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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
- Split Sampling Results
- 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

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Introductions

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Status of AOC Parties' Data Requests

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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.

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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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.

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.

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.

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.

Split Sampling Results

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Split Sampling Results:

Purpose and Summary

- Groundwater samples were split with EPA Region 9 (R9) Laboratory to compare results with those obtained by the Navy's contracted laboratory in accordance with the Split Sampling Analysis Plan (EPA 2017).
- Six split sampling events have been conducted between January 2017 to July 2018.
- Initial split sampling event results showed apparent bias for Navy-contracted laboratory results compared to EPA R9 Lab for TPH-d, and to a lesser extent PAHs. All other results were consistent between the two laboratories.
- The Navy-contracted laboratory (APPL) implemented changes to their EPA Method 8015 and EPA Method 8270 SIM laboratory protocols to improve analyte recoveries.
- The July 2018 split sample results showed similar TPH-d and PAH recoveries between the two laboratories.

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Split Sampling Results:

Recap

- Split sampling initially conducted during the Jan, Feb, and Mar 2017 groundwater monitoring events
  - Split samples were collected from all existing groundwater monitoring locations in the LTM program.
  - EPA/DOH issued a letter in Sept 2017 discussing split sampling results.
    - For samples with high TPH-d concentrations (i.e., RHMW02), EPA R9 Lab's TPH-d recoveries were approximately 2x higher than APPL's TPH-d recoveries.
    - Nitrate concentrations between the two laboratories were inconsistent, but were not extensively examined as nitrate is not a COPC.
    - All other results were consistent between the two laboratories.
- Navy began evaluation of the TPH-d analysis, and also proactively evaluated the PAH analysis.
  - *Inherent uncertainties associated with TPH analysis were not unexpected and required further evaluation.*

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Split Sampling Results:
Recap

- **Per the October 2017 Navy response letter, the following actions were identified:**
  1. **Follow-on discussion with the EPA QA Office regarding analytical options utilized in each step of the TPH analysis.**

     Status: Conducted discussion with EPA Region 9 Lab during the Jan 25, 2018 split sampling call/update. Both laboratories are following the same guidance method (8015).
  2. **Third-party validation of EPA lab data packages (Jan, Feb, Mar 2017).**

     Status: Completed in Dec 2017.
  3. **Single-blind performance testing (PT) samples for EPA R9 Lab and APPL.**

     Status: Completed PT sample analysis as follows:
     - *Completed analysis of 3 TPH-DRO PT samples utilizing the same analytical protocols used during the Jan-Mar 2017 events.*
     - *Completed 1 TPH-DRO PT sample utilizing 1-L extraction protocol.*
  4. **Additional split groundwater sampling and analyses for select monitoring wells (RHMW01, RHMW02, and RHMW03) for TPH-d, TPH-o, and PAHs (1-methylnaphthalene, 2-methylnaphthalene, and naphthalene).**

     Status: Conducted the split sampling during the 4th Qtr 2017 groundwater monitoring event.

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Split Sampling Results:

Recommendations to Improve Data Accuracy

- Based on results of the October 2017 split sampling event and PT samples, the following actions were taken in early 2018:
  - Optimized APPL laboratory protocols to achieve results comparable to EPA R9 Lab.
  - Performed additional PT sample analyses for APPL to evaluate recovery improvement after optimization steps performed.
  - Conducted additional split sampling events to confirm that APPL can achieve recoveries comparable to EPA R9 Lab recoveries in groundwater samples.

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Split Sampling Results:

Lab Protocol Optimization

- **Initial Method Optimization**
  - **October 2017 PT sample results indicated a low bias for TPH-d, which warranted further review of APPL's laboratory procedures.**
  - **Quantitation/Analysis:**
    - Results from direct inject of PT standard on to GC indicate no issues with:
      - Calibration Standards – APPL and EPA R9 Lab to use the same Diesel calibration standard
      - Calibration Curve
      - Integration Protocols
  - **Extraction:**
    - Comparison of automated liquid-liquid (L-L) vs. manual separatory funnel (SF) shaking methods indicated:
      - L-L method improved recoveries by ~10%, and results were more consistent
  - **Concentration:**
    - Comparison of rotary evaporator vs. DryVap methods indicated:
      - Rotary evaporator method improved recoveries by ~20%

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Split Sampling Results:

Lab Protocol Optimization

- Conducted follow-on internal PT sample study:
  - APPL analyzed the two additional TPH-d PT samples utilizing the optimized method (L-L/rotary evaporator) and the SF/rotary evaporator.
  - While APPL's performance improved (~10% increase in recovery), further refinement of their method was pursued.
- Performed additional method optimization:
  - Adjusted initial sample extraction volume pH to <2 using HCl.
  - Reduced initial sample volume to 800mL.
- Conducted additional split sampling:
  - March 2018 (1st Qtr 2018 event)
  - July 2018 (3rd Qtr 2018 event)

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Split Sampling Results:

Inherent Issues with TPH-d Analysis

- TPH is a method-defined parameter and it is, by definition, method/lab dependent.
  - Variability in extraction, concentration, cleanup methods
  - Variation in calibration standards
- Variability of TPH results is significantly higher than for single-component measurements like BTEX.
  - DoD/DOE (2018) *Quality Systems Manual for Analytical Services* acceptance criteria for the laboratory control sample (LCS) are 36–132% of the expected value. Acceptance criteria for BTEX are tighter, in the range of 78–121%.
  - Performance testing samples from vendors have acceptance criteria of 30–125% of the spiked concentrations.
- TPH includes parent petroleum hydrocarbons, petroleum hydrocarbon–related metabolites and any matter detected in the analysis.
  - Presence of polar compounds and metabolites has large impact on results.

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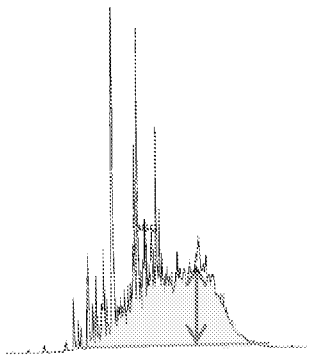
Split Sampling Results:

Comparison of TPH Chromatograms

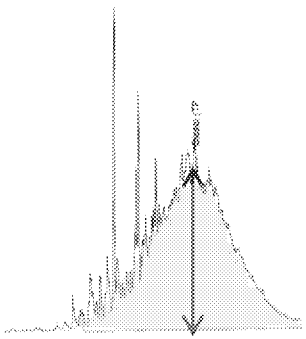
RHMW02

Jan 2017



APPL

TPH-d:	1400 µg/L
Naphthalene:	69 µg/L
2-Methylnaphthalene:	11 µg/L
1-Methylnaphthalene:	25 µg/L



EPA R9 Lab

TPH-d:	4000 µg/L
Naphthalene:	77 µg/L
2-Methylnaphthalene:	11 µg/L
1-Methylnaphthalene:	33 µg/L

- **Significantly higher "hump" measured by EPA R9 Lab accounting for the higher TPH differences:**
  - **Polar compounds/metabolites**
- **Polar compounds/metabolites are more difficult to extract from water than hydrocarbons (non-polar). These compounds are also more difficult to analyze with methods that were developed for hydrocarbons.**
- **Both laboratories have comparable results for PAHs.**

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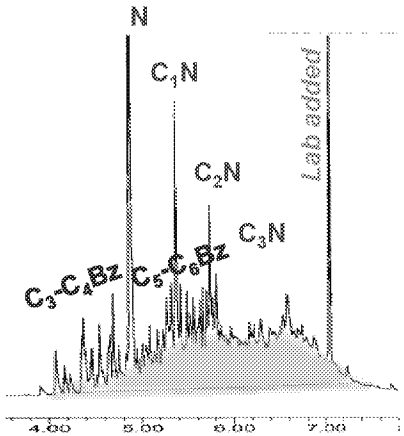
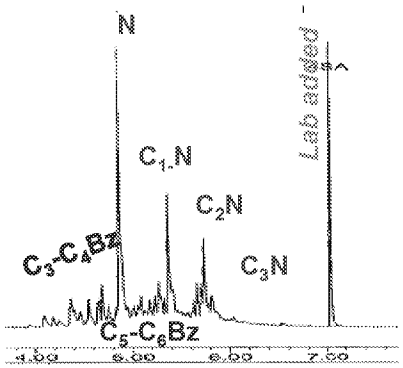
Split Sampling Results:

TPH Chromatograms without and with SGC

RHMW02

TPH-d (C10–C24)
Before Silica Gel Cleanup





TPH-d (C10–C24)
After Silica Gel Cleanup

- TPH-d in RHMW02 is 66–86% polar compounds/metabolites.
  - Likely products of biodegradation of hydrocarbons.
- Polar compounds/metabolites can be removed with silica gel.

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Split Sampling Results:
EPA Method 8015 TPH-d

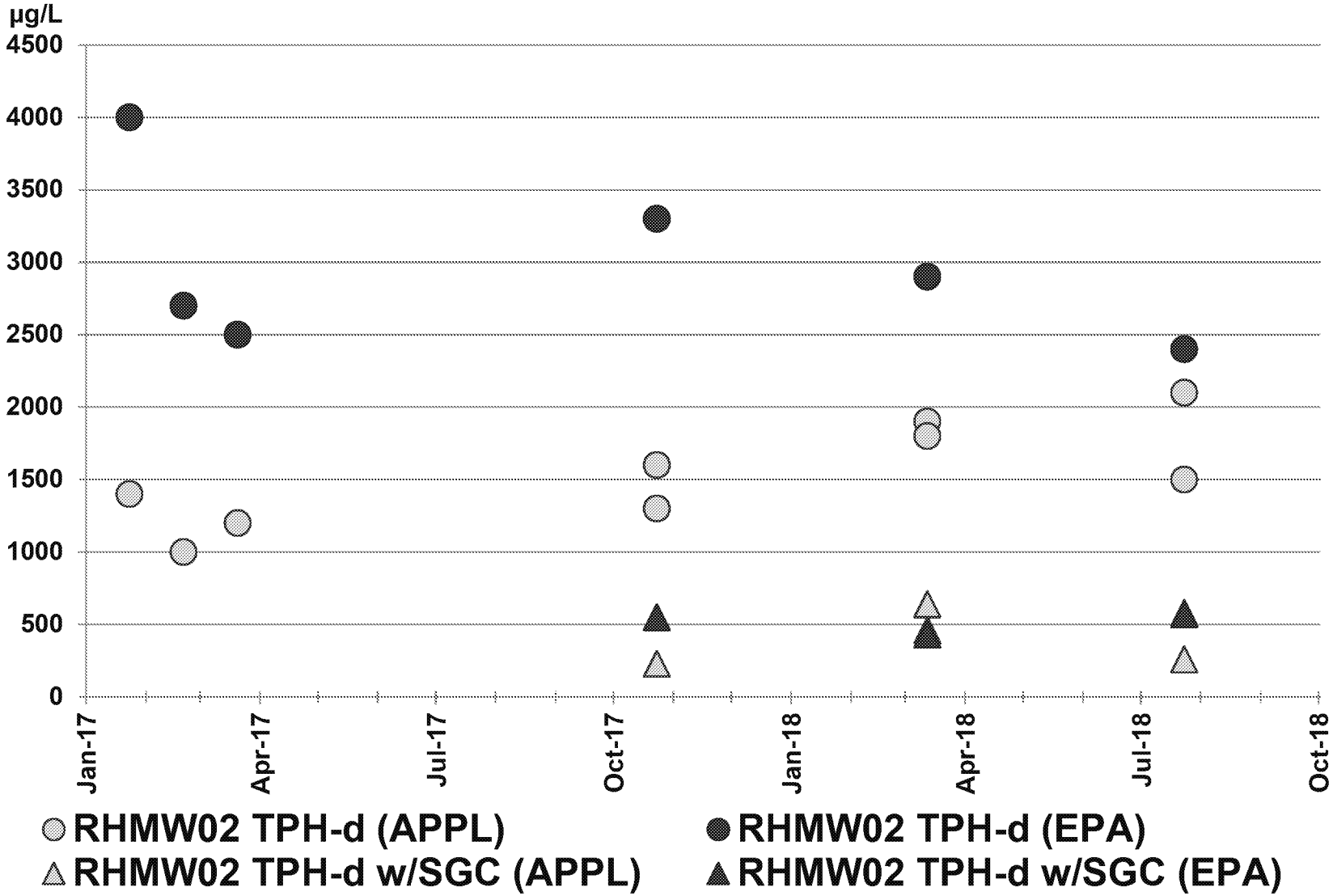
Monitoring Well	Monitoring Event	Analyte:	TPH-d			TPH-d w/SGC		
		EAL:	400			400		
		Lab:	APPL	EPA	RPD	APPL	EPA	RPD
RHMW01	2018 Q3 (Jul)	primary; ERH637	350	160	75%	< 25 U	< 75 U	—
	2018 Q1 (Mar)	primary; ERH545	150	180	18%	< 25 U	< 75 U	—
	2017 Q4 (Oct)	primary; ERH412	86	210	84%	< 25 U	< 75 U	—
		duplicate; ERH413	83	—	—	< 25 U	—	—
	2017 Mar	primary; ERH275	83	130	44%	—	—	—
	2017 Feb	primary; ERH223	150	300	67%	—	—	—
	2017 Q1 (Jan)	primary; ERH172	88	280	104%	—	—	—
RHMW02	2018 Q3 (Jul)	primary; ERH639	2100	2400	13%	580	570	2%
		duplicate; ERH640	1500	—	—	260	—	—
	2018 Q1 (Mar)	primary; ERH547	1900	2900	42%	640	430	39%
		duplicate; ERH548	1800	—	—	460	—	—
	2017 Q4 (Oct)	primary; ERH415	1300	3300	87%	230	550	82%
		duplicate; ERH416	1600	—	—	230	—	—
	2017 Mar	primary; ERH265	1200	2500	70%	—	—	—
	2017 Feb	primary; ERH216	1000	2700	92%	—	—	—
	2017 Q1 (Jan)	primary; ERH174	1400	4000	96%	—	—	—
RHMW03	2018 Q3 (Jul)	primary; ERH642	300	180	50%	< 25 U	< 75 U	—
	2018 Q1 (Mar)	primary; ERH550	190	150	24%	< 25 U	< 75 U	—
	2017 Q4 (Oct)	primary; ERH418	160	180	12%	< 25 U	< 75 U	—
		duplicate; ERH419	210	—	—	< 25 U	—	—
	2017 Mar	primary; ERH268	55	170	102%	—	—	—
	2017 Feb	primary; ERH231	67	170	87%	—	—	—
	2017 Q1 (Jan)	primary; ERH181	51	190	115%	—	—	—

Grey shaded text indicates analyte exceeds DOH EAL.
Light blue shaded text indicates RPD greater than 30%, with APPL values higher than EPA values.
Purple shaded text indicates RPD greater than 30%, with APPL values lower than EPA values.

- Based on the Jan–Mar 2017 events, APPL results were biased low compared to EPA R9 Lab.
- During the 2017 Q4 (Oct) event, APPL and EPA R9 Lab used the same calibration standard, and APPL still had lower recoveries than EPA R9 Lab.
- During the 2018 Q1 (Mar) event, recoveries improved after further method optimization: pH<2; automated liquid-liquid extraction; rotary evaporation; and 800mL sample volume.
  - Better recovery of polar compounds/metabolites.

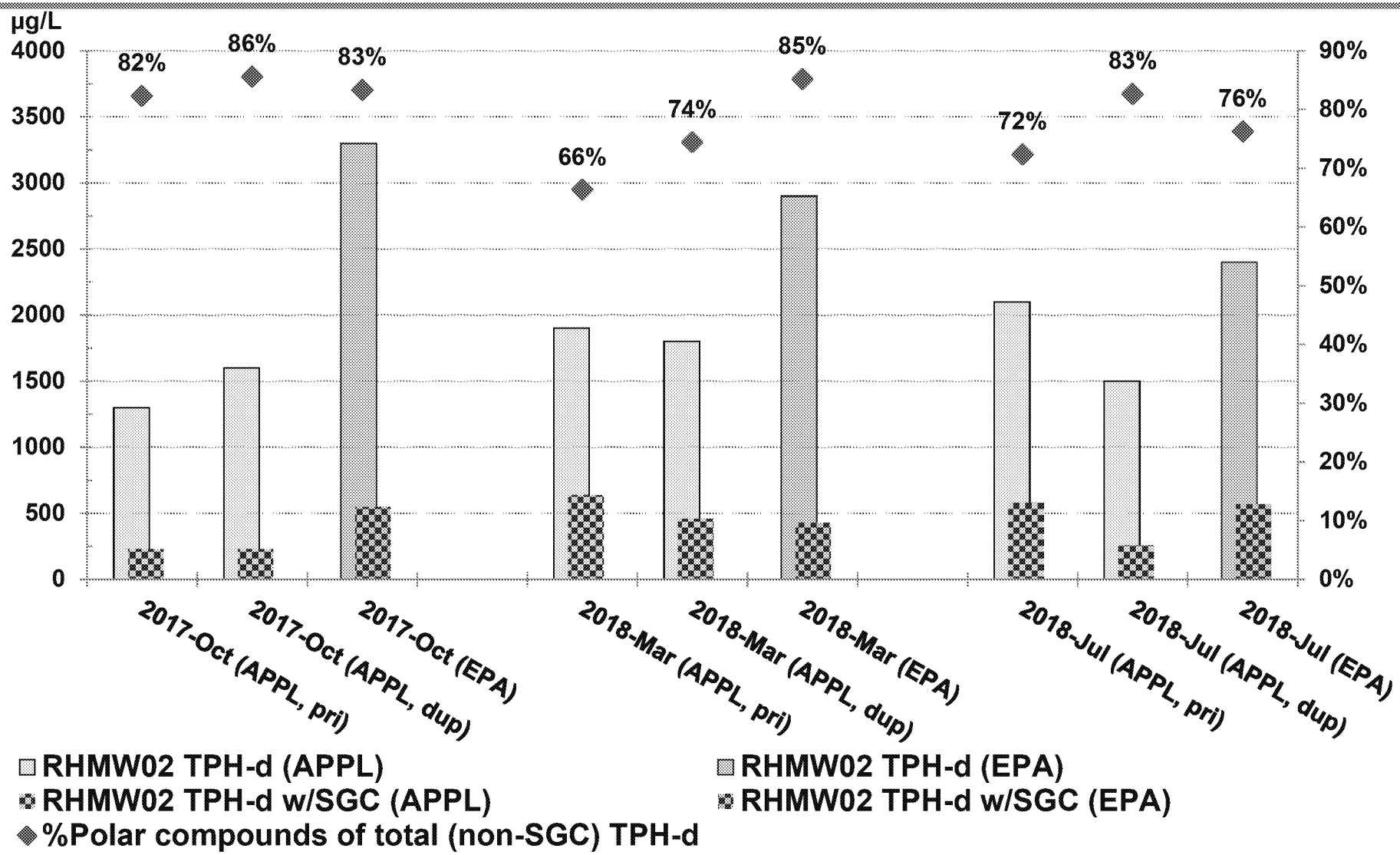
RPD = relative percent difference
SGC = silica gel cleanup

Split Sampling Results:
EPA Method 8015 TPH-d



Split Sampling Results:

EPA Method 8015 TPH-d w/ SGC



 Between 66–86% of the total RHMW02 TPH-d result is from polar material/non-hydrocarbons. *01/17/2019*

Split Sampling Results:

EPA Method 8270SIM PAHs

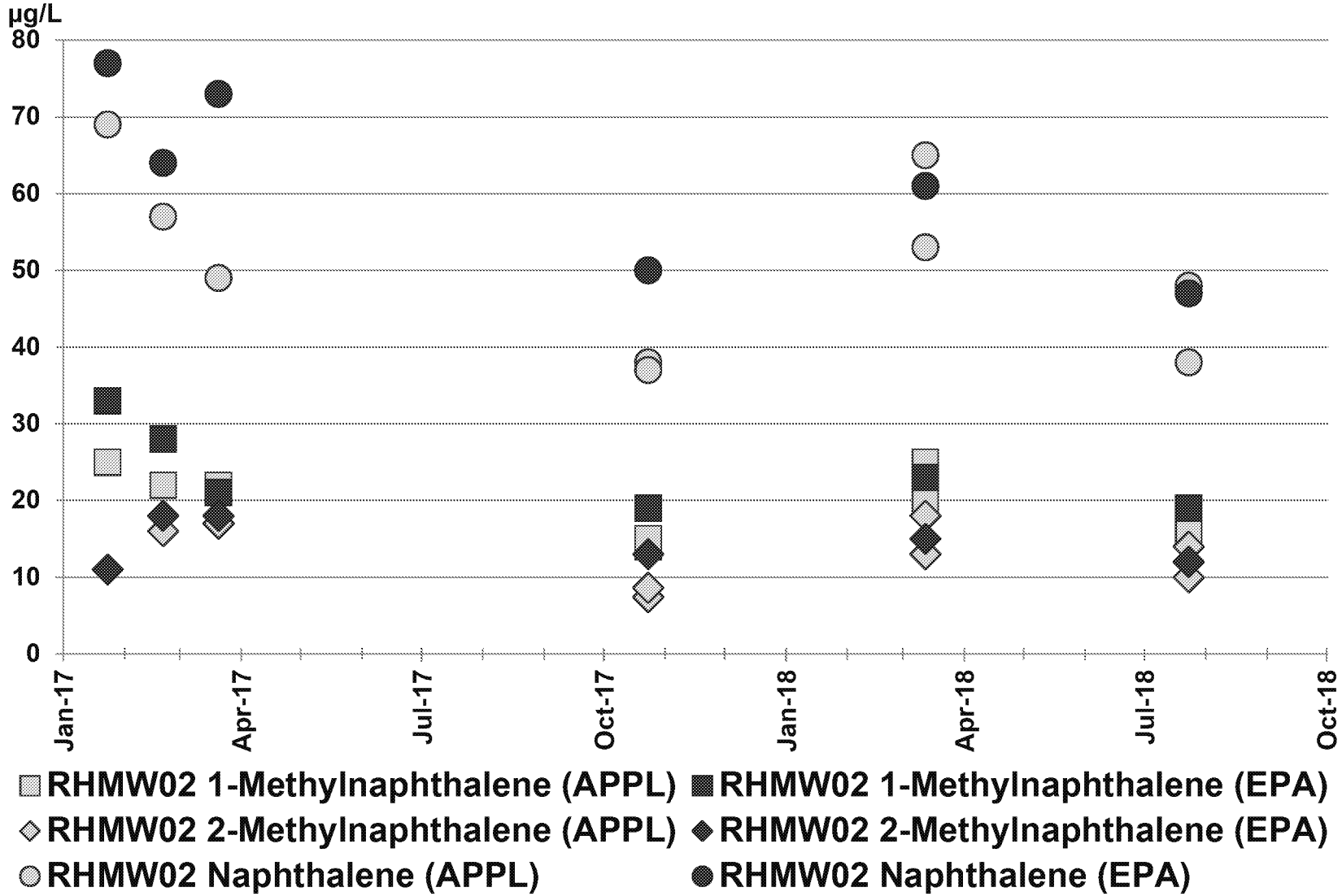
Monitoring Well	Monitoring Event	Analyte:	1-Methylnaphthalene			2-Methylnaphthalene			Naphthalene		
		EAL:	10			10			17		
		Lab:	APPL	EPA	RPD	APPL	EPA	RPD	APPL	EPA	RPD
RHMW01	2018 Q3 (Jul)	primary; ERH637	< 0.1 U	< 0.025 U	—	< 0.1	< 0.025 U	—	< 0.1 U	0.13	—
	2018 Q1 (Mar)	primary; ERH545	< 0.1 U	< 0.025 U	—	< 0.1	< 0.025 U	—	< 0.1 U	0.19	—
	2017 Q4 (Oct)	primary; ERH412	< 0.1 U	< 0.025 U	—	< 0.1	< 0.025 U	—	< 0.1 U	0.17	—
		duplicate; ERH413	< 0.1 U	—	—	< 0.1	—	—	< 0.1 U	—	—
	2017 Mar	primary; ERH275	< 0.1 U	< 0.026 U	—	< 0.1	< 0.026 U	—	< 0.1 U	0.089	—
	2017 Feb	primary; ERH223	< 0.1 U	< 0.025 U	—	< 0.1	< 0.025 U	—	< 0.1 U	0.13	—
	2017 Q1 (Jan)	primary; ERH172	< 0.1 U	< 0.025 U	—	< 0.1	< 0.025 U	—	< 0.1 U	< 0.025 U	—
RHMW02	2018 Q3 (Jul)	primary; ERH639	16	19	17%	10	12	18%	38	47	21%
		duplicate; ERH640	19	—	—	14	—	—	48	—	—
	2018 Q1 (Mar)	primary; ERH547	20	23	14%	13	15	14%	53	61	14%
		duplicate; ERH548	25	—	—	18	—	—	65	—	—
	2017 Q4 (Oct)	primary; ERH415	14	19	30%	7.4	13	55%	38	50	27%
		duplicate; ERH416	15	—	—	8.6	—	—	37	—	—
	2017 Mar	primary; ERH265	22	21	5%	17	18	6%	49	73	39%
	2017 Feb	primary; ERH216	22	28	24%	16	18	12%	57	64	12%
	2017 Q1 (Jan)	primary; ERH174	25	33	28%	11	11	0%	69	77	11%
RHMW03	2018 Q3 (Jul)	primary; ERH642	< 0.1 U	< 0.027 U	—	< 0.1	< 0.027 U	—	< 0.1 U	< 0.027 U	—
	2018 Q1 (Mar)	primary; ERH550	< 0.1 U	< 0.025 U	—	< 0.1	< 0.025 U	—	< 0.1 U	< 0.025 U	—
	2017 Q4 (Oct)	primary; ERH418	< 0.1 U	< 0.025 U	—	< 0.1	< 0.025 U	—	< 0.1 U	< 0.025 U	—
		duplicate; ERH419	< 0.1 U	—	—	< 0.1	—	—	< 0.1 U	—	—
	2017 Mar	primary; ERH268	< 0.1 U	< 0.027 U	—	< 0.1	< 0.027 U	—	< 0.1 U	< 0.027 U	—
	2017 Feb	primary; ERH231	< 0.1 U	< 0.025 U	—	< 0.1	< 0.025 U	—	< 0.1 U	< 0.025 U	—
	2017 Q1 (Jan)	primary; ERH181	< 0.1 U	< 0.025 U	—	< 0.1	< 0.025 U	—	< 0.1 U	< 0.025 U	—

Grey shaded text indicates analyte exceeds DOH EAL.
Light blue shaded text indicates RPD greater than 30%, with APPL values higher than EPA values.
Purple shaded text indicates RPD greater than 30%, with APPL values lower than EPA values.

- **APPL reported slightly lower concentrations than EPA R9 Lab for PAHs, but recoveries are similar for most events.**

RPD = relative percent difference

Split Sampling Results:
EPA Method 8270SIM PAHs



Split Sampling Results:

Summary and Recommendations

- Method optimization performed by APPL improved TPH-d recoveries.
  - Based on comparison between TPH with and without SGC, majority of the TPH concentration is from polar compounds/metabolites and not hydrocarbons.
  - Optimization improved APPL's ability to recover both the nonpolar and polar hydrocarbons.
- Based on the 2018 Q3 (July) results, APPL and EPA R9 Lab have similar TPH-d and PAH recoveries.
- Recommended split sampling.
  - Collect split sample from RHMW02 once a year.
    - Analyze for TPH–d (with and without SGC) and PAHs (1–methylnaphthalene, 2–methylnaphthalene, and naphthalene only).
  - If a new laboratory is contracted to analyze the groundwater LTM samples, collect split samples from all wells in monitoring well network.
    - Analyze for all analytes in the LTM analytical program.

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Synoptic Study Data Review

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Synoptic Study Data Review:

Purpose

NAVFAC

Previously analyzed Synoptic Study data to:

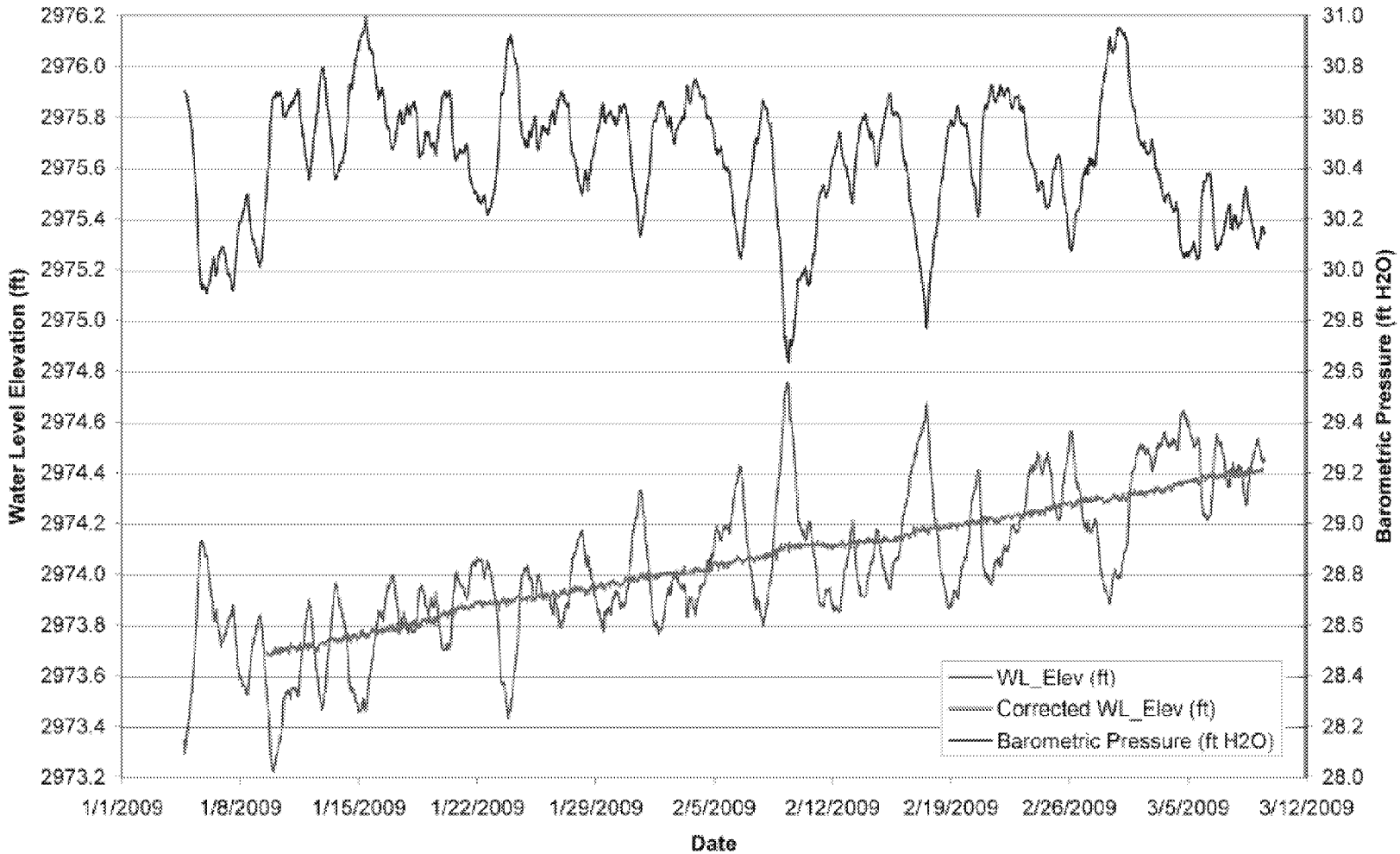
- **Evaluate regional basal aquifer response to pumping from**
  - BWS Halawa Shaft
  - Navy Aiea Shaft
  - Navy Red Hill Shaft
  - BWS Moanalua Wells
- **Evaluate hydraulic head changes in the regional basal aquifer**
  - Various pumping conditions/combinations
  - Non-pumping conditions (locally)
- **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

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

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	0.566333333

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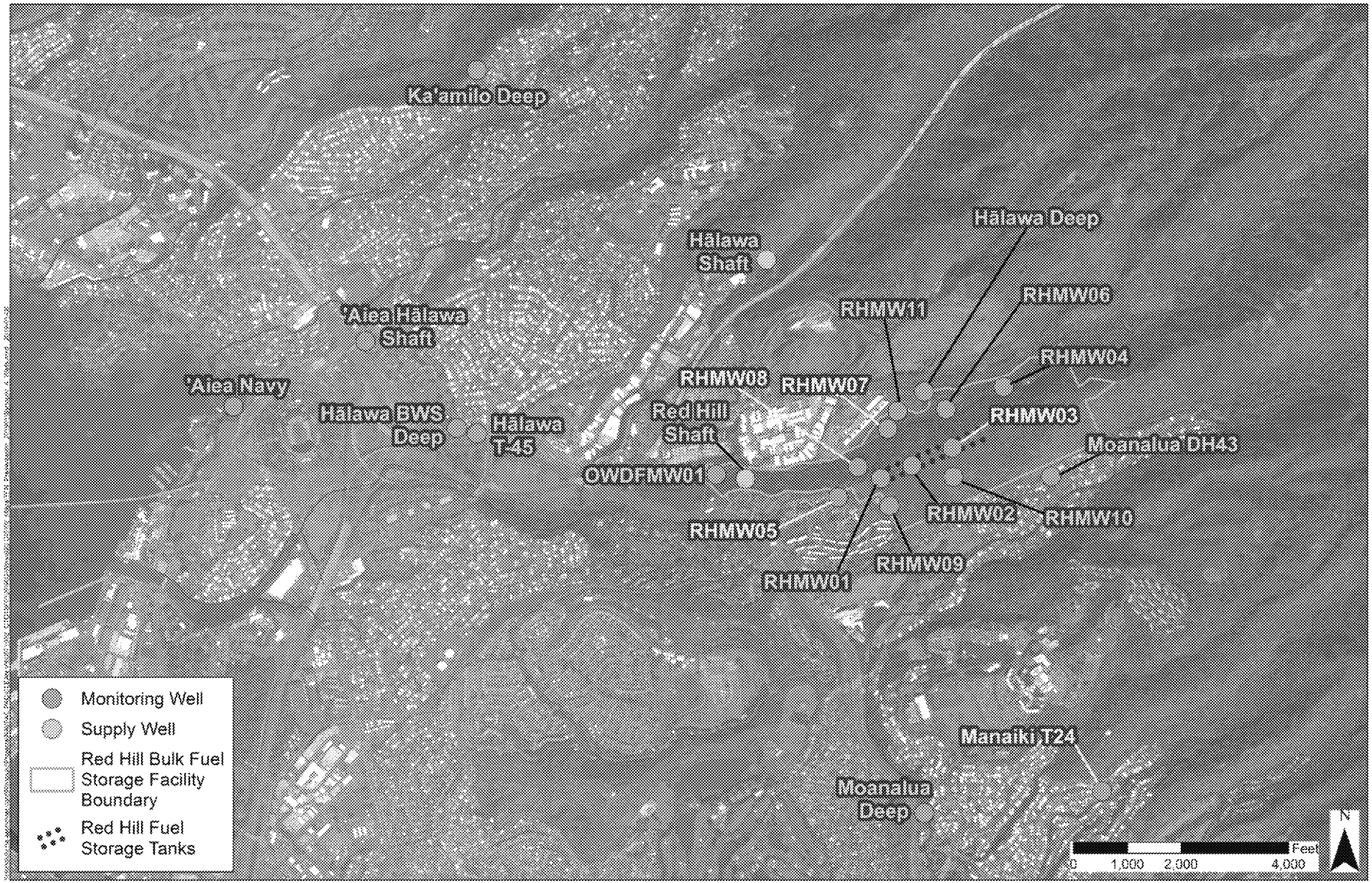
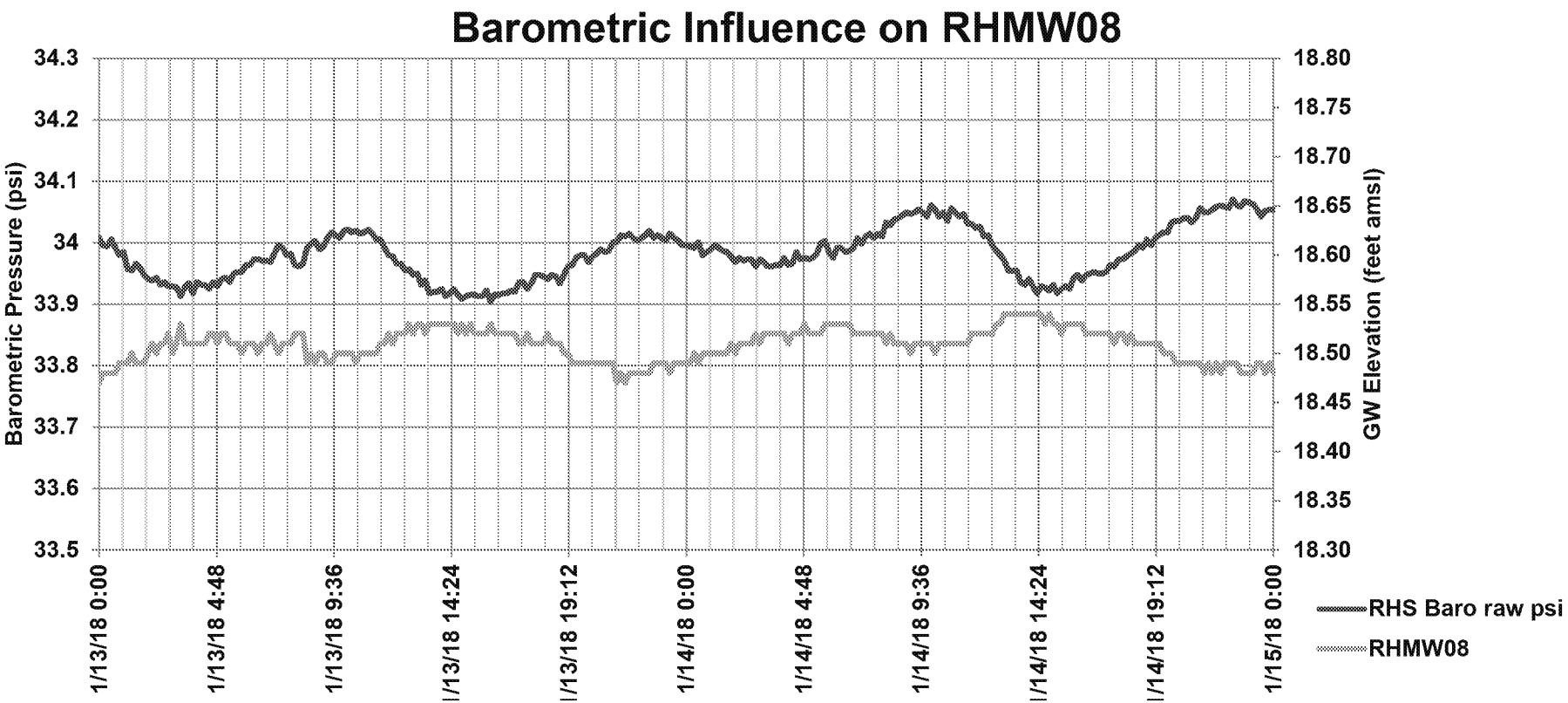
Synoptic Study Data Review:

