Enclosure (1) - Navy's Response to DOH Comments on *Draft Groundwater Model Report*, dated September 24, 2024

Introductory Comments -

1. According to the 2015 Administrative Order on Consent (2015 AOC), the purpose of the groundwater flow models (GWFM) was to estimate contaminant fate and transport of a potential release from the previously in-service underground storage tank (UST) system, as well as past releases (Section 7, AOC, 2015).

Navy Response - For completeness and clarification, the Navy notes that Section 7 of the 2015 AOC Statement of Work (SOW) described the overall purpose of the modeling as follows:

> "… to monitor and characterize the flow of groundwater around the Facility … update the existing Groundwater Protection Plan to include response procedures and trigger points in the event that contamination from the Facility shows movement toward any drinking water well … [and] may include the installation of additional monitoring wells as needed." (AOC SOW Section 7.)

To help achieve these overall goals,

- The purpose of groundwater flow modeling is:

> "… to refine the existing groundwater flow model and improve the understanding of the direction and rate of groundwater flow within the aquifers around the Facility." (AOC SOW Section 7.1.)

- The purpose of contaminant, fate, and transport (CF&T) modeling is:

> "… to utilize the Groundwater Flow Model to improve the understanding of the potential fate and transport, degradation, and transformation of contaminants that have been and could be released from the Facility." (AOC SOW Section 7.2.)

To achieve these goals, the Navy has engaged modeling experts, solicited and incorporated constructive suggestions from Regulatory Agencies' and other subject matter experts, performed extensive monitoring of groundwater conditions, and developed Groundwater Flow and CF&T Models that improve the understanding of flow and potential transport, all of which can be used to achieve the stated goals.

The stated overall goals of the modeling will continue to be achieved: groundwater protection plans will continue to be updated, and additional wells have been installed, as envisioned by AOC SOW Section 7.

2. Given the changes to the system since 2015[1] and the Navy's inability over the last decade to provide a GWFM that accurately represents known aquifer behaviors and real-world data, the DOH continues to question the utility of this complex regional model. The critical issues we currently face are determining the nature and extent of past releases, identifying potential remedial options, and evaluating potential risk. The Navy's current models cannot be used to answer any of these questions for the reasons stated below and in our previous letters.

Navy Response - The Navy respectfully but strongly disagrees with the statement that the Groundwater Flow Model (GWFM) does not accurately represent known aquifer behaviors and real-world data. The current GWFM is calibrated to a vast number of data points collected from an extensive network of pre-existing and recently installed monitoring wells, barrel logs, responses to stresses from Red Hill Shaft (RHS) pumping during several prolonged tests, heterogeneity in rock types and properties, and other aquifer chemistry data. Measured quantitatively, the model results calibrate very well to the vast data set that the Navy has collected under a variety of pumping and other conditions. Flow directions in the Red Hill area predicted by the model are consistent with reports published by the United States Geological Survey (USGS) and the State of Hawaii Department of Land and Natural Resources (DLNR) (Oki; Hunt; Visher & Mink).

The model represents known aquifer behaviors better than any previous model developed for the site. In its review of this model, EPA and its modeling experts recently noted that "*The September 2024 groundwater flow model (GWFM) is the most comprehensive, best supported version of the model submitted to date and represents significant progress in developing an accurate, functional model of groundwater flow and contaminant transport at Red Hill.*"

To the extent the model is "complex," this evolved primarily in response to suggestions the Navy received during model development and Regulators' comments on prior versions of the models. Key stakeholders, including DOH, have asked the Navy to incorporate many details in the models including, for example, specific geological structural features, model grid restructuring, variable rock properties ("heterogeneity"), a substantial calibration data set, and an array of real-world sources and sinks of groundwater, which are several of the main causes of the model's complexity. The model is also complex because the subsurface setting itself is complex. Nevertheless, the Navy has endeavored to make the model only as complex as needed to address regulatory review comments and to adequately represent the key processes affecting groundwater flow and chemical migration.

The "regional" extent of the model was agreed to by all parties, including DOH, during scoping meetings held in 2015. The model extents and boundaries were set far enough away from the main area of interest so that the simulations of flow and transport in the Red Hill area are not overly affected by the boundary conditions. Specification of physical boundaries far from the area of greatest interest is standard practice in the creation of groundwater flow models, and the Navy has not received any recommendations to revise the model domain since the scoping meetings in 2015.

The "utility" of the GWFM and CF&T models lies in their ability to identify the key subsurface processes and predict flow, fate, and transport at a scale appropriate for decision-making. The models indicate that most constituents originating at the Red Hill Bulk Fuel Storage Facility Tank Farm migrate to RHS when the shaft is pumping, but do not migrate to Honolulu Board of Water Supply's Halawa Shaft under foreseeable pumping conditions. This information is of great value, suggesting that Halawa Shaft is not threatened by past releases at the Tank Farm. These predicted flow directions are consistent with the fact that no data collected during recent decades indicate any petroleum-related impacts to Halawa Shaft. The model-predicted flow directions are also consistent with the overall pattern of the total petroleum hydrocarbon (TPH) data. They are also consistent with the flow directions estimated by the USGS and DLNR (Oki; Hunt; Visher & Mink). When updated and combined with the in-progress vadose zone model (VZM), the GWFM and CF&T models will enable further assessment of risk and appropriate response actions to address prior releases.

The models described in the September 2024 Groundwater Model [GWM] Report provide a foundation, along with other lines of evidence, for addressing the issues described in DOH's comment. As our information and understanding of the subsurface improves, models can be updated and refined to help better answer these questions. EPA recently affirmed this approach when it wrote that "*Groundwater modeling is inherently an iterative process, and EPA is optimistic that through additional refinement, calibration and validation, the model will be a useful tool for guiding the site investigation at Red Hill, evaluating past impacts and present risk to drinking water resources, and selecting a suitable long-term remedy for groundwater contamination. It is important to note that the model is just one of many lines of evidence used to support critical decisions*."

General Comments –

1. Anisotropy - The simulated anisotropy is critical for the model to obtain a fair agreement with the measured groundwater elevations and, in the September 2024 submission, it simulated a groundwater

flow trajectory (as indicated by particle track simulations) that is approximately down the axis of the Red Hill Ridge. The model does a reasonable job of matching measured groundwater elevations on a regional scale. However, the simulated groundwater particle trajectories are oblique to the simulated groundwater contours. When the Red Hill Shaft is not pumping, the simulated groundwater flow trajectory from beneath the USTs passes down the Red Hill Ridge, flowing beneath 'Aiea Bay, and eventually being captured by Kalauao Springs (GWMR Figure 2-20). These flow trajectories depend heavily on a very high horizontal anisotropy that is much greater than what has been historically used in groundwater models of the area. The basalt horizontal anisotropy (Kx:Ky) used for the GWFM is 14, much greater than 3 used in Oki, 2005.

