-00084

Analysis of Aquifer Anisotropy

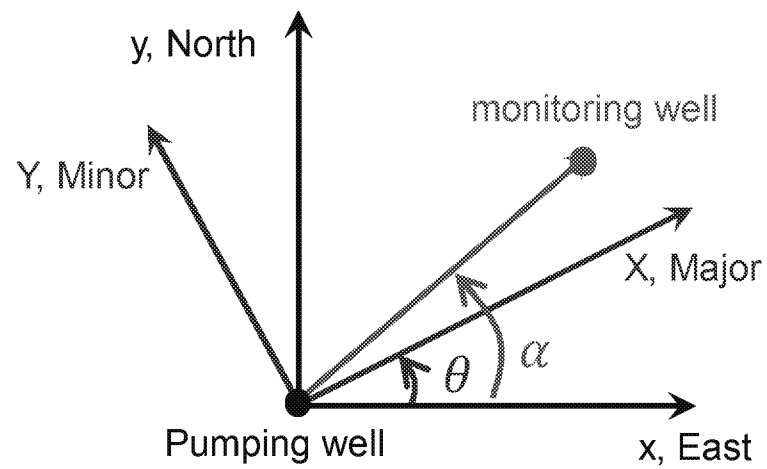
$$s = \frac{Q}{4\,\pi\,T_e}\,W(u_{XY})$$

$$u_{XY} = \frac{r^2\,S}{4\,T_\alpha\,t}$$

$$T_e = \sqrt{T_X\,T_Y}$$

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

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



ED_006532_00002904-00085

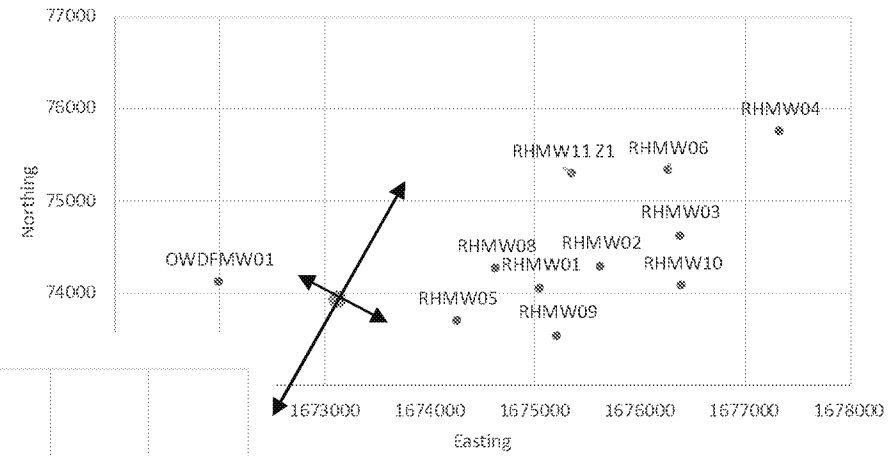
TFN Analysis:

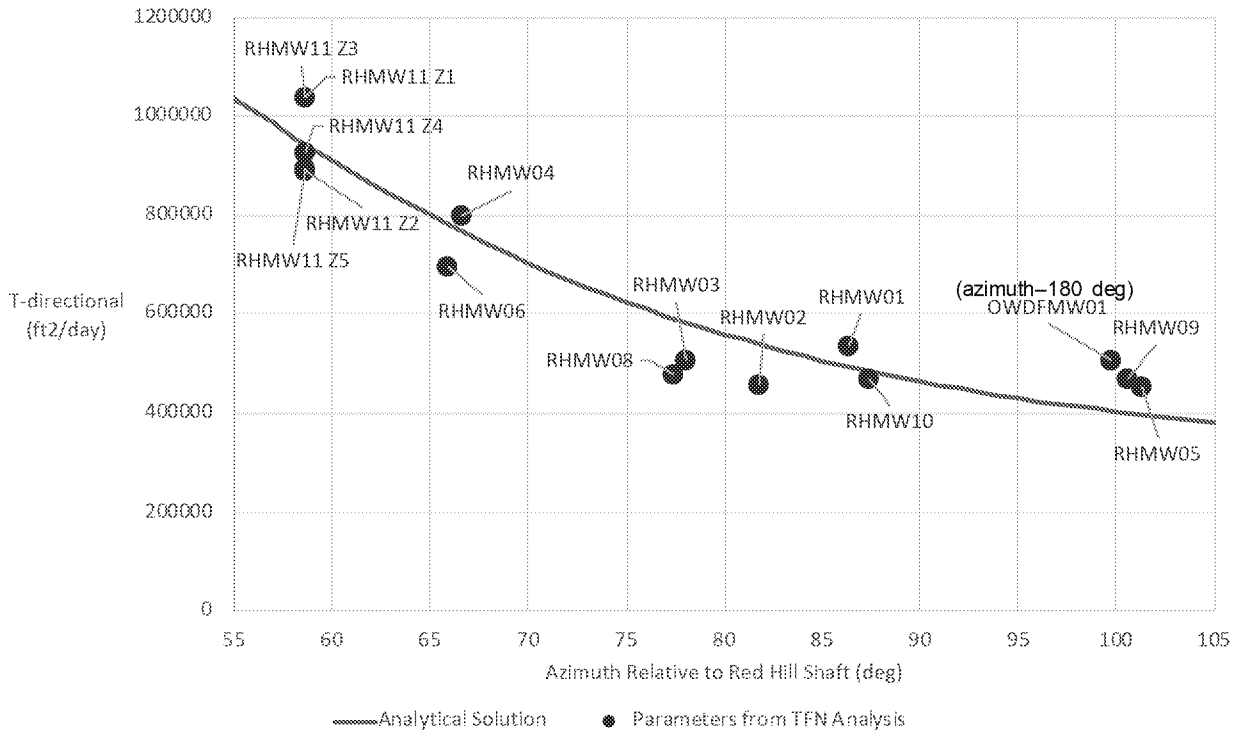
Analysis of Aquifer Anisotropy – Red Hill Shaft Shutdown & Restart

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

ED_006532_00002904-00086

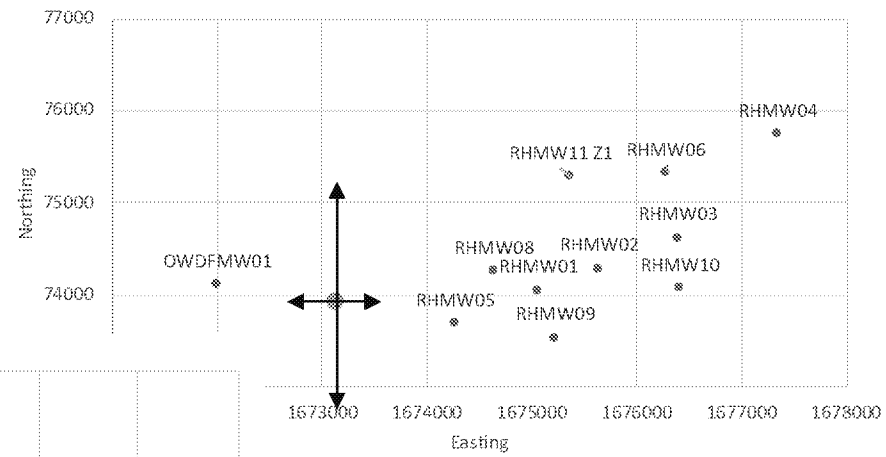
TFN Analysis:

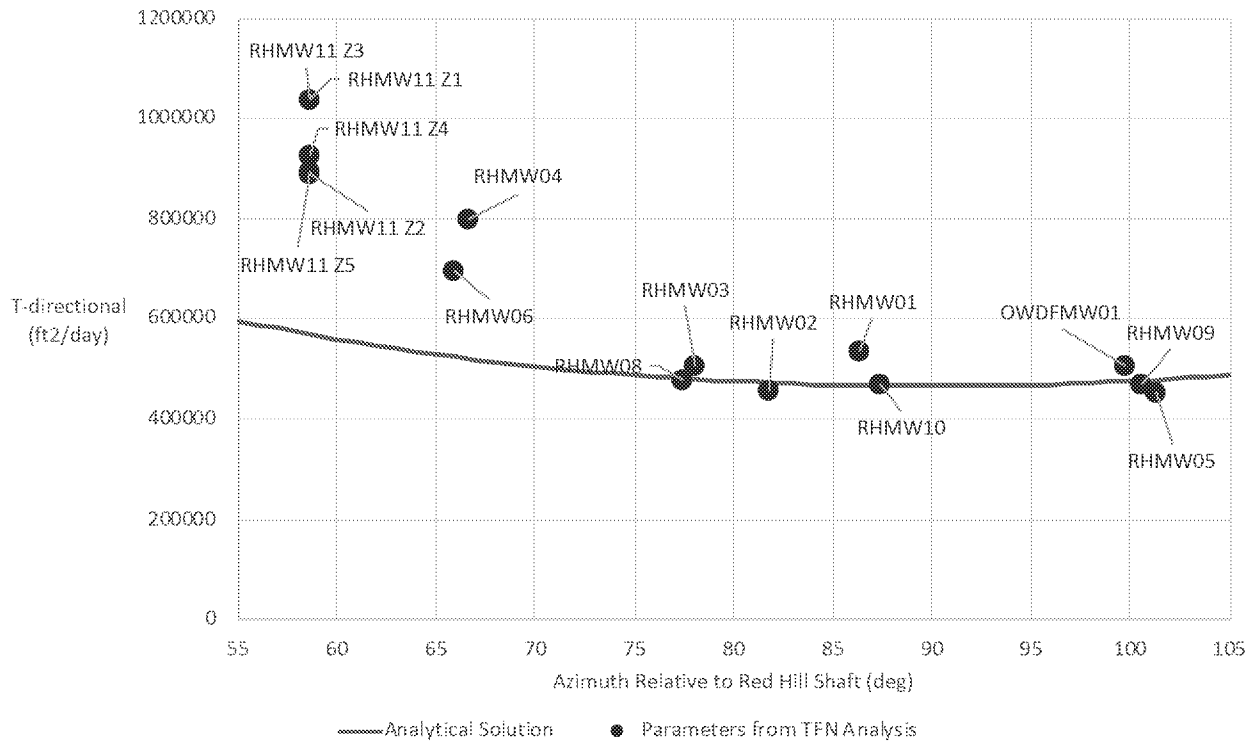
Analysis of Aquifer Anisotropy – Red Hill Shaft Shutdown & Restart (cont.)

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

ED_006532_00002904-00087

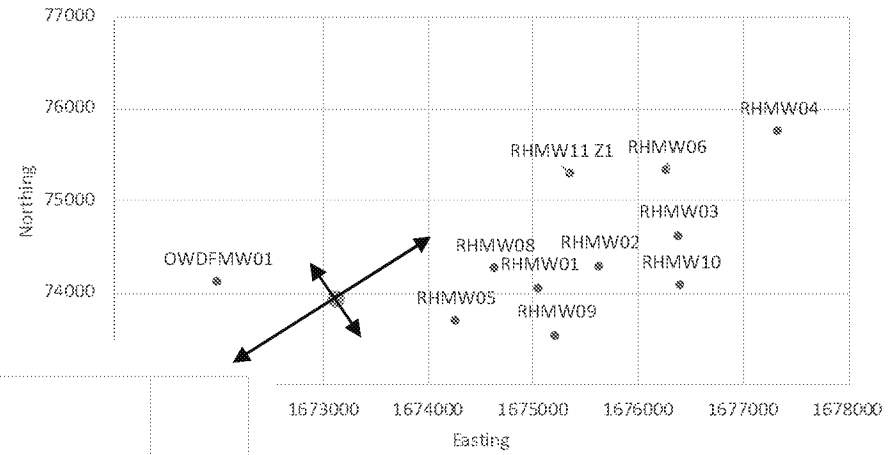
TFN Analysis:

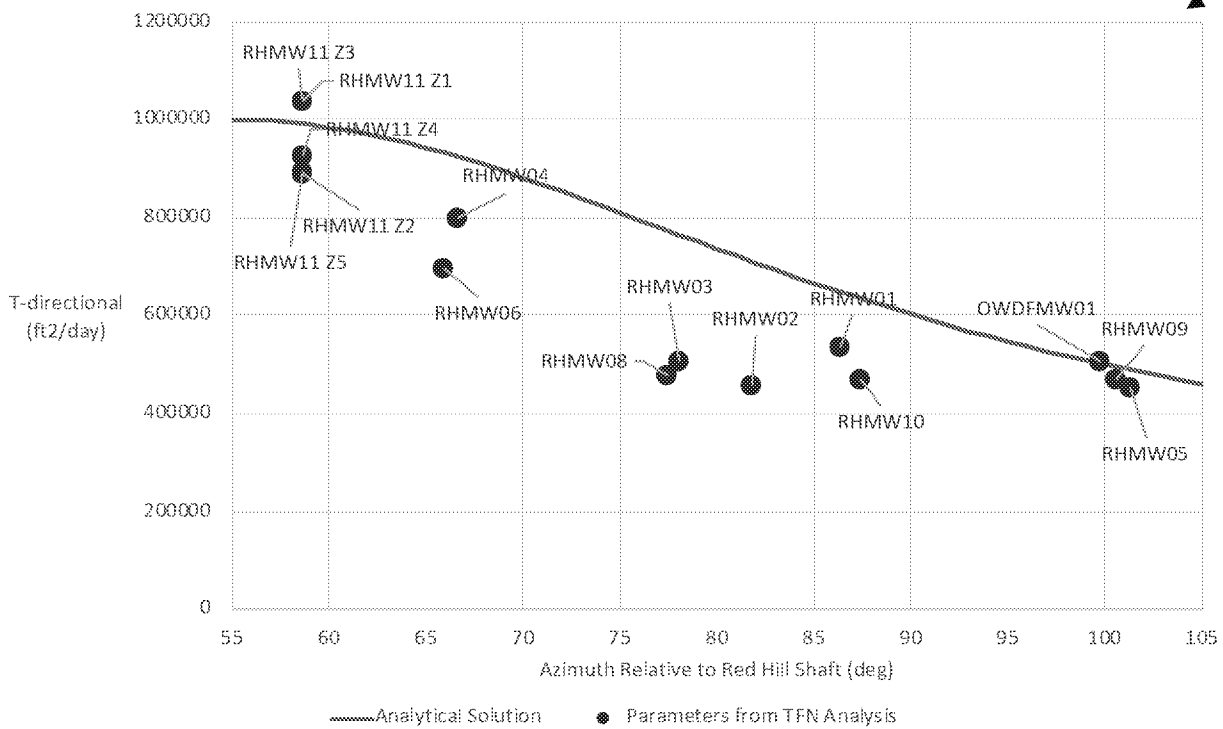
Analysis of Aquifer Anisotropy – Red Hill Shaft Shutdown & Restart (cont.)