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



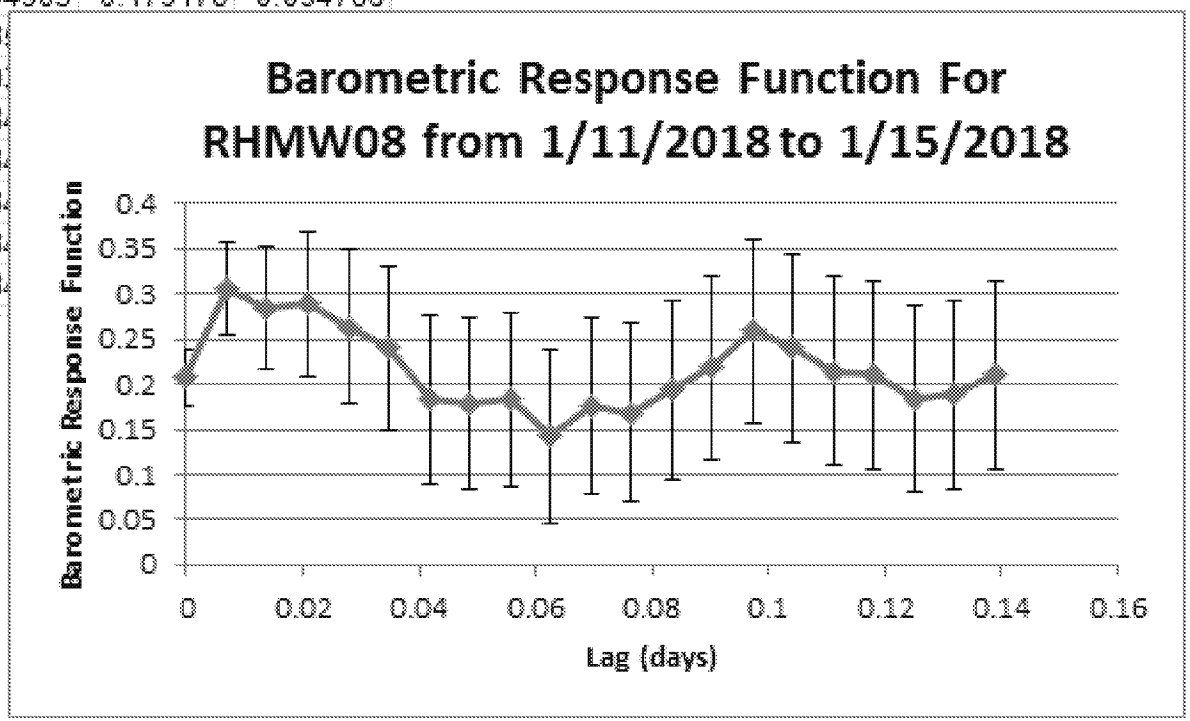
Synoptic Study Data Review:

Barometric Response During Non-pumping at Red Hill Shaft

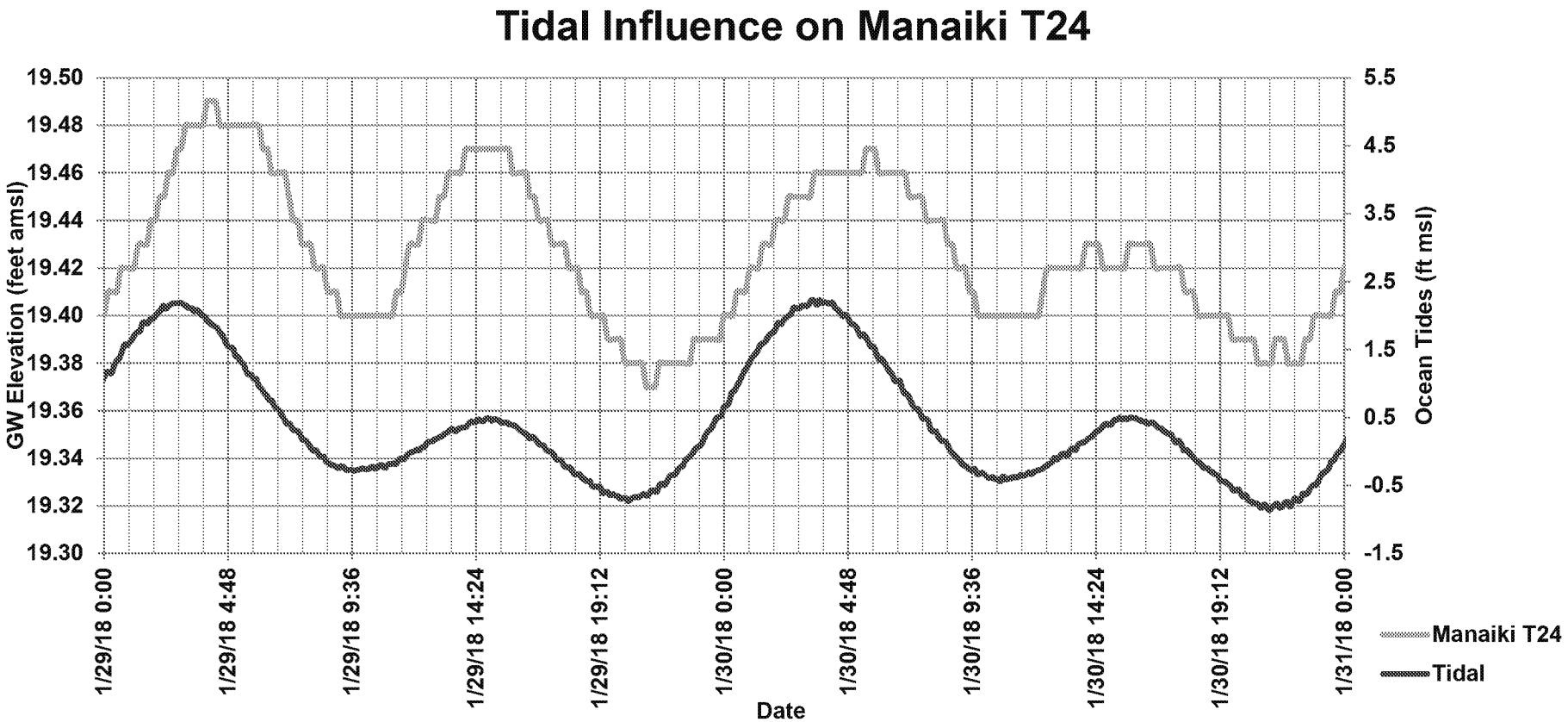


Selecting Barometric Lag

		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		

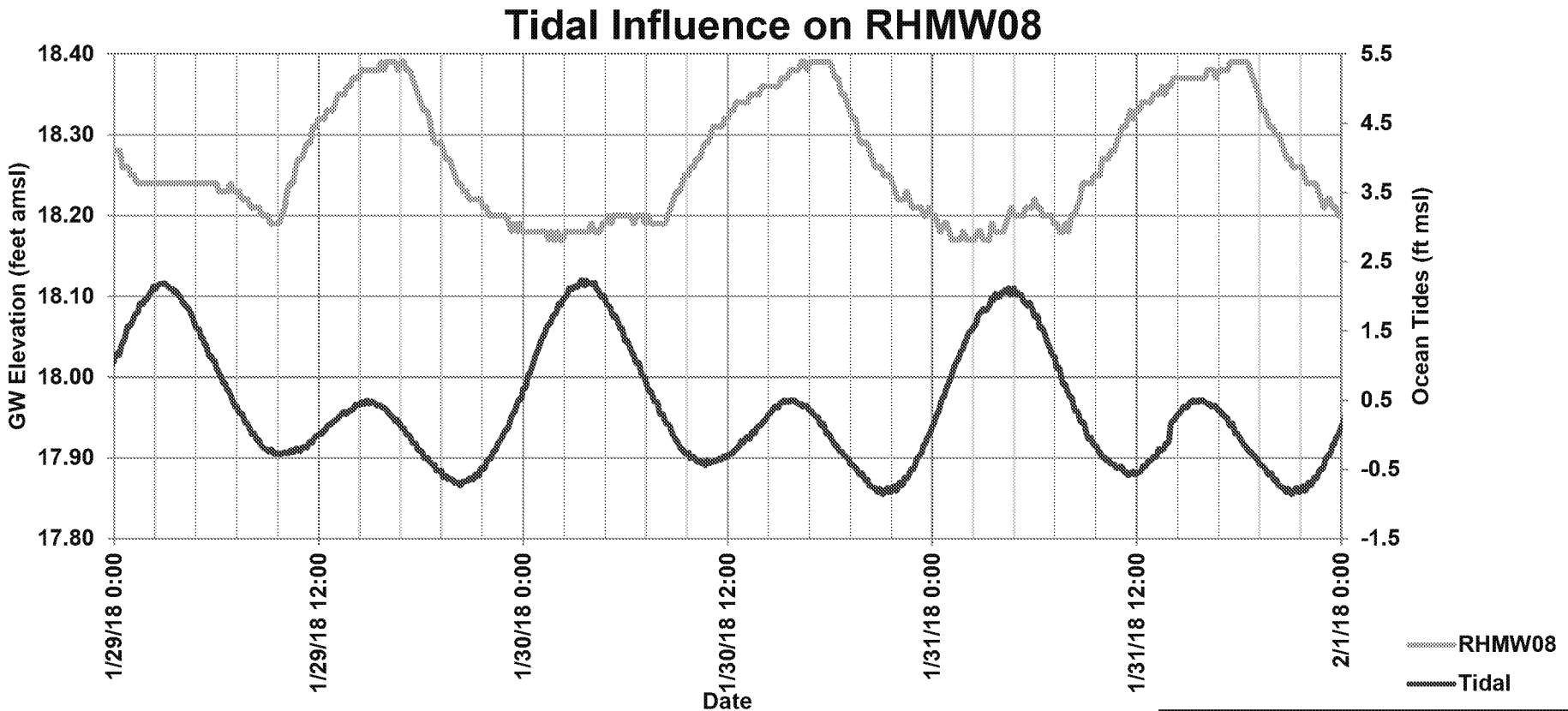


Selecting Tidal Lag



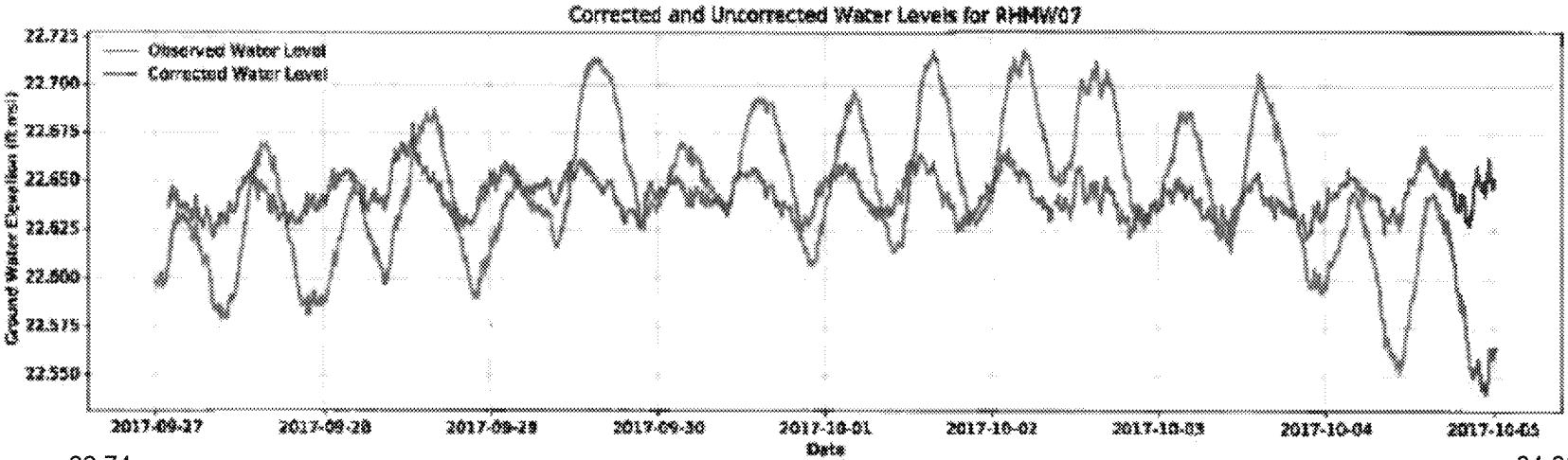
Synoptic Study Data Review:

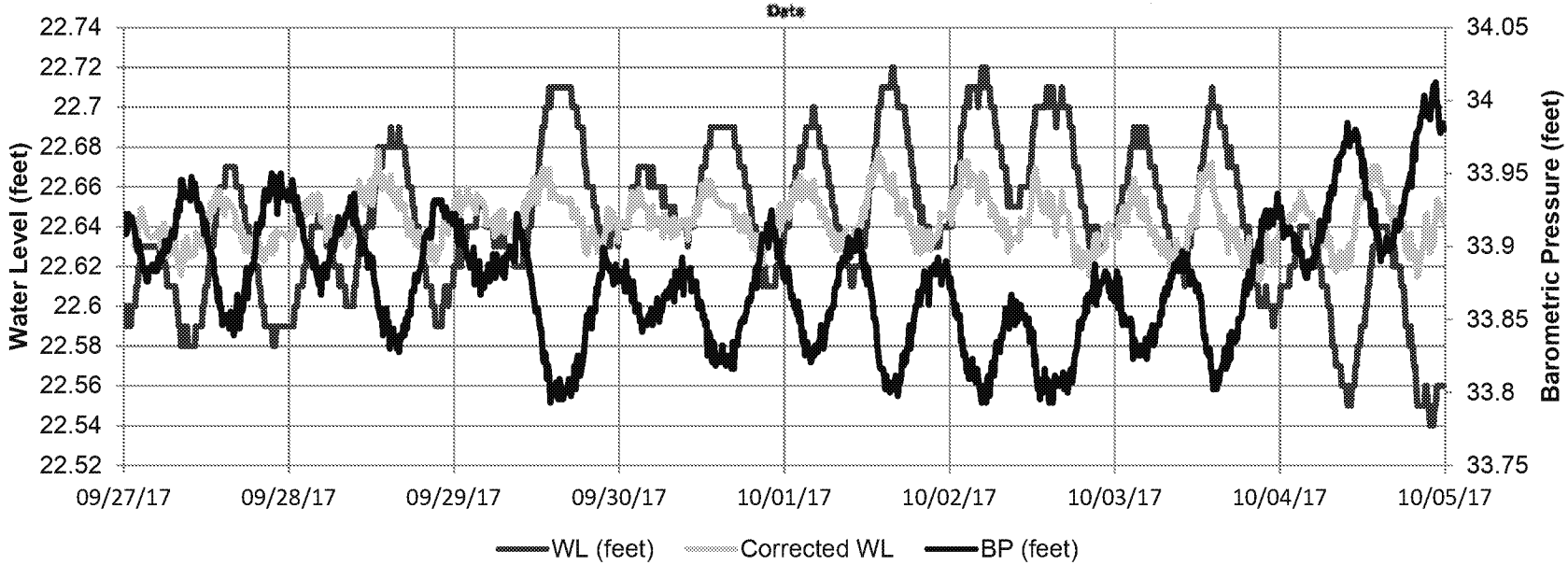
Selecting Tidal Lag



		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





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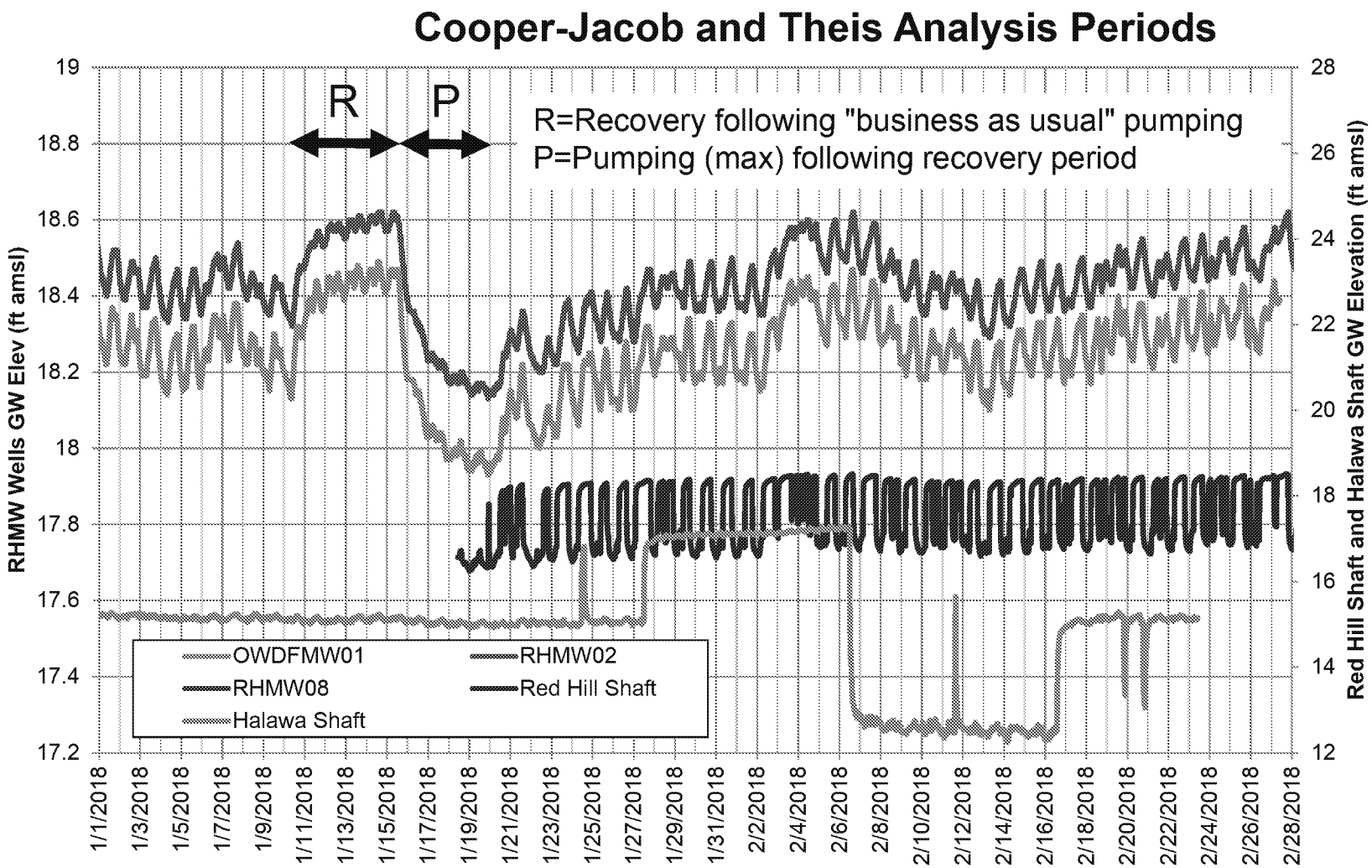
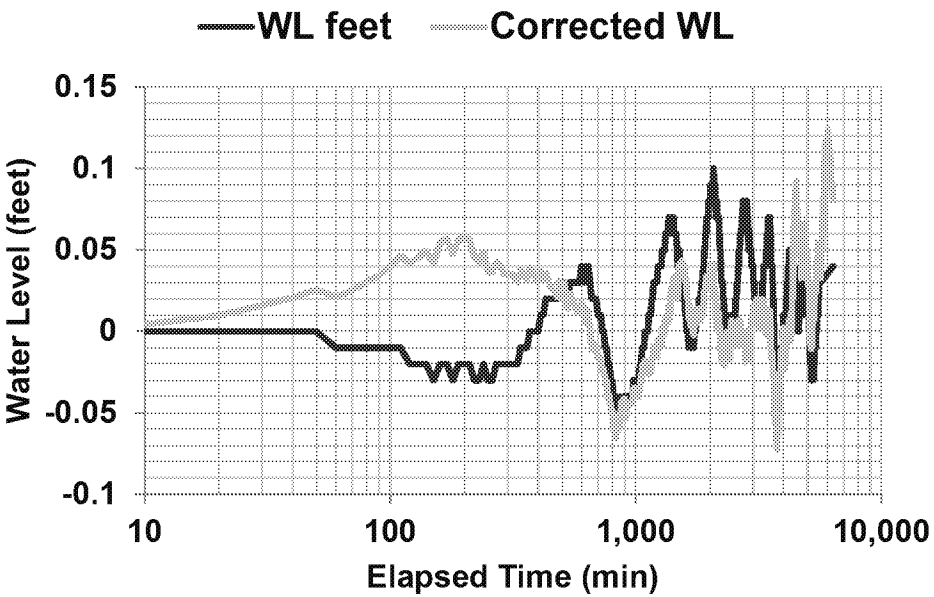
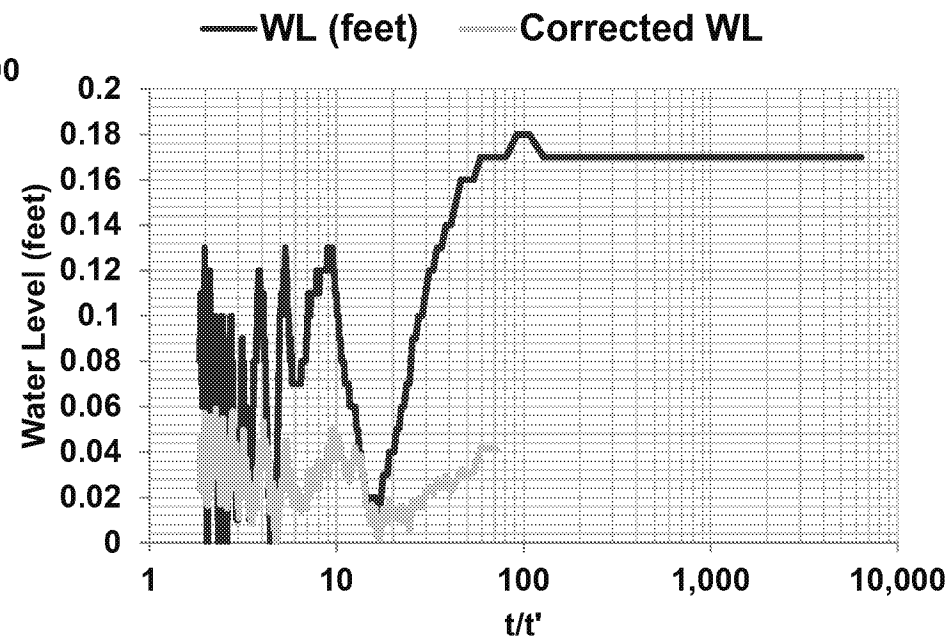
Analysis Periods for Cooper-Jacob and Theis Evaluations



Synoptic Study Data Review:

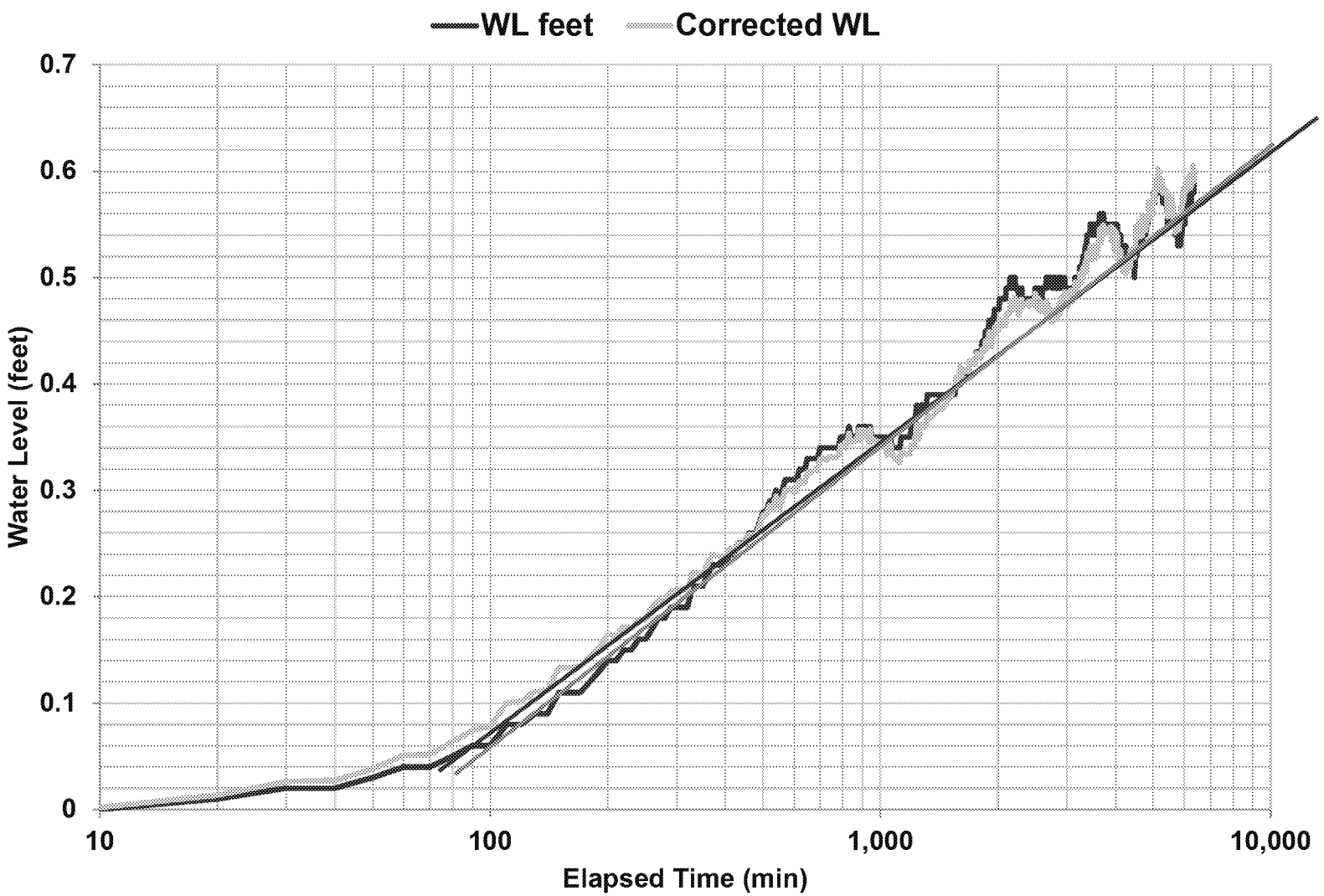
RHMW07 - Semi-log Plots Corrected for BP





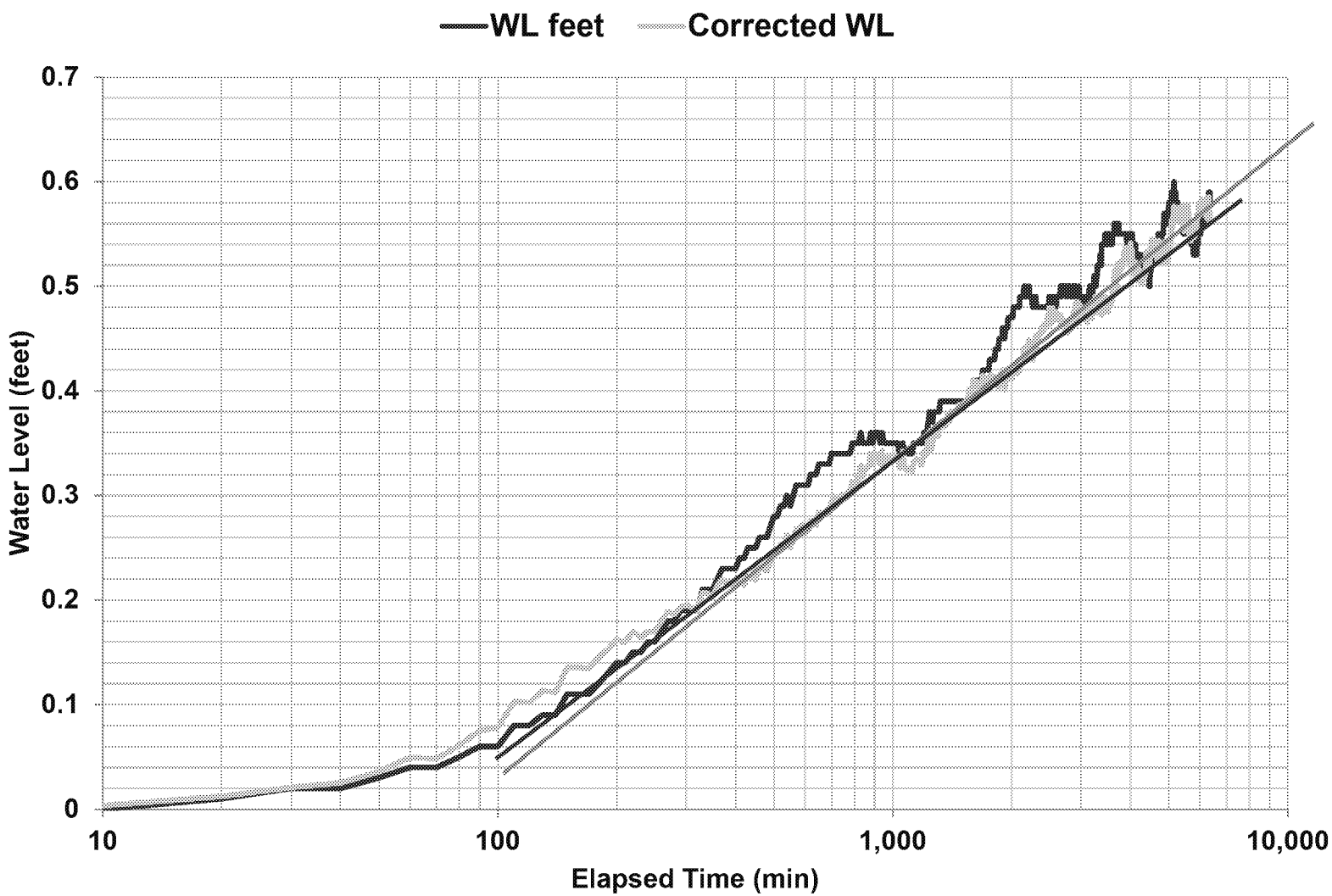
Synoptic Study Data Review:

BP Corrections – Cooper-Jacob RHMW08 Drawdown



Synoptic Study Data Review:

BP & Tidal Corrections – Cooper-Jacob RHMW08 Drawdown



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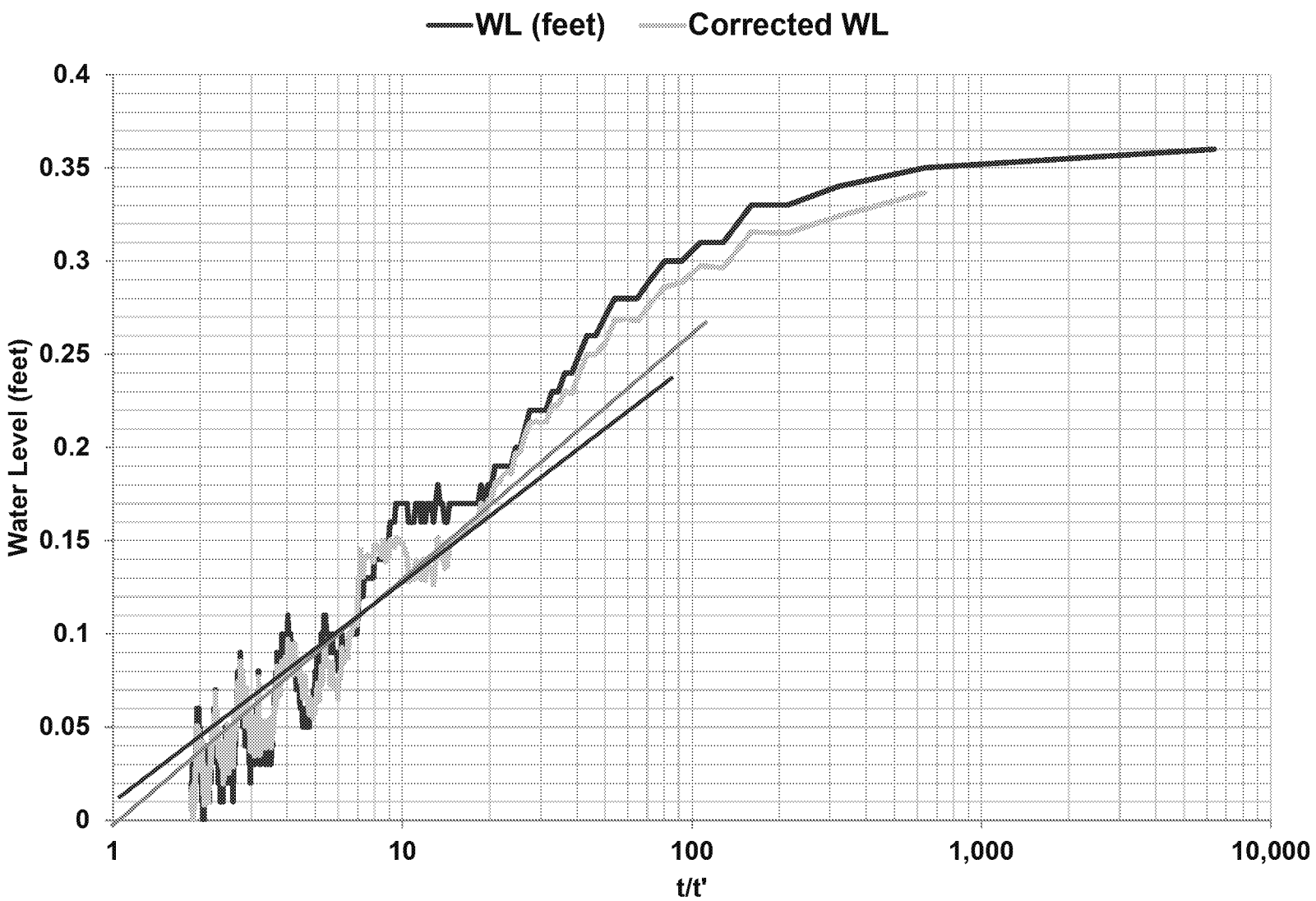
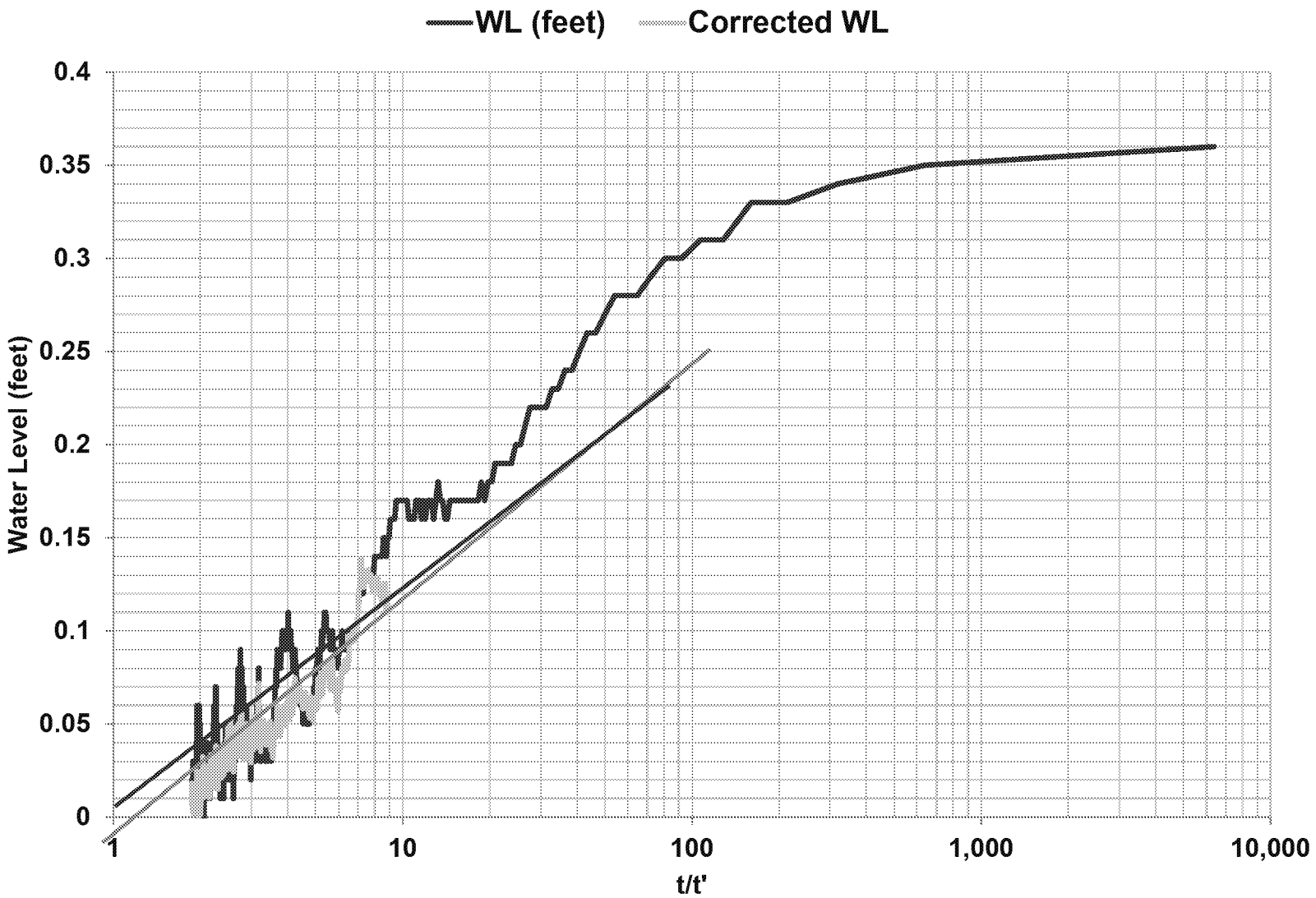
Synoptic Study Data Review:

BP Corrections – Cooper-Jacob RHMW08 Recovery



Synoptic Study Data Review:

BP & Tidal Corrections – Cooper-Jacob RHMW08 Recovery



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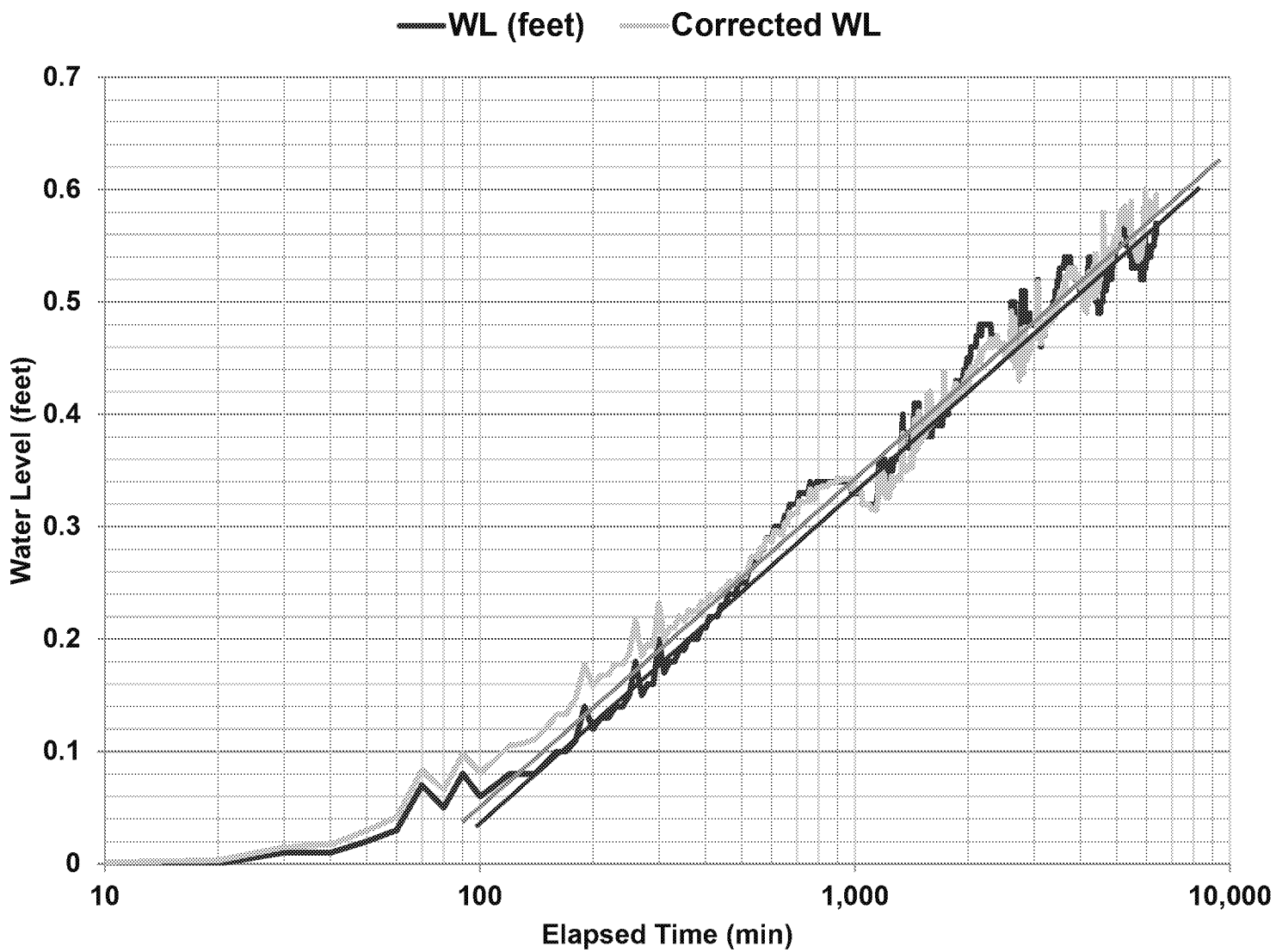
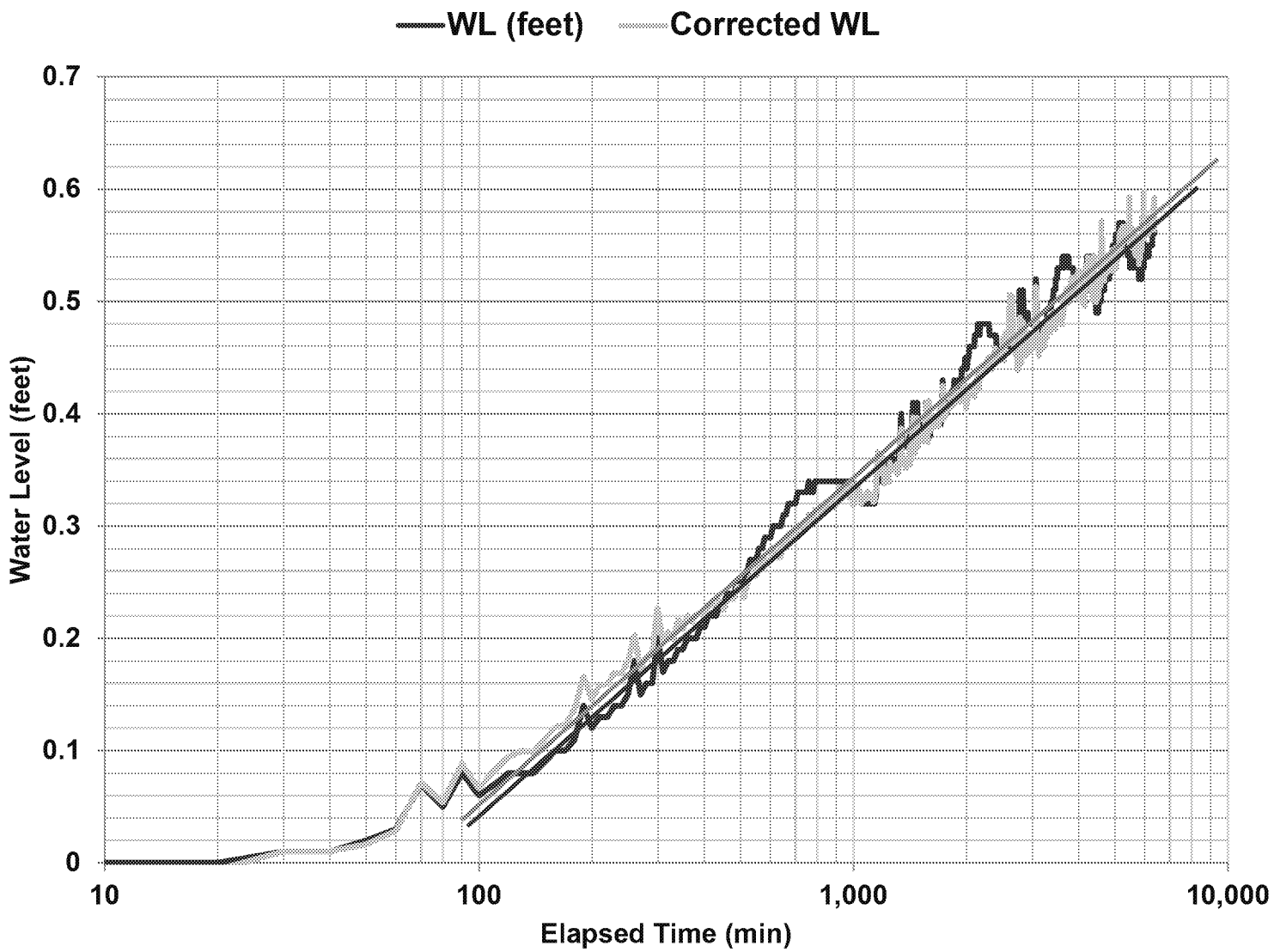
Synoptic Study Data Review:

BP Corrections – Cooper-Jacob RHMW05 Drawdown



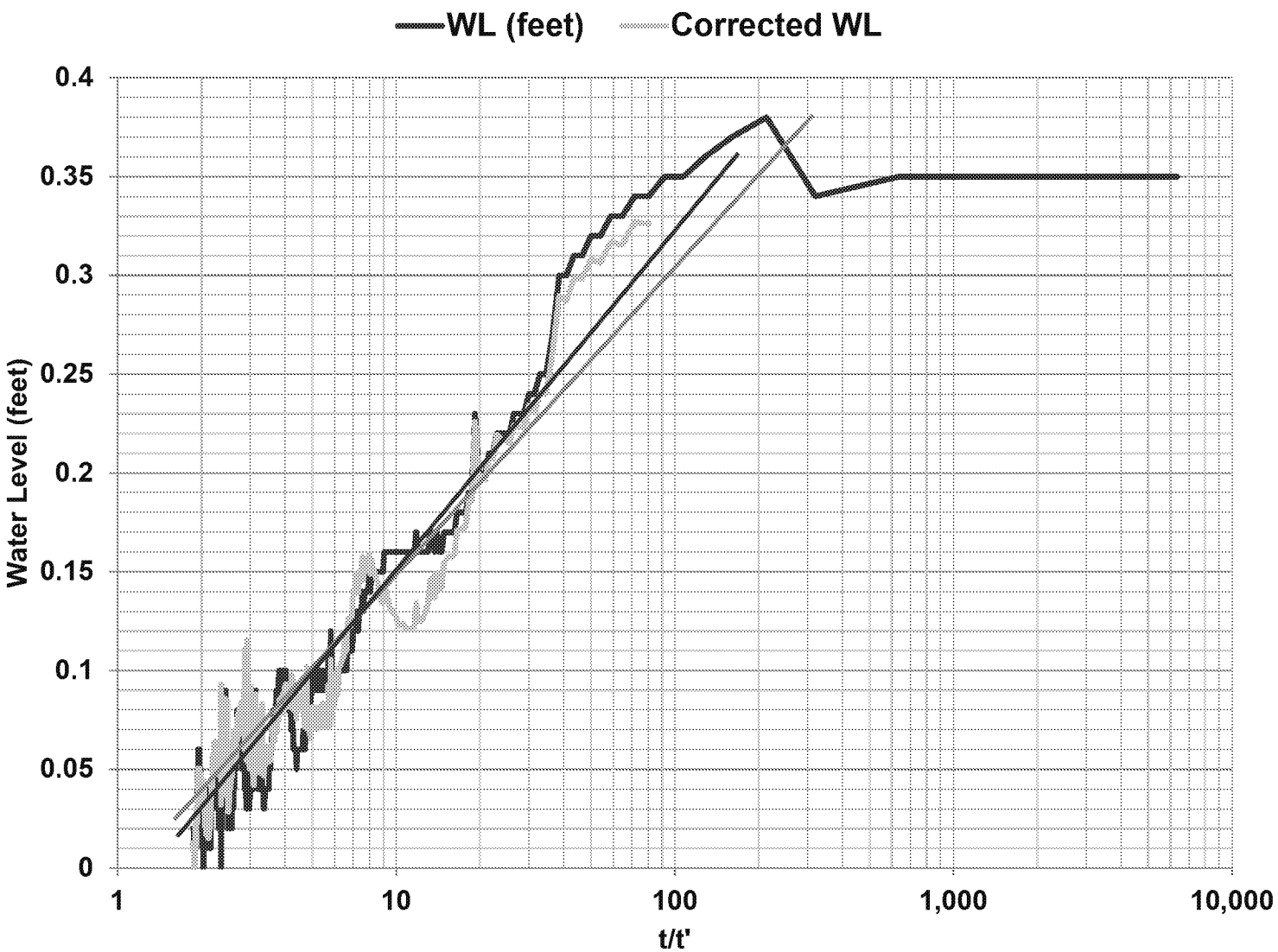
Synoptic Study Data Review:

BP & Tidal Corrections – Cooper-Jacob RHMW05 Drawdown



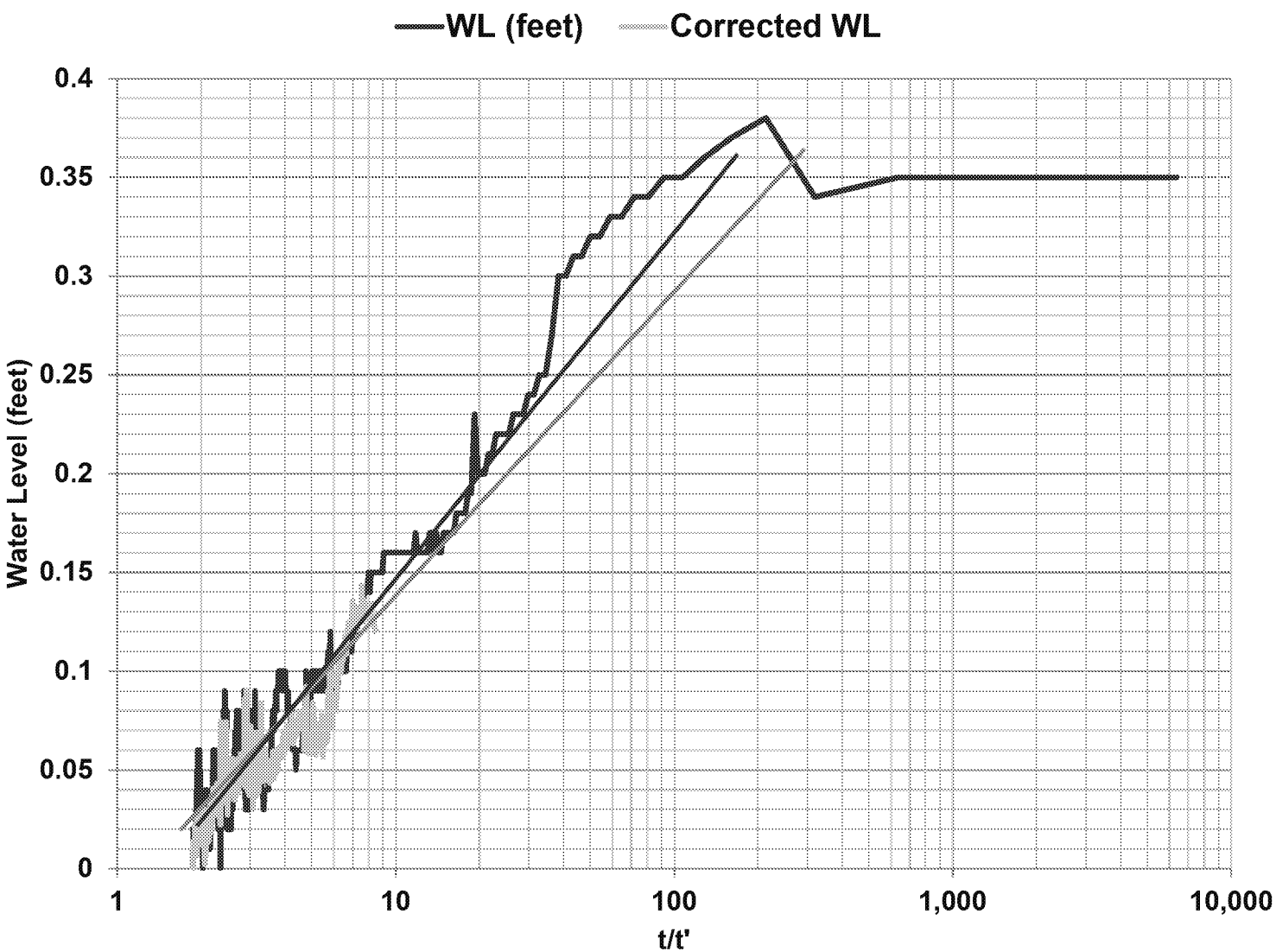
Synoptic Study Data Review:

BP Corrections – Cooper-Jacob RHMW05 Recovery



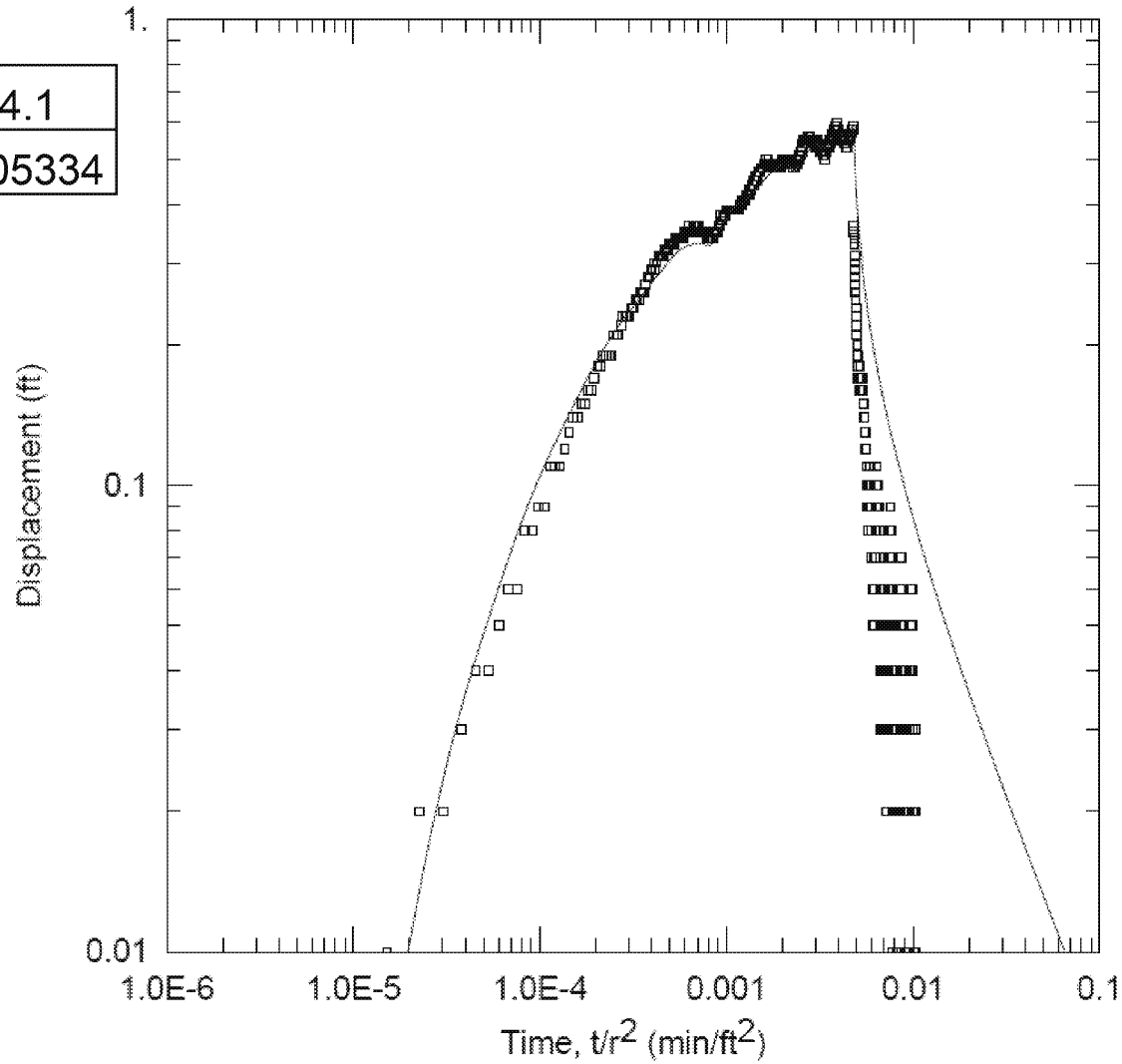
Synoptic Study Data Review:

BP & Tidal Corrections – Cooper-Jacob RHMW05 Recovery



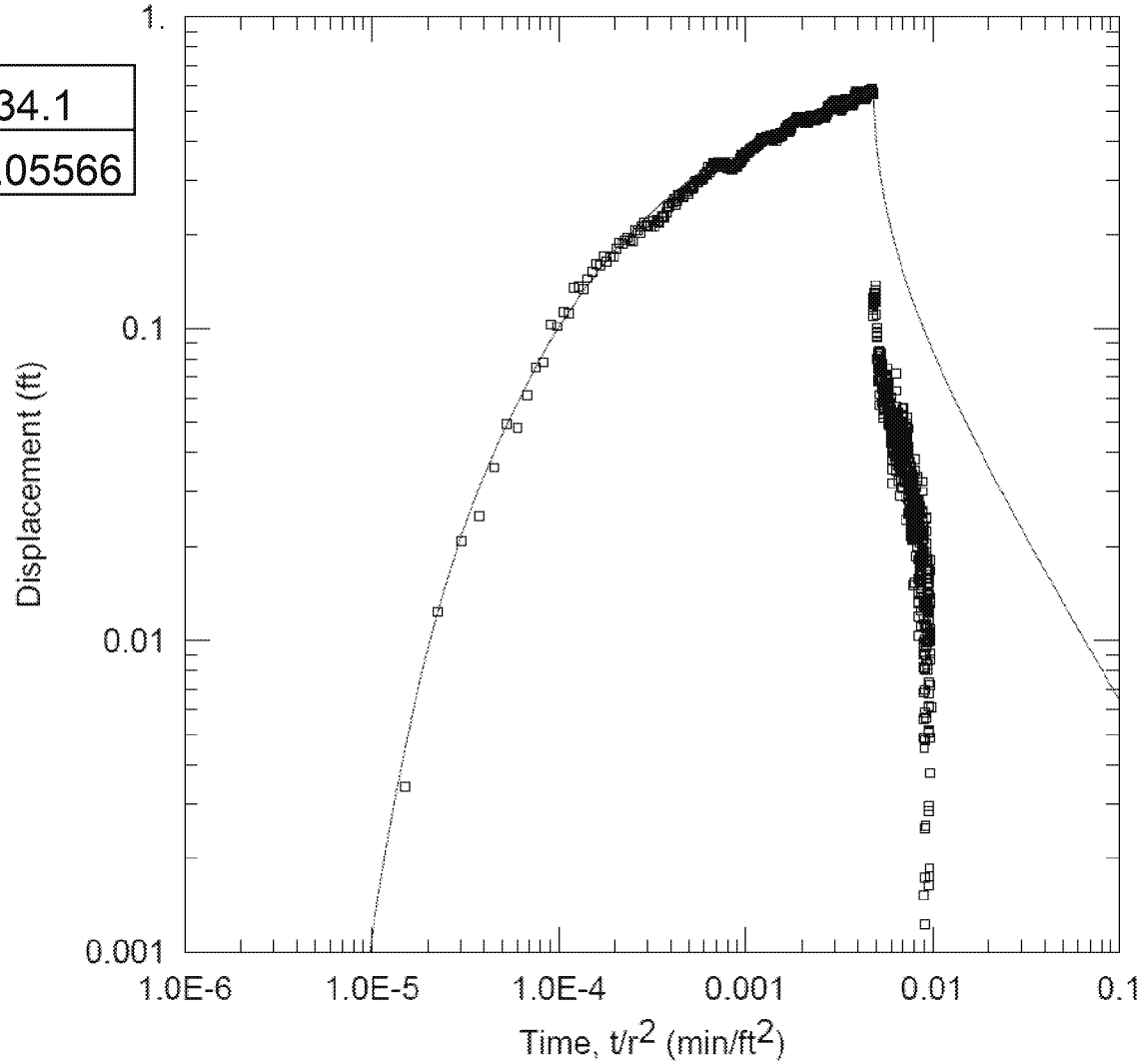
Uncorrected – Theis RHMW08

Transmissivity (ft^2/min)	434.1
Storativity	0.05334



BP & Tidal Corrections – Theis RHMW08 Drawdown

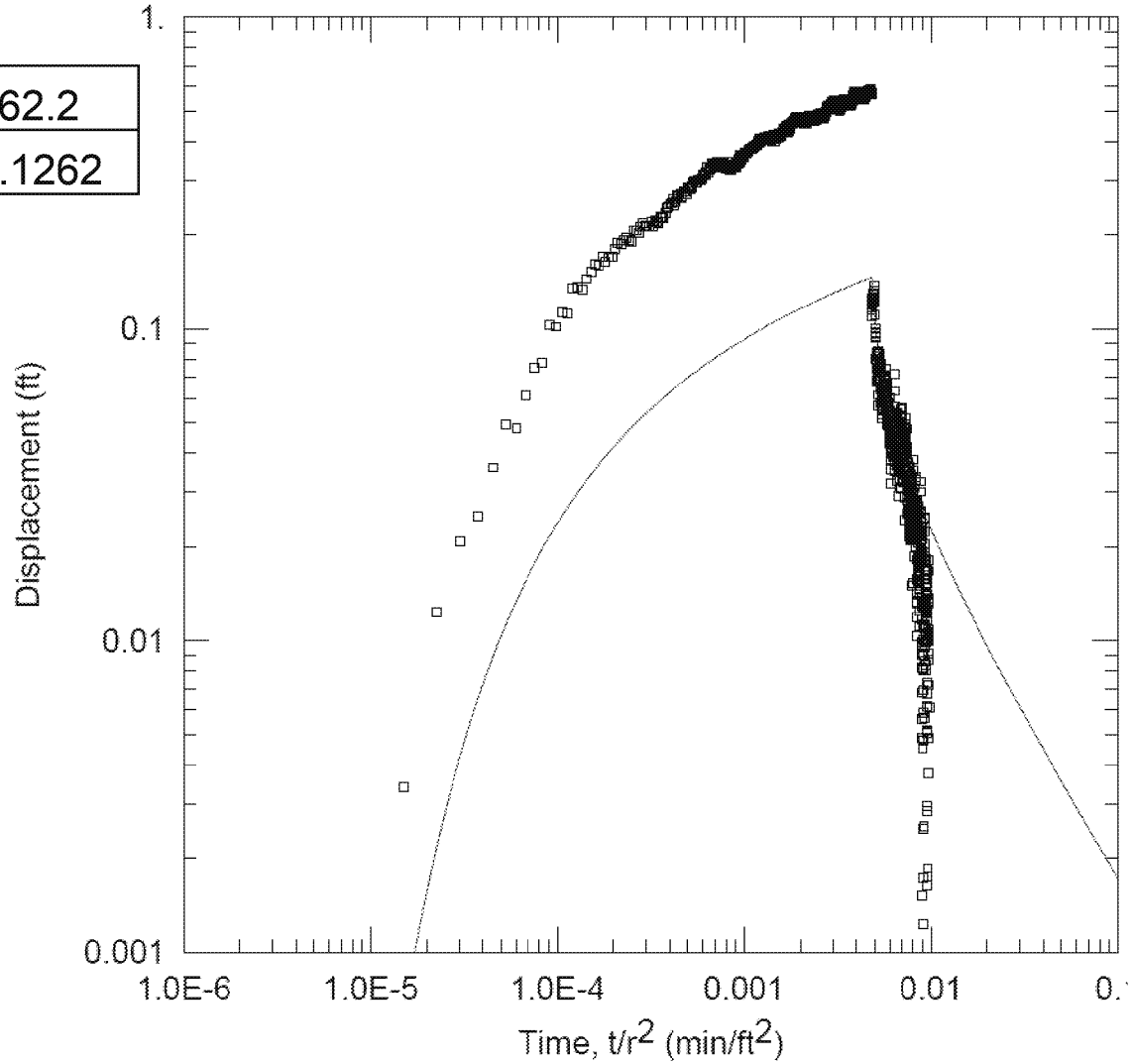
Transmissivity (ft^2/min)	434.1
Storativity	0.05566



Synoptic Study Data Review:

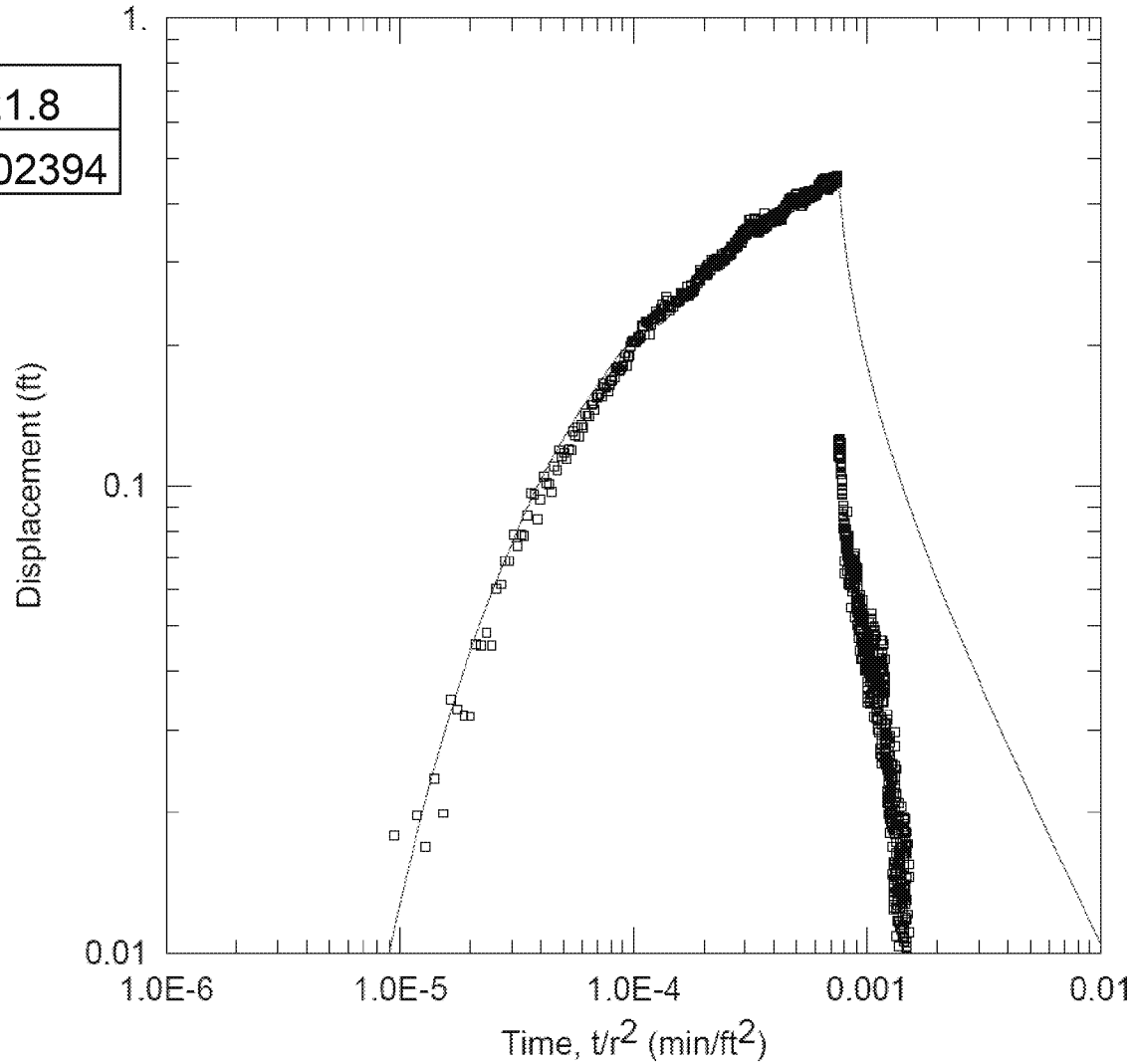
BP & Tidal Corrections – Theis RHMW08 Recovery

Transmissivity (ft^2/min)	762.2
Storativity	0.1262



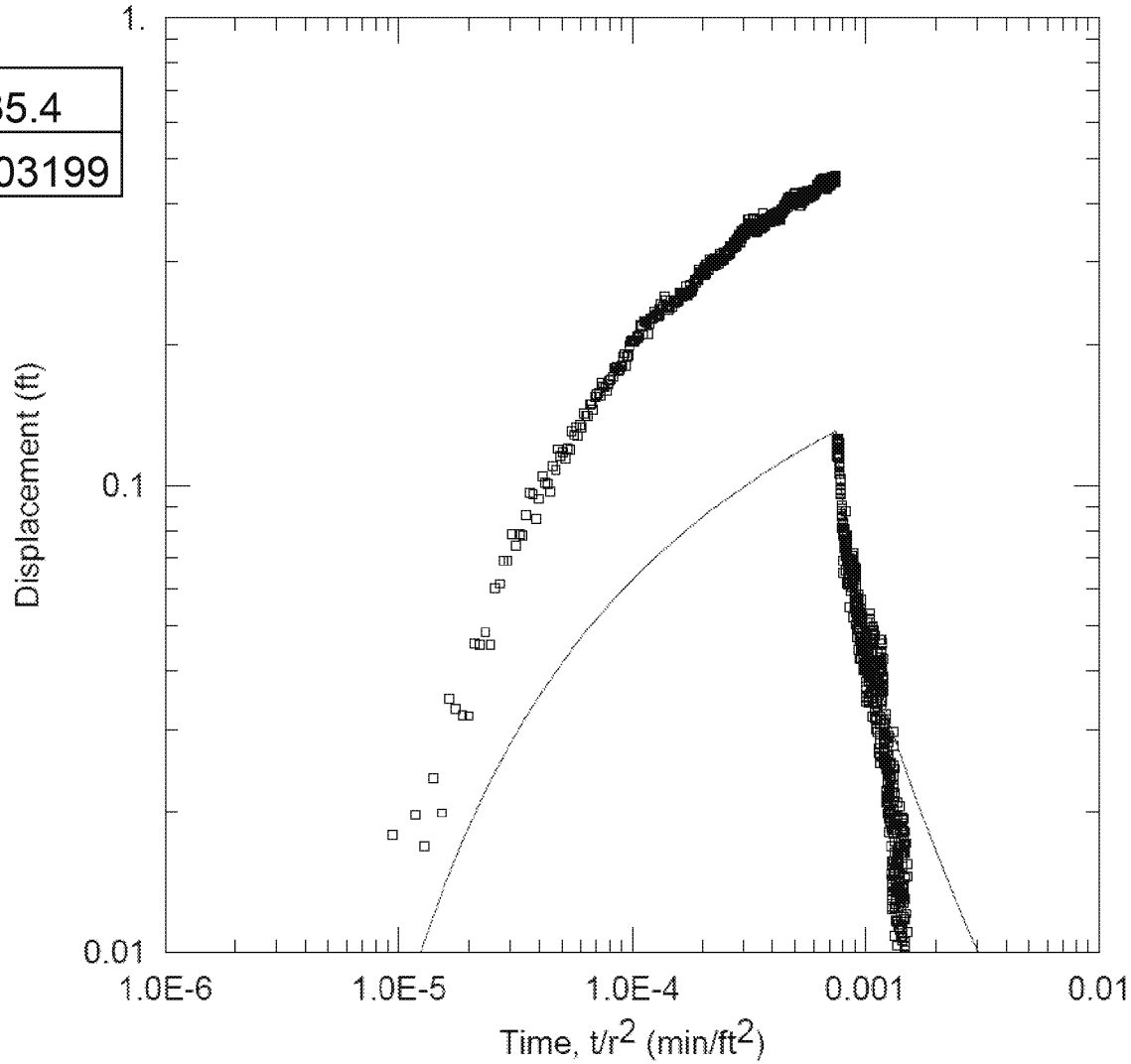
BP & Tidal Corrections – Theis RHMW03 Drawdown

Transmissivity (ft^2/min)	421.8
Storativity	0.02394



BP & Tidal Corrections – Theis RHMW03 Recovery

Transmissivity (ft^2/min)	735.4
Storativity	0.03199



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.