Navy Response - The anisotropy value that best calibrated to the site data sets (14) is different from the value that Oki assigned (3) in his model; however, that previous model was conducted at a different scale, with different objectives, and using different target data for calibration.

Oki's model also (reasonably, for its scale and purposes) did not include Red Hill-specific aquifer response data from pumping stresses, which is the most valuable information in understanding the hydraulic properties of an aquifer, especially in a specific area of interest. Additionally, previous models did not account for the dipping orientation of the lava flows in the vicinity of Red Hill in the vertical direction. Moreover, while Oki's model used published data for the horizontal conductivity in the direction of the lava flows, and cited a source for the vertical anisotropy (Souza and Voss 1987), the transverse conductivity (and thus the anisotropy ratio) was an estimated value that was assigned, but not based, on any cited data or study (see page 46-47 of Oki 2005).[2] The anisotropy ratio used in the Navy's model was based on best-fit correlations to several extensive transducer study datasets conducted in different years, under different pumping conditions, and many wells, in the specific vicinity of Red Hill. While the Navy does not question the parameter values used by Oki to serve that model's scale and purposes, there is no data-driven reason to reject a parameter value specific to the Red Hill site that better matches local field data.

Moreover, the Navy explored anisotropy values closer to those used in other groundwater models in the area, but they did not fit the extensive local Red Hill data set as well, and in any case did not have an appreciable effect on the flow results. The sensitivity analysis in Section 2.5 of the GWM Report documents two scenarios where the horizontal anisotropy was assigned much lower values: Scenario 2 is a model recalibrated with the horizontal anisotropy fixed at 3, and Scenario 8 is a model recalibrated with a horizontally isotropic aquifer (i.e., anisotropy fixed at 1). In both of these cases, all particles originating at the water table under the Tank Farm were captured by RHS when pumping, even at the reduced flow rate of [redacted] mgd, as shown on Figures 2-23, 2-24, and 2-27 and summarized in Table 2-19 of the GWM Report. This indicated that while anisotropy is important, the primary driver of flow direction may be the overall structure of the aquifer with dipping layers and valley fill incised into the basalt layers, which inhibit flow to the north and northwest. Notably, these lower anisotropy values resulted in a worse fit to the field data than the calibrated local value and were therefore deemed less appropriate for this model. The Navy recommends using the calibrated data that best fit the extensive site-specific data sets.

2. Model Parameterization - A summary of the most important hydraulic parameterization is provided below. Refer to Table 2-10 of the GWMR.

a. The GWFM used a basalt hydraulic conductivity value of 18,546 feet per day (ft/d), much greater than literature values of 4,500 ft/d (Oki, 2005) and 500-5,000 ft/d (Hunt, 1996).

Navy Response - As noted in the response to the prior comment, previous modeling was conducted at different scales, with different objectives, and using different target data for calibration that was not collected from within the area of interest. Hunt Jr. (1996) states: "Averaged over several lava-flow thicknesses, lateral hydraulic conductivity of dike-free lava flows is about 500 to 5,000 feet per day, with smaller and larger values not uncommon." Values as high as 85,000 feet per day have been reported in the literature (Hunt Jr. 1996; Soroos 1973). The Navy used the hydraulic conductivity values from previous modeling reports as a starting point, but then refined them to calibrate a site-specific value based upon multiple vast and more detailed high resolution field datasets spanning different pumping conditions in the Red Hill area of interest. Specific differences between the Navy's 2024 model and Oki (2005) and Hunt Jr. (1996) are presented in Table 1 Specific Differences between Select Models, below.

Oki (2005) has the most similar domain, but still is much larger than the 2024 GWFM. In the model limitations section, Oki states:" The distributions of parameter values assigned in the model were kept simple to avoid creating an overly complex model that could not be justified on the basis of existing information. Heterogeneity in the ground-water system likely exists but is currently poorly understood. Values assigned to model parameters generally were based on existing estimates. However, some of these parameter values may be poorly known. Improved estimates of the distribution of hydraulic characteristics in the study area can be obtained using controlled aquifer tests as well as by careful monitoring of pumping and water level conditions throughout the aquifer. Accurate pumping data in conjunction with water-level drawdown and recovery data can be used for calibration of a numerical ground-water flow model, particularly during periods when recharge does not vary."

In this statement, Oki acknowledges that the hydraulic properties are uncertain and best estimated from site data, referencing previous studies for the values used. Hunt Jr. (1996) summarized many aquifer testing results to arrive at its estimates; however, there are many assumptions associated with these analyses, most specifically boundary effects, partial well penetration, and the assumption of saturated thickness. Similarly, Soroos conducted numerous intra-well studies (each based on one well) and then applied the Cooper-Jacob method, which incorporates assumptions of three-dimensional radial flow in an isotropic, homogenous, and constant thickness confined aquifer, an environment significantly different than that at Red Hill. In addition, in reviewing transmissivity rather than hydraulic conductivity, which eliminates the need for an assumption of saturated thickness, the estimates in Table 1 from Hunt Jr. (1996) are as high as 8.4E6 ft^2/d, with many values in the range of 0.3E6 to 2E6 ft2/d. The Red Hill GWFM Report provides estimates ranging from 0.9E6 to 3.4E6 ft^2/d. Use of values derived from site-specific data, such as those in the 2024 GWFM, are reasonable and appropriate.

Moreover, the Navy explored conductivity values closer to those used in prior reports, but (like the anisotropy discussed in the previous comment) those values produced similar flow directions but did not fit the extensive local Red Hill dataset as well as the calibrated value. Scenario 1 of the sensitivity analysis in Section 2.5 of the GWM Report documents a flow model recalibrated with a fixed hydraulic conductivity along the primary axis of 4,500 ft/day, consistent with Oki (2005). This recalibrated model was the worst performer of all sensitivity models with respect to the calibration metrics presented in Table 2-18, which compare the modeled values to the extensive local field dataset. Particle tracking results under RHS pumping also did not differ significantly from the base model calibration, showing that all particles originating at the water table under the Tank Farm were captured by RHS, even at the reduced flow rate of [redacted] mgd. Flow directions were also not significantly different under non-pumping conditions, as shown on Figures 2-23 through 2-27 of the GWM report. The Navy recommends using the calibrated data that best fits the extensive site-specific data sets.

b. The GWFM used a basalt vertical anisotropy (Kh:Kz) of 50, while literature values are 600 (Oki, 2005) and 600 (Rotzoll and El-Kadi, 2007).

Navy Response - The vertical anisotropy ratio that best calibrated to the Red Hill dataset (50) is different from those used in the two other models cited (600). Other modelers have used other values; for example, Souza and Voss (1987) reported a range of 1–1,000 and used 200 in their model; Eyre (1983) reported a value of 10; Eyre and Nichols (1996) used a value of 3. The two previous models mentioned in this comment did not account for dipping layers, which results in the water table intersecting many lava flows down Red Hill ridge. Increasing the vertical anisotropy ratio to very high values such as 600 results in a simulated hydraulic head gradient turning directly down Red Hill ridge, which is inconsistent with observed water levels and comments received on previous version of the flow model. Increases to the vertical anisotropy also create large upward gradients in the model, which is inconsistent with the observed vertical gradients at most multilevel wells.