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

ED_006532_00002904-00088

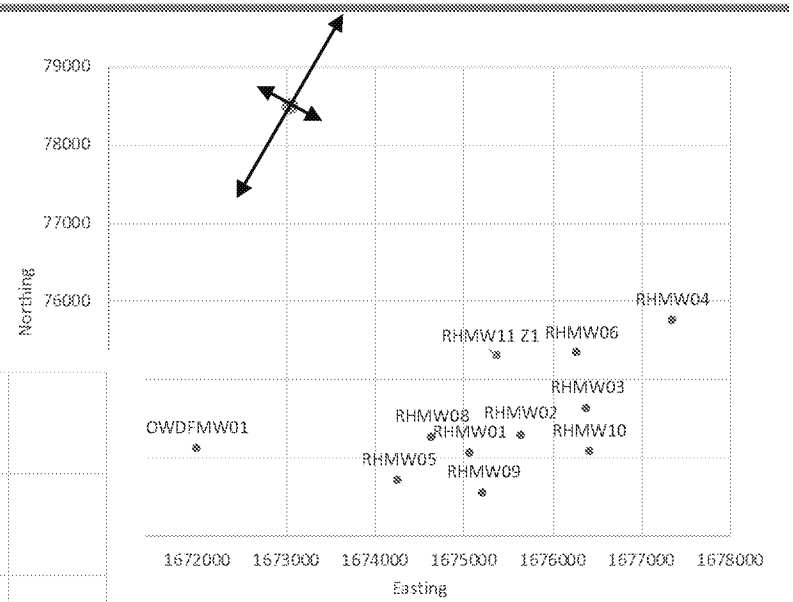
TFN Analysis:

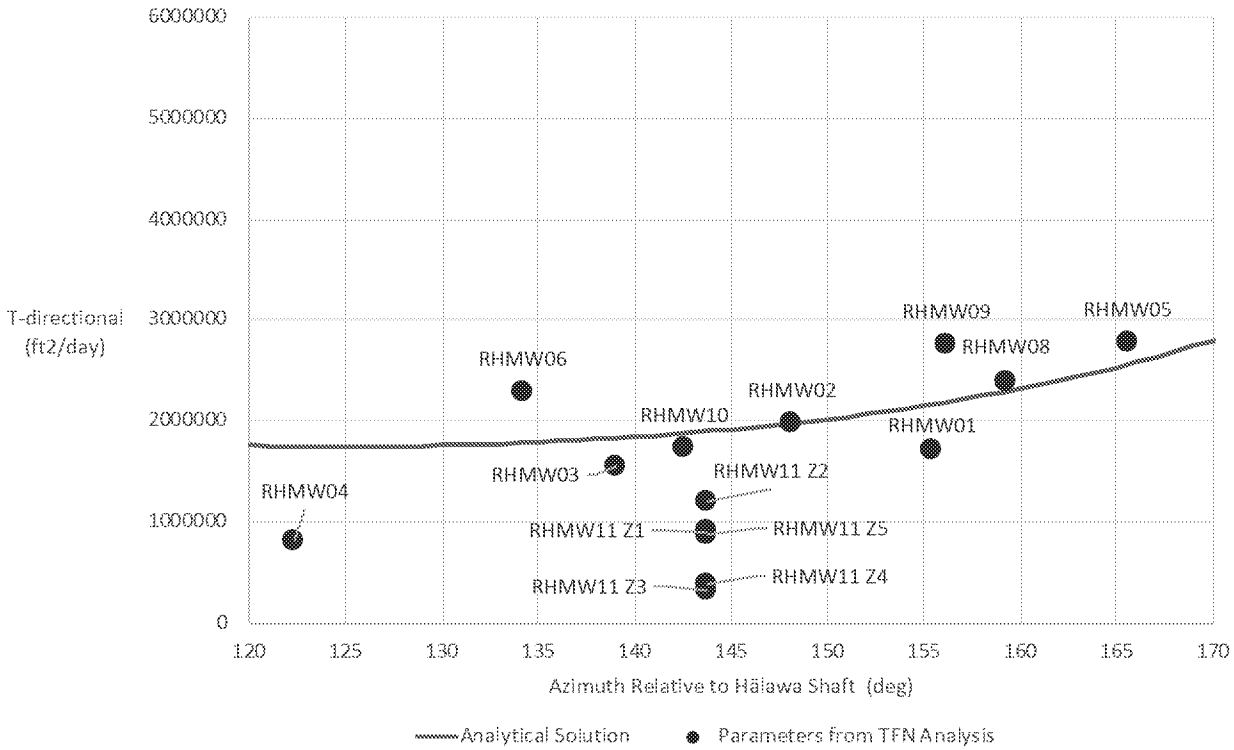
Analysis of Aquifer Anisotropy – Halawa Shaft Shutdown & Restart