Summary and Next Steps

NAVFAC

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)

Transfer Function Noise Analysis

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**

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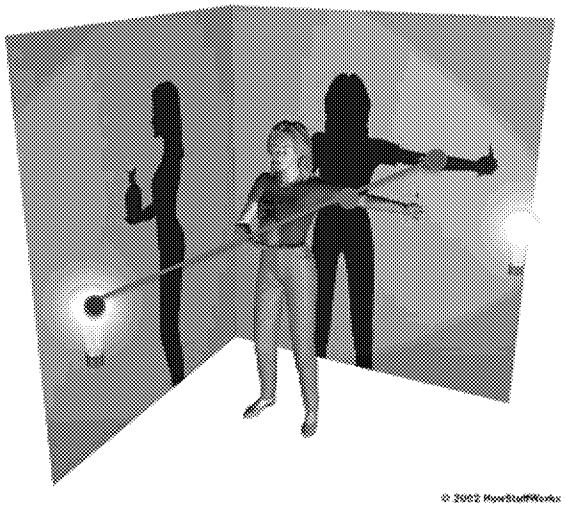
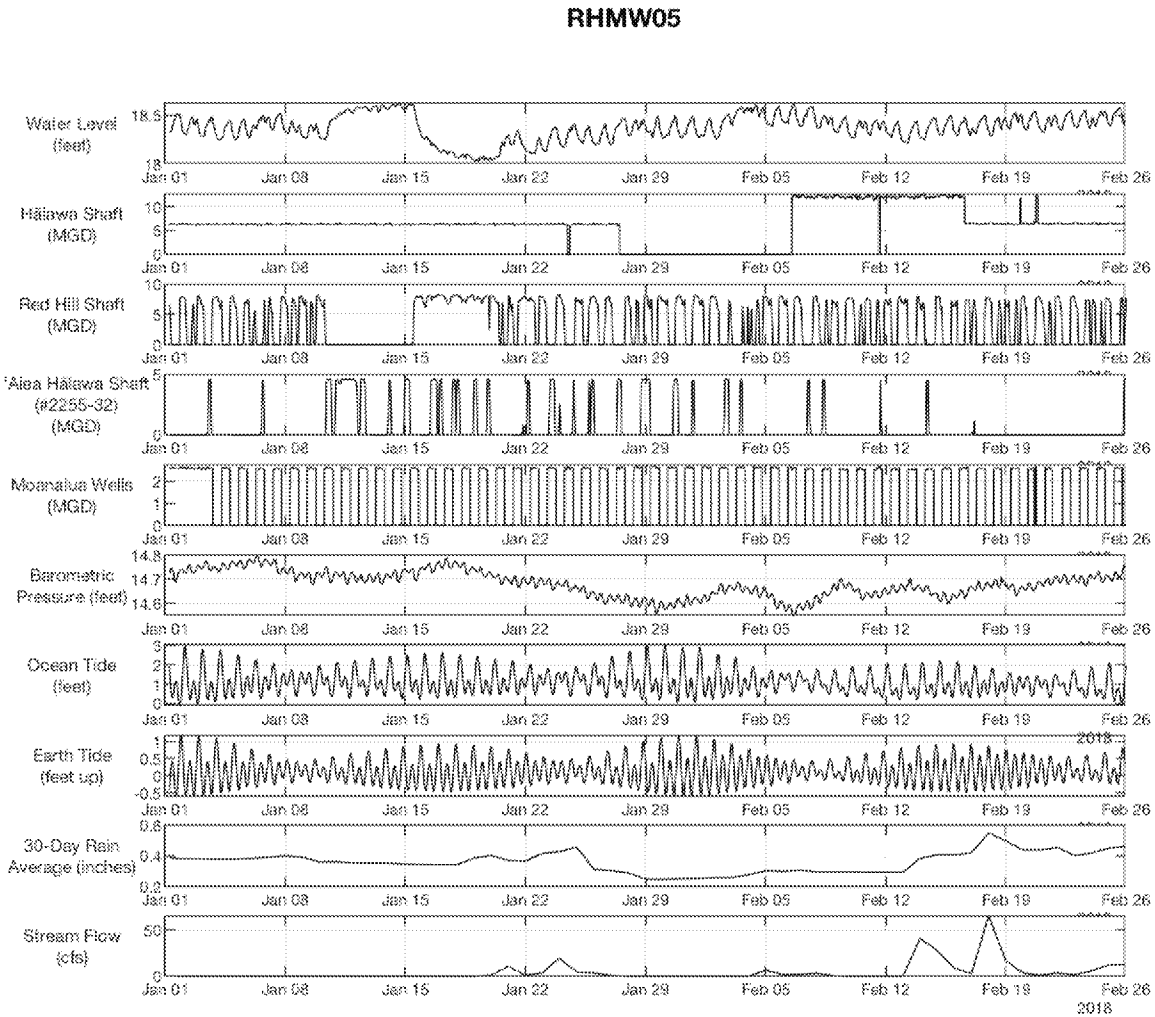
Value of TFN Analysis

- **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

TFN Analysis:
Synoptic Water Level Data



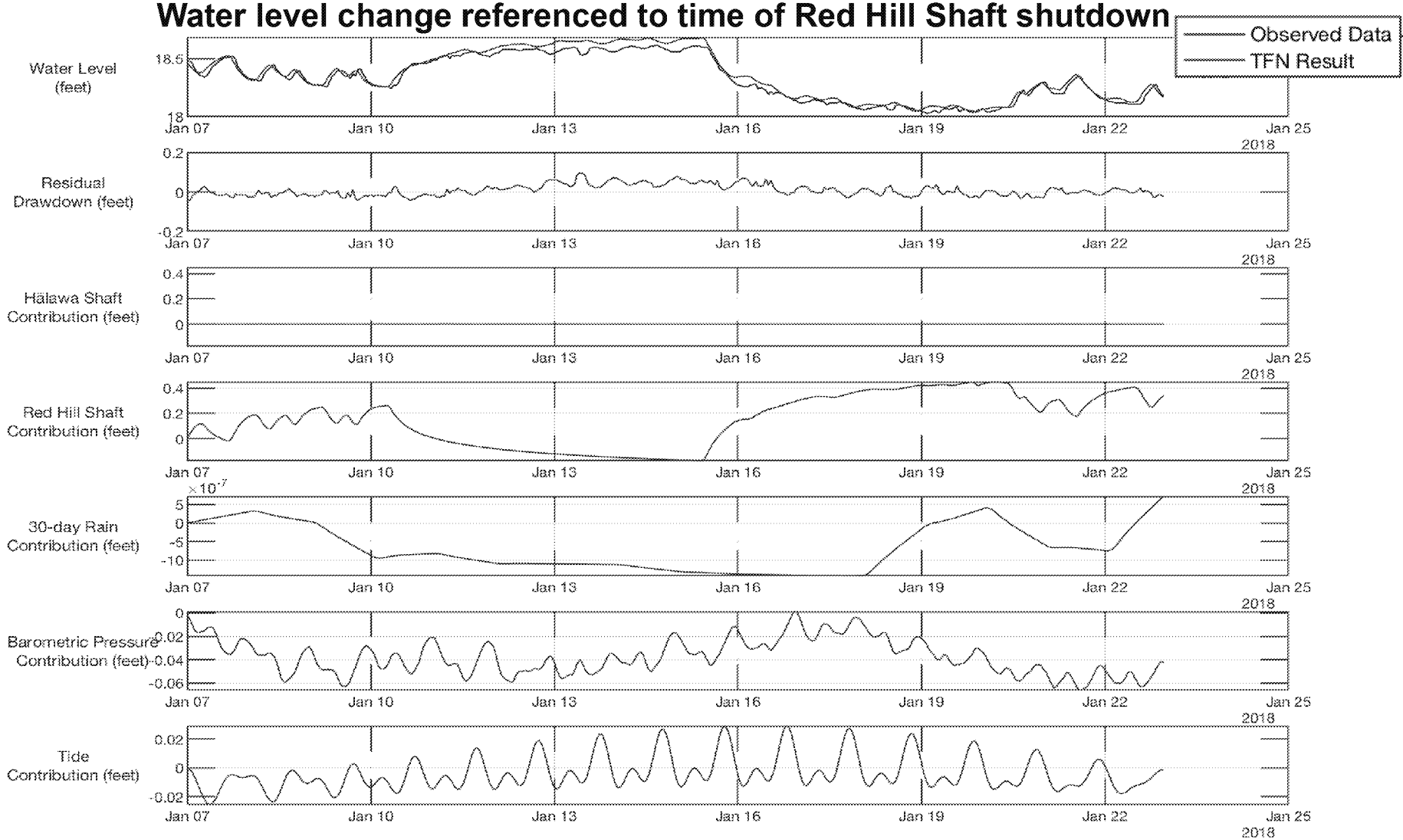
- Multiple sources and multiple observations
- Analogous to recording videos from different angles with known and unknown light sources flickering at different frequencies, durations, and intensities.



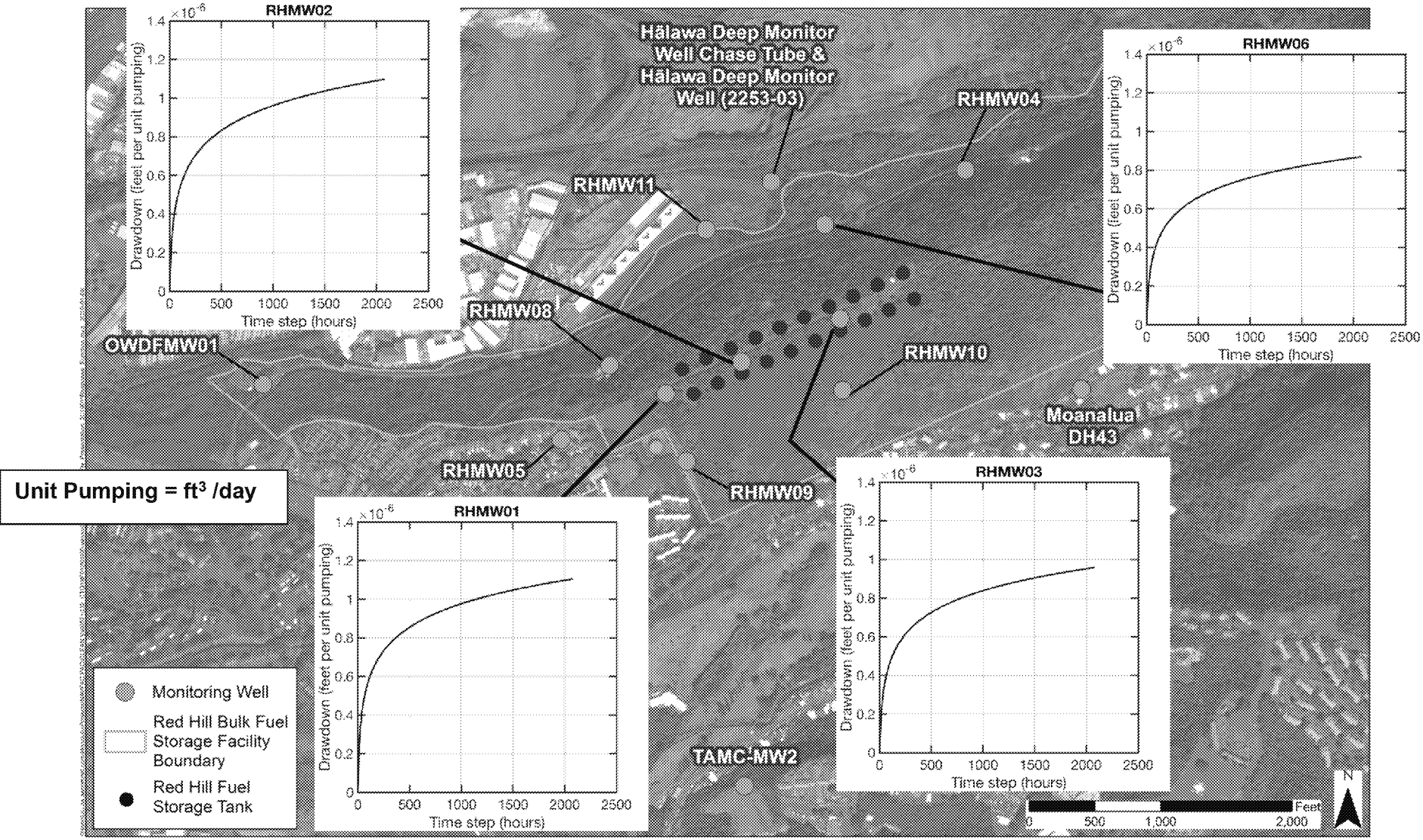
TFN Analysis:

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

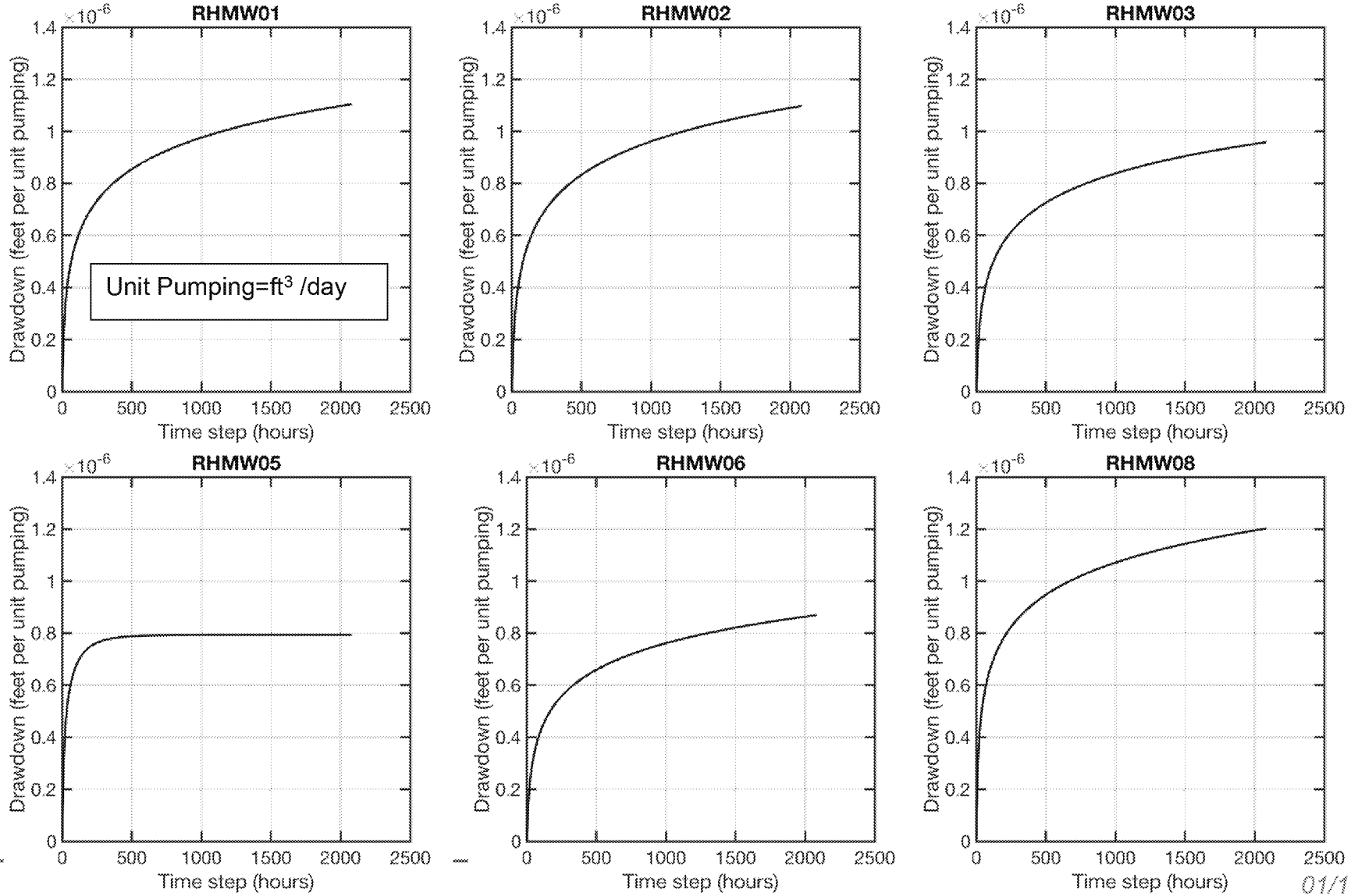
Water level change referenced to time of Red Hill Shaft shutdown



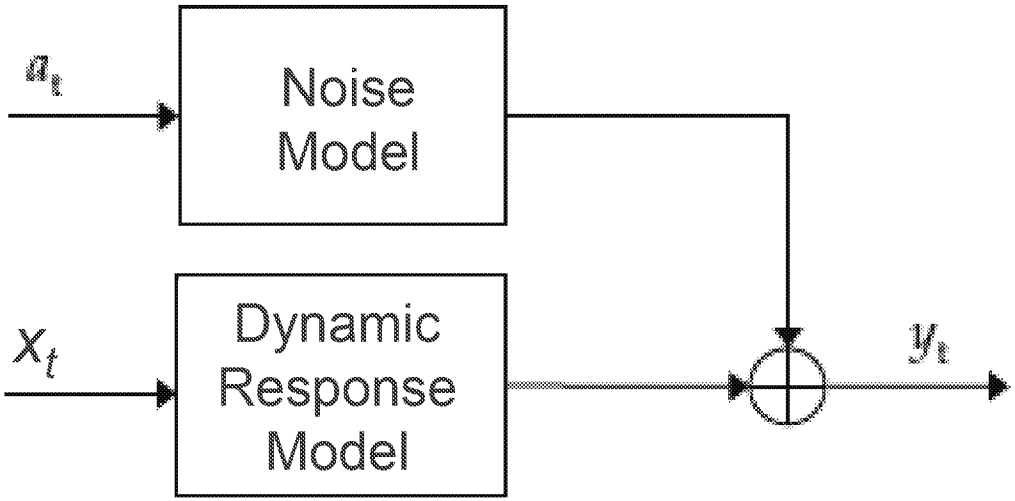
TFN Analysis:
Estimation of Step Response Functions for Groundwater Model Calibration (Red Hill Shaft Pumping)



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

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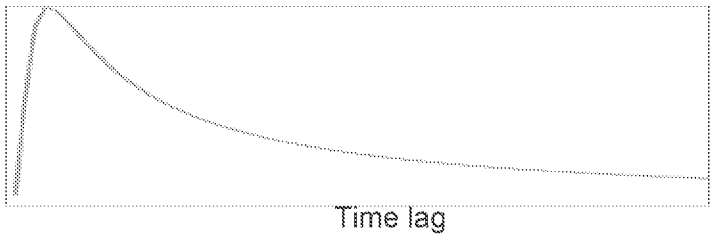
Discrete Transfer Function

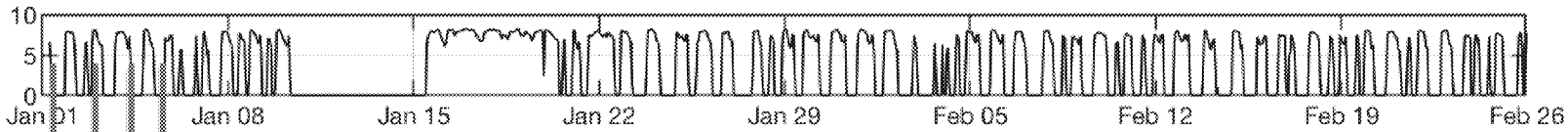
Unit impulse response function as transfer function

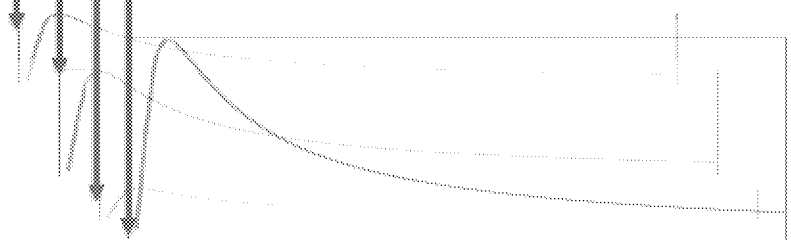
$$y_t = v_0 x_t + v_1 x_{t-1} + v_2 x_{t-2} + \cdots$$
$$= v(B) x_t$$
$$where\ v(B) = v_0 + v_1 B + v_2 B^2$$

Unit impulse response function



Source



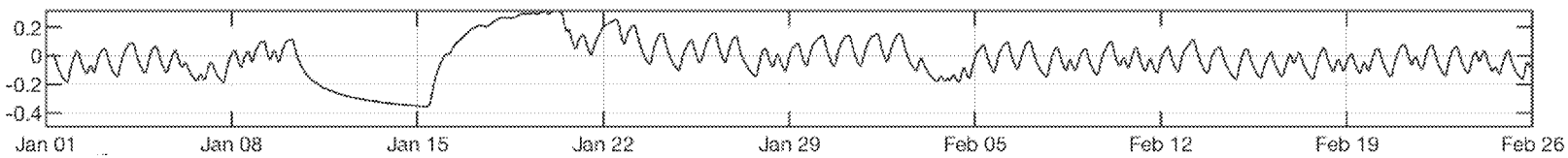


Responses to individual impulses

CONVOLUTION

Summing all responses to impulses

Response



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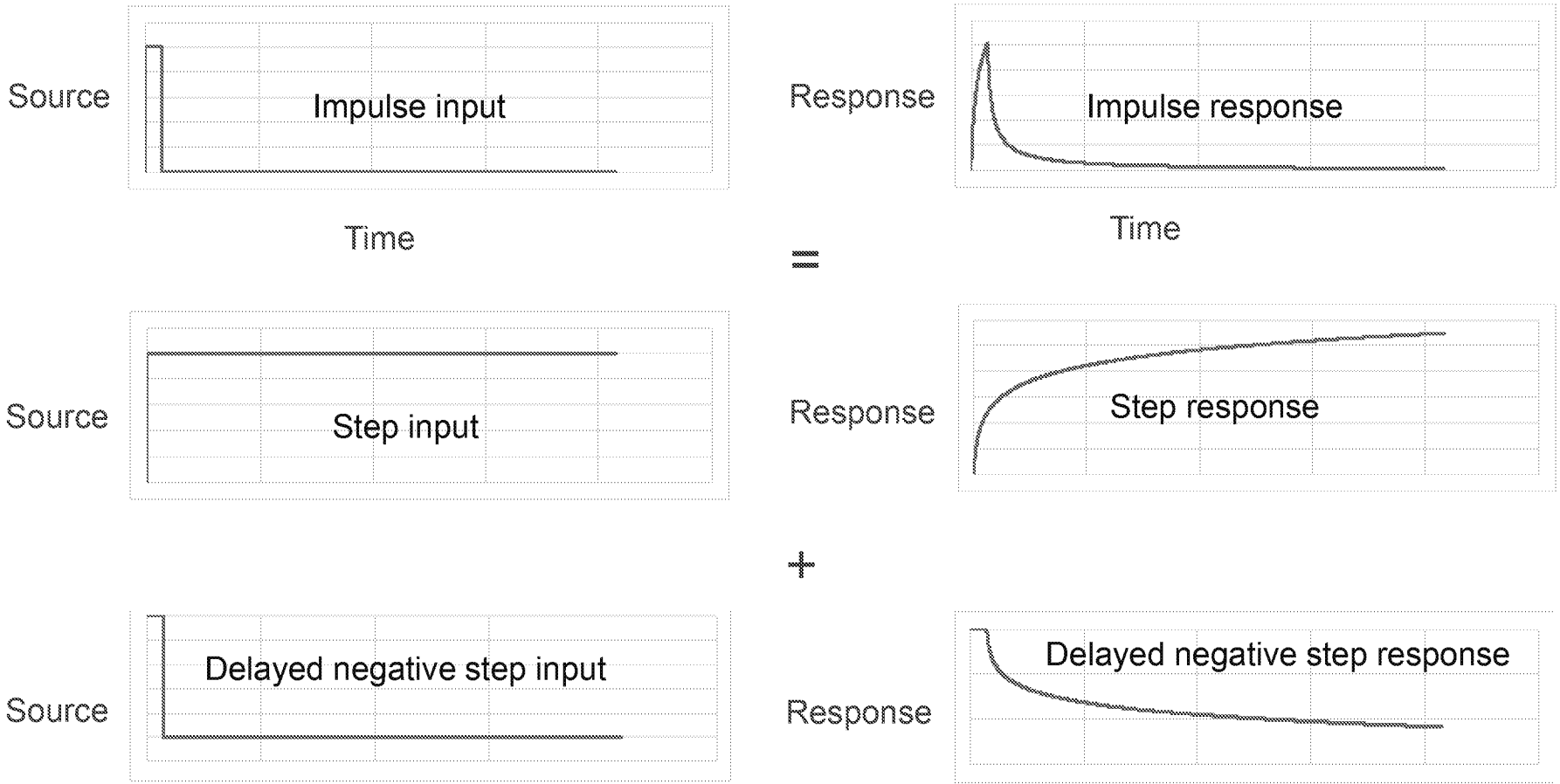
TFN Analysis:

Relationship Between Impulse Response and Step Response Functions



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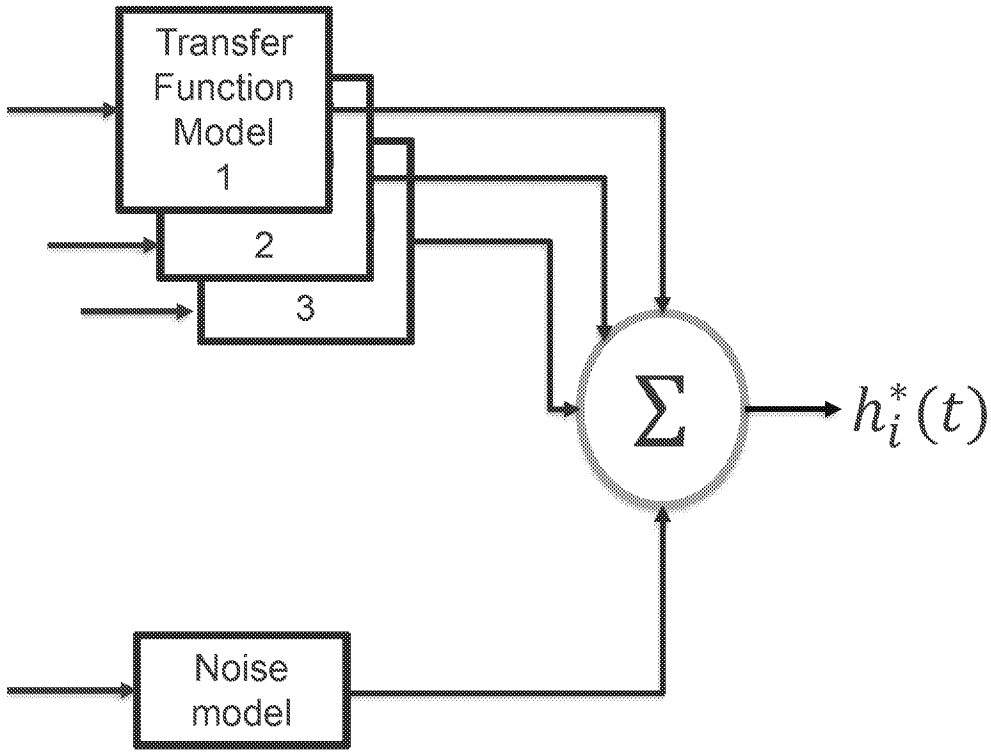
TFN Model with Multiple Input Sources

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

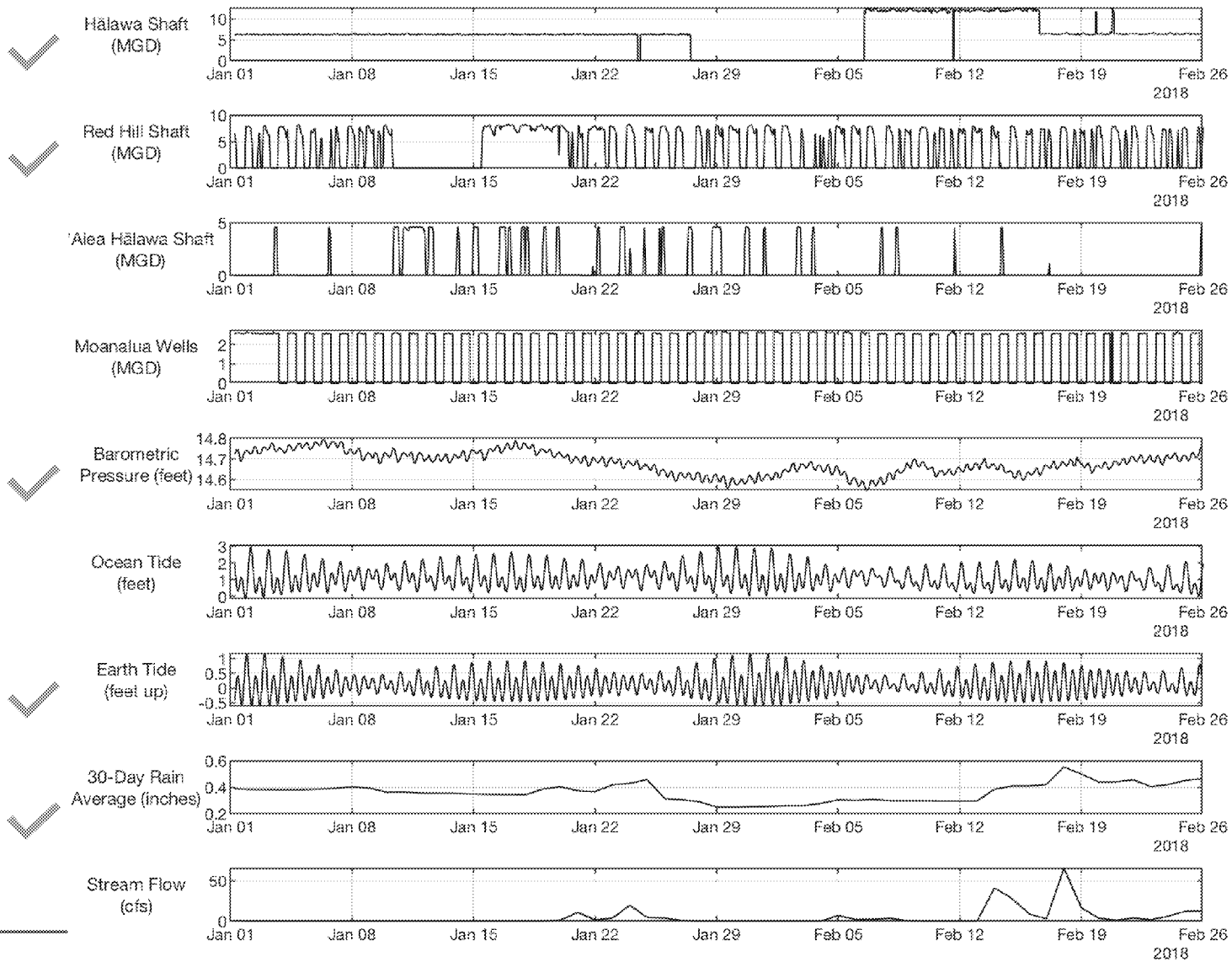


$$(y - \mu_y) = f(\boldsymbol{k}, \boldsymbol{x}, t) + N_t$$

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

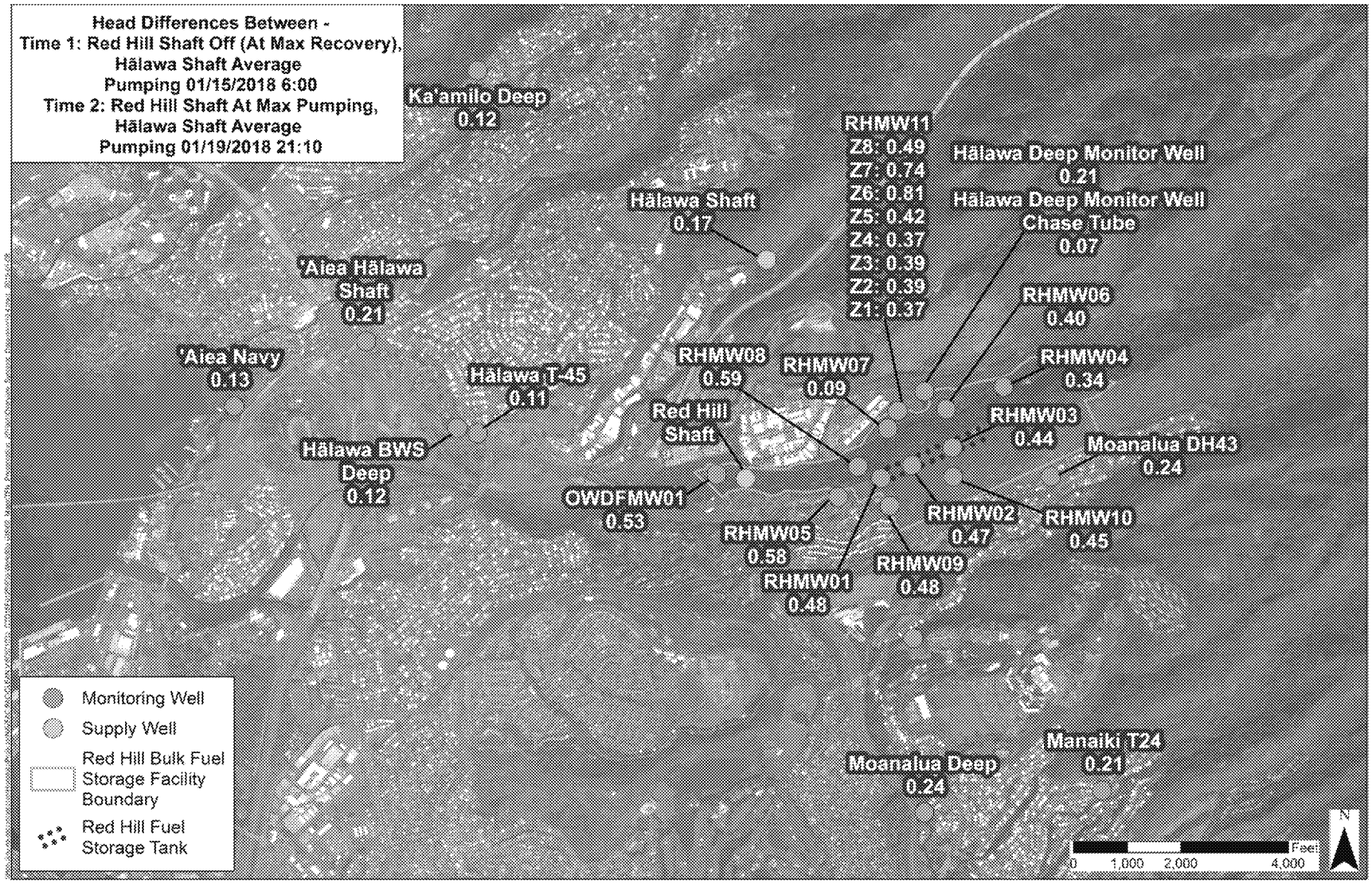
TFN Analysis:

Sources Included in TFN Analysis



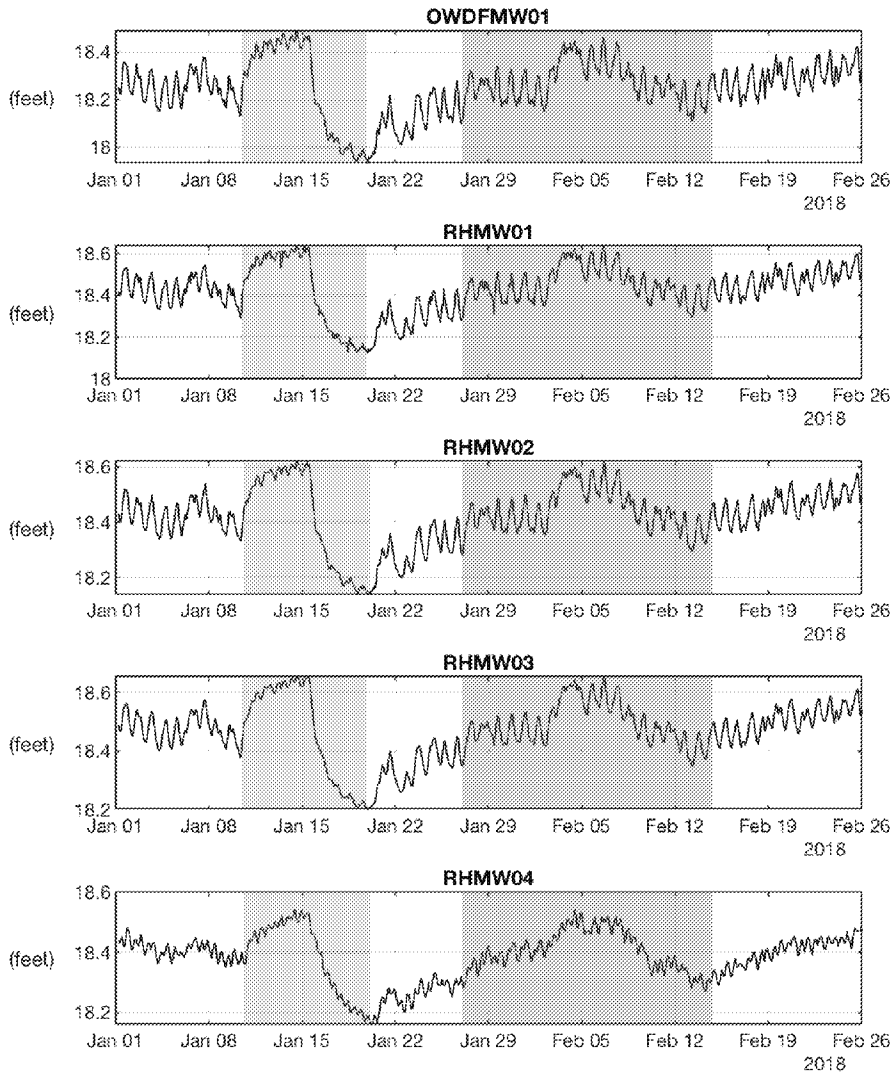
TFN Analysis:

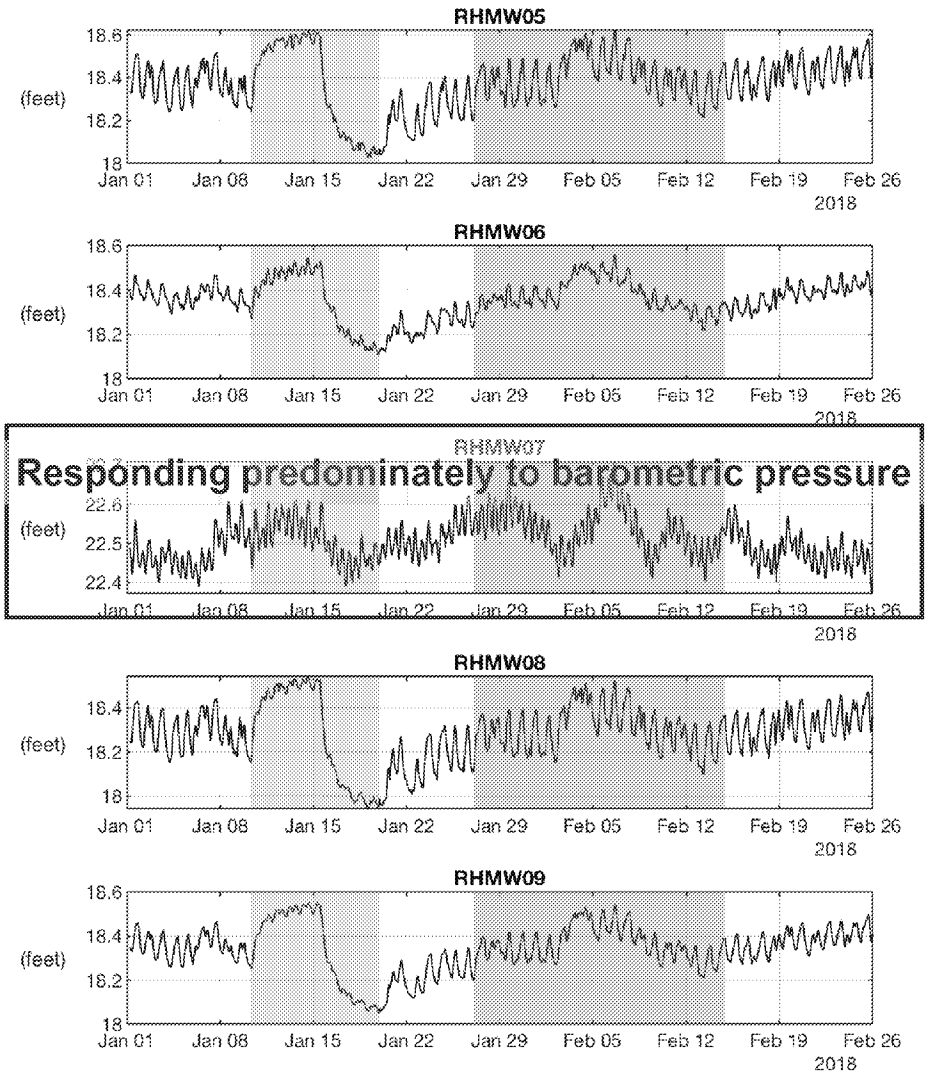
Overview of Synoptic Data – Head Differences at Select Wells for Two Red Hill Shaft Stress Conditions



TFN Analysis:

Wells Responding to Red Hill Shaft Shutdown





Responding predominately to barometric pressure

Red Hill Shaft Off

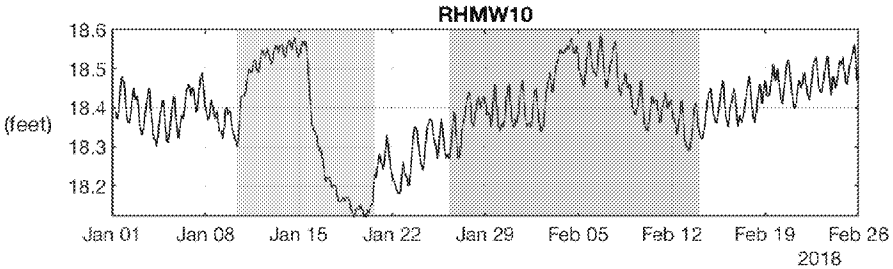
Red Hill Shaft On, Max Pumping

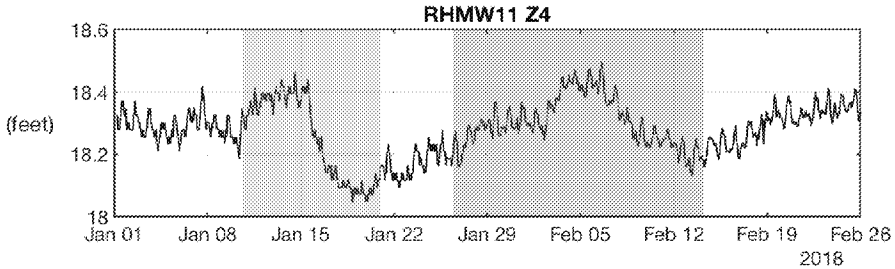
Halawa Shaft Off

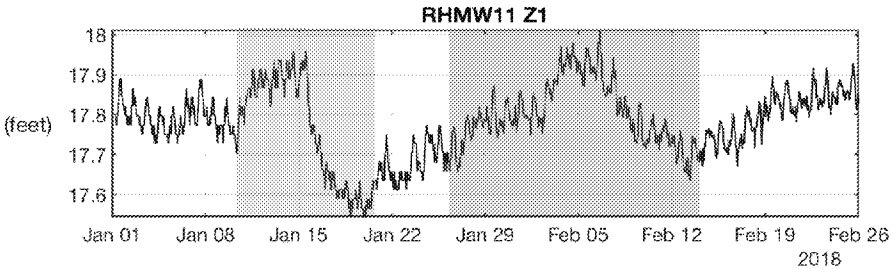
Halawa Shaft On, Max Pumping

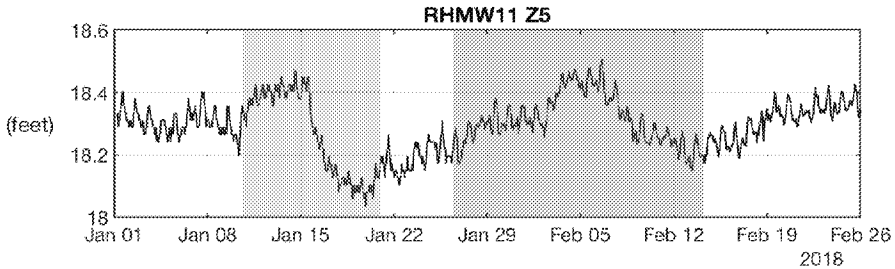
TFN Analysis:

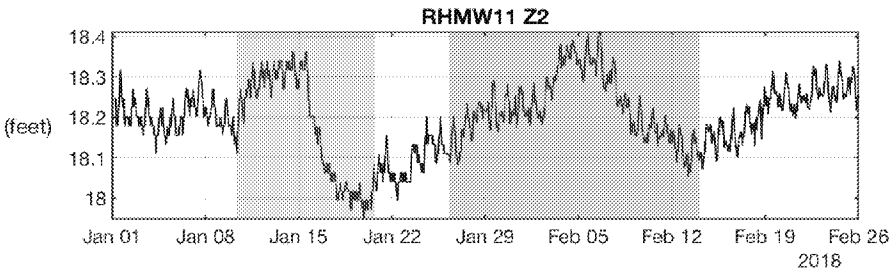
Wells Responding to Red Hill Shaft Shutdown (cont.)