Moreover, the Navy explored vertical anisotropy ratios closer to those mentioned in this comment, but those values produced similar flow results and did not fit the extensive local Red Hill data set as well as the calibrated value. Scenario 3 of the sensitivity analysis in Section 2.5 of the GWM Report documents a model recalibrated with a fixed vertical anisotropy ratio of 200. The recalibrated model required an unreasonably high horizontal hydraulic conductivity, bringing the vertical hydraulic conductivity into a similar range as the original model calibration, despite the increased ratio. Particle tracking results did not differ significantly from the base model calibration with 100% of particles originating at the water table under the Tank Farm were captured by RHS, even at the reduced flow rate of [redacted] mgd, as shown on Figures 2-23 through 2-27 of the GWM Report.

Based on the results of this modeling study, using a vertical anisotropy as high as 600 would require more gently dipping or flat model layers such as those used in previous models. The Navy recommends using the calibrated data that best fit the site geology and the extensive site-specific data sets.

b.i. Note: Table 2-10 of the GWMR states Rotzoll and El-Kadi used a vertical anisotropy of 10. That is incorrect, they used a vertical anisotropy of 600, in agreement with Oki.

Navy Response - Concur. The reported vertical anisotropy value used by Rotzoll and El-Kadi will be corrected to 600 in future reports.

c. Using parameter values that deviate from those used by previous modelers is not necessarily incorrect, if sufficient basis is provided and the model results are supported by field data. However, the simulated GWMR trajectories do not conform with previous data collected, as well as emerging data.

Navy Response - As described in responses to comments 1, 2.a, and 2.b, parameter values used in the current model differ from those used in previous models because of differences in model domains, larger and site-specific data used for calibration, model codes, dipping layers, and modeling objectives. When such significant differences in models exist, it is inevitable that calibrated model parameters will differ. Because parameters used by previous modelers were based on calibration of different models and not on site-specific measurements in the Red Hill area, there is no basis for assuming that previous model parameters are more accurate than the site-specific parameters used in the current model. The Navy's GWFM uses much more site-specific data (collected under varying conditions) than previous models did. Therefore, the site conceptual model on which the Navy's GWFM is more detailed and likely more representative of true subsurface conditions in the local Red Hill area than are previous models.

The Navy also disagrees with the statement that the GWFM trajectories do not conform with previous data collected. Rather, the model parameters are *based on* the extensive data collected. Simulated potentiometric elevations closely match measured potentiometric elevations in the RHS and Tank Farm area. With the horizontal anisotropy used in the model, the flow lines between the Tank Farm and RHS are consistent with the dip azimuth that indicates down-ridge flow, and with the USGS and other studies mentioned above in responses to previous comments. Currently, the Navy is not aware of data confirming a northwest groundwater flow direction.

The Navy also does not believe that the GWFM is inconsistent with emerging (recent) data, which we assume refers to the preliminary borescope data gathered by the University of Hawaii (UH) and USGS. Although colloidal borescope data can provide direct measurements of groundwater flow magnitude and directions under certain conditions (Kearl and Roemer 1998), there are significant limitations in using colloidal borescope datasets to represent entire aquifers. Colloidal borescopes survey only the screened interval of a monitoring well, which at Red Hill varies between 20 and 30 feet in length; this relatively small interval is not representative of the entire aquifer. In addition, the colloidal borescope surveys were run in under an hour, this finite time interval represents a small snapshot of aquifer behavior and should not be considered fully representative of various aquifer conditions. As explained in Wilson et al. (1999), "Typically, flowmeter measurements alone cannot delineate hydrogeologic framework."

Moreover, it is not clear that UH's data, which has not been finalized and is still being analyzed, will result in a clear and consistent depiction of flow in the area of interest, especially given the complex stratigraphy and other conditions present at the site. For example, even looking at the available limited borescope data sets from two wells published by USGS:

- Significant differences in groundwater flow measured by a borescope can occur over short vertical distances in a well, sometimes over as little as 2 feet. For example, despite the same pumping conditions at RHS, flow magnitudes at RHMW16 decreased by approximately 4 ft/day and changed direction by 27 degrees over just 2 feet of the borehole. At RHMW16, average groundwater flow was reported to be 103–157 degrees (E to SSE) at five depths between 490 and 511 feet below ground surface, a variation of 54 degrees.

- Significant differences in apparent flow can occur at the same location over the course of 1 day. For example, in RHP04B at 319 feet bgs, on October 10, 2024 the average direction was 227.8 degrees (SW), but the next day the reported direction was 55.4 degrees (NE), a 180-degree difference. The flow velocities for the same readings also changed by a factor of 3, from 8.9 ft/day to 28.4 ft/day.[3] RHS was off on October 10, 2024 and was pumping at [redacted] mgd when the colloidal borescope was run on October 11, 2024.
- Groundwater velocities also changed over time, even for flow measured at the same depth in a single well. At RHMW16, within 30 minutes, flow rates ranged between 15.8 to 56.2 ft/day. In RHP04B, groundwater velocities ranged between 13.3 and 33.2 ft/day over roughly 20 minutes. At RHMW04B, the average flow direction was 346 degrees on October 10, 2024, but 304 degrees the next day (October 11, 2024), a difference of 42 degrees over a 24-hour period at the same depth.

It is important to note that USGS' data discussed above has been finalized and published.

UH's colloidal borescope data set has not been finalized and analyzed and therefore does not now provide a comprehensive indication of average groundwater flow directions. Preliminary data collected by UH from NMW24 suggest that groundwater flowed at 135 degrees (SE) during high tide. These are preliminary interpretations of results currently available and may not be representative of the full final data sets. The Navy intends to wait until UH completes it work rather than incorporating preliminary data into its models.

The Navy GWFM is consistent with the data collected from the Red Hill area and will be updated with other finalized data, as appropriate.

c.i. The 2021 fuel releases indicated a contaminant migration to the northwest. The model indicates a hydraulic pathway (GWMR Figure 2-20) from the Red Hill Bulk Fuel Storage Facility (Facility) to beneath the Department of Agriculture Animal Quarantine Station in Halawa, eventually passing beneath 'Aiea Bay and being captured by Kalauao Springs. However, the recently installed NMW27 indicates there is little flow in this zone, as shown by hydraulic and colloidal borescope testing (Thomas, 2024). Other colloidal borescope testing also fails to indicate groundwater flow trajectories produced by the model.