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

ED_006532_00002904-00089

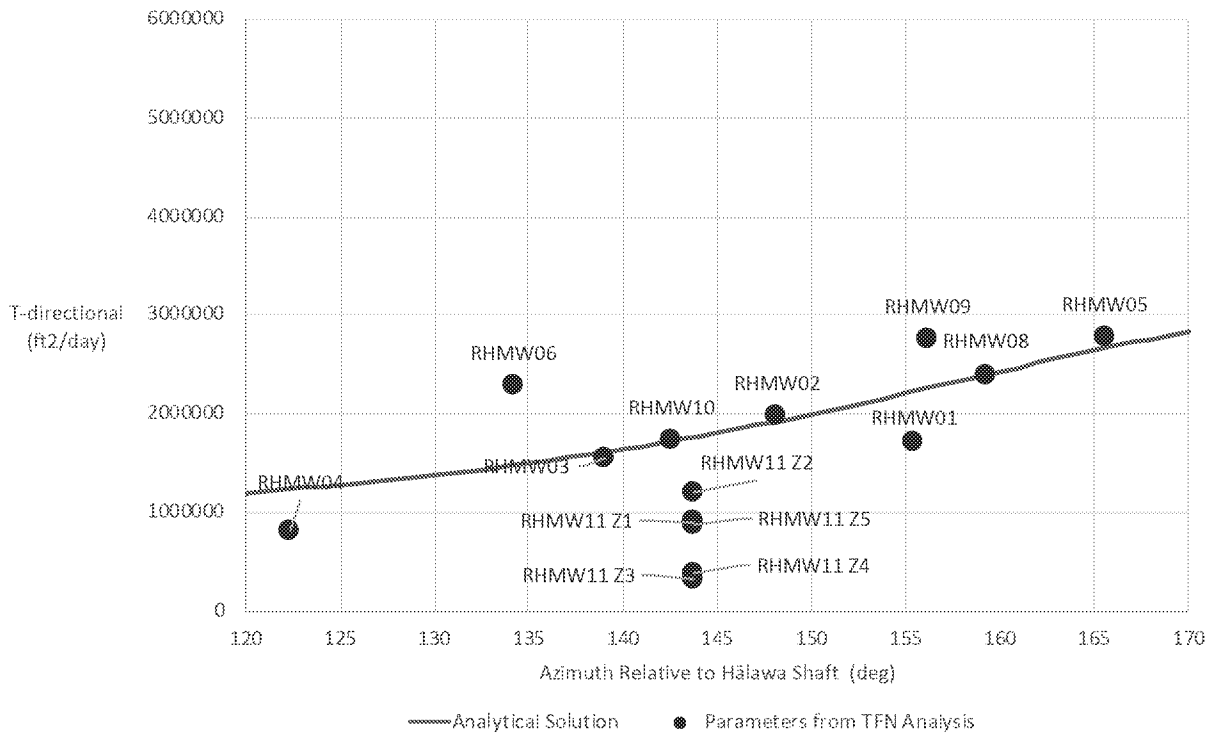
TFN Analysis:

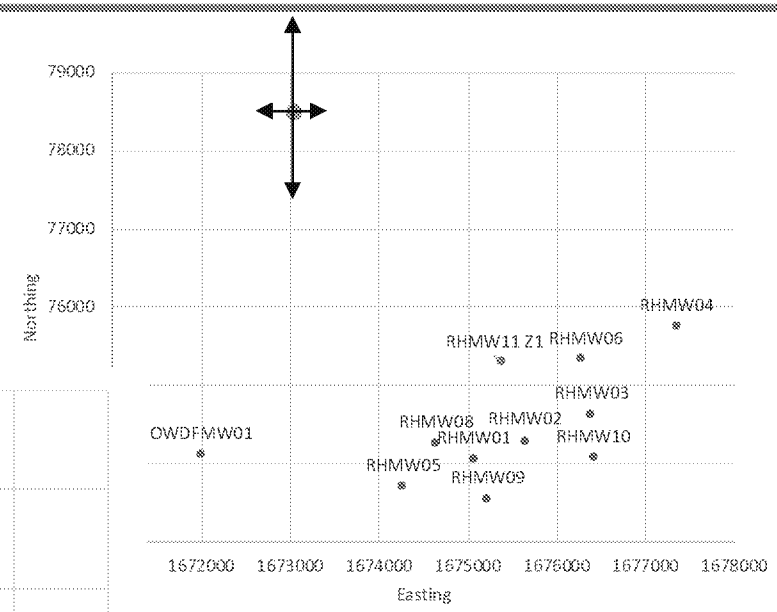
Analysis of Aquifer Anisotropy – Halawa Shaft Shutdown & Restart (cont.)

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

ED_006532_00002904-00090

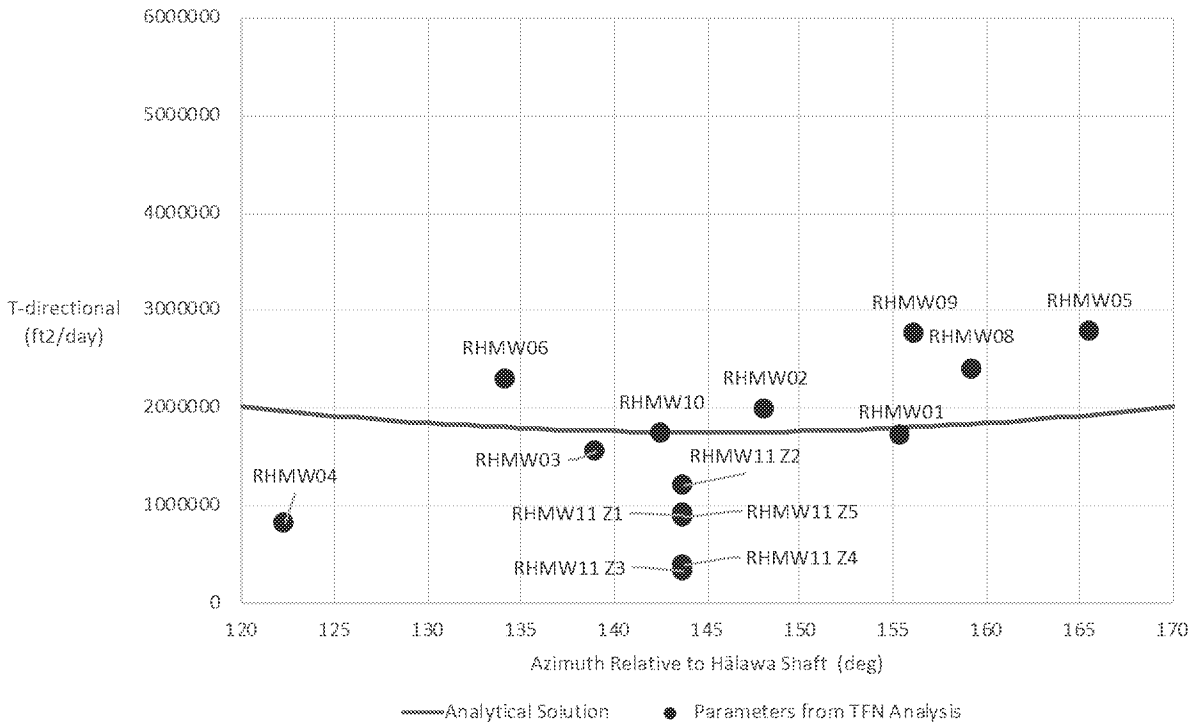
TFN Analysis:

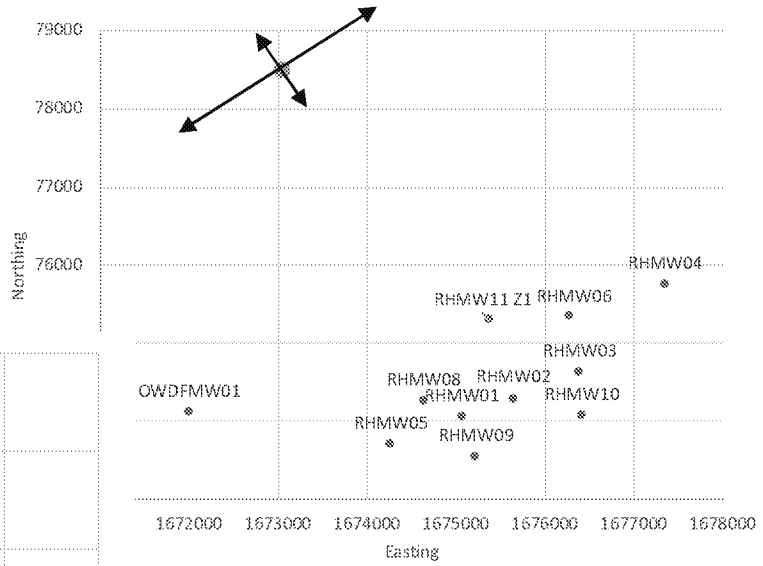
Analysis of Aquifer Anisotropy – Halawa Shaft Shutdown & Restart (cont.)

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

ED_006532_00002904-00091

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 anisotropy of approximately 215° azimuth.

ED_006532_00002904-00092

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Modeling Update Approach

ED_006532_00002904-00093

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

ED_006532_00002904-00094

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.

ED_006532_00002904-00095

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Model Update Progress

ED_006532_00002904-00096

Model 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

ED_006532_00002904-00097

Model Update Progress:

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

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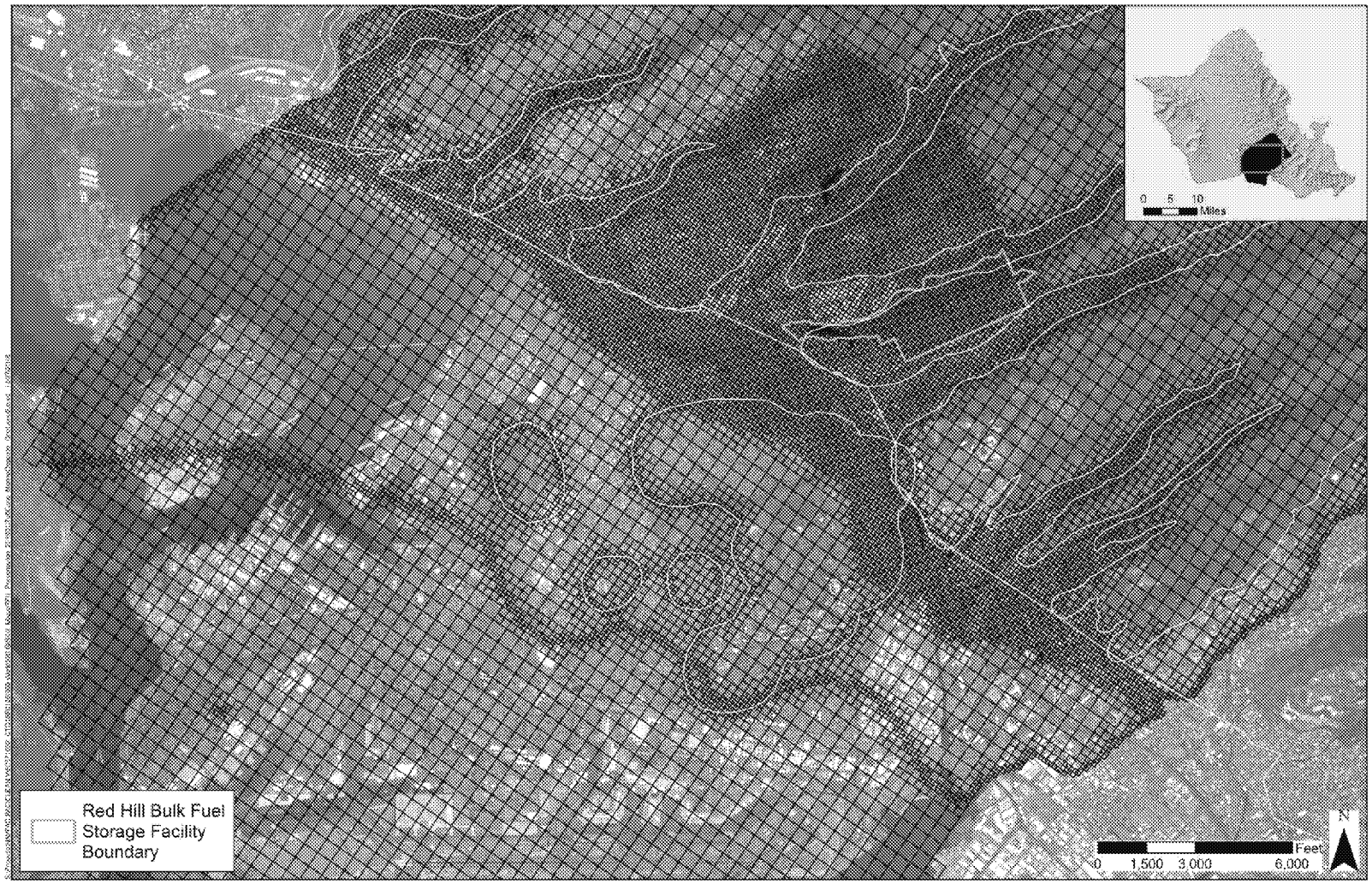
Model Update Progress:
Model Grid Aerial View