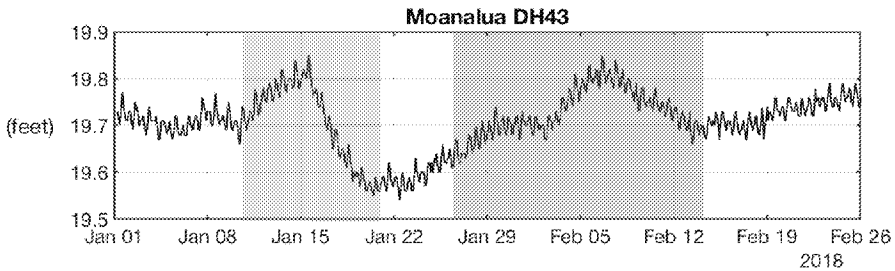


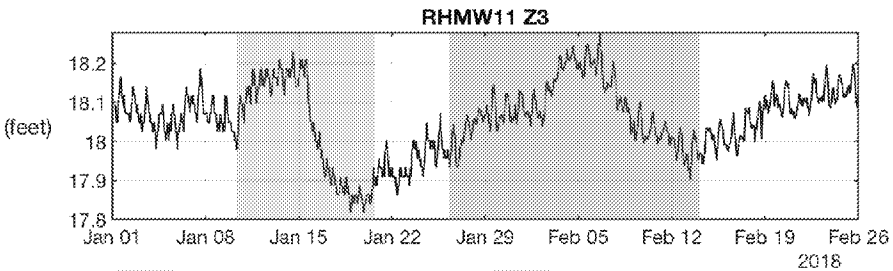


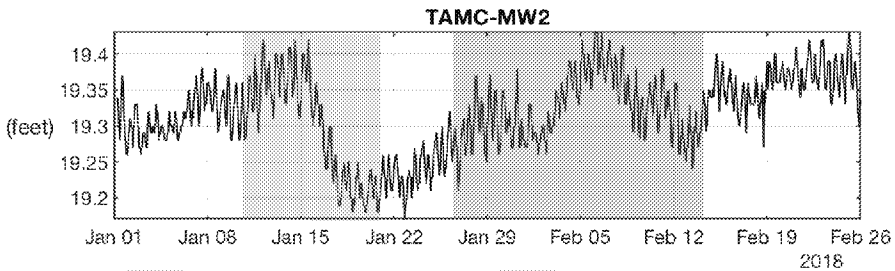












Red Hill Shaft Off

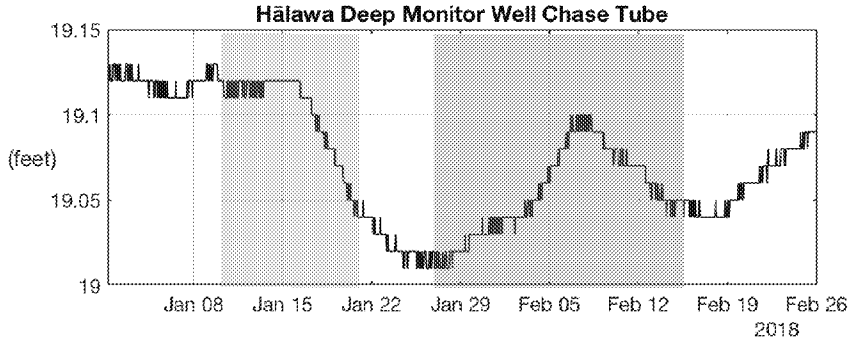
Red Hill Shaft On, Max Pumping

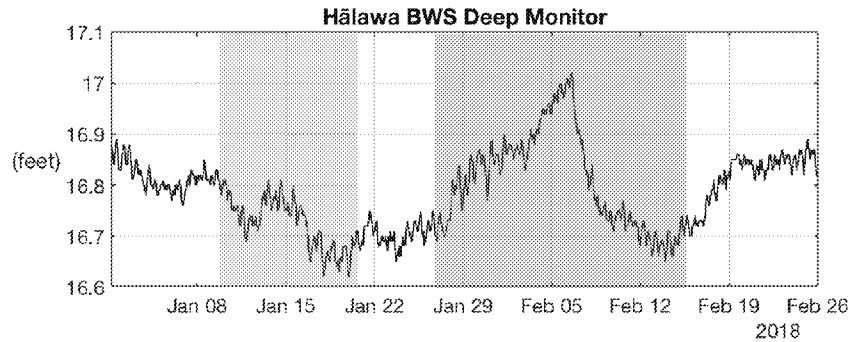
Halawa Shaft Off

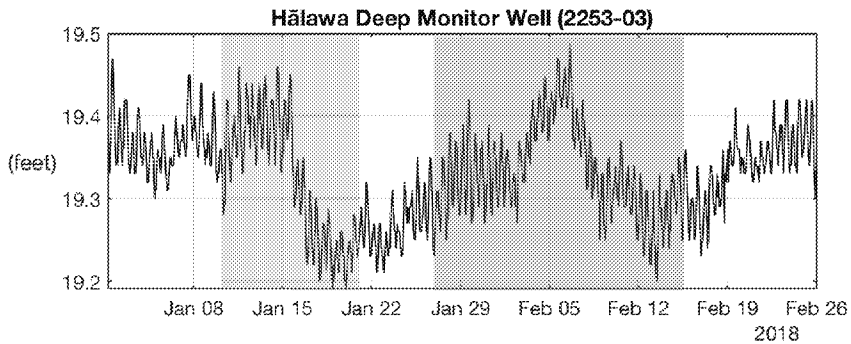
Halawa Shaft On, Max Pumping

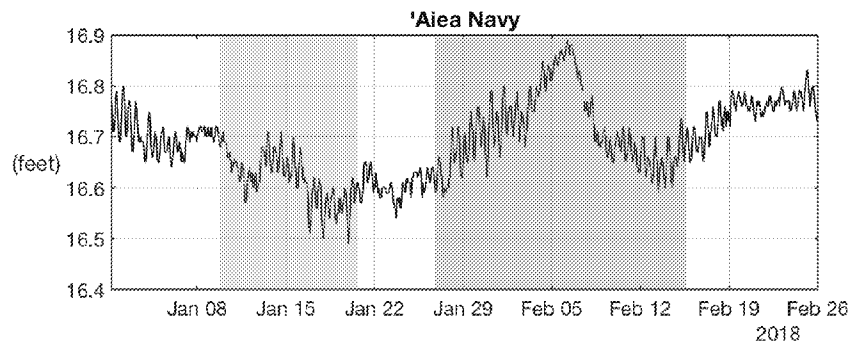
TFN Analysis:

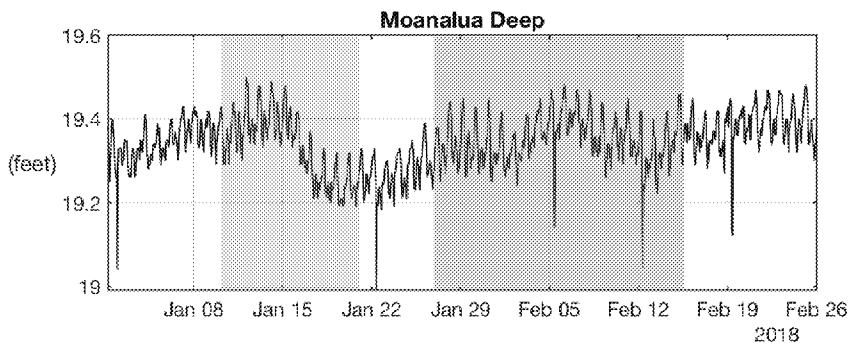
Wells Not Responding to Red Hill Shaft Shutdown

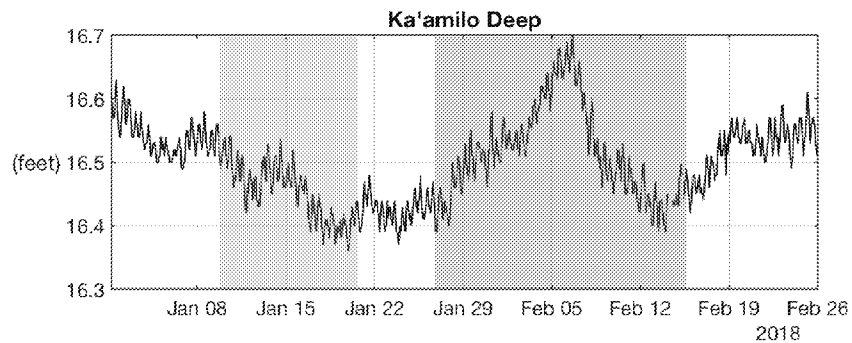








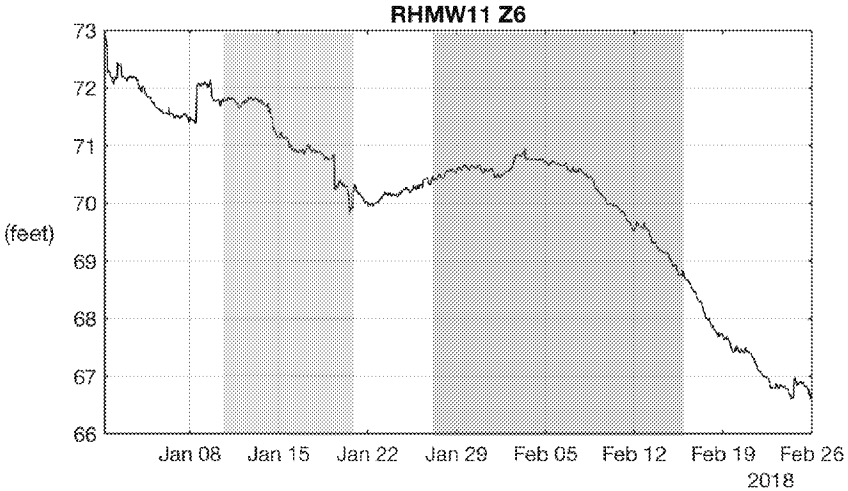


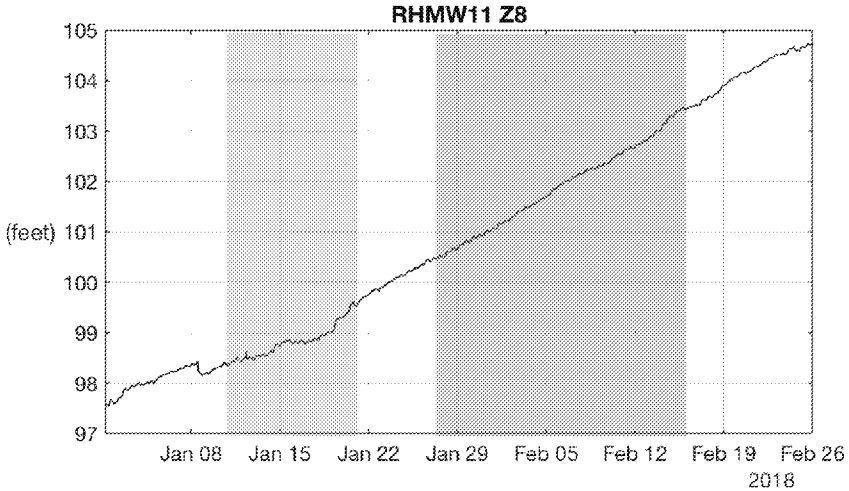


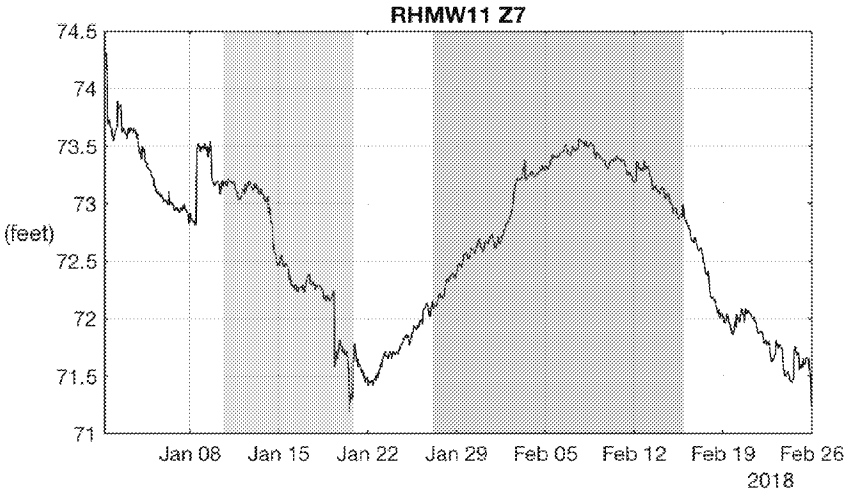
Red Hill Shaft Off | **Red Hill Shaft On, Max Pumping** | **Halawa Shaft Off** | **Halawa Shaft On, Max Pumping**

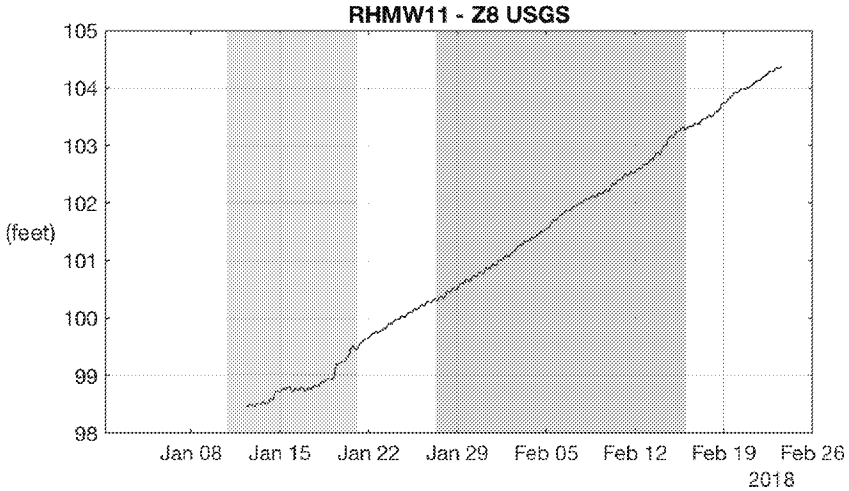
TFN Analysis:

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









Red Hill Shaft Off

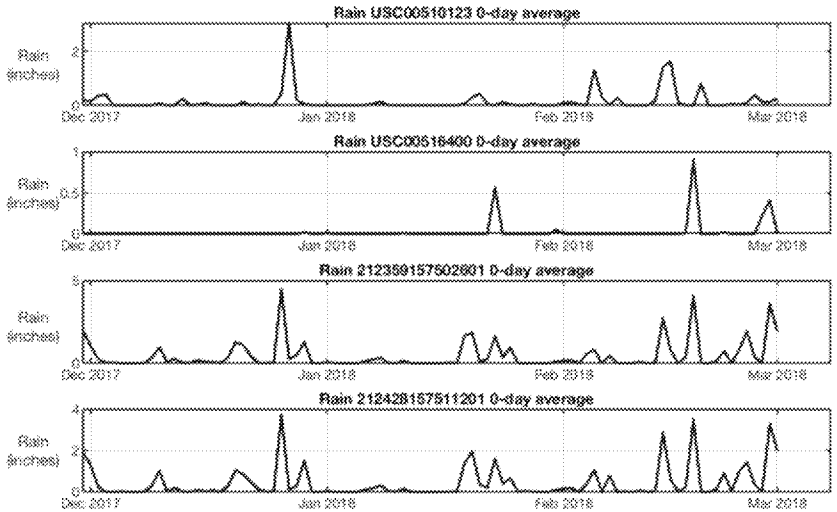
Red Hill Shaft On, Max Pumping

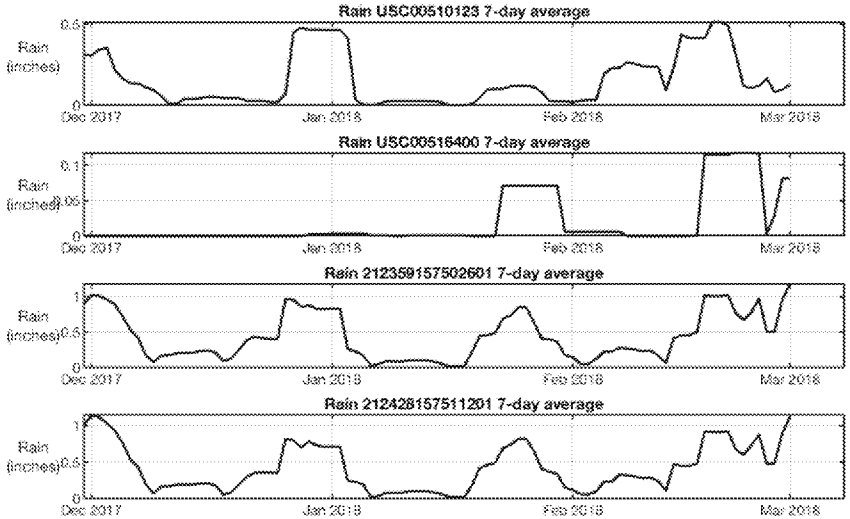
Halawa Shaft Off

Halawa Shaft On, Max Pumping

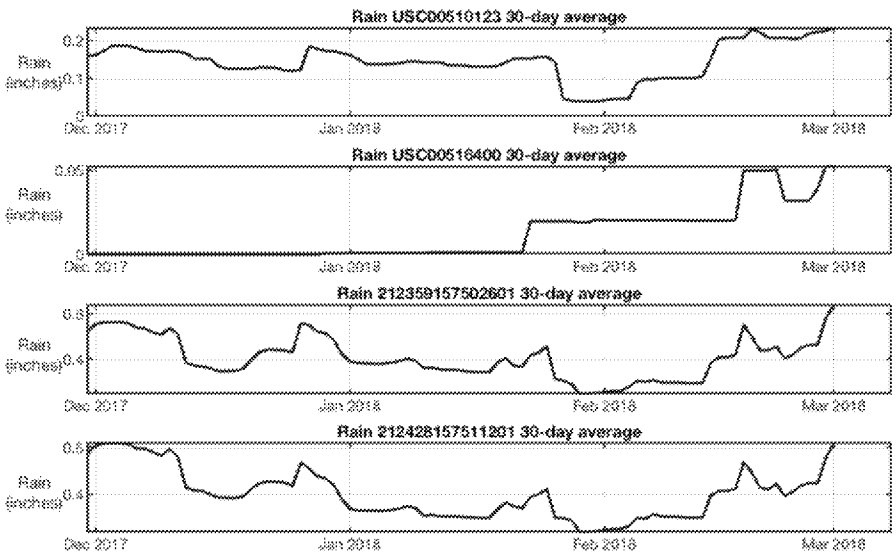
TFN Analysis:
Location of Rain Gauges

TFN Analysis:
Rainfall Data Coherency





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

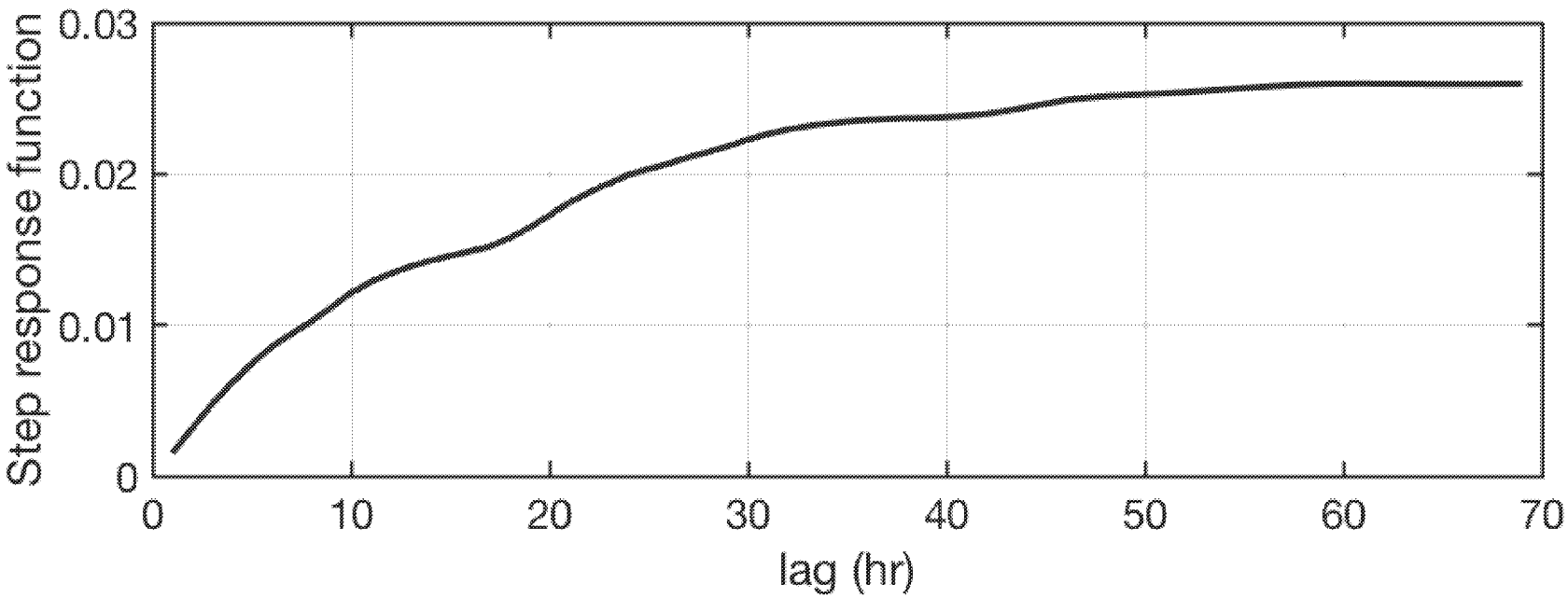


Implementation of TFN Analysis

- 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

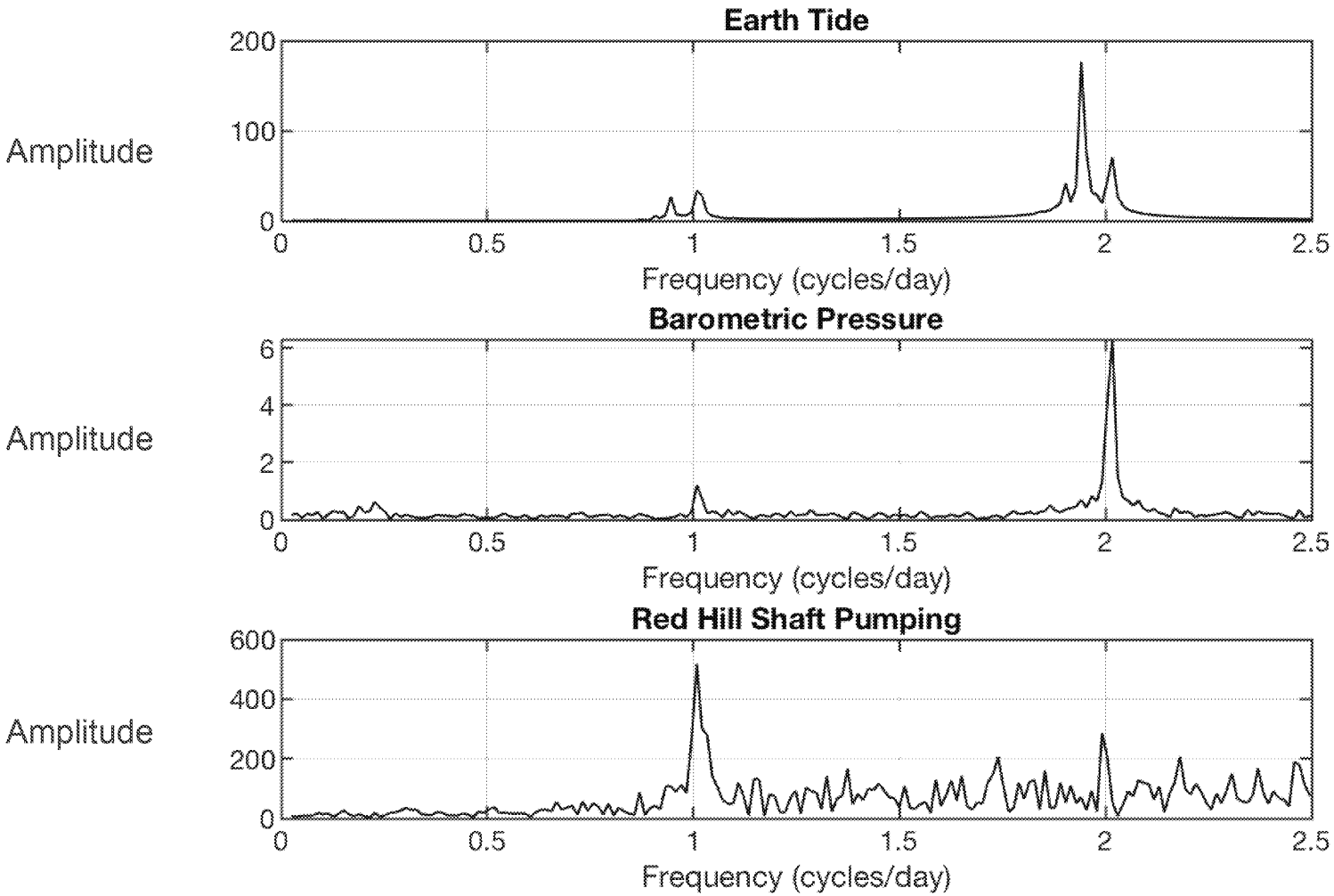


Resembles Hantush leaky aquifer solution

ED_006532_00002883-00081

TFN Analysis:

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



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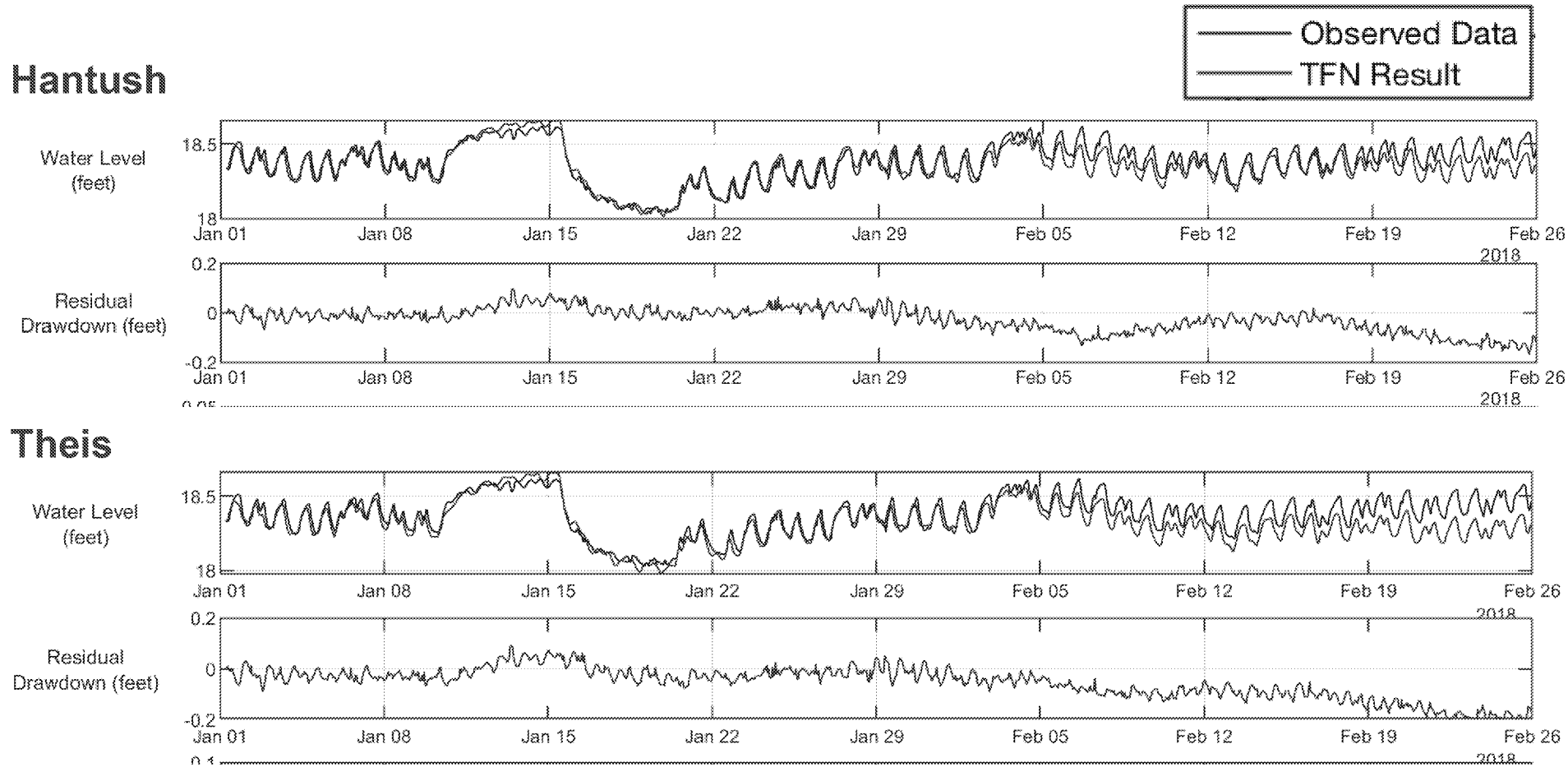
TFN Analysis:

Hantush vs. Theis Step Response Functions



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

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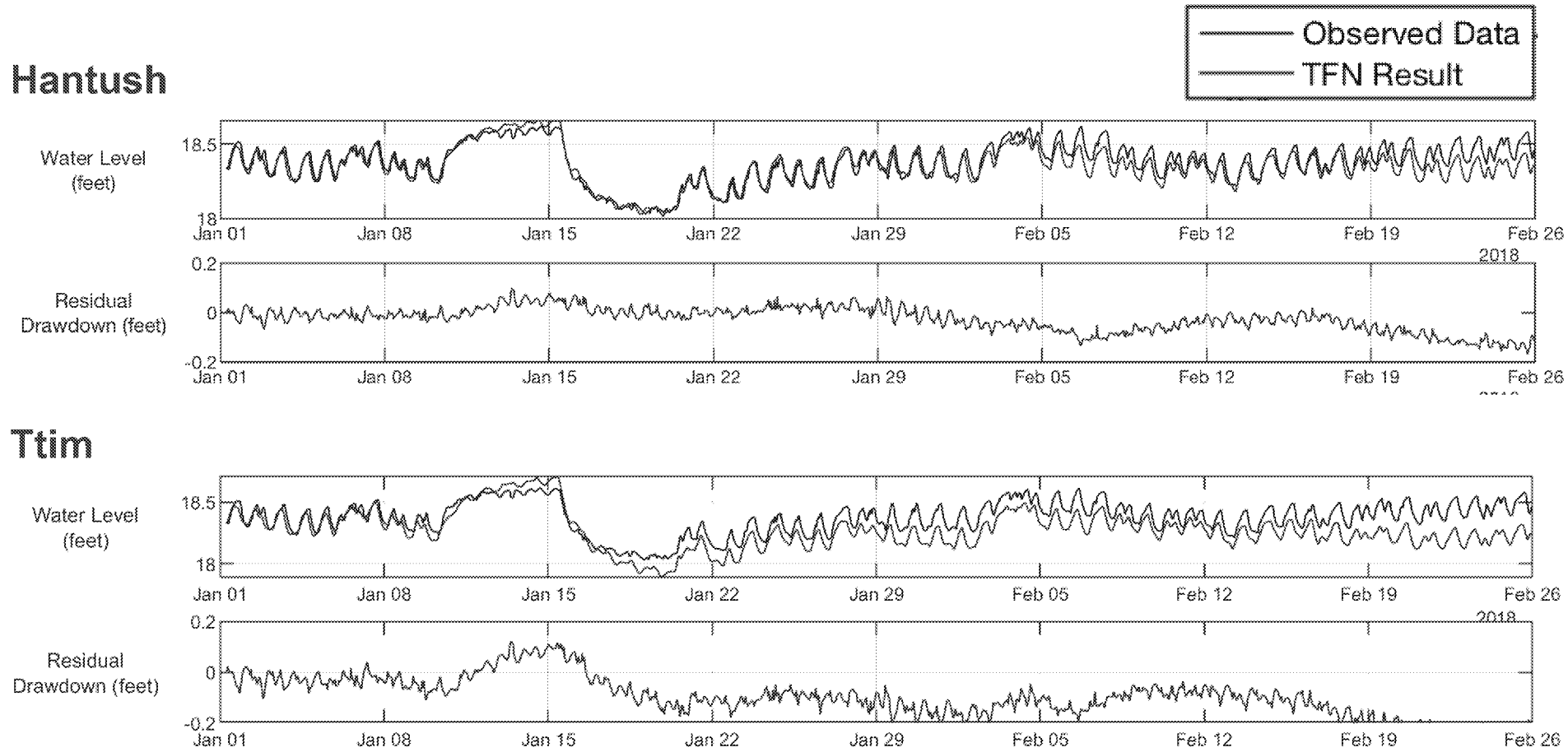
TFN Analysis:

Hantush vs.Ttim Step Response Functions

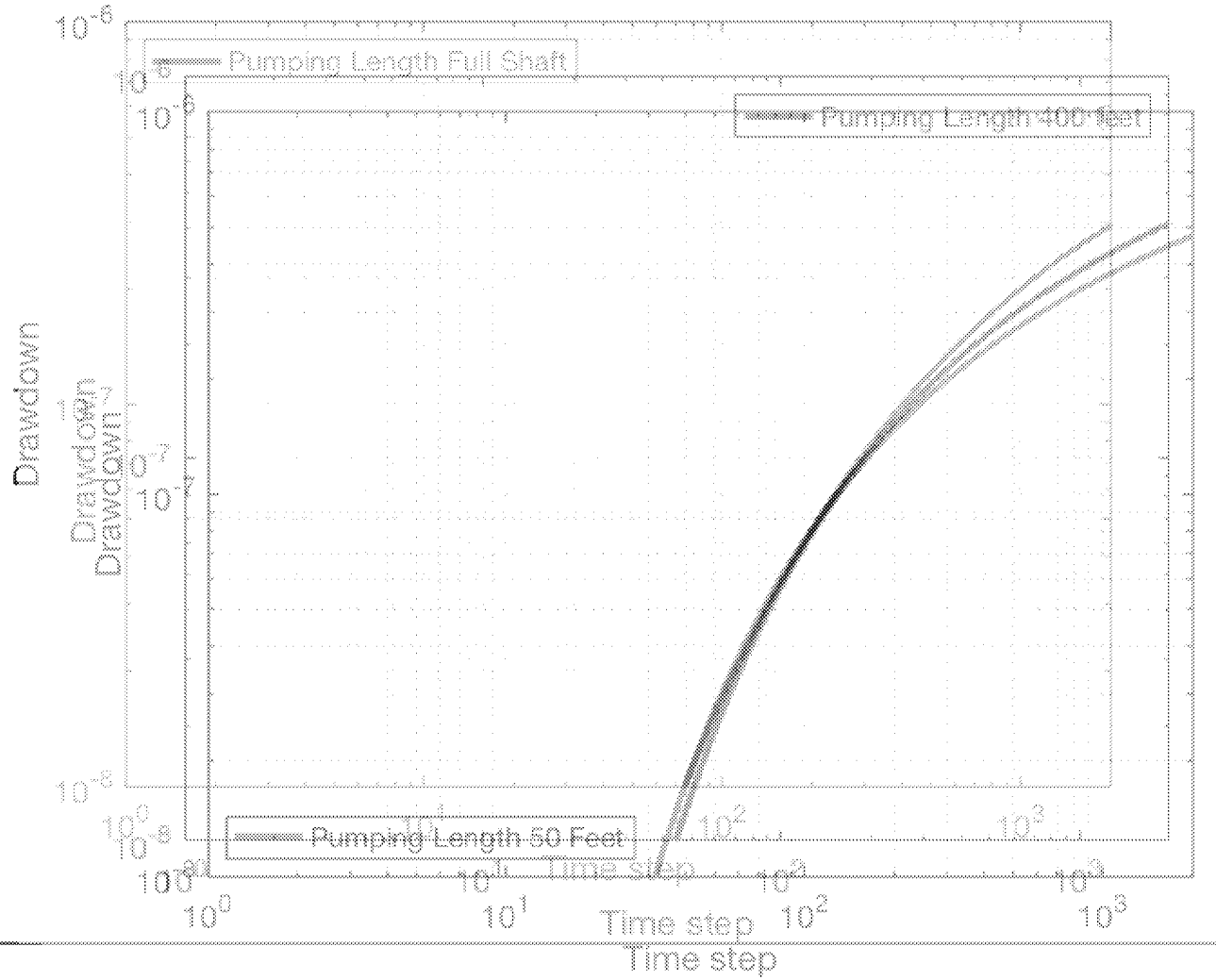


Using Hantush step response function results in better matching than Ttim

TFN Analysis:

Variation of Ttim Step Response Functions

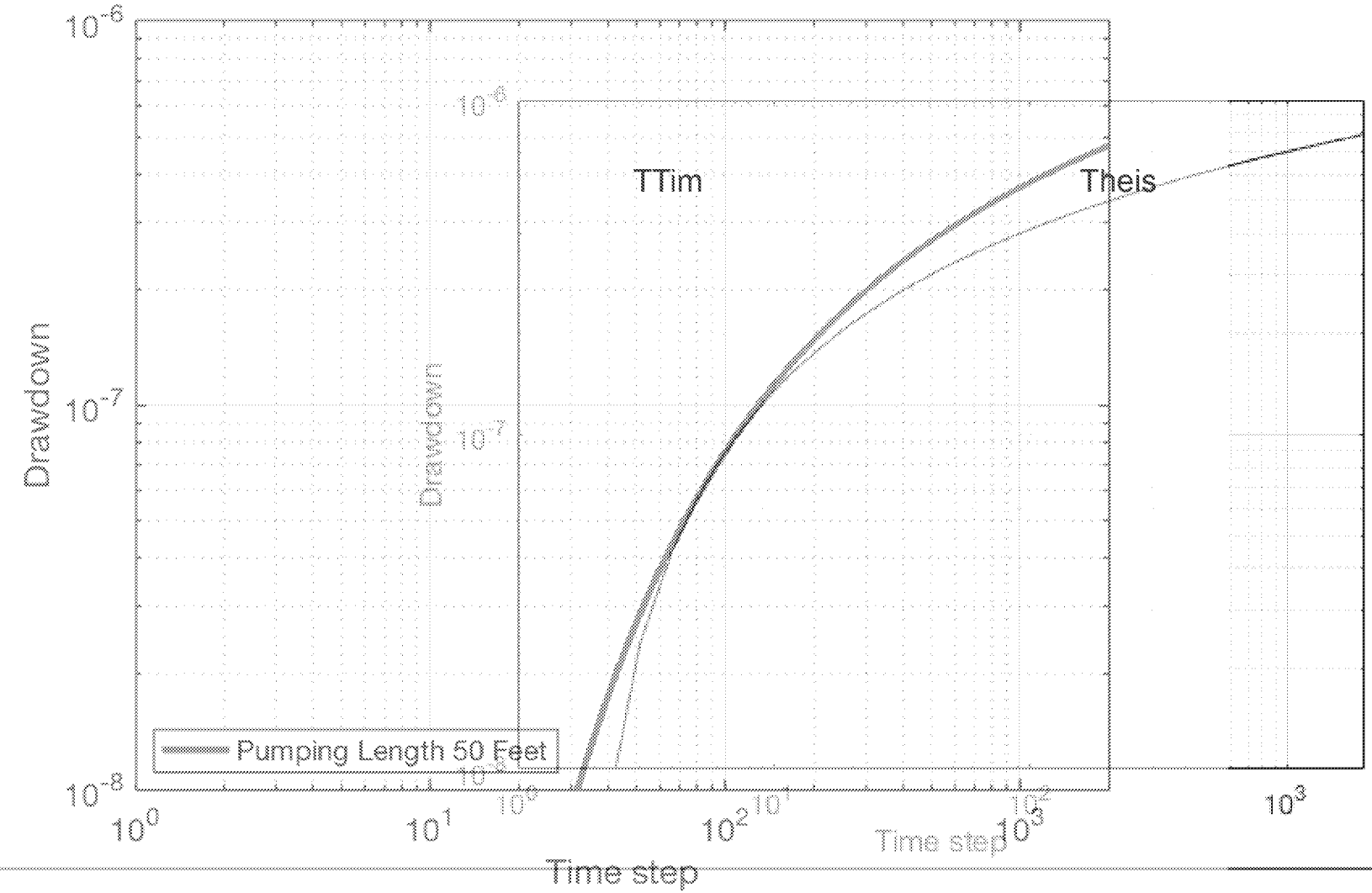
Drawdown curvature as a function of shaft pumping length



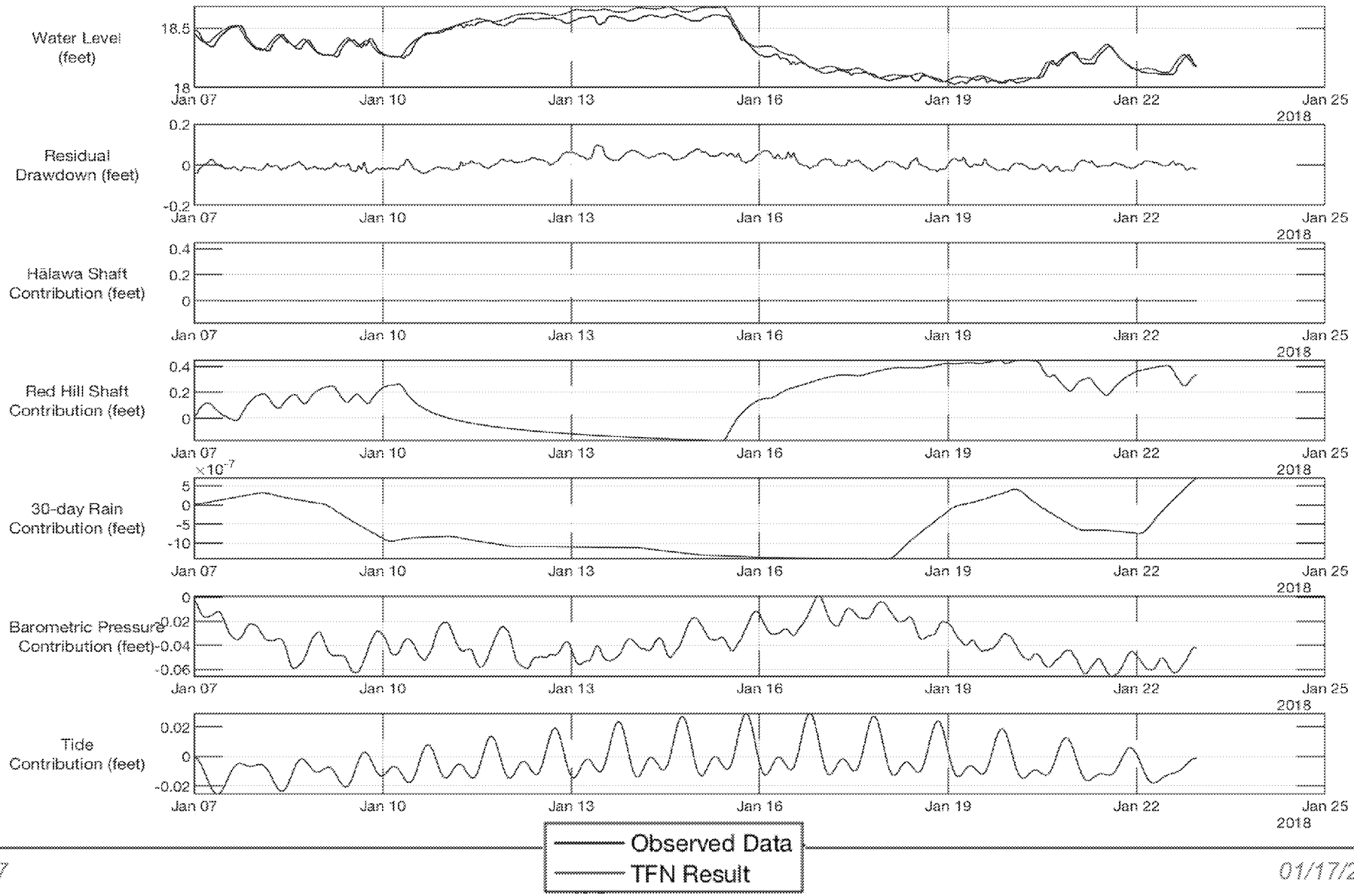
TFN Analysis:

Comparison of Ttim and Theis Step Response Functions

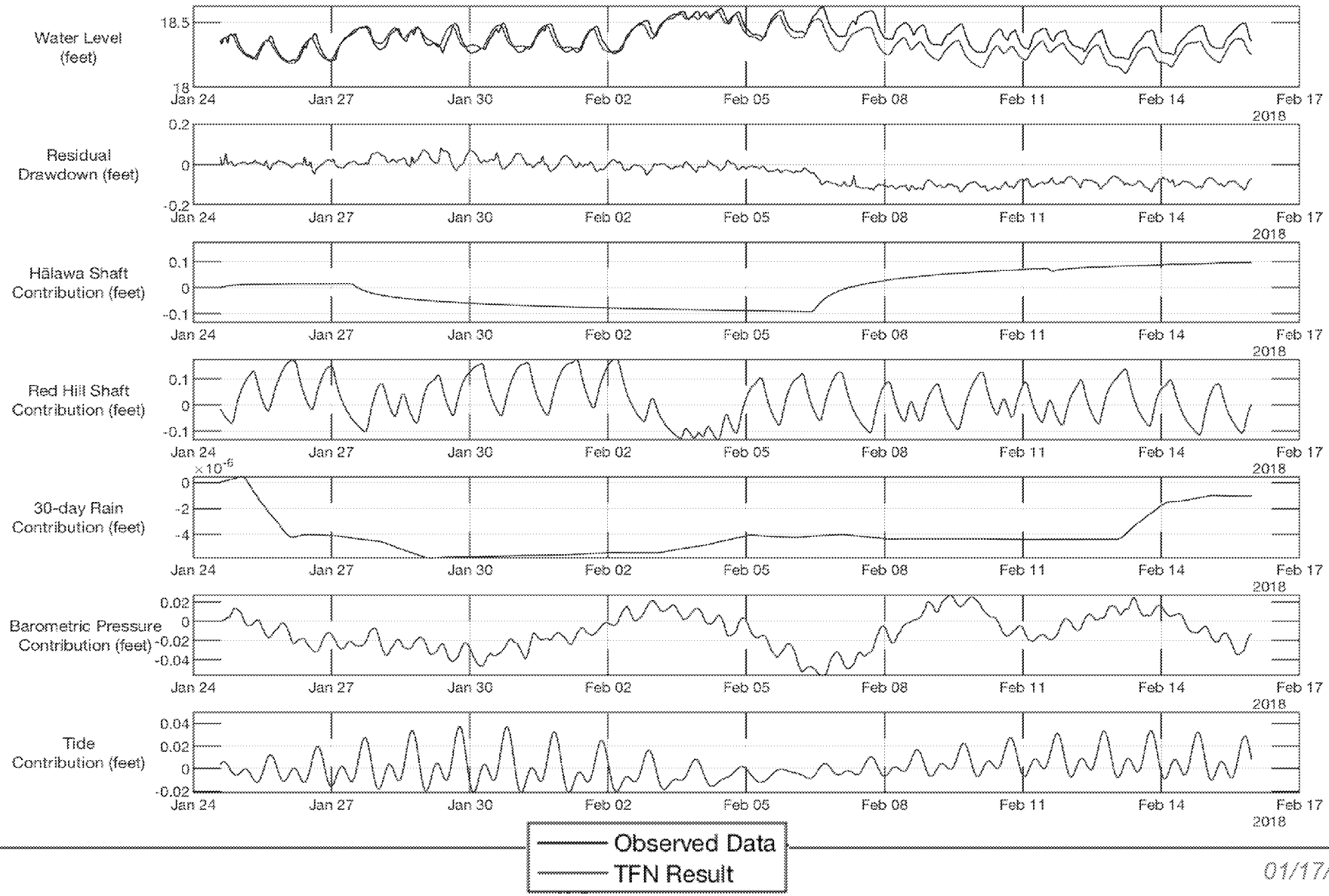
Ttim step response function shows less abrupt curvature than Theis



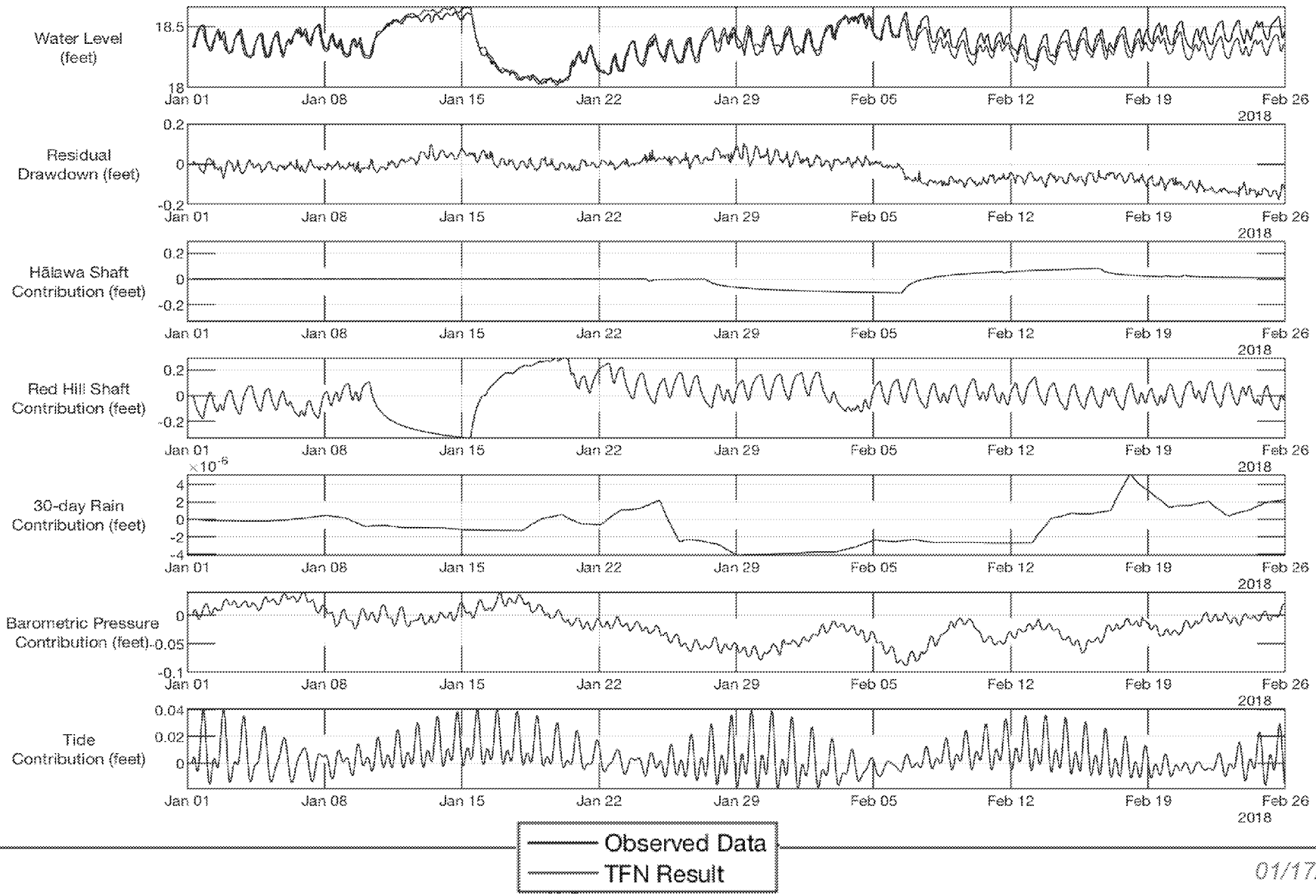
TFN Analysis:
Results for RHMW05 – Red Hill Shaft Shutdown & Restart



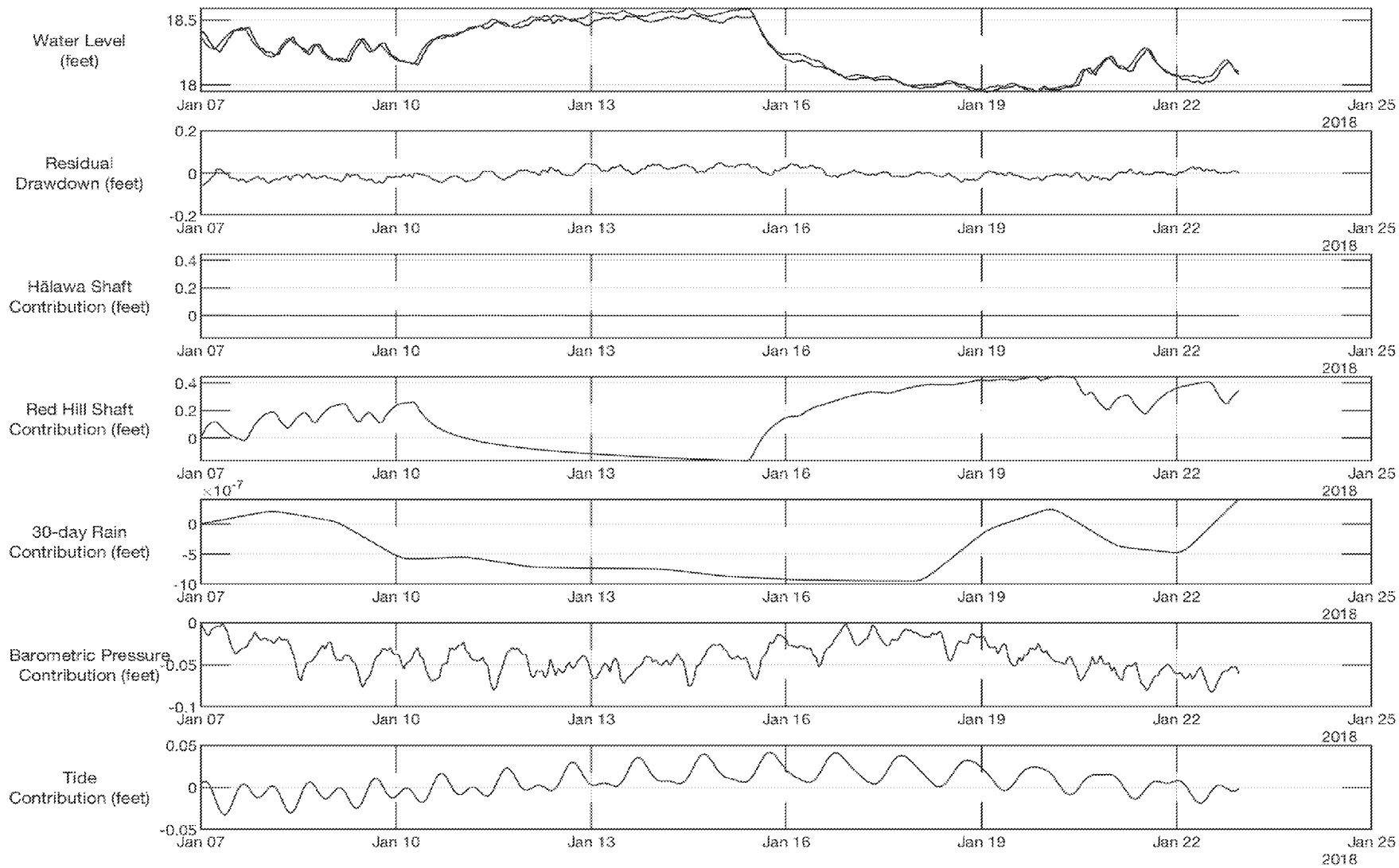
TFN Analysis:
Results for RHMW05 – Halawa Shaft Shutdown & Restart



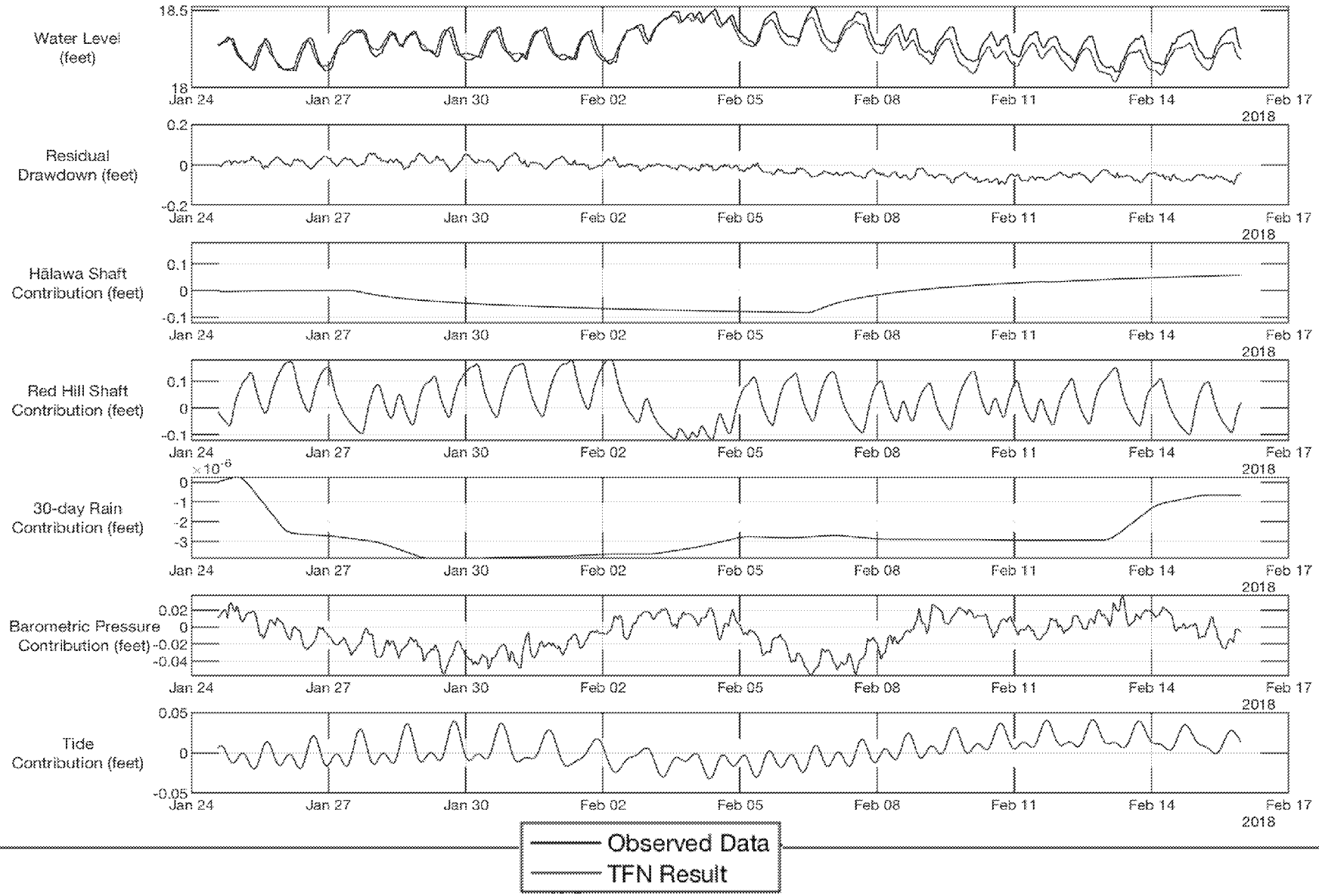
TFN Analysis:
Results for RHMW05 – Synoptic Data Period



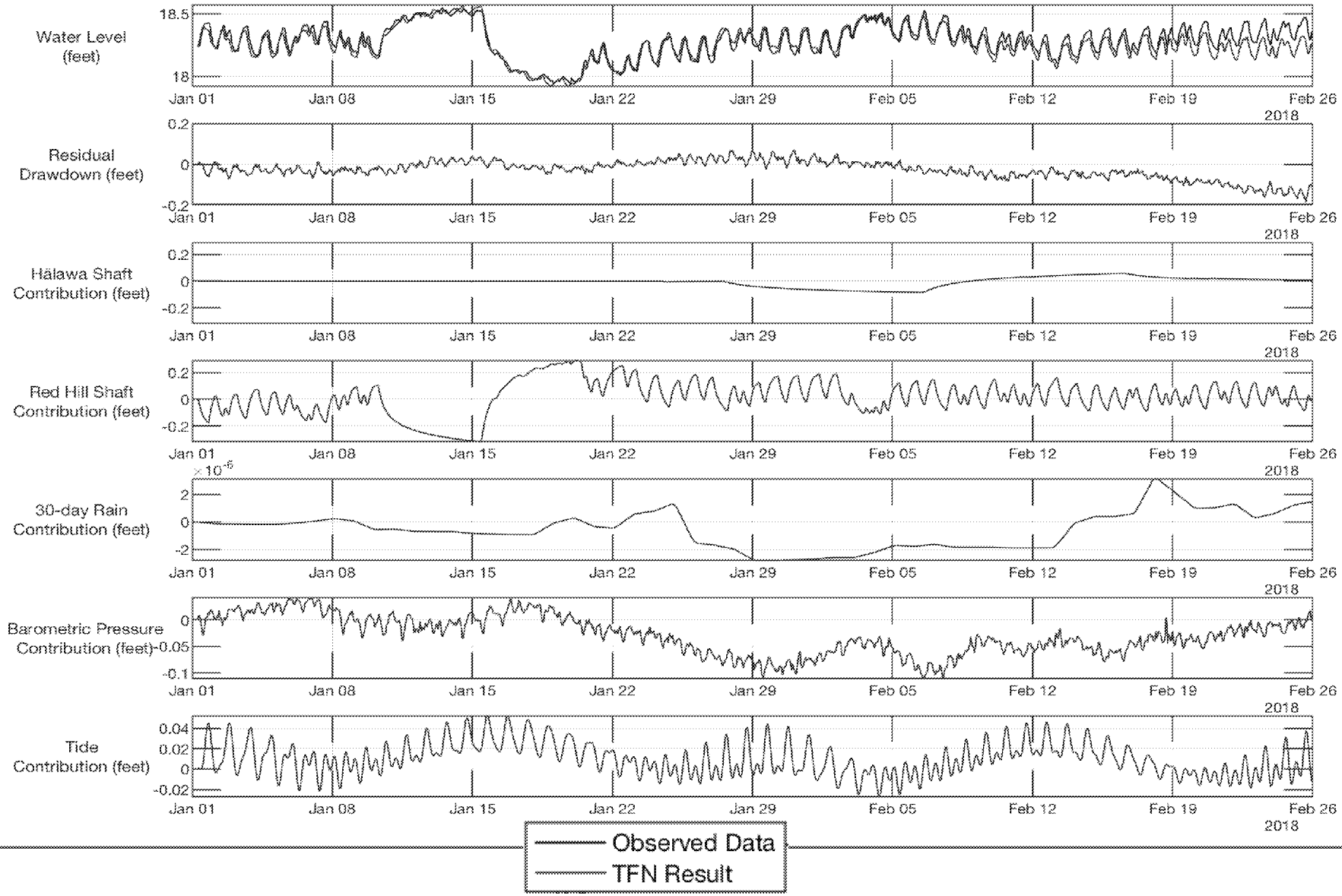
TFN Analysis:
Results for RHMW08 – Red Hill Shaft Shutdown & Restart



TFN Analysis:
Results for RHMW08 – Halawa Shaft Shutdown & Restart

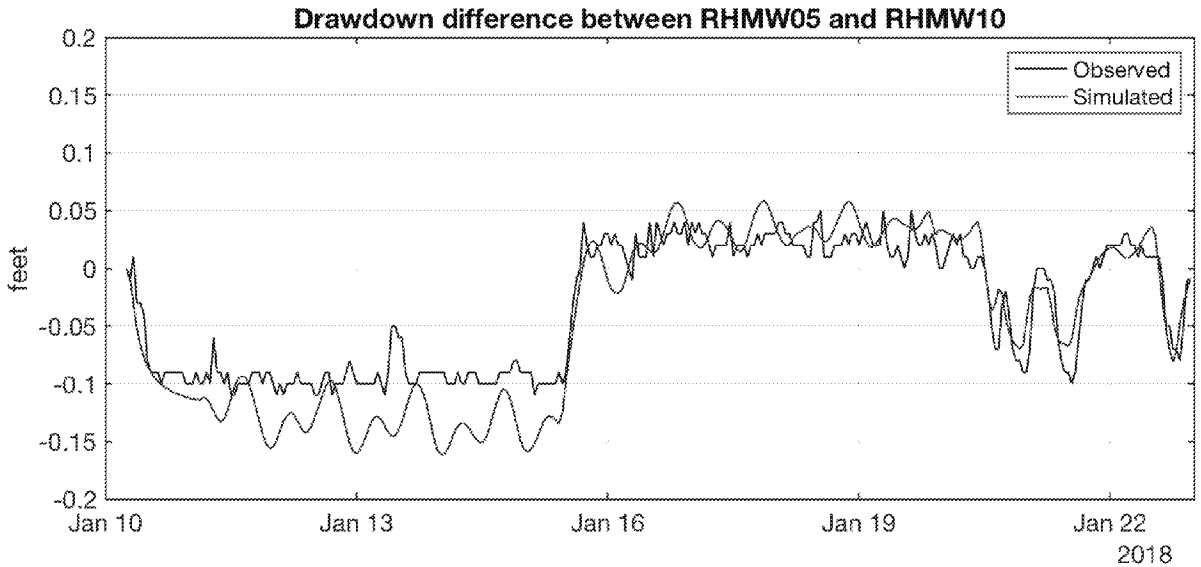


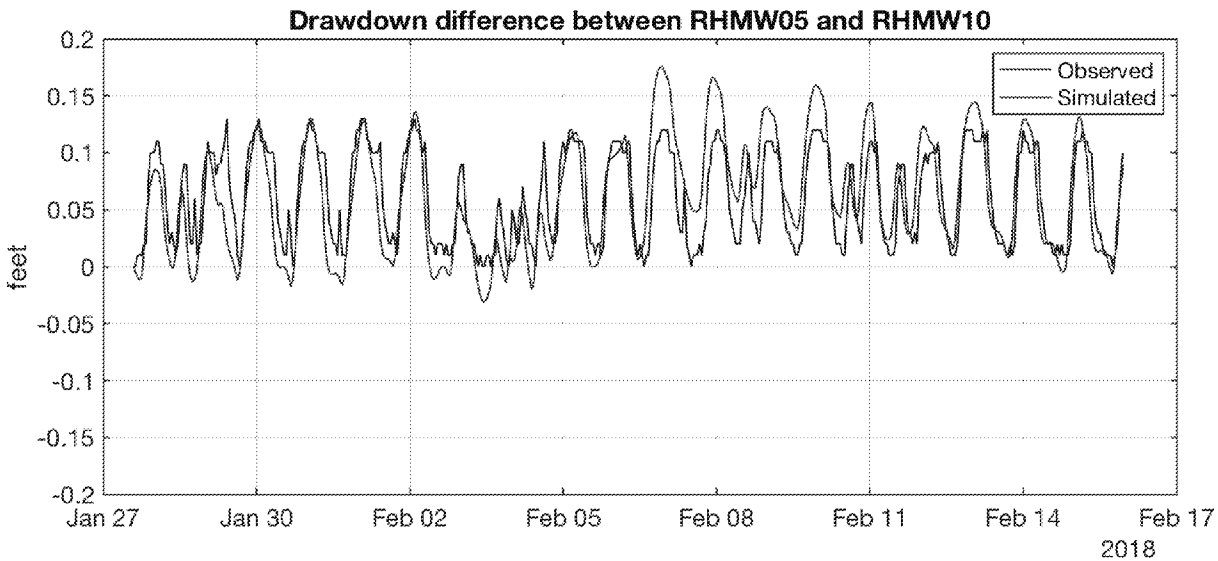
TFN Analysis:
Results for RHMW08 – Synoptic Data Period



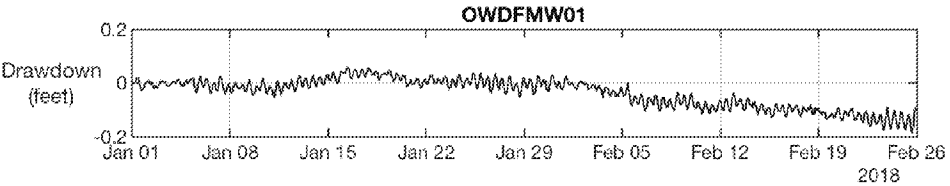
TFN Analysis:

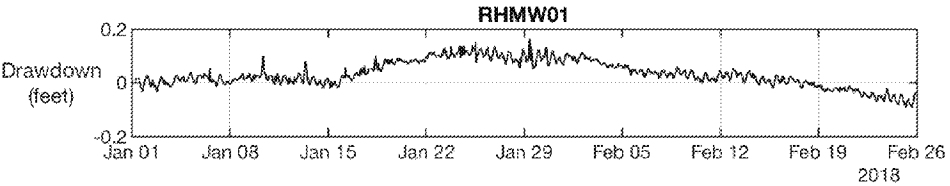
Differential Head Time Series between RHMW05 and RHMW10