Navy Response - The Navy respectfully but strongly disagrees with statement that the 2021 fuel releases indicated contaminant migration to the northwest. As discussed during special purpose meetings (SPMs) held on April 27, 2022, and January 31, 2024, on TPH and its use for CF&T modeling, the sporadic detections of TPH-d in the perimeter monitoring wells do not appear to be evidence of migration from the Tank Farm in groundwater because 1) the nature of the TPH-d detected in the perimeter wells is different from the nature of TPH at the Tank Farm or RHS, as indicated by the chromatograms, 2) the detections are interspersed with *far* more numerous non-detects, 3) the detections that occur in many wells occurred months after the May 5, 2021 release, 4) the TPH-d detected at many of these wells is composed of polar organics as indicated by the silica gel cleanup data, which is inconsistent with a recent release of petroleum, 5) many detections in perimeter wells also contain TPH-o, which is not present in the JP-5 that was released in the 2021 event, and 6) sporadic detections of TPH-d are also occasionally reported in other perimeter wells surrounding the Tank Farm, not just wells to the northwest, but also to the north, northeast, southwest, south, and west.

As indicated above, the nature of the perimeter well TPH detections are inconsistent with a petroleum source at the Tank Farm or RHS. Each time a detection of TPH occurs at perimeter wells, the laboratory chromatograms are examined to determine if the detected TPH could have plausibly originated from fuels stored at the Tank Farm. To date, many of the TPH detections in perimeter wells are inconsistent with fuel releases as indicated by the substantial differences in perimeter well chromatograms as compared to chromatograms originating from Tank Farm well samples (at wells RHMW01R, RHMW02, and RHMW03) or from samples collected in the vicinity of RHS after November 2021. Moreover, the detections are interspersed between many more "non-detects" and do not follow clear or consistent breakthrough curves, as would be evidenced if the 2021 releases caused a plume to spread to the northwest.

The weight of evidence does not confirm significant transport of petroleum through the groundwater to perimeter wells northwest of the Tank Farm. The inconsistent detections of TPH in the past, typically without detections of identified fuel constituents or specific breakdown products, should not be interpreted to define the groundwater flow direction to the detriment of all other lines of evidence. Because "TPH" analyses cannot identify actual compounds measured, it may never be possible to conclusively identify the precise nature or source of these TPH-d detections, which have generally diminished in frequency over time. In a recent carbon study, USGS confirmed both that some of the TPH in the aquifer did not appear to be ancient carbon" and that there also appears to be "a natural source of ancient carbon in the basalt aquifer" that is not attributable to Red Hill; "Background groundwater has 38 percent ancient" carbon (Trost et al. 2024). What has been confirmed is that many of the chromatograms from these wells are not related to recent or older releases of petroleum fuel from Red Hill, as explained in detail in many memoranda that have been submitted to the Regulators. As discussed in the SPM on January 31, 2024, groundwater models based on chemical and fluid continuity cannot realistically simulate sporadic detections, with a preponderance of non-detections interspersed with few detections, that do not form clear breakthrough curves.

As to the preliminary data from the colloidal borescope testing of well NMW27, the Navy notes that this is only one of many wells that UH has tested, and UH has not completed their analyses or produced any final reports. The Navy will wait for all the colloidal borescope and other UH data to be gathered, validated, and interpreted before drawing any conclusions. Preliminarily, it is noted that NMW27 is located in a highly weathered zone beneath the valley floor, with reduced hydraulic conductivity and significantly elevated heads. Although flow is simulated through this area, it occurs at a rate significantly slower than beneath the Tank Farm or near RHS. Groundwater velocities beneath the Tank Farm are simulated as approximately 1–2 ft/day, whereas the simulated groundwater velocity the vicinity of well NMW27 is 0.2–0.3 ft/day as it moves through weathered basalt. Figure 1 (enclosed) shows particle tracking results with 1-year travel-time tick marks, demonstrating the impacts of weathering on groundwater flow. In this case, particles generally flow around the area where NMW27 is located, and groundwater velocities in the area are significantly slowed due to weathering of the basalt and the elevated heads. Therefore, the model is consistent with slower flow in this well.

As discussed above, available colloidal borescope data are highly variable and inconsistent from well to well and from day to day. For example, while only one depth from one well was shown, the preliminary data indicate flow directions ranging from approximately 60 degrees or less (NE) to 240 degrees or more (W-SW) over a period of 12 minutes. The two data sets (for RHMW16 and RHP04B) published by the USGS similarly show a wide range in potential flow direction over short periods of times (as described in more detail in the response to comment #2.c). The data indicate flow variations on a scale much smaller than what can practically be modeled. However, it is important to note that colloidal borescope data is a localized measurement of groundwater velocity, which can be heavily influenced by local-scale heterogeneity, the presence of the borehole itself, and localized effects of drilling and well construction and development. It is not technically valid to use these highly variable local velocities to infer overall groundwater flow directions over a larger region.

More relevant at this time than the preliminary UH colloidal borescope data for well NMW27 are the final USGS colloidal borescope data and analyses. Figures 3.1 through 3.5 (enclosed) duplicate figures published by USGS to their website’ based on their analyses of borescope data from well RHMW16.[4] Well RHMW16 is directly northwest of the Red Hill Tank Farm. In all these figures, not a single data point suggests flow to the northwest. Overall, based on the available preliminary results, it is not clear whether all the colloidal borescope tests run in different wells indicate a consistent flow direction.

The Navy will evaluate the colloidal borescope and other data gathered by UH once it has completed its analyses and revise the models as appropriate.

3. Density Dependent Flow Model - The model code used assumes a uniform water density, yet the model results presented in the GWMR simulate groundwater flow processes involving the freshwater/saltwater transition zone.

a. The simulated groundwater flow trajectories at the western portions of the model occur where the freshwater lens lies between the saltwater of Pearl Harbor and the saline groundwater. To support the results in the GWMR, the model needs to be converted to a density dependent model. The current model uses a fixed no-flow bottom boundary, which will not properly replicate seawater upconing and transport deep in the aquifer because the saltwater circulation part of the groundwater flow system is not included. The particle tracks that trace flow beneath Pearl Harbor and which abruptly turn toward the Kalauao Springs cannot be modeled with confidence without a density dependent model.

Navy Response - During modeling discussions among the Navy, EPA, and DOH in 2015, it was agreed that density-dependent modeling was not required. Density-dependent modeling was not requested until this 2025 comment, and it would be an additional complication that is not warranted by the conditions in the field. Moreover, although the final calibrated groundwater flow model did not incorporate density-dependent flow, simulation of the freshwater-saltwater interface in the unit concentration source models did include the density-driven flow (DDF) module of MODFLOW-USG Transport. To test the impact of density-dependent flow on groundwater flow directions, this model was used to simulate particle tracks from the Tank Farm with RHS off and Halawa Shaft pumping at [redacted] mgd both with and without the DDF package activated. Figure 2 (enclosed) shows the particles for the two simulations. Minimal differences are noted between the two simulations. Additionally, the contributions to RHS and Halawa Shaft from the saltwater interface were not significantly different between the two simulations. The lack of differences are likely attributable to chloride concentrations that are significantly lower over a short distance from the freshwater-saltwater interface, such that density effects become negligible only a few model cells away from the midpoint of the transition zone.