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

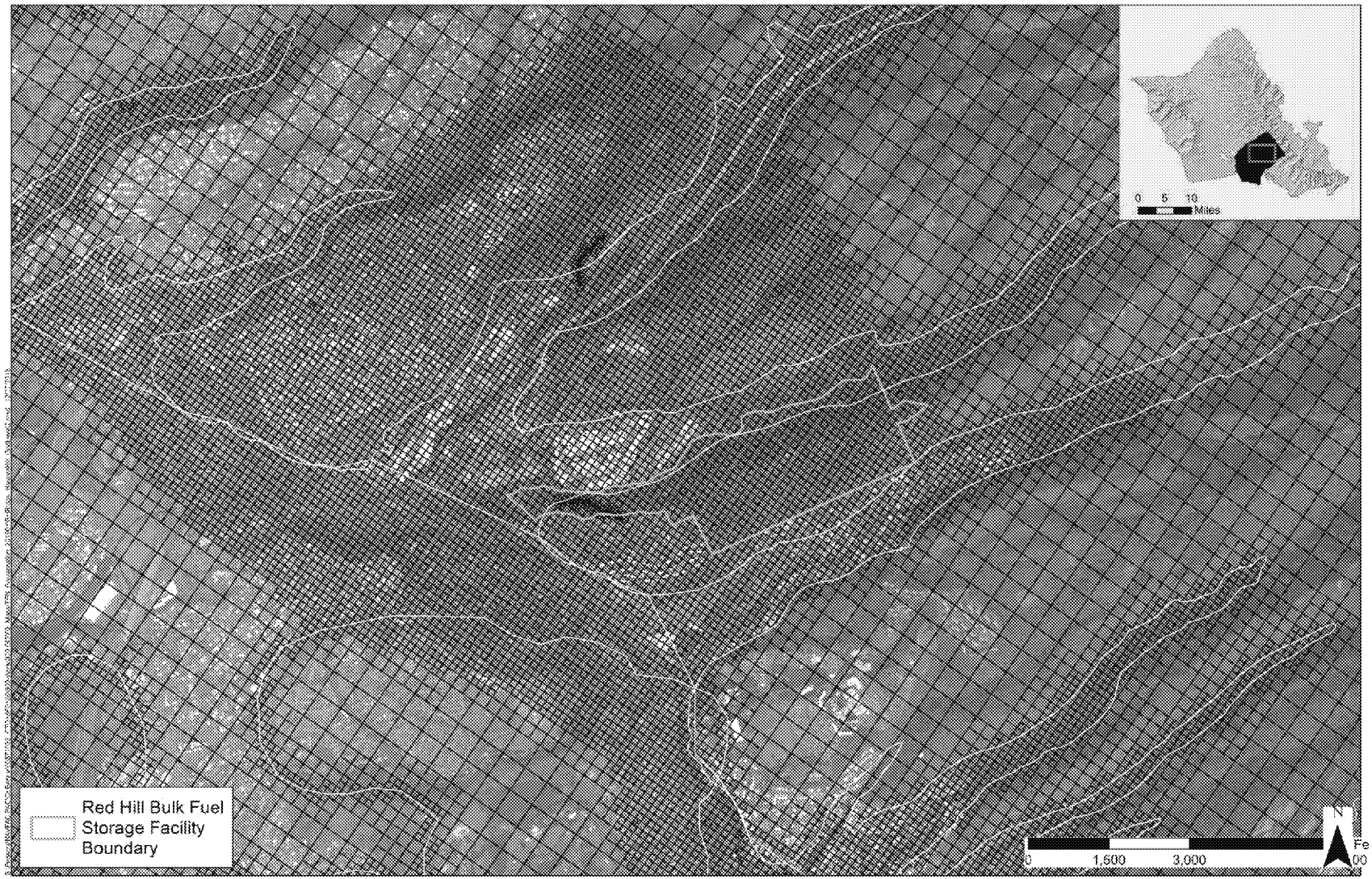
Model Update Progress:
Tuff Cone and Marine Deposits Extent (Grid Level 2)



Marine deposits perimeter extent connects both NW and SE boundaries.

Model Update Progress:

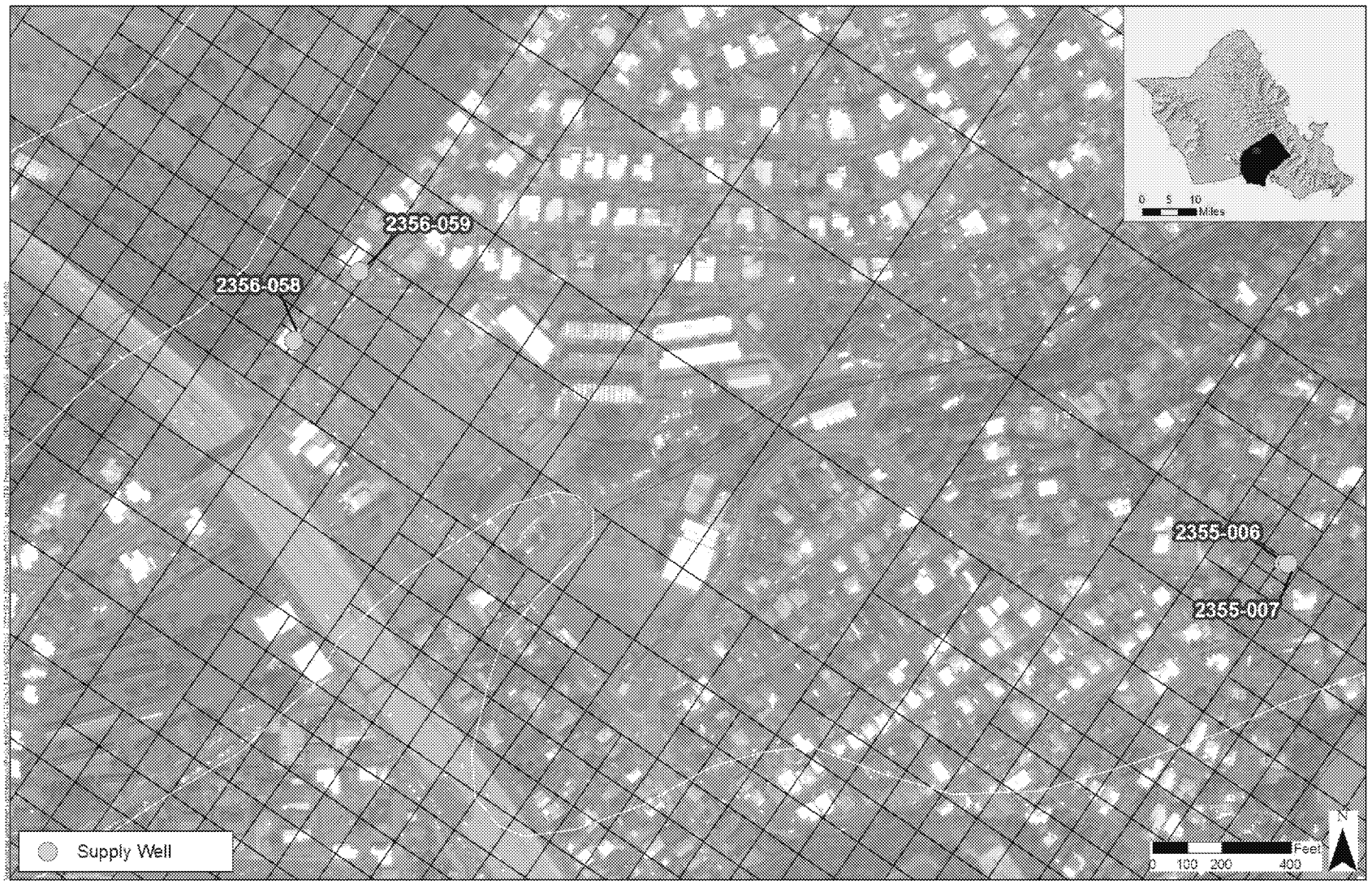
Red Hill Ridge, Adjacent Ridges, and Area of Interest (Grid Level 2)



Model Update Progress:
NW Boundary (Grid Level 2)