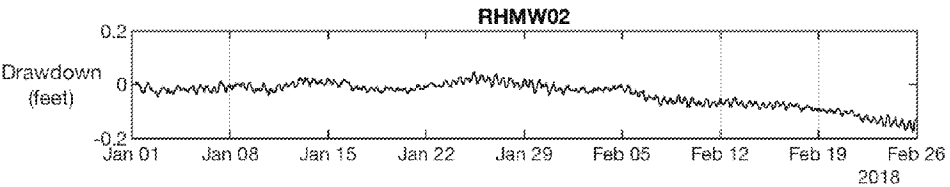


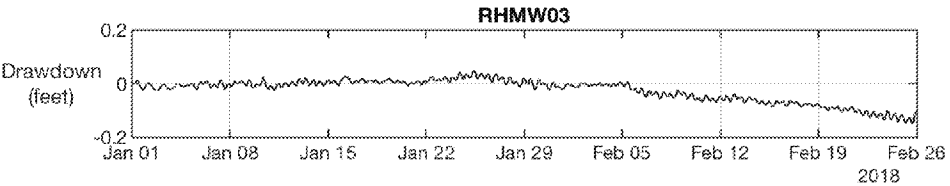


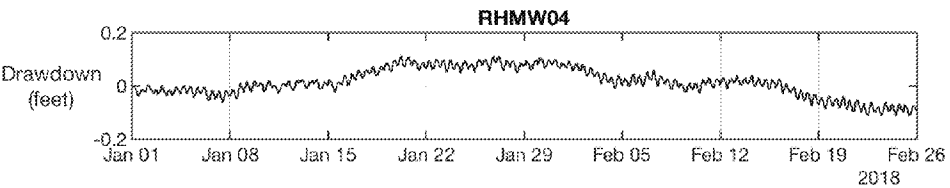
TFN Analysis:
Residuals

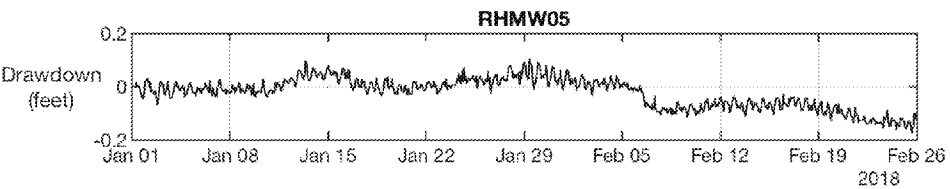


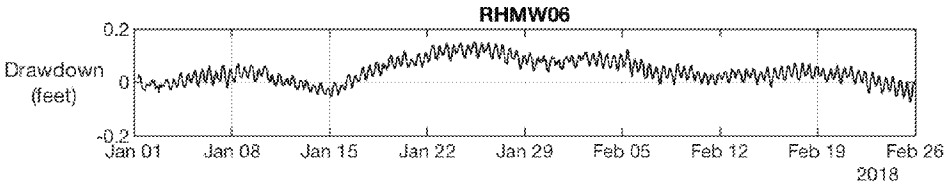


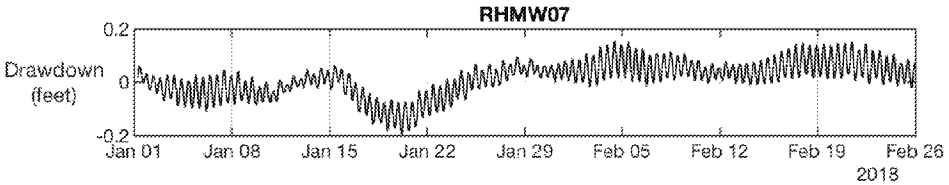


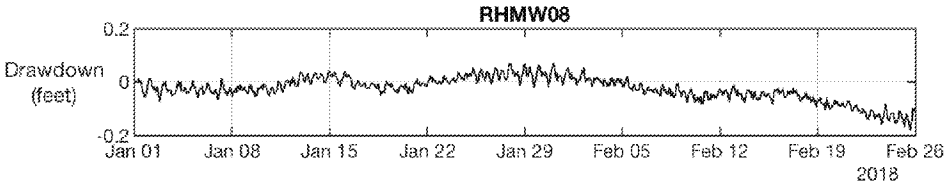


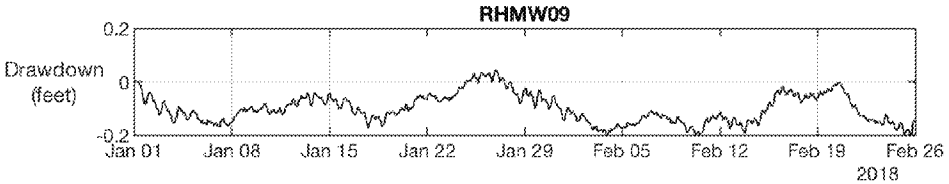


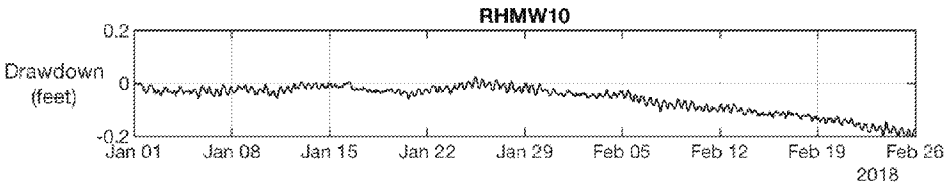


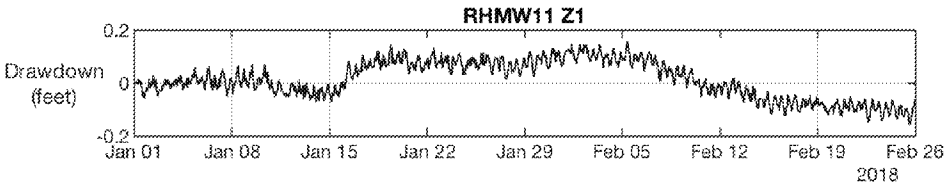




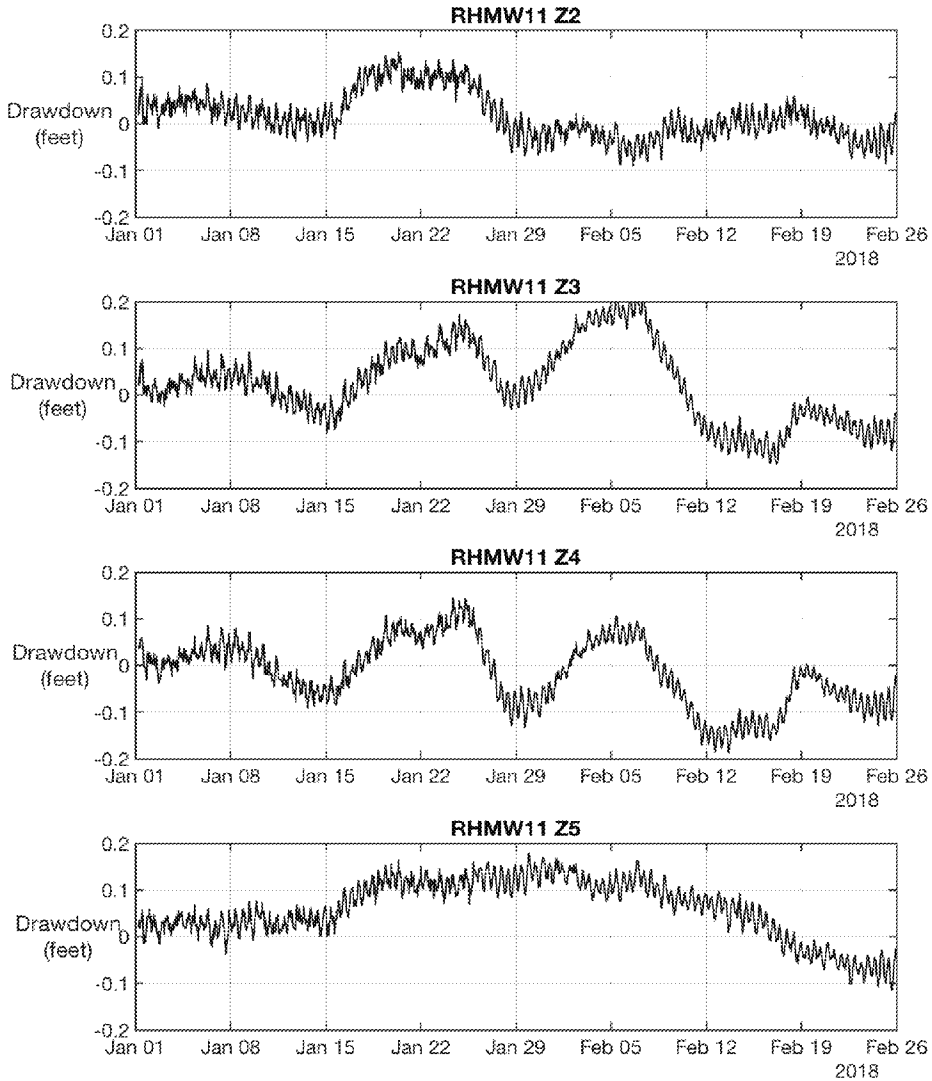






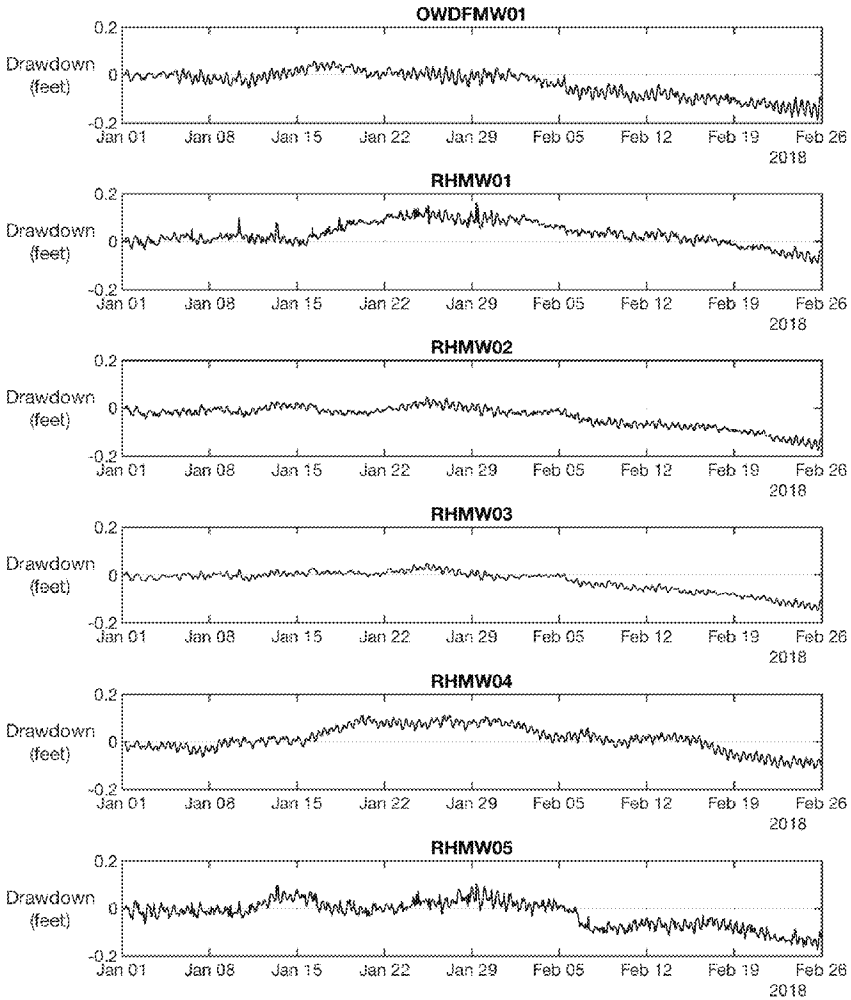


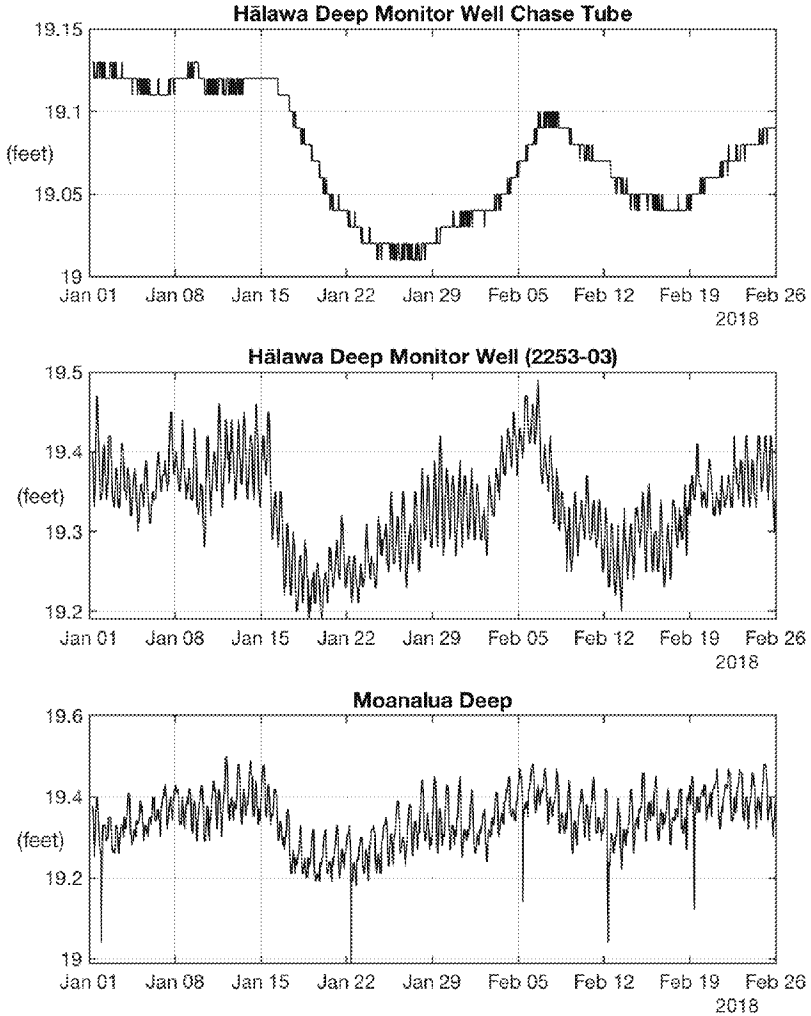
TFN Analysis:
Residuals (cont.)



TFN Analysis:

Slight Resemblance of Residuals with Deep Well Time Series





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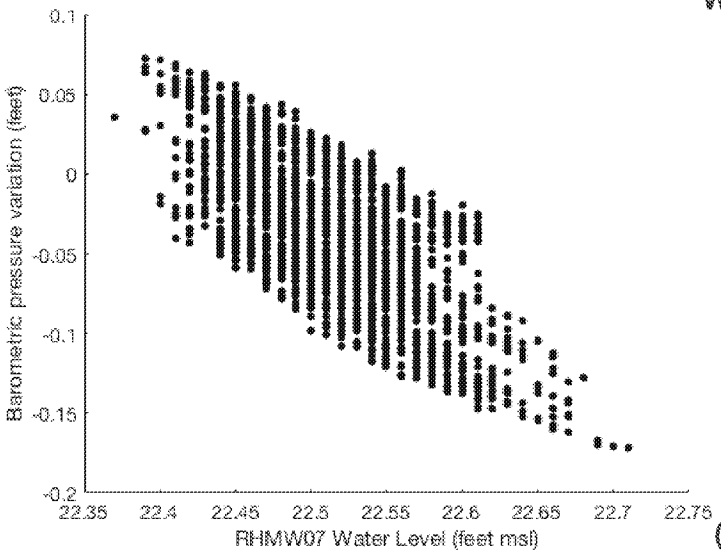
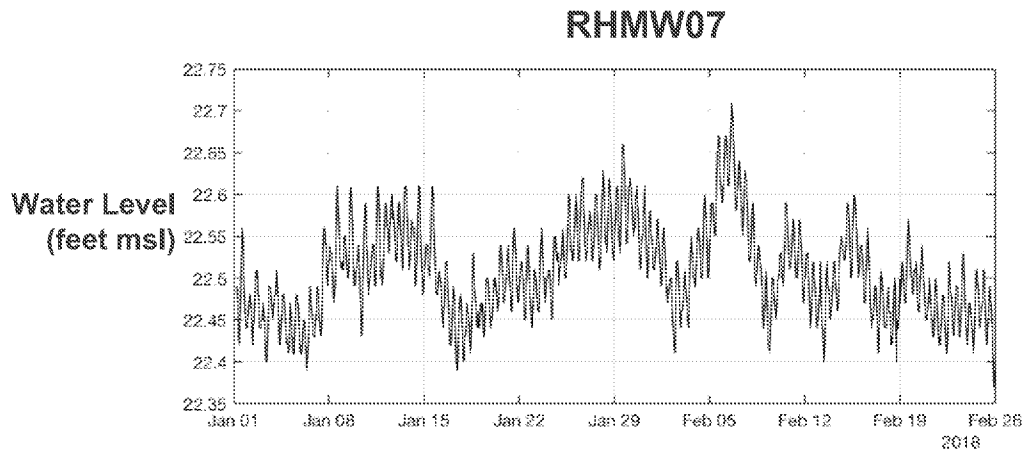
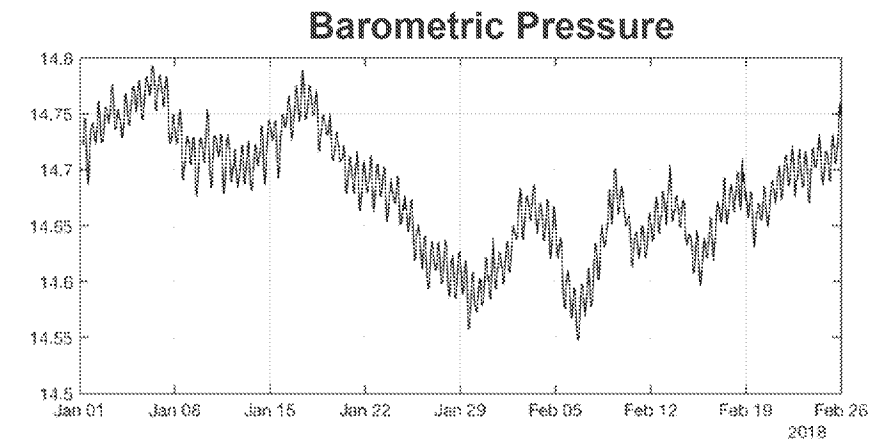
TFN Analysis:

Strong Correlation of RHMW07 and Barometric Pressure Variation

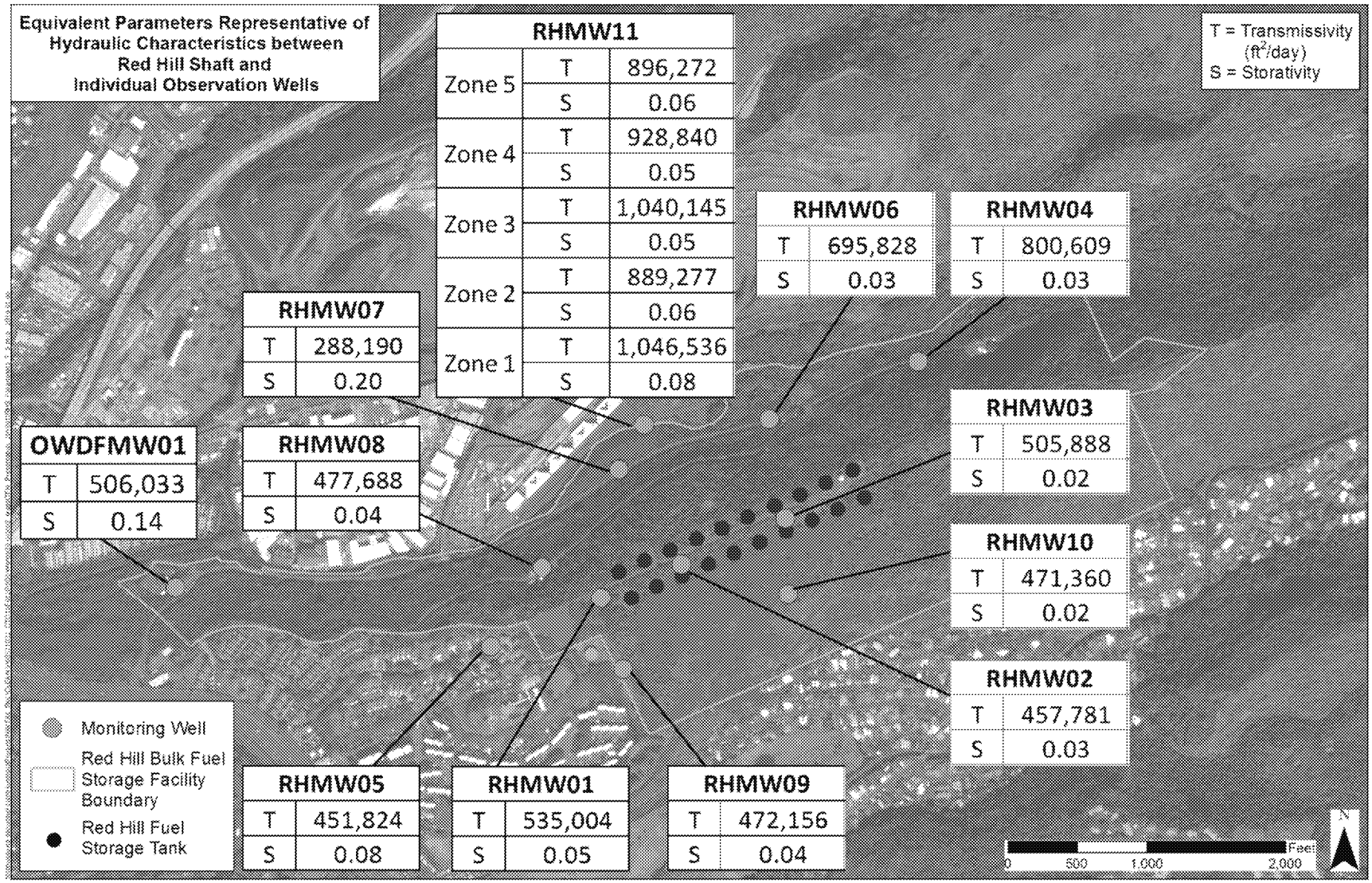






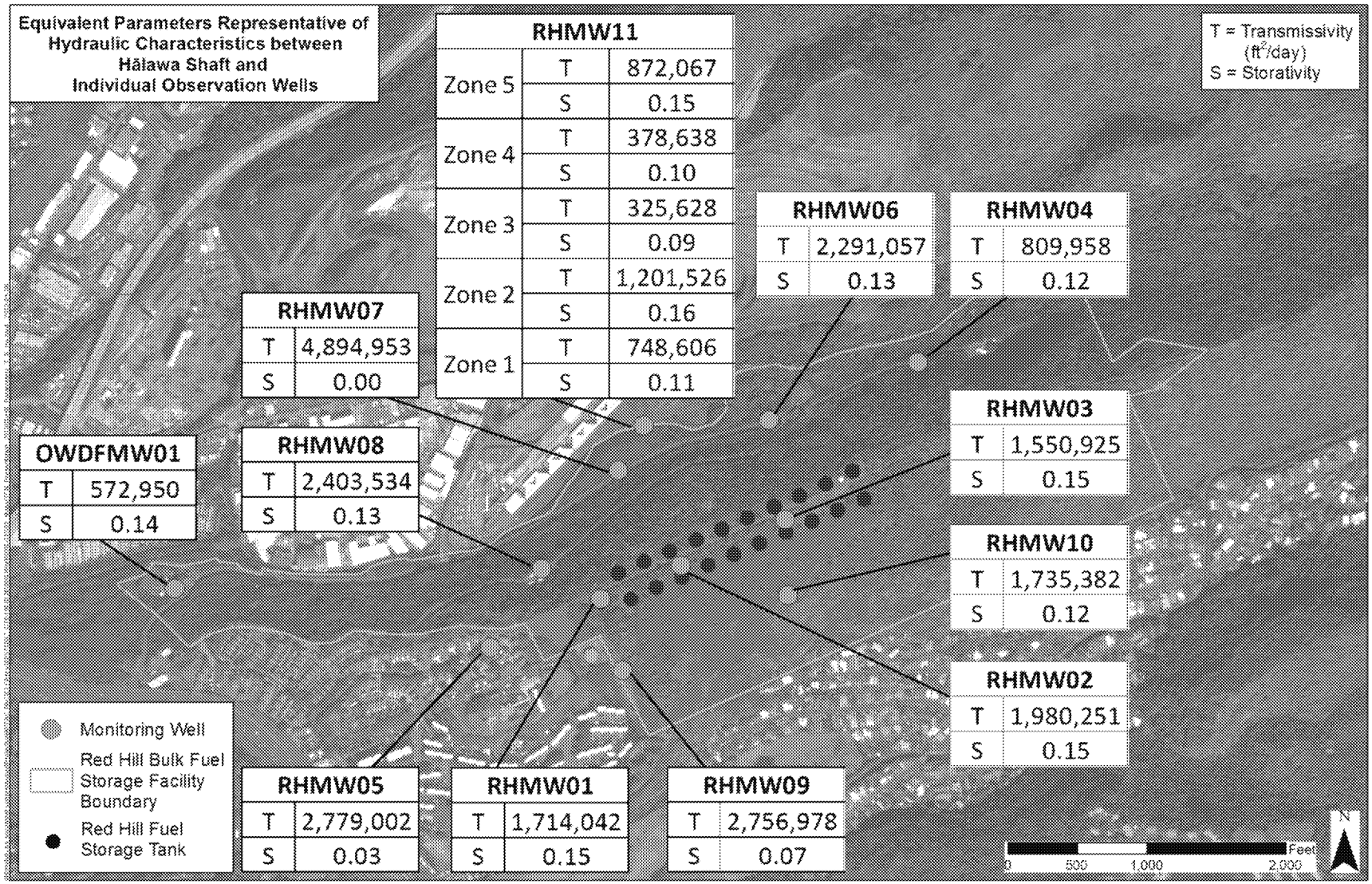
TFN Analysis:

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

Analysis of Aquifer Anisotropy

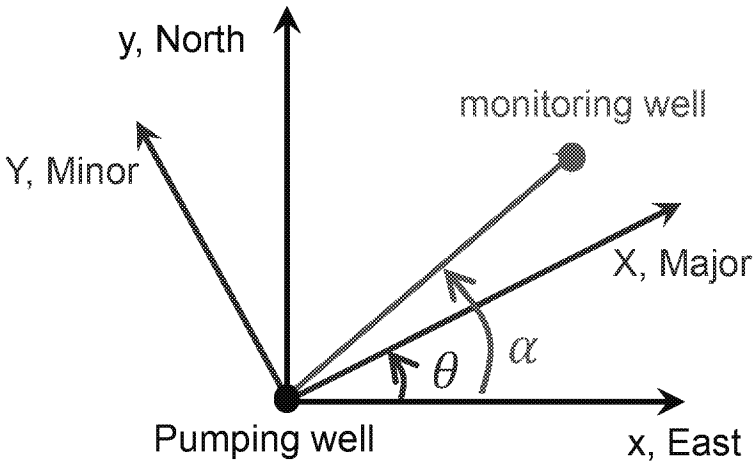
$$s = \frac{Q}{4\,\pi\,T_e}\,W(u_{XY})$$

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

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

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

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



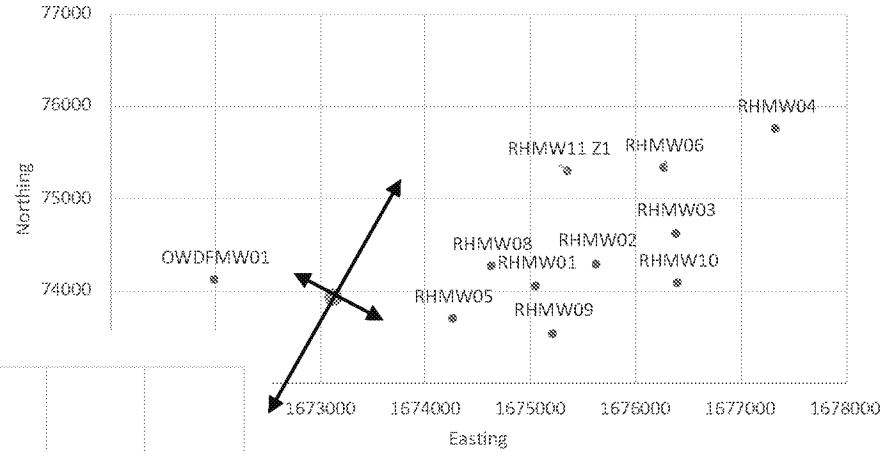
TFN Analysis:

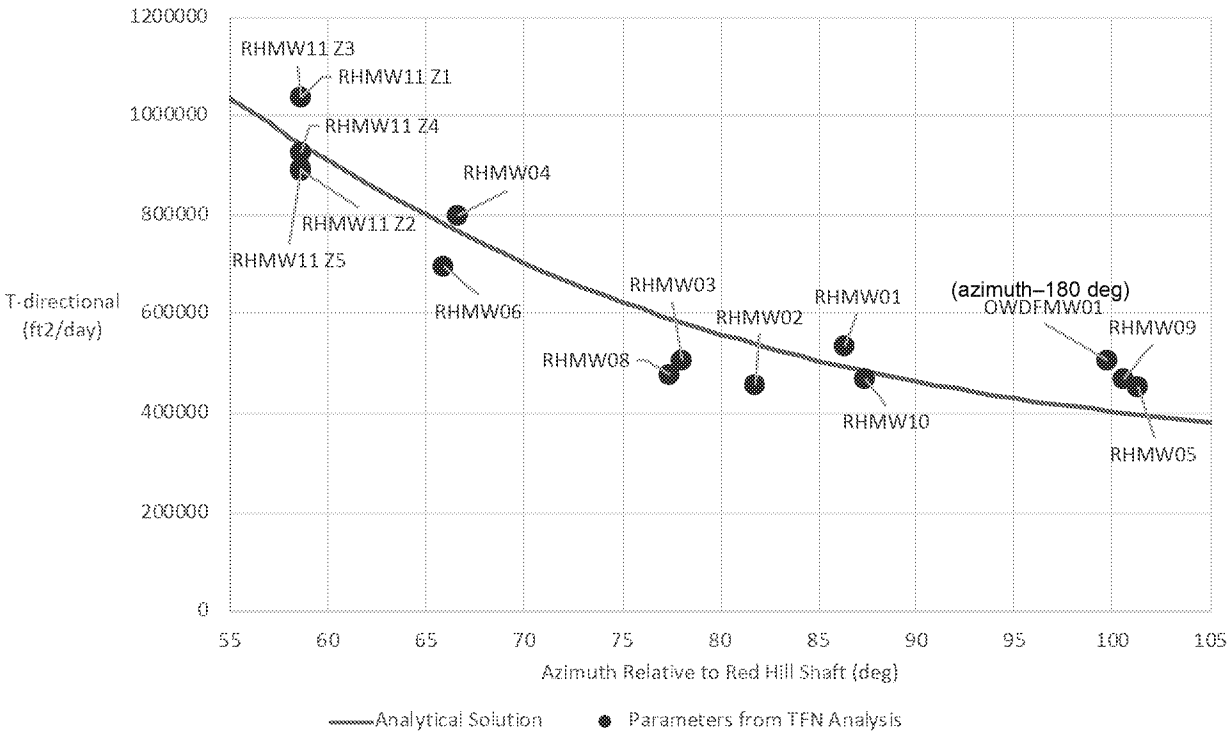
Analysis of Aquifer Anisotropy – Red Hill Shaft Shutdown & Restart

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

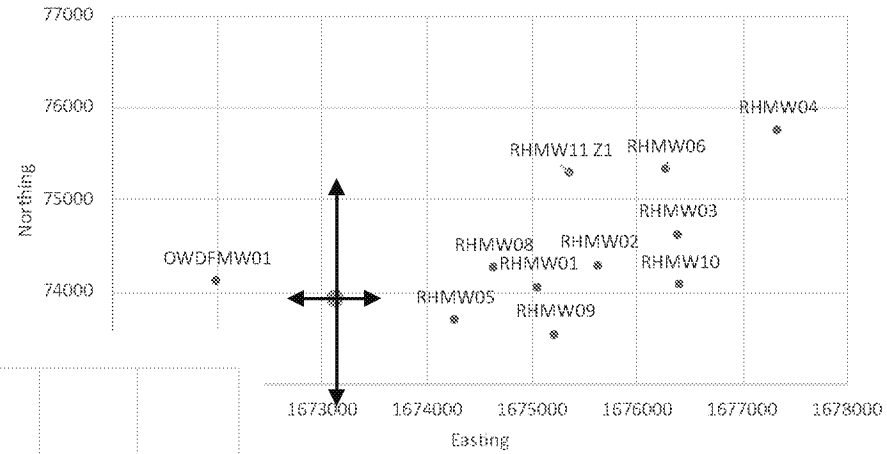
TFN Analysis:

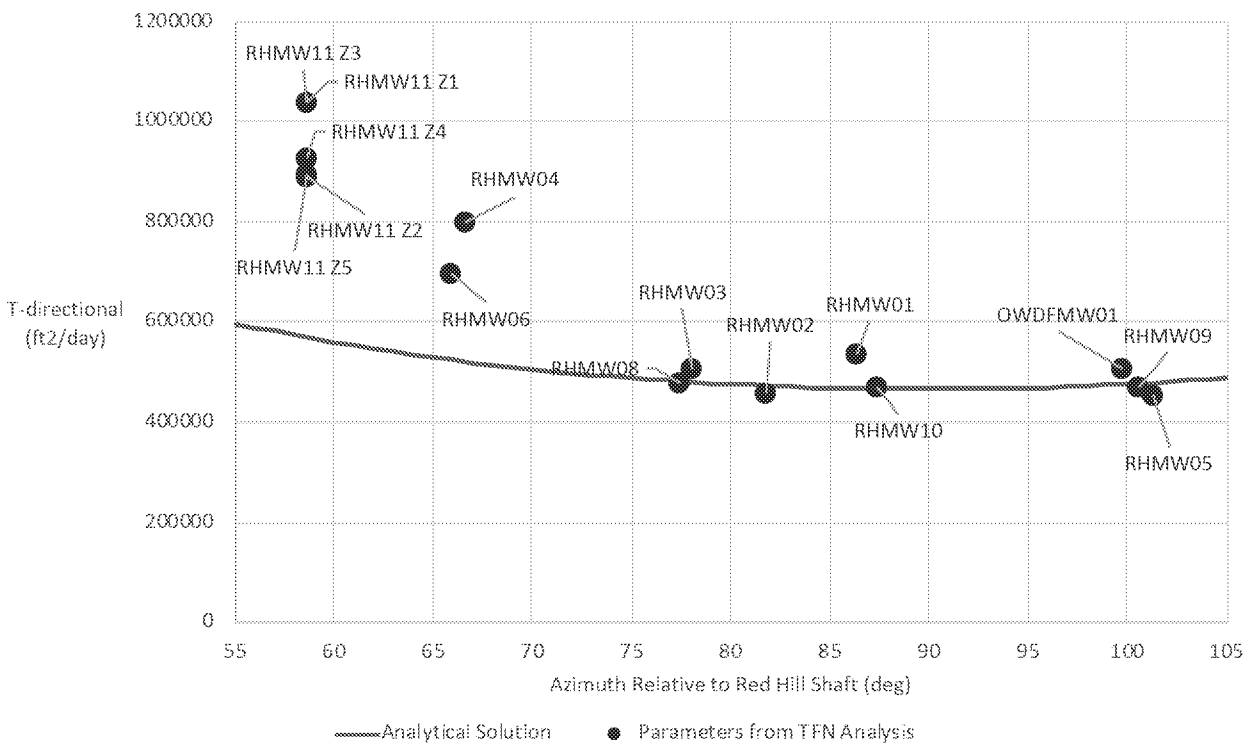
Analysis of Aquifer Anisotropy – Red Hill Shaft Shutdown & Restart (cont.)

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

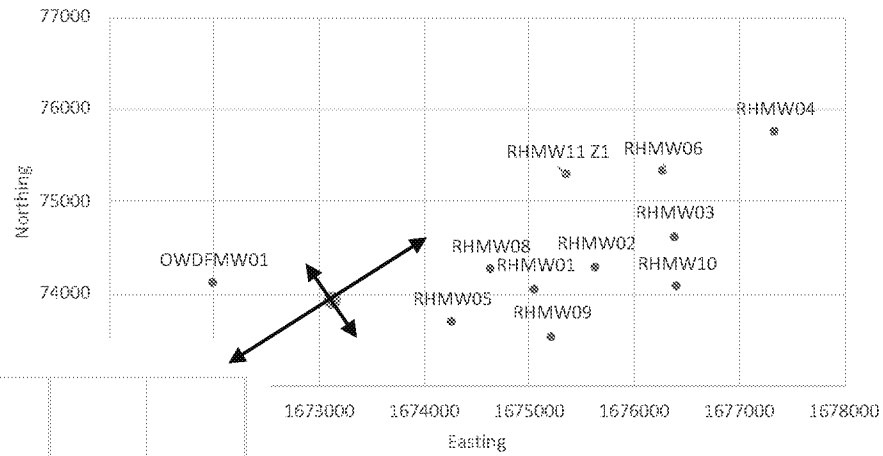
TFN Analysis:

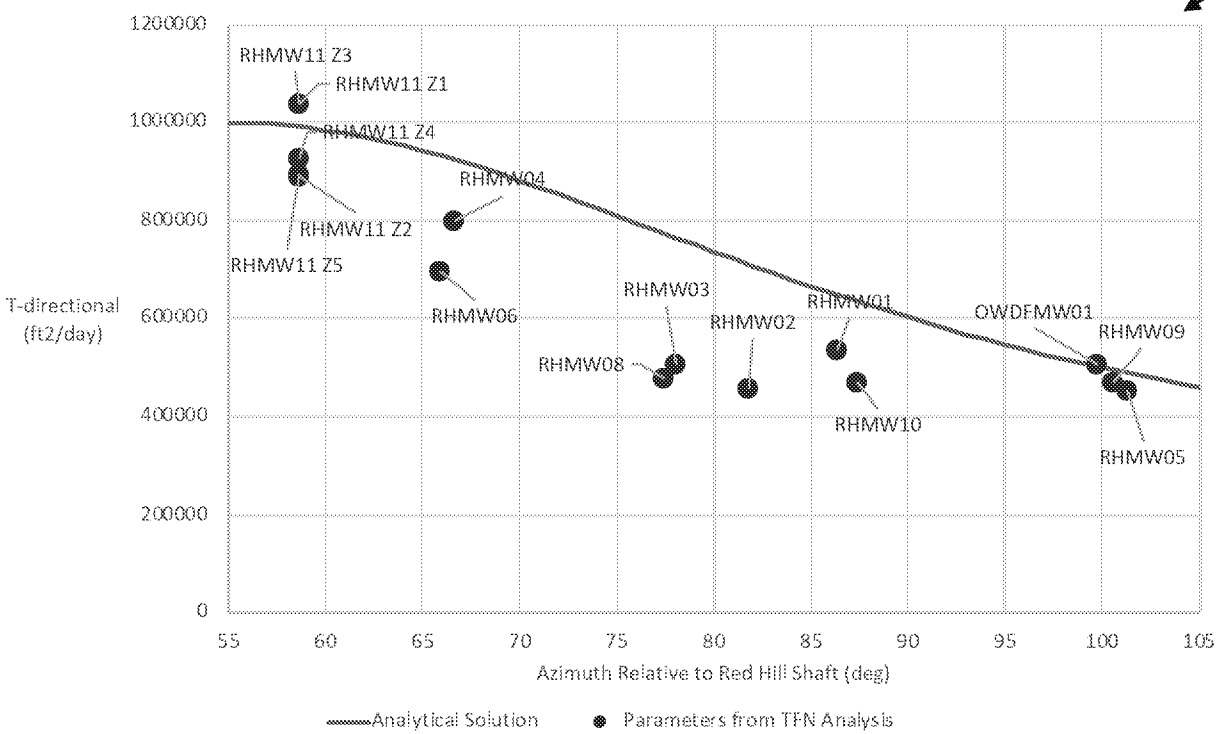
Analysis of Aquifer Anisotropy – Red Hill Shaft Shutdown & Restart (cont.)