There are many potential downsides that would likely outweigh the likely negligible changes to the flow field under density-dependent flow, including: increase in the number of model cells, longer run time, larger file sizes, and most importantly numerical instability, particularly when implementing heterogeneity. As noted in the response to the first comment, the Navy advises against making the model needlessly complex.

b. Section 2.3.6 attempts to address the longstanding DOH concern that the general groundwater chemistry measured within the Facility wells is not consistent with the dominant downridge groundwater flow simulated by the GWFM (e.g., DOH presentation in August 2018 and DOH and

U.S. Environmental Protection Agency Disapproval of the Groundwater Flow Model Report, dated March 17, 2022). b.i. For example, the chloride concentrations measured in the Red Hill Shaft monitoring point and elsewhere throughout the Facility are higher than would be expected if the groundwater flowed directly from the recharge zones down the axis of the Red Hill Ridge. The Navy simulated the percent flow contribution to model from the upper, northeast, southeast, and bottom boundary (mid-point of the saltwater-freshwater transition zone [MPTZ]) and assigned representative chloride concentrations to these boundaries. Table 2-16 of the GWMR lists the percent contribution and assumed chloride concentrations at these boundaries. Using this approach, there was a fair agreement between calculated measured chloride concentration at the Red Hill Shaft. While the simulated water contribution from the MPTZ was only 2 percent, the high assumed chloride concentration of 9,500 milligrams per liter (mg/L) increases the chloride derived from the MPTZ to nearly 60 percent of the mass. The issue is that this approach is invalid because the modeling code assumes a uniform water density. Without considering the density difference between freshwater aquifer and that at the MPTZ, the model will significantly overestimate the contribution from the MPTZ. Since the actual contribution from the MPTZ is much less than that simulated, the chloride deficit must be made with groundwater from one of the other boundaries. This suggests that the chloride contribution from the Southeast boundary is much greater than the model can account for.

Navy Response - This statement is incorrect. The unit concentration source simulation of the freshwater-saltwater interface did in fact account for density changes using the density-driven flow (DDF) package of MODFLOW-USG Transport, as discussed in Section 2.3.6 of the GWM Report.

In a previous DOH response to the Flow Optimization Study Report, DOH stated:

> "No rationale is given in the BAGWFM Report as to why a chloride concentration of 40 mg/l was chosen for the GHB Southeast Boundary. The chloride concentration for this boundary can be estimated using available groundwater data. Figure 1 shows that the USGS NAWQA Study (Hunt, 2004) sampled two wells near the GHB Southeast Boundary, The Kamehameha School B Well with a chloride concentration of 41.1 mg/L and the Kalihi Pump Station with a chloride concentration of 80.9 mg/L. **Using the available data, the most appropriate chloride concentration for the GHB Southeast Boundary would be 60 mg/L**, an average of the two wells' chloride concentrations" (bold emphasis added)."

The Navy implemented DOH's recommendation to set the chloride concentration to 60 mg/L at the southeast boundary in the 2024 model. However, measured chloride concentrations at RHS and Halawa Shaft were 98 and 152 mg/L. No amount of increased contribution from a 60 mg/L source to the southeast could increase the chloride concentrations to 98 and 152 mg/L.

4. Model simulated groundwater flow trajectories are not consistent with real-world observations

a. NMW27 is located where Figure 5-15 in the GWMR shows the simulated contaminant plume extending from the Facility toward the Animal Quarantine Station. However, borehole testing conducted by the University of Hawai'i indicates very poor transmissivity in this borehole, greatly reducing the probability that any significant flow is occurring from the Facility toward the Animal Quarantine Station (Thomas, 2024).

Navy Response - Please see response to comment 2.c.i.

b. The distribution of petroleum related compounds following the 2021 fuel releases was to the northwest of the USTs. There was no strong indication of contaminant flow directly down the Red Hill Ridge, as the model indicates.

Navy Response - As explained above, the Navy disagrees that flow trajectories are inconsistent with real-world observations. The weight of the data indicates that the sporadic and inconsistent detections of TPH-d to the north of the Tank Farm are not the result of petroleum-fuel constituent migration in groundwater from the Tank Farm. In addition, the model calibration relied on matching groundwater heads under various pumping conditions, which greatly reduces the uncertainty in flow model calibration. This recalibration was in part performed to better match the groundwater elevation data from the wells, as requested in DOH's 2022 comments on the prior GWFM. The generally successful match of the groundwater model simulated heads to the observed heads under pumping conditions is strong evidence that the groundwater flow model trajectories match the data.

c. Consistent with the contaminant detections to the northwest of the USTs, the groundwater gradient is much steeper in that direction than down the axis of the Red Hill Ridge, as the model predicts. The model should objectively investigate the apparent cross ridge gradients.

Navy Response - As explained above and discussed in the SPMs conducted on April 27, 2022 and January 31, 2024, there is strong evidence that the detections of TPH-d and TPH-o north and northwest of the Tank Farm are not associated with migration of groundwater from the Tank Farm. Attachment 1 (enclosed) provides cross-ridge plots presented in the same format as the ridgeline gradients presented in the 2024 GWM Report. The three sections span these wells:

1. RHMW09, RHMW01R, RHMW08, RHMW14-Zone3
2. RHMW19, RHMW01R, RHMW16
3. RHMW03, RHMW20, RHMW12A

Reasonable matches to the cross-ridge gradients were achieved with the current groundwater flow model. On average, the simulated cross-ridge gradients are slightly greater than observed, which would be conservative with respect to northwest groundwater flow as well as hypothetical risk to Halawa Shaft. These plots will be included in future reports and the gradient targets will be integrated into the model calibration.

d. RHMW11, located on the south edge of South Halawa Valley, consistently shows a downward gradient, which could indicate groundwater flowing beneath the alluvial/saprolite wedge and to the northwest. The residuals shown in Figure 2-15 in the GWMR show the model fails to capture this apparent downward gradient. A downward gradient at RHMW11, the apparent extension of the May 2021 contaminant plume to the northwest, and a hydraulic gradient from the Red Hill Ridge to the northwest suggest flow is occurring from the Facility beneath the alluvial/saprolite wedge toward the Halawa side of Halawa Valley. It is important to note that while dissolved phase contamination may be entrained in the deeper flow, LNAPL (light non-aqueous phase liquid) would be blocked by the saprolite wedge because it floats on the top of the water table.

Navy Response - It is acknowledged that vertical gradients have not been fully incorporated at this point, in part due to the limited number of wells offering such data. The Navy continues to evaluate methods and parameterization to better match vertical gradients. Currently, the model simulates vertical head differences between RHMW11-Zone 5 and the lower zones ranging from 0.05 to 0.1, whereas measured values range from approximately 0.1 to 0.47. Since the 2024 modeling data cutoff point, two additional paired well clusters were installed (RHP04A/B/C and RHP08/B/C), and the Navy is gathering more vertical head data from all available wells with vertical components, which will be used in the next phase of modeling.

Downward vertical gradients beneath the valley fill are likely caused by both seepage from valley fill into the basal aquifer and vertical anisotropy of the basal aquifer. With the current model construction, the simulated plume from the Tank Farm takes the path of least resistance down-dip rather than downward vertically. Decreased permeability in the vertical direction may better match gradients but may not necessarily induce more flow beneath the valley fill due to the presence of lower hydraulic conductivity materials. In our experience, varying the parameterization of the model may change the simulated hydraulic heads, but flow directions appear to change very little, indicating that the structure of the aquifer is the primary driver of groundwater flow directions.

e. While there is reasonable agreement between the modeled measured gradients down the axis of the Red Hill Chart 2-6 in the GWMR and along the northwest side of the Facility (GWMR Chart 2-7), the model fails to capture a strong hydraulic gradient from beneath the USTs to the northwest and regional gradient to the northwest from the Moanalua region through the Red Hill Ridge and toward Halawa.

Navy Response – The Navy respectfully disagrees with this statement; the model does capture measured groundwater head elevations. Please see response to comment 4.c.

5. Vadose Zone Transport – While the GWMR does include vadose zone modeling, the GWFM is unable to adequately reflect the primary processes responsible for the plume migration observed around the Facility following the 2021 releases. Consequently, the DOH questions whether performing contaminant transport, risk, and cleanup evaluations based in large part on the GWFM is appropriate.

Navy Response - Evaluation of risk and potential response actions should primarily stem from the vast amount of actual data that the Navy has been collecting, the weight of which indicates that impacts are stable or contracting. There are few lasting impacts to groundwater other than near the center of the Tank Farm in the vicinity of RHMW02. Nevertheless, models can be useful tools in supplementing the data. For instance, the models corroborate the laboratory and forensic data, which confirm that petroleum-related groundwater impacts are primarily confined onsite and there is no evidence of impacts or risk to offsite drinking water sources. As discussed in the TPH and CF&T SPMs, no groundwater flow model would reasonably be able to reproduce the sporadic perimeter-well TPH detections, even if they were attributable to Tank Farm releases, without unjustifiable manipulation of boundary conditions and flow parameters. If DOH has concluded that other "primary processes" are "responsible for the plume migration," the Navy respectfully requests an explanation of these processes, the underlying data, and the bases for the conclusions.

As described in the CF&T SPM in which the Navy solicited specific recommendations for model calibration datasets, the only potential plume migration data that the Navy could identify following the May 2021 release that are useful for model calibration were the concentration changes in the three Tank Farm wells RHMW01R, 02, and 03. CF&T simulations of TPH-d transport were successful in replicating the timing of TPH-d concentration breakthrough curves at these wells, albeit not the amplitude, and did so only by using multiple sources. Given the tremendous uncertainties in the source characteristics, TPH composition, and the complex geology beneath the release sites, it is not surprising that the groundwater CF&T model required adjustments to duplicate the observed TPH-d concentrations in the Tank Farm wells.

Specific Comments –

6. PDF Page 25, Section 2.1.3.2 – Anisotropy is a very important parameter, as it allows the Navy to generally match heads across the study area and still get particle and particle transport down the Red Hill Ridge, to the west where it flows beneath Pearl Harbor, then veers north to be captured by the Kalauao Springs. This trajectory is not adequately tested to account for the deviation from assumptions posed by the geometry of the Red Hill Shaft infiltration gallery versus a point extraction well and proximity to the alluvial/saprolite wedge. Since the conclusions depend heavily on drawdown, this could be a situation where there is a very high anisotropy within the plane of the lava bedding, but much less within the horizontal plane of groundwater flow. The result of this disparity is that contaminant transport will be governed by a different anisotropy than the response to pumping stresses. Groundwater modeling and the difference between groundwater flow and contaminant transport are further discussed in Voss, 2011.

Navy Response - As discussed in the responses to comments 1 and 2, anisotropy has a muted influence on groundwater flow directions in the GWFM, as directions remain similar across a range of different parameters. The geometry of the RHS water development tunnel is accurately represented in the GWFM as a connected linear network. Therefore, the calibrated value of anisotropy conforms to the site-specific drawdown data and does not depend on an assumption of a single point extraction.

While the behavior of groundwater flow and transport systems may differ due to differing scales, they are coupled, and it is unlikely that the contaminant plume will travel in a significantly different direction than groundwater flow at the site scale. As the discussion of concentration and temperature in Voss' two-part editorial (2011a) states, use of a different set of hydraulic parameters for transport modeling than for flow modeling is not possible for the Red Hill models and would run contrary to Voss' other recommendations to simplify models to the extent feasible (2011b). Voss' two-part editorial (2011a; 2011b) focuses on the complexity of groundwater models and parameter optimization, cautioning against unnecessary model complexity. Here, a significant degree of the complexity in the current model was introduced in response to comments and recommendations that the Navy received from experts reviewing prior models.

The Navy agrees that there could be high anisotropy within the plane of the lava bedding. This fact, combined with the Navy's restructuring of the layering of the model in response to DOH and EPA's 2022 comments, may help explain the calibrated hydraulic conductivity values discussed above in comment 2.a.

7. PDF Page 27; Table 2-1 – The estimated hydraulic conductivities are several times higher than those used by other modelers. While not necessarily incorrect, it certainly does raise concerns. With a gradient of 6x10-5, a hydraulic conductivity of 12,000 ft/d and porosity of 0.05 gives a particle velocity of 14.4 ft/d. Tracer tests indicate approximately 1 to 2 meters per day (m/d) distance from pumping centers (Glenn et al., 2014; AFCEE, 2007) and up to approximately 12 m/d from a major pumping center (Gupta et al., 1990).

Navy Response - As stated in previous responses, hydraulic conductivities were used from other modeling studies as a starting point. However, these previous studies had different modeling objectives, different model domains and designs, and were not collected from high-resolution inter-well field studies. In addition, the groundwater velocities for each of the eleven figures reported by the USGS colloidal borescope studies averaged 23 ft/day and ranged from 8.9 to 32 ft/day, which are consistent with the Navy GWFM seepage velocities. These data suggest that the hydraulic conductivities used in the Navy GWFM are reasonable. It should also be understood that focusing of flow in a well can result in increased measured velocities.

Glenn et al. (2013) was conducted in Lahaina, Maui, close to the shore (makai) in an environment different from the inland (mauka) Red Hill site. Fluorescein tracer dye was added to injection wells at the Lahaina Wastewater Reclamation Facility. The dye was observed in submarine springs along the coast at two seeps. The injection wells were located less than half a mile from the coast. It is anticipated that groundwater along the coast will travel slower through more weathered coastal materials, as opposed to through the basalt aquifer located higher up on a ridge almost 3 miles from the coast in a high yield aquifer (as is the case for the Red Hill Facility).

The Gupta et al. (1990) investigation used dissolved helium gas as an injected water tracer and injected the tracer a short distance (119 m; 390 ft) from an active pumping well (Experiment 4). The particle velocities that can be derived from this experiment range from 5.9 m/day (19.5 ft/day) for peak arrival, to 40 m/day (130 ft/day) for first arrival. Particle velocities reported by the USGS colloidal borescope studies and those produced by the GWFM are consistent with the Gupta experiment, especially considering the different objectives and physical design of each field effort as compared to the GWFM. Calibrated hydraulic conductivity and other parameter values used in the GWFM result in simulated particle velocities that compare well with field experiments.

Enclosure (1) - Navy's Response to DOH Comments on *Draft Groundwater Model Report*, dated September 24, 2024

Table 1: Specific Differences between Select Models
(see Response to Item 2.a., above)

Model	Objective	Parameterization	Numerical Code	Domain
2024 Navy Model	Per the 2015 AOC, Section 7.1, the objectives of the Navy's GWFM are to improve the understanding of the direction and rate of groundwater flow around the Red Hill Facility.	The Navy conducted (and continues to conduct) extensive field investigations to increase our understanding of the hydrogeologic conceptual site model. These studies include but are not limited to: detailed lithologic logging at the 0.1 ft interval of coreholes during monitoring well installation; downhole geophysical logging; multiple extensive synoptic water level studies with different pumping conditions; and traditional hydrologic analyses of aquifer test data. Based on the evaluation of field data, the Navy has computed the hydraulic conductivity (Kh) of basalt to fall between 6,195 and 22,562 ft/day. A Kh of 18,516 ft/day was derived via model calibration to best fit the extensive data set localized near Red Hill. In addition, site-specific drawdown data were analyzed to estimate hydraulic properties of the aquifer, which is always preferable to using parameters from previous models, particularly models developed at different scales for different purposes. The Navy acknowledges that there is some uncertainty in application of standard time-and-distance drawdown models due to the simplifying assumptions that must be utilized, but they nonetheless provide an industry standard and reasonable basis for expanding the range of acceptable Kh values for model calibration. The data collected, regardless of the anisotropy assumed, indicated a higher hydraulic conductivity than 500 to 5,000 ft/day.	MODFLOW-USG (Panday 2022; Panday et al. 2013)	From the dike-intruded Koolaus down into Pearl Harbor. From Waimalu Valley on the northwest to Kalihi Valley on the southeast.
(Oki 2005)	(1) Obtain a better understanding of the hydrologic effects of valley-fill barriers in the entire Pearl Harbor study area, (2)	The hydraulic conductivity values were selected based on values used in the following references: (Soroos 1973; Mink and Lau 1980; Hunt Jr. 1996).	SUTRA (version 2D3D.1) (Voss and Provost 2003)	The Pearl Harbor study area comprises a significant portion of the island of Oahu, stretching west to the Waianae ridge and Ewa coast, north to the Schofield ground-water area, east to the Koolau

	Determine the possible effects of valley-fill barriers on water levels and salinity in the Pearl Harbor area using a three-dimensional, density-dependent groundwater flow model. (3) Estimate the effects of redistributing existing withdrawal on the freshwater resource.			and Red Hill ridges, and several miles offshore (to 5,906 ft below mean sea level) to include where groundwater discharges to the ocean. The Navy's 2024 Red Hill model domain lies inside and outside of the eastern edge of the Pearl Harbor study area.
(Hunt Jr. 1996)	(1) Develop a better understanding of the complex hydrology and hydraulics of Oahu's ground-water flow system. (2) Provide a framework for future hydrologic studies and data-collection methods.	"Averaged over several lava-flow thicknesses, lateral hydraulic conductivity of dike-free lava flows is about 500 to 5,000 feet per day, with smaller and larger values not uncommon."	N/A	The entire island of Oahu.

References -

Department of the Navy (DON). 2023. Conceptual Site Model Appendix E Addendum: Geological Modeling Framework Technical Memorandum, Red Hill Bulk Fuel Storage Facility, JBPHH, O'ahu, Hawai'i. Prepared for NAVFAC Hawaii by AECOM Technical Services Inc.

Eyre, P. R. 1983. The Effects of Pumpage, Irrigation Return, and Regional Ground-Water Flow on the Water Quality at Waiawa Water Tunnel, Oahu, Hawaii. Water-Resources Investigations Report 83–4097. U.S. Geological Survey.

Glenn, C. R., R. B. Whittier, M. L. Dailer, H. Dulaiova, A. I. El-Kadi, J. Fackrell, J. L. Kelly, C. A. Waters, and J. Sevadjian. 2013. Lahaina Groundwater Tracer Study, Lahaina, Maui, Hawai'i. Final Report. Prepared for State of Hawaii Department of Health, U.S. Environmental Protection Agency, and U.S. Army Engineer Research and Development Center. June.

Gupta, S. K., L. S. Lau, P. S. Moravcik, and A. El-Kadi. 1990. Injected Helium: A New Hydrological Tracer. Special Report 06.01: 90. Water Resources Research Center, University of Hawaii.

Hunt Jr., C. D. 1996. Geohydrology of the Island of Oahu, Hawaii. Professional Paper 1412-B. Regional Aquifer-System Analysis—Oahu, Hawaii. U.S. Geological Survey.

Kearl, P. M., and K. Roemer. 1998. "Evaluation of Groundwater Flow Directions in a Heterogeneous Aquifer Using the Colloidal Borescope." Advances in Environmental Research 1:12–23.

Mink, J. F., and L. S. Lau. 1980. Hawaiian Groundwater Geology and Hydrology, and Early Mathematical Models. Project Completion Report for: Transfer of Hawaii Water Research Results by User-Oriented Publications, Phase II, OWRT Project No.: A-077-HI. Technical Memorandum Report No. 62. http://hdl.handle.net/10125/3246.

Nichols, W. D., P. J. Shade, and C. D. Hunt Jr. 1996. Summary of the Oahu, Hawaii, Regional Aquifer-System Analysis. Professional Paper 1412-A. Regional Aquifer-System Analysis—Oahu, Hawaii. U.S. Geological Survey.

Oki, D. S. 2005. Numerical Simulation of the Effects of Low-Permeability Valley-Fill Barriers and the Redistribution of Ground-Water Withdrawals in the Pearl Harbor Area, Oahu, Hawaii. Scientific Investigations Report 2005-5253. U.S. Geological Survey.

Panday, S. 2022. USG-Transport Version 1.10.0: The Block-Centered Transport Process for MODFLOW-USG. GSI Environmental. http://www.gsi-net.com/en/software/free-software/USG-Transport.html.