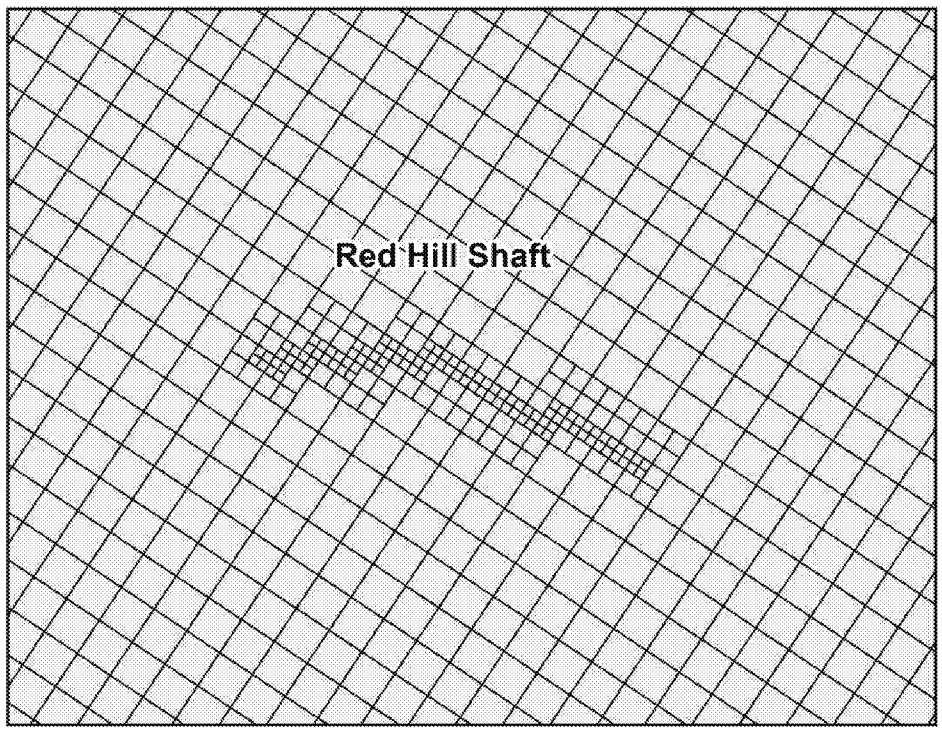
Model Update Progress:
SE Boundary (Grid Level 2)

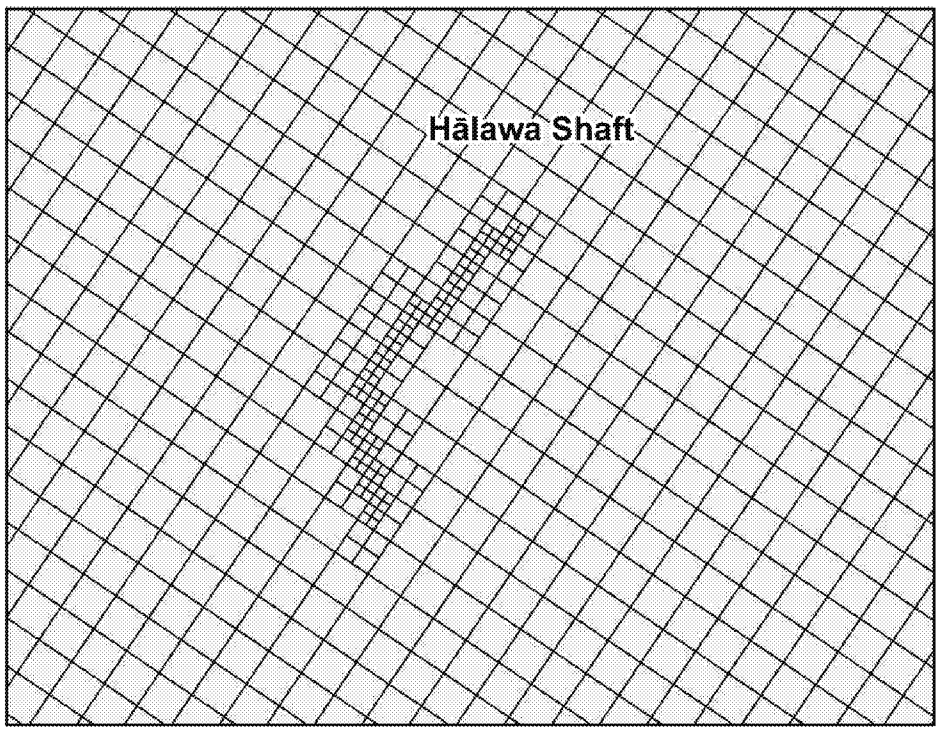
Model Update Progress:
Pumping Wells (Grid Level 3)



Model Update Progress:

Red Hill Shaft and Halawa Shaft (Grid Level 4)