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

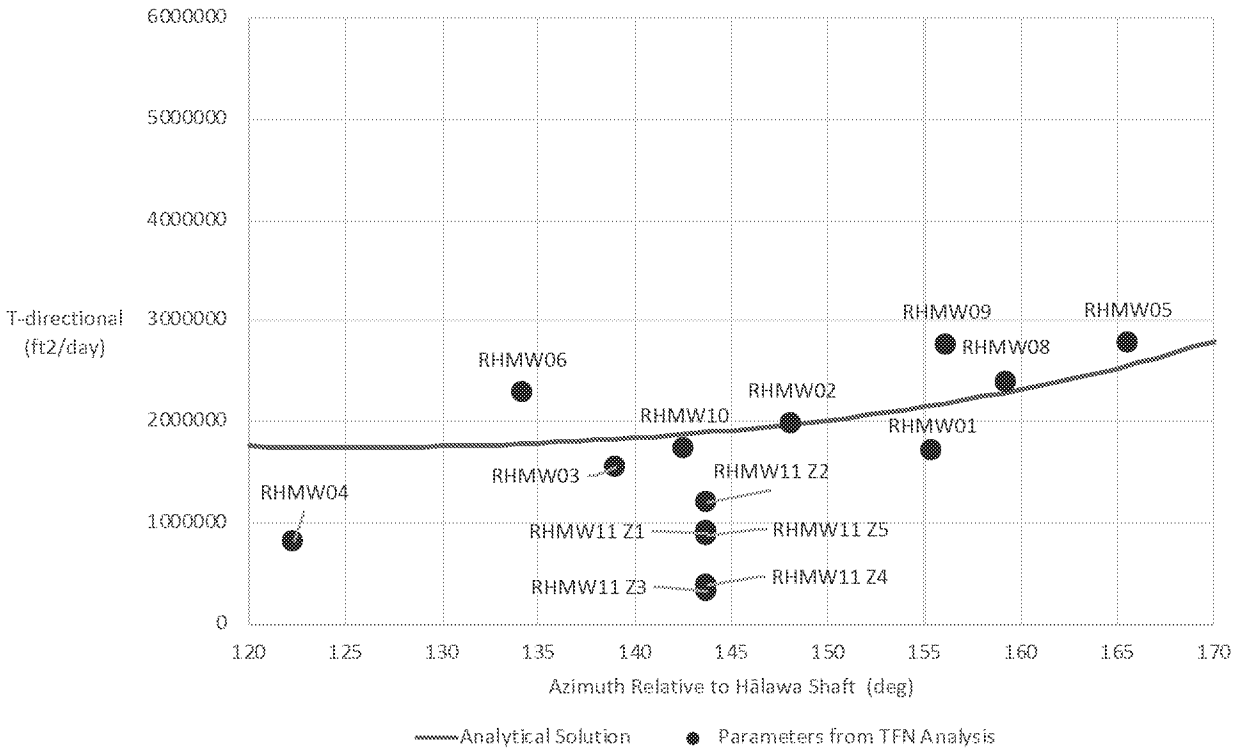
TFN Analysis:

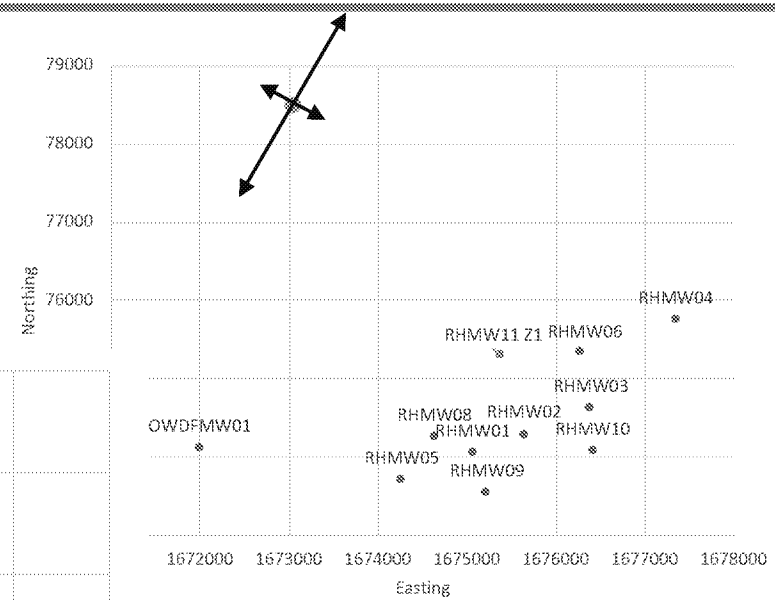
Analysis of Aquifer Anisotropy – Halawa Shaft Shutdown & Restart

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

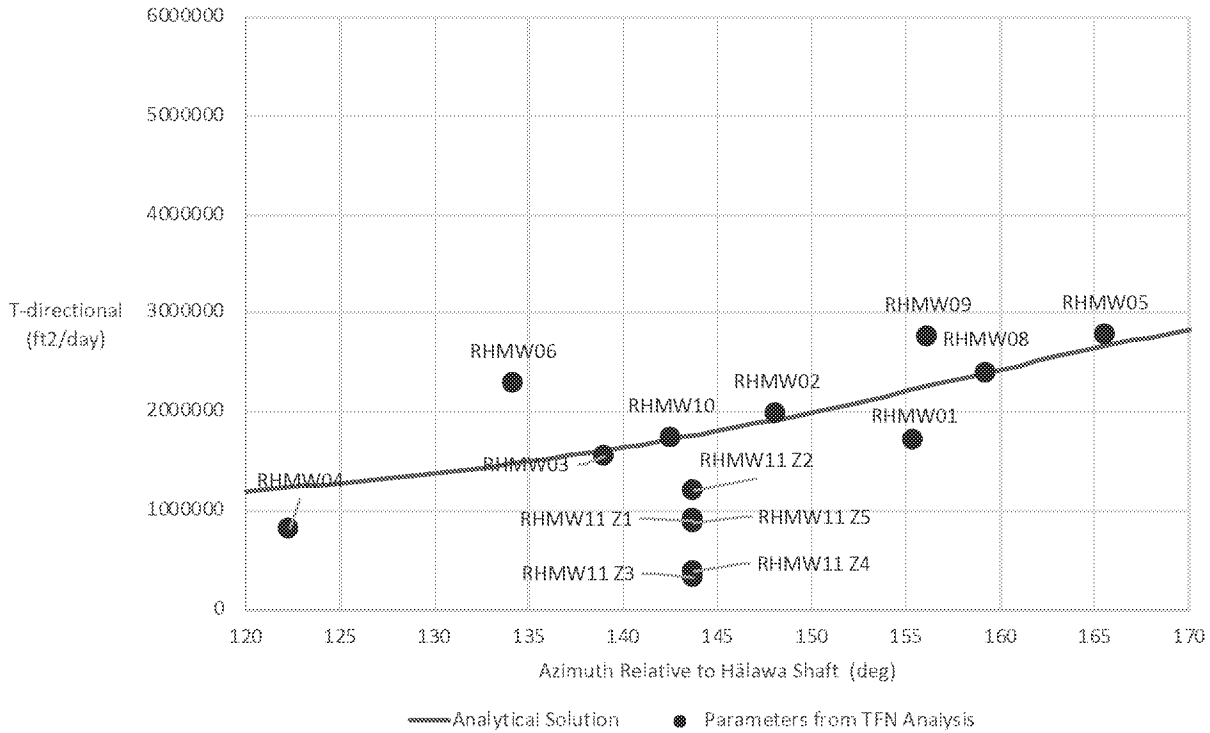
TFN Analysis:

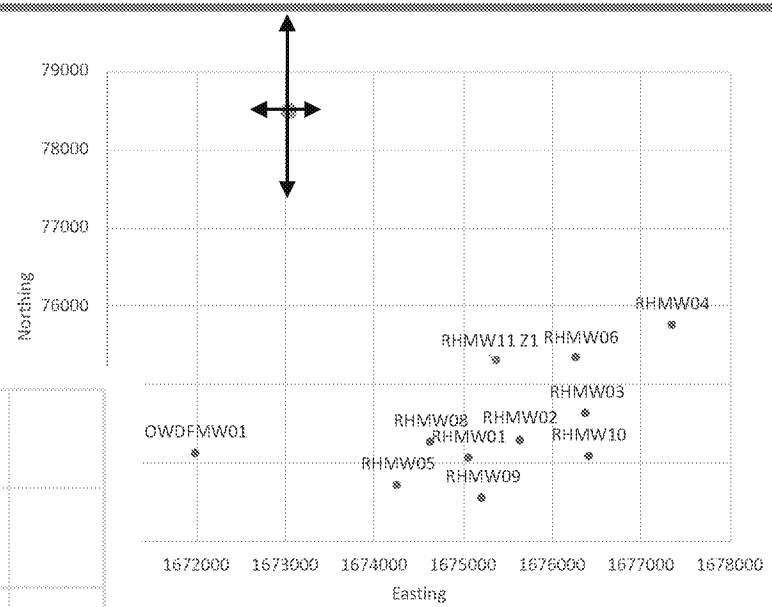
Analysis of Aquifer Anisotropy – Halawa Shaft Shutdown & Restart (cont.)

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

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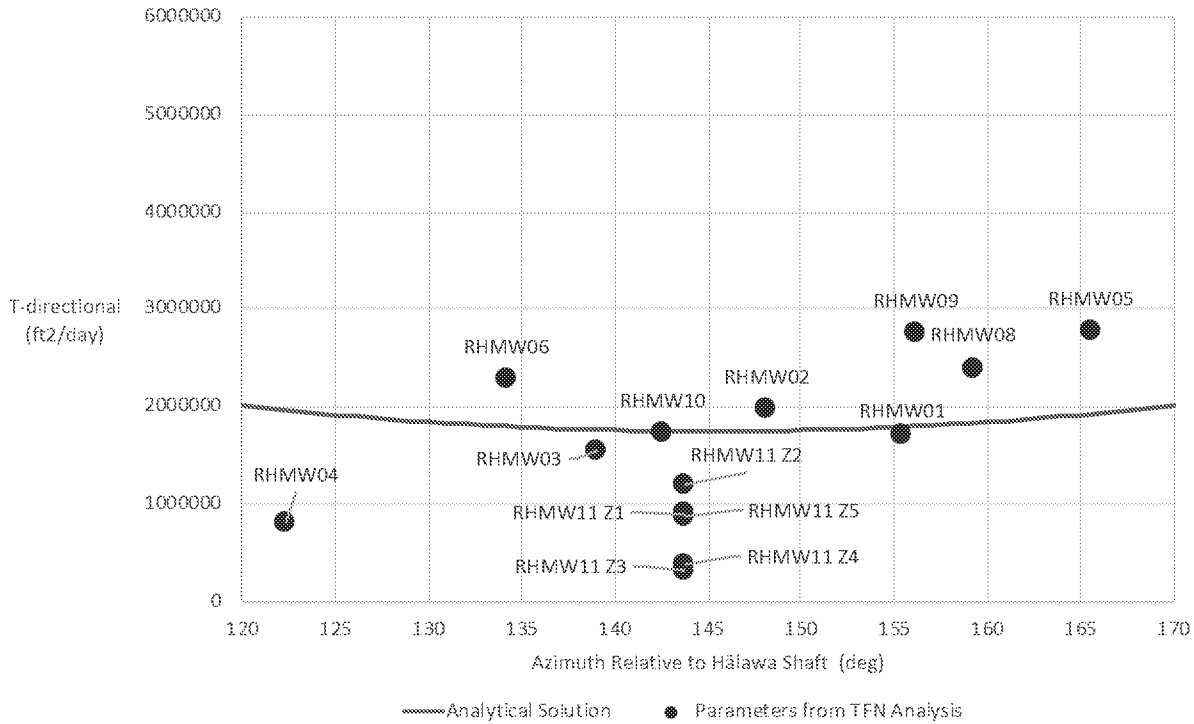
TFN Analysis:

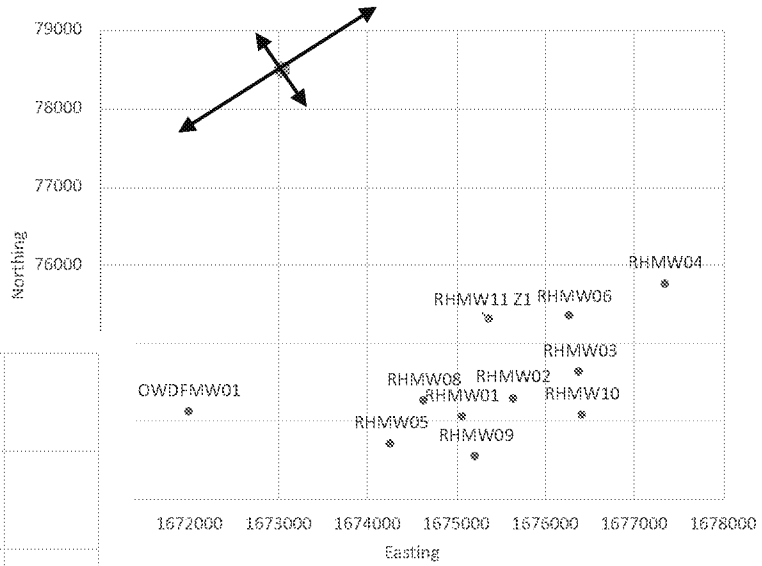
Analysis of Aquifer Anisotropy – Halawa Shaft Shutdown & Restart (cont.)

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_00002883-00107

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_00002883-00108

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Modeling Update Approach

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_00002883-00110

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.

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Model Update Progress

ED_006532_00002883-00112

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

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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

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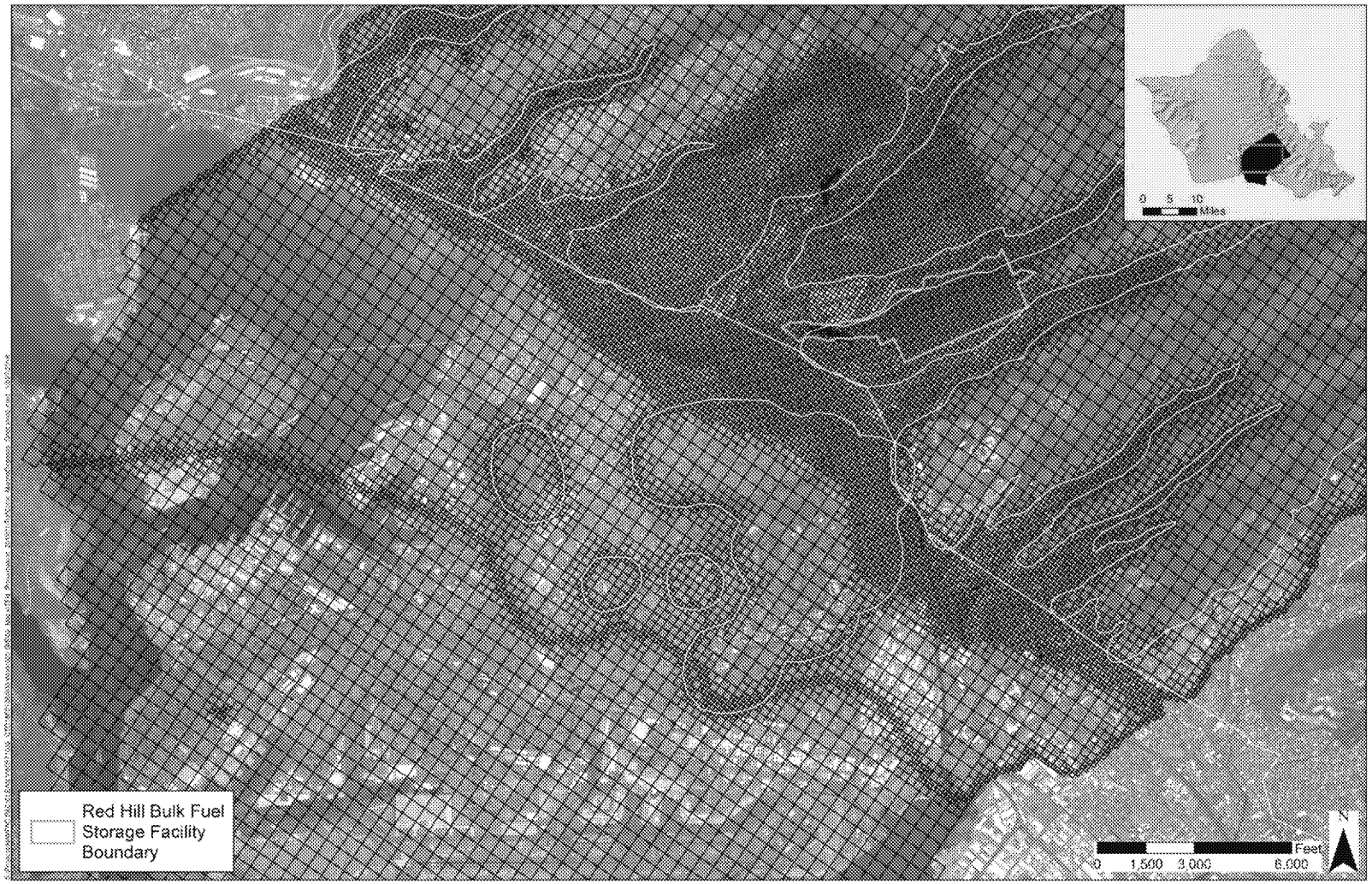
Model Update Progress:

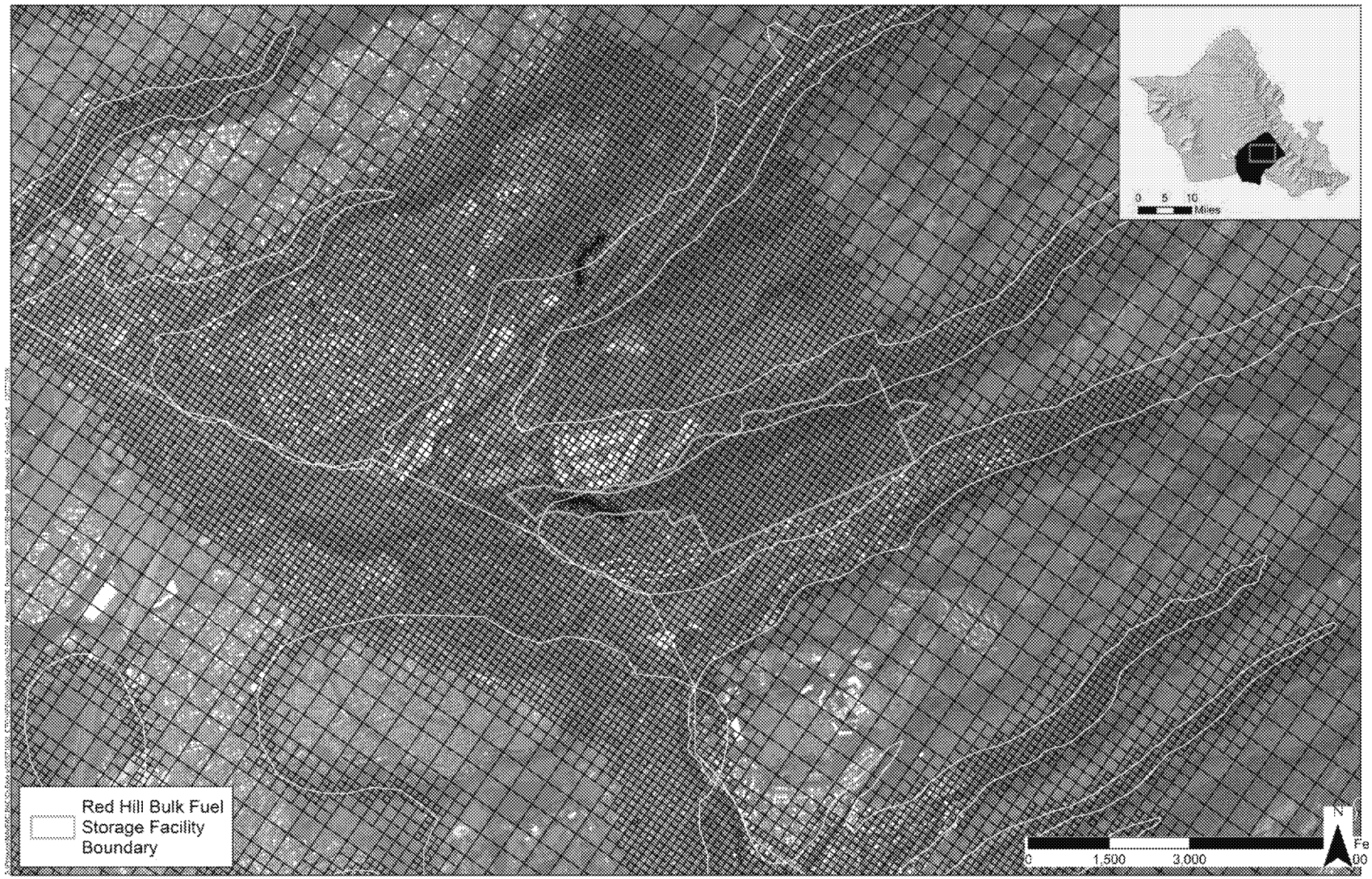
Tuff Cone and Marine Deposits Extent (Grid Level 2)



Marine deposits perimeter extent connects both NW and SE boundaries.

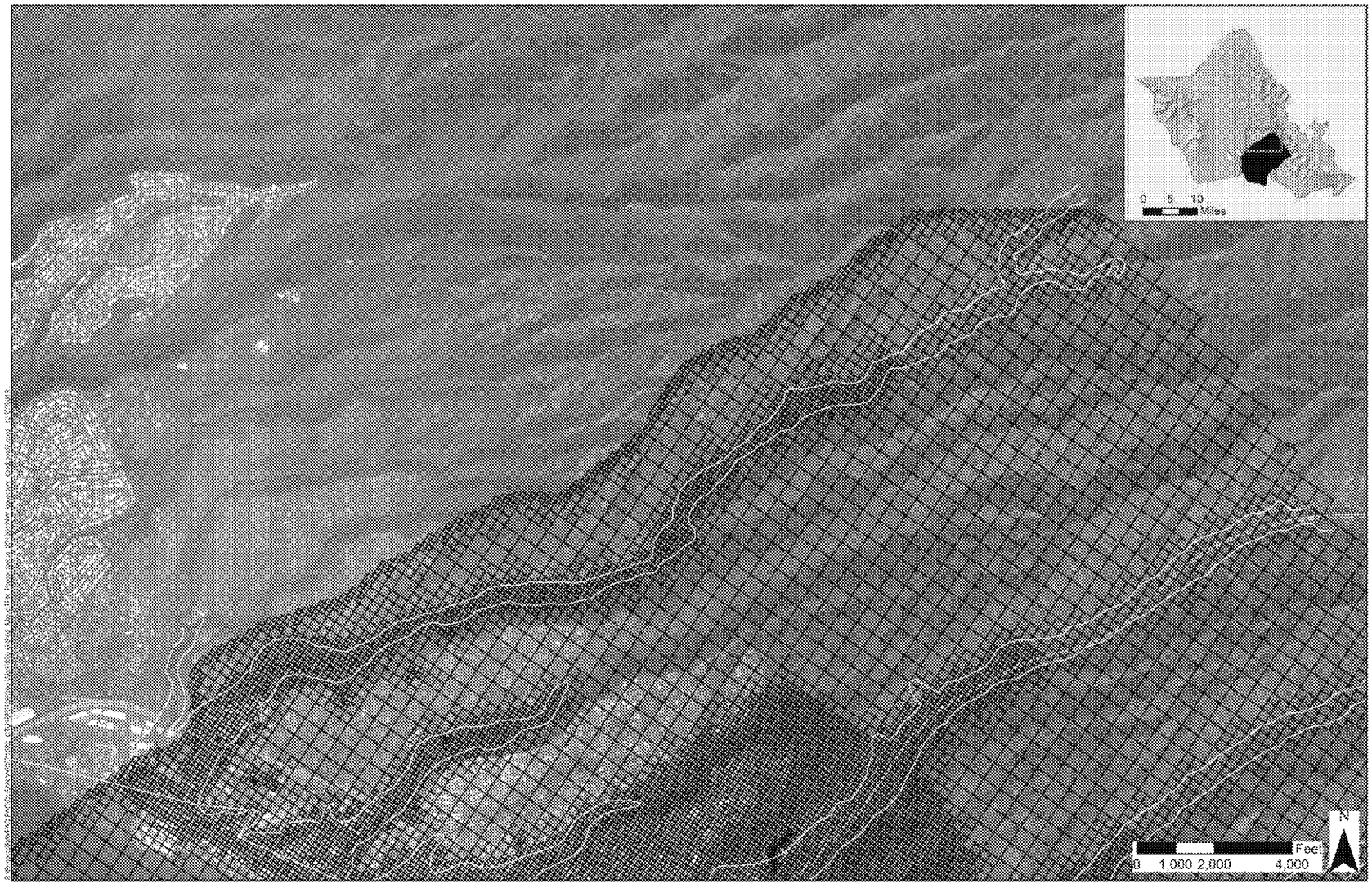
Model Update Progress:

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



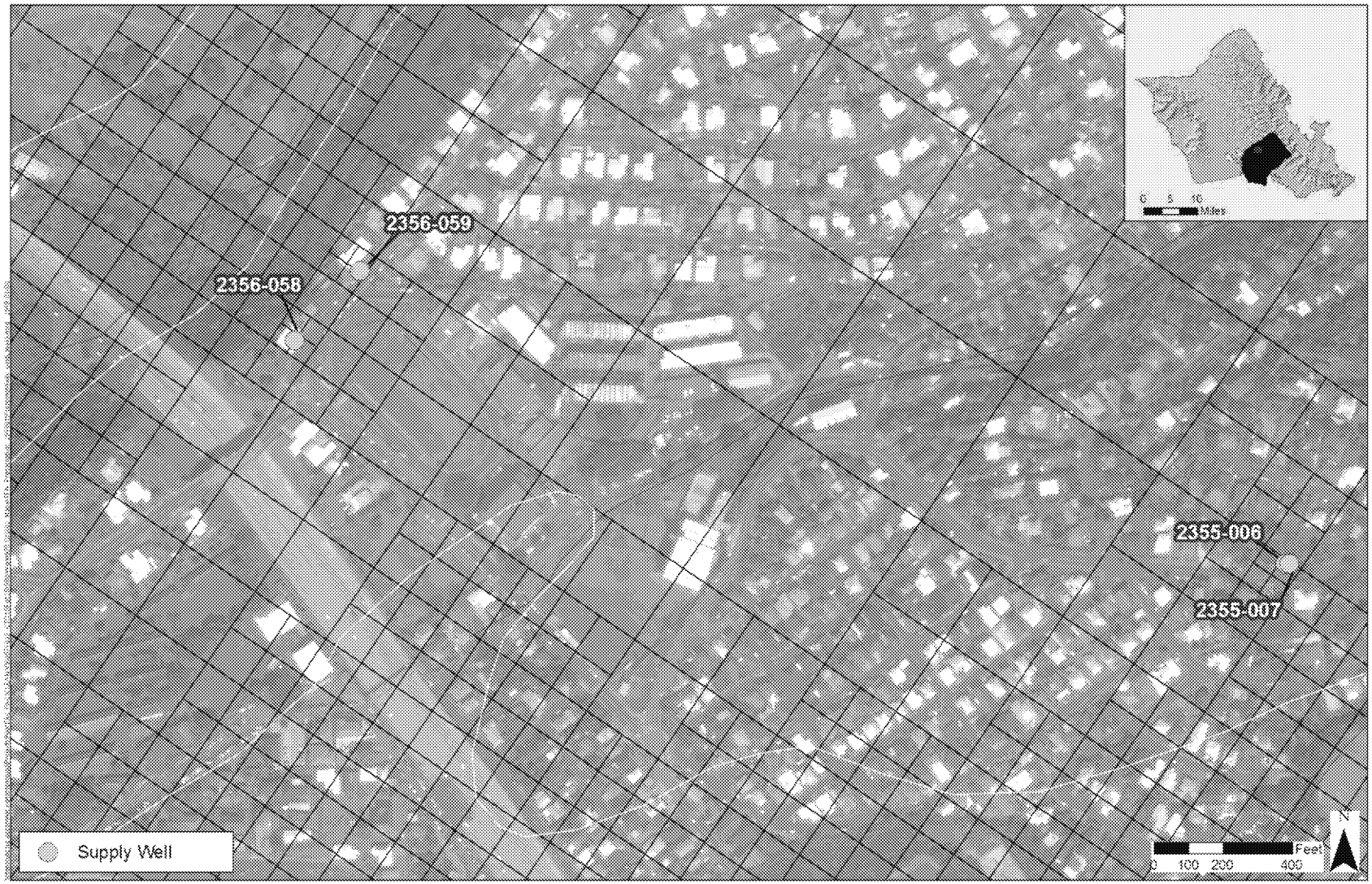
Model Update Progress:

NW Boundary (Grid Level 2)



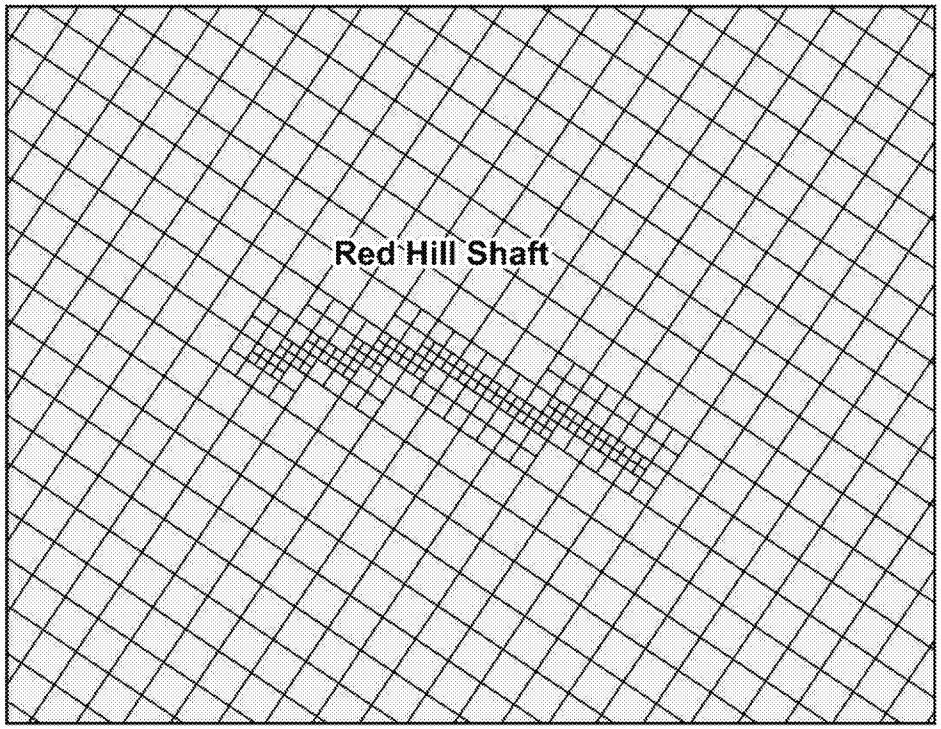
Model Update Progress:
SE Boundary (Grid Level 2)

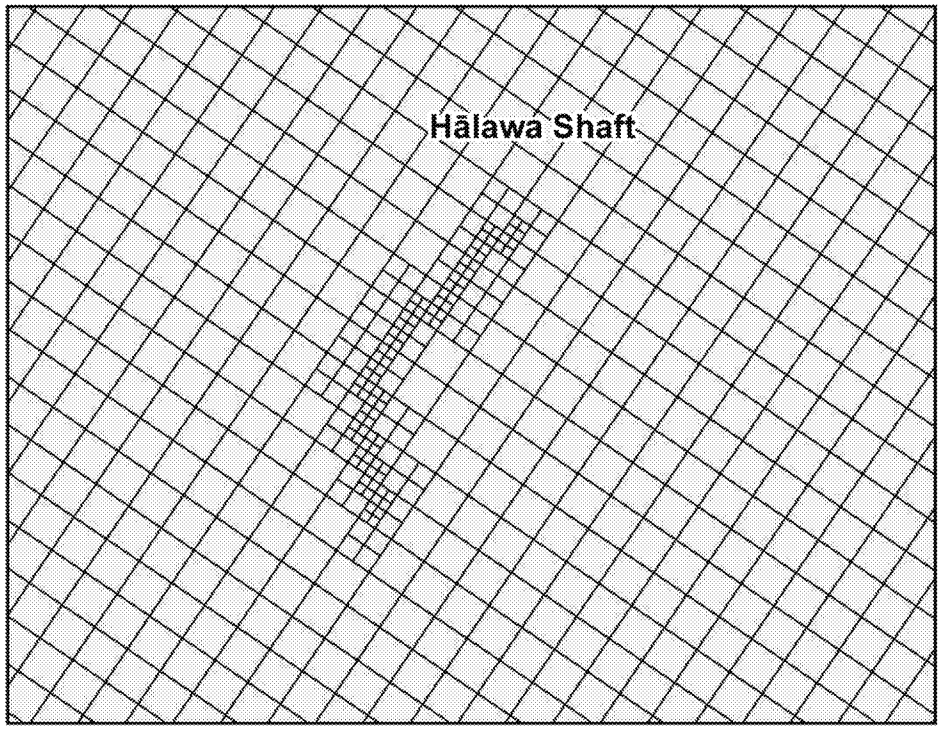
Model Update Progress:
Pumping Wells (Grid Level 3)



Model Update Progress:

Red Hill Shaft and Halawa Shaft (Grid Level 4)

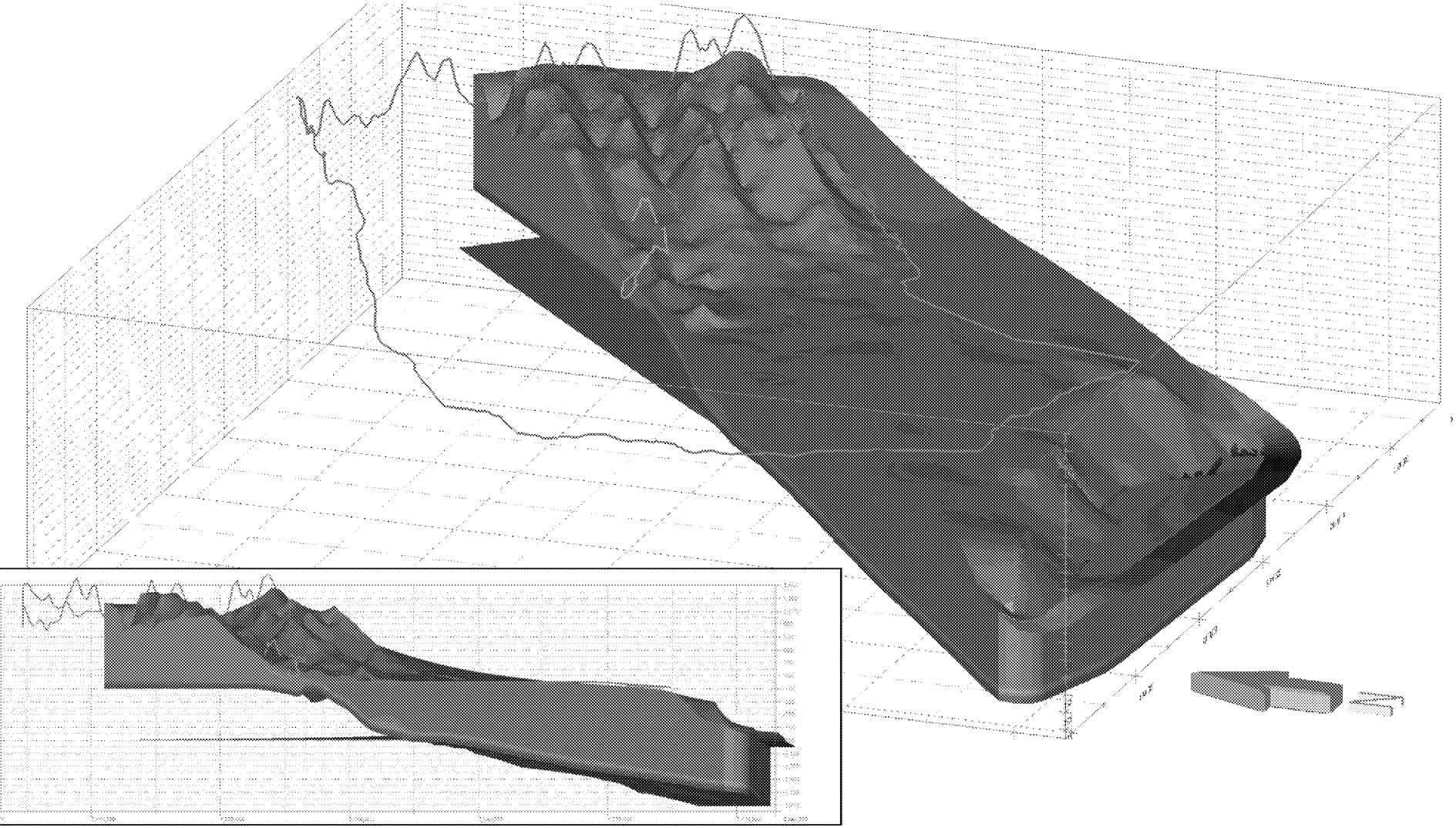




Model Update Progress:

Cross Section through Model Domain: NE–SW

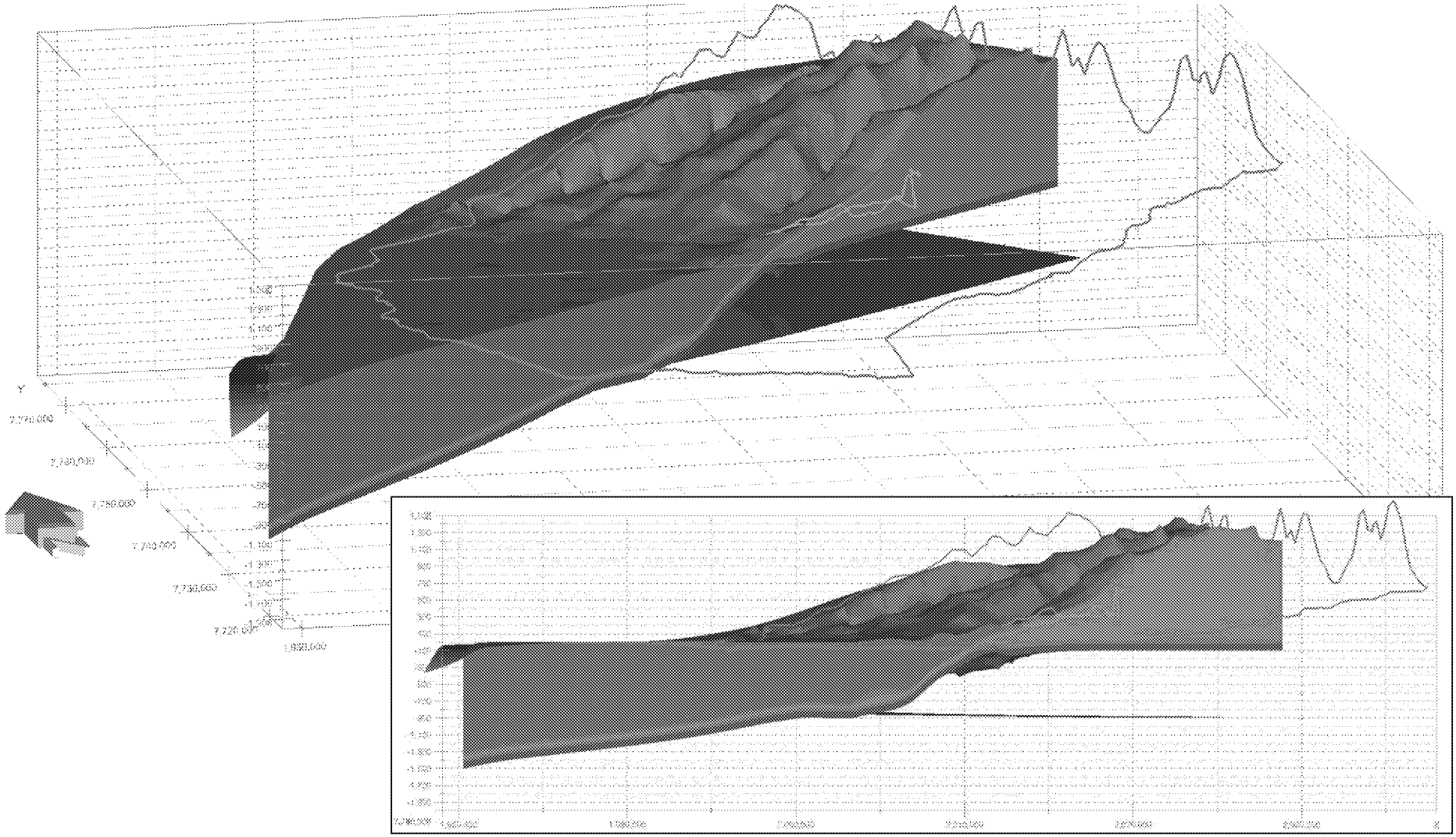
Groundwater Flow Model Layers 1–9



Model Update Progress:

Cross Section through Model Domain: SE–NW

Groundwater Flow Model Layers 1–9



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

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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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AOC Parties' SME Input/Discussion

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February 2019 Face-to-Face Meetings

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

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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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