Panday, S., C. D. Langevin, R. G. Niswonger, M. Ibaraki, and J. D. Hughes. 2013. MODFLOW–USG Version 1: An Unstructured Grid Version of MODFLOW for Simulating Groundwater Flow and Tightly Coupled Processes Using a Control Volume Finite-Difference Formulation. U.S. Geological Survey Techniques and Methods, Book 6, Chap. A45. https://dx.doi.org/10.5066/F7R20ZFJ.

Soroos, R. L. 1973. Determination of Hydraulic Conductivity of Some Oahu Aquifers with Step-Drawdown Test Data. M.S. Thesis, Univ. of Hawaii, Honolulu, HI.

Souza, W. R., and C. I. Voss. 1987. "Analysis of an Anisotropic Coastal Aquifer System Using Variable-Density Flow and Solute Transport Simulation." Journal of Hydrology 92 (1–2): 17–41.

Trost, J. J., B. A. Bekins, J. B. Jaeschke, G. N. Delin, D. A. Sinclair, J. K. Stack, R. K. Nakama, U. M. Miyajima, L. D. Pagaduan, and I. M. Cozzarelli. 2024. Distribution of Ancient Carbon in Groundwater and Soil Gas from Degradation of Petroleum near the Red Hill Bulk Fuel Storage Facility, Oʻahu, Hawaiʻi. Scientific Investigations Report 2024–5034. Environmental Health Program. Prepared in Cooperation with the U.S. Navy and the Defense Logistics Agency. Reston, VA: U.S. Geological Survey.

Voss, C. I. 2011a. "Editor's Message: Groundwater Modeling Fantasies—Part 1, Adrift in the Details." Hydrogeology Journal 19 (October):1281–84. https://doi.org/10.1007/s10040-011-0789-z.

2011b. "Editor's Message: Groundwater Modeling Fantasies—Part 2, Down to Earth." Hydrogeology Journal 19 (8): 1455–58. https://doi.org/10.1007/s10040-011-0790-6.

Voss, C. I., and A. M. Provost. 2003. SUTRA, A Model for Saturated-Unsaturated Variable-Density Ground-Water Flow with Solute or Energy Transport. U.S. Geological Survey Water-Resources Investigations Report 02-4231.

Wilson, J. T., W. A. Mandell, F. L. Paillet, E. R. Bayless, R. T. Hanson, P. M. Kearl, W. B. Kerfott, M. W. Newhouse, and W. H. Pedler. 1999. An Evaluation of Borehole Flowmeters Used to Measure Horizontal Ground-Water Flow in Limestones of Indiana, Kentucky, and Tennessee. U.S. Geological Survey Water-Resources Investigations Report 01-4139.

<u>Figures -</u>

Enclosure (1) - Navy's Response to DOH Comments on *Draft Groundwater Model Report*, dated September 24, 2024

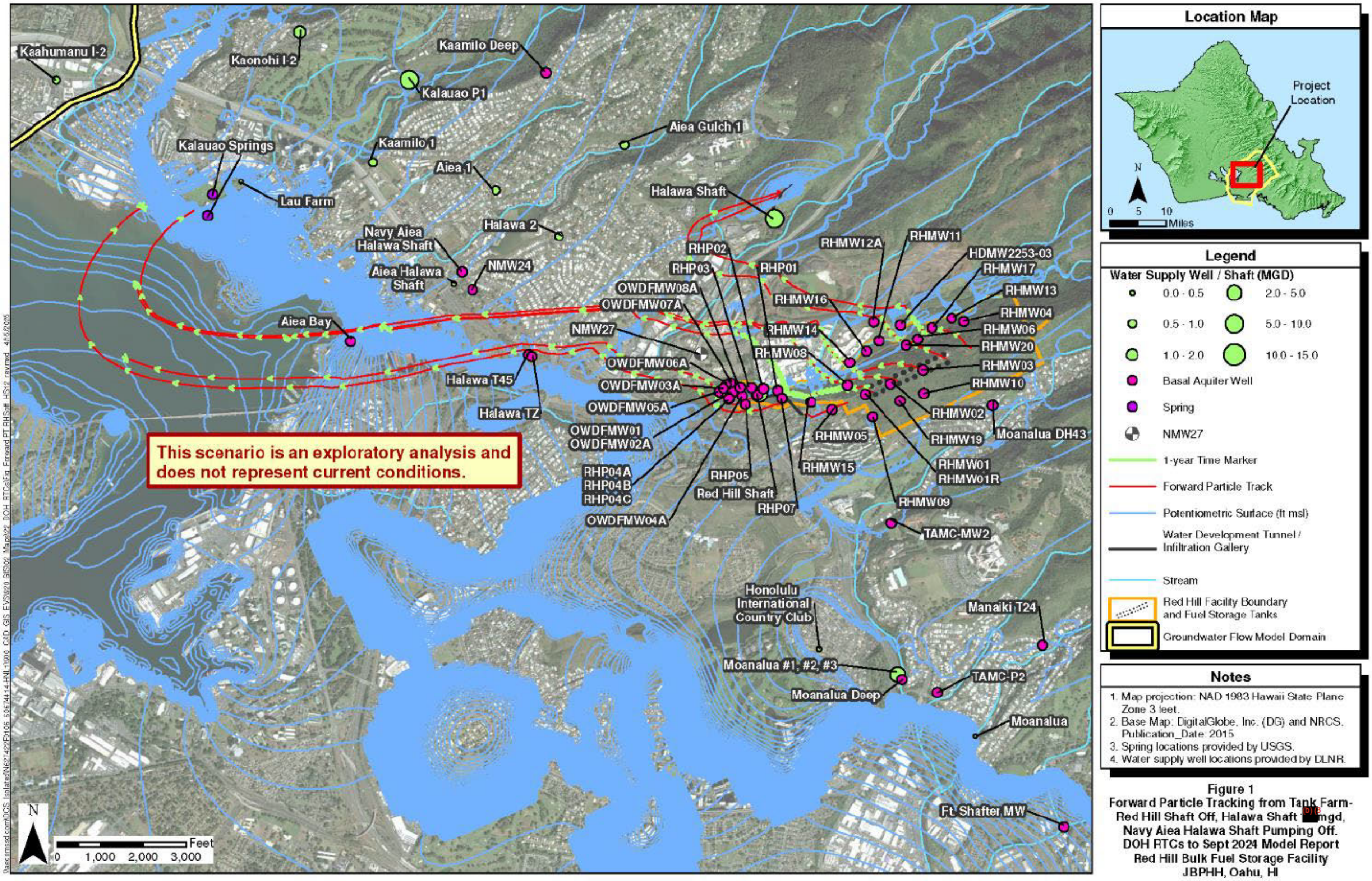

Figure 1
Forward Particle Tracking from Tank Farm-
Red Hill Shaft Off, Halawa Shaft [redacted] mgd,
Navy Aiea Halawa Shaft Pumping Off.
DOH RTCs to Sept 2024 Model Report
Red Hill Bulk Fuel Storage Facility
JBPHH, Oahu, HI