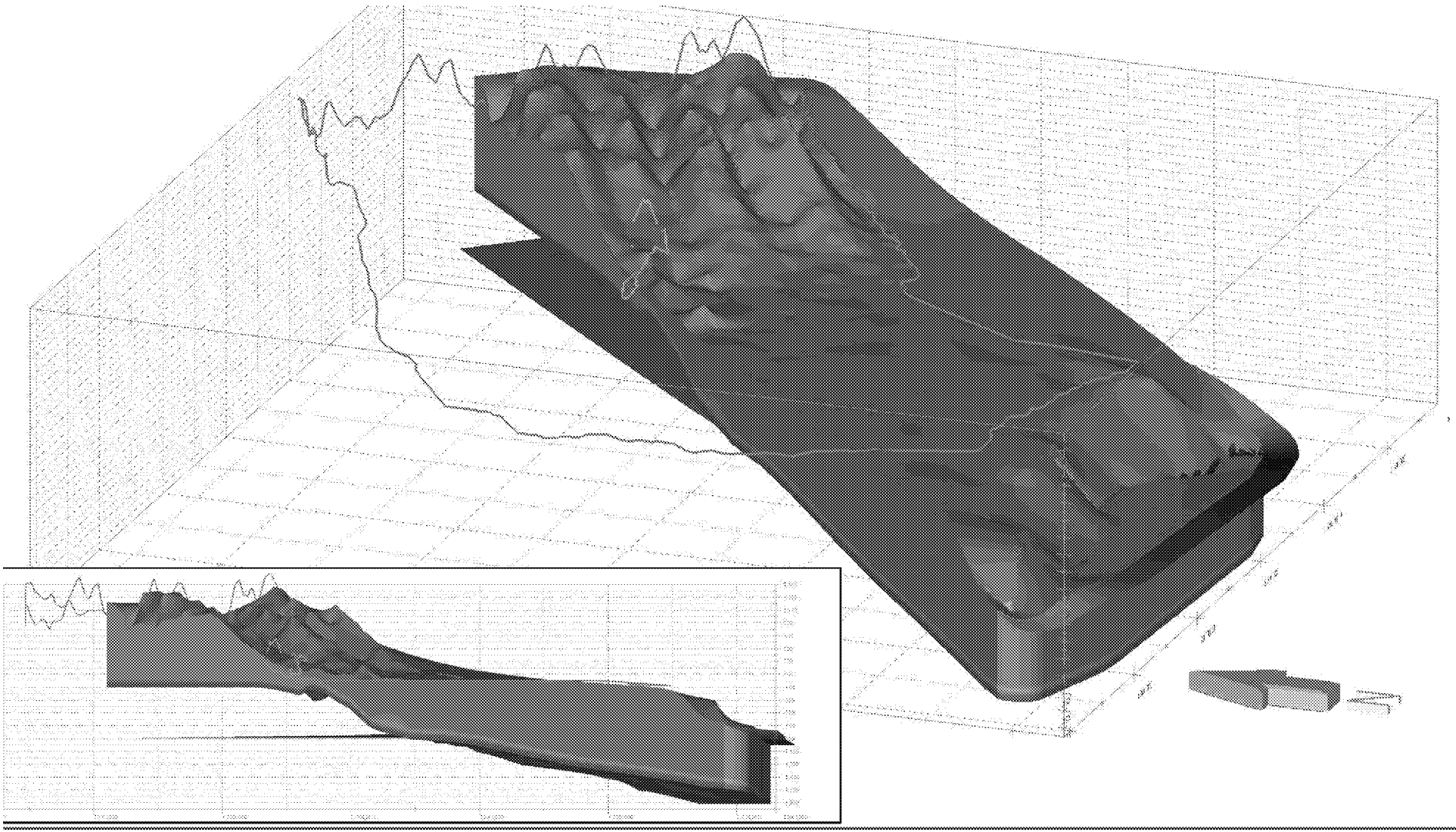




Model Update Progress:

Cross Section through Model Domain: NE–SW

Groundwater Flow Model Layers 1–9



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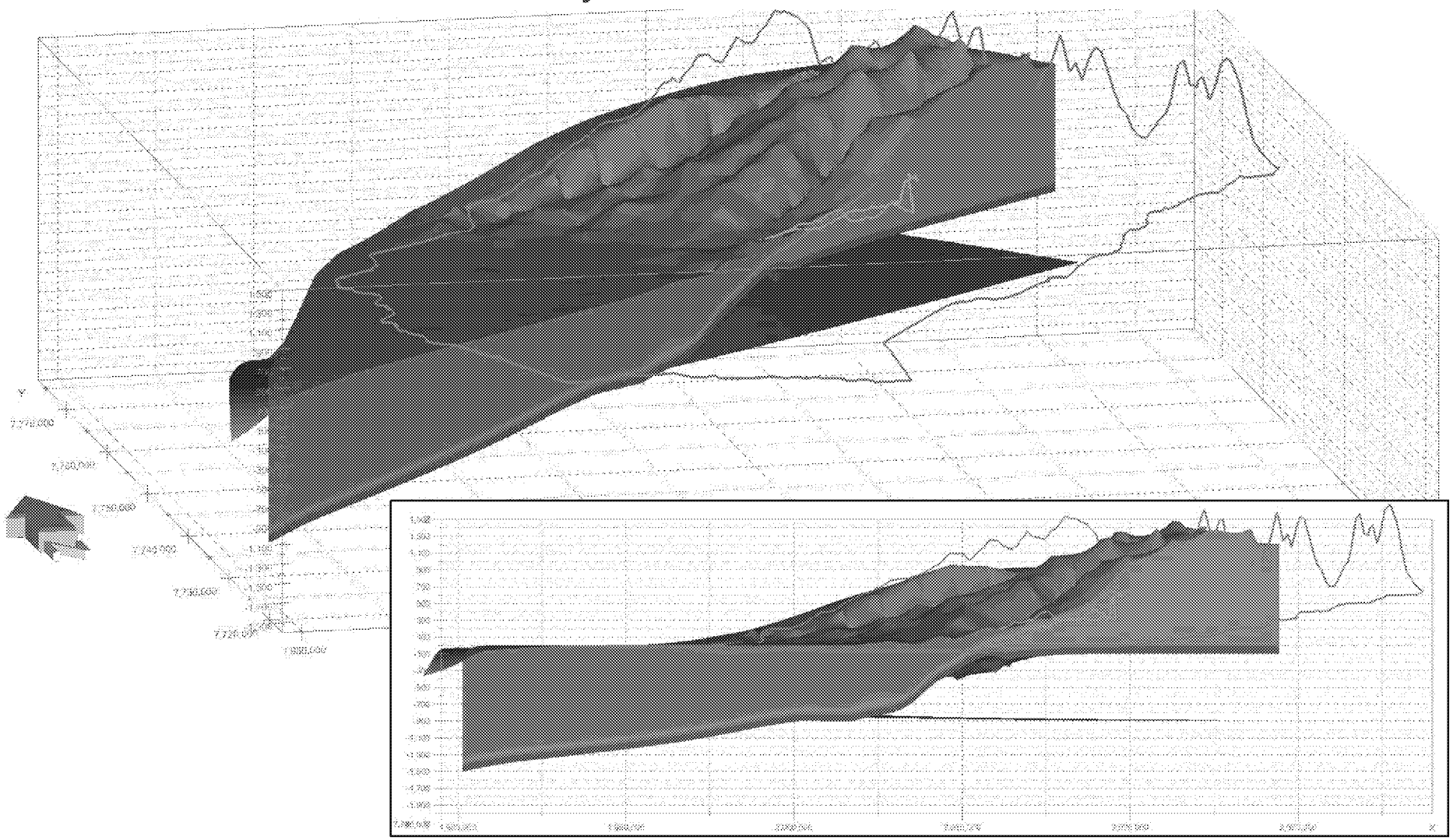
Model Update Progress:

Cross Section through Model Domain: SE–NW

Groundwater Flow Model Layers 1–9



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Model 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

ED_006532_00002904-00108

Model 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

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NAVFAC
Naval Facilities Engineering Command
NAVFAC HAWAII

AOC Parties' SME Input/Discussion

ED_006532_00002904-00110

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February 2019 Face-to-Face Meetings

ED_006532_00002904-00111

February Face-to-Face Technical Working Group Meeting

- Organic and Inorganic Chemistry
- Path Forward for Evaluating LNAPL
  - Strike and Dip
  - Core Lab Data
  - Adjusting Monte Carlo approach for LNAPL evaluation in the unsaturated zone (reflecting new strike and dip and geologic properties)
  - Hydrocarbon Spill Screening Model (HSSM) to Evaluate NAPL Spreading on Groundwater

ED_006532_00002904-00112

February GWMWG Meeting

- Synoptic Water Level Study and Transfer-Function Noise Analysis
- Recent Sensitivity Analyses Based on Interim Groundwater Flow Modeling
- Revised Grid Orientation with Sensitivity Analysis of Alternative Orientation
- Integration of Geologic Features
  - Development of Saprolite Extent Variants
  - Development of Pearl Harbor and Offshore Flow Boundaries
  - Development of Tunnel Inflows Representation
- Path forward to October 2019 Groundwater Flow Model Submittal

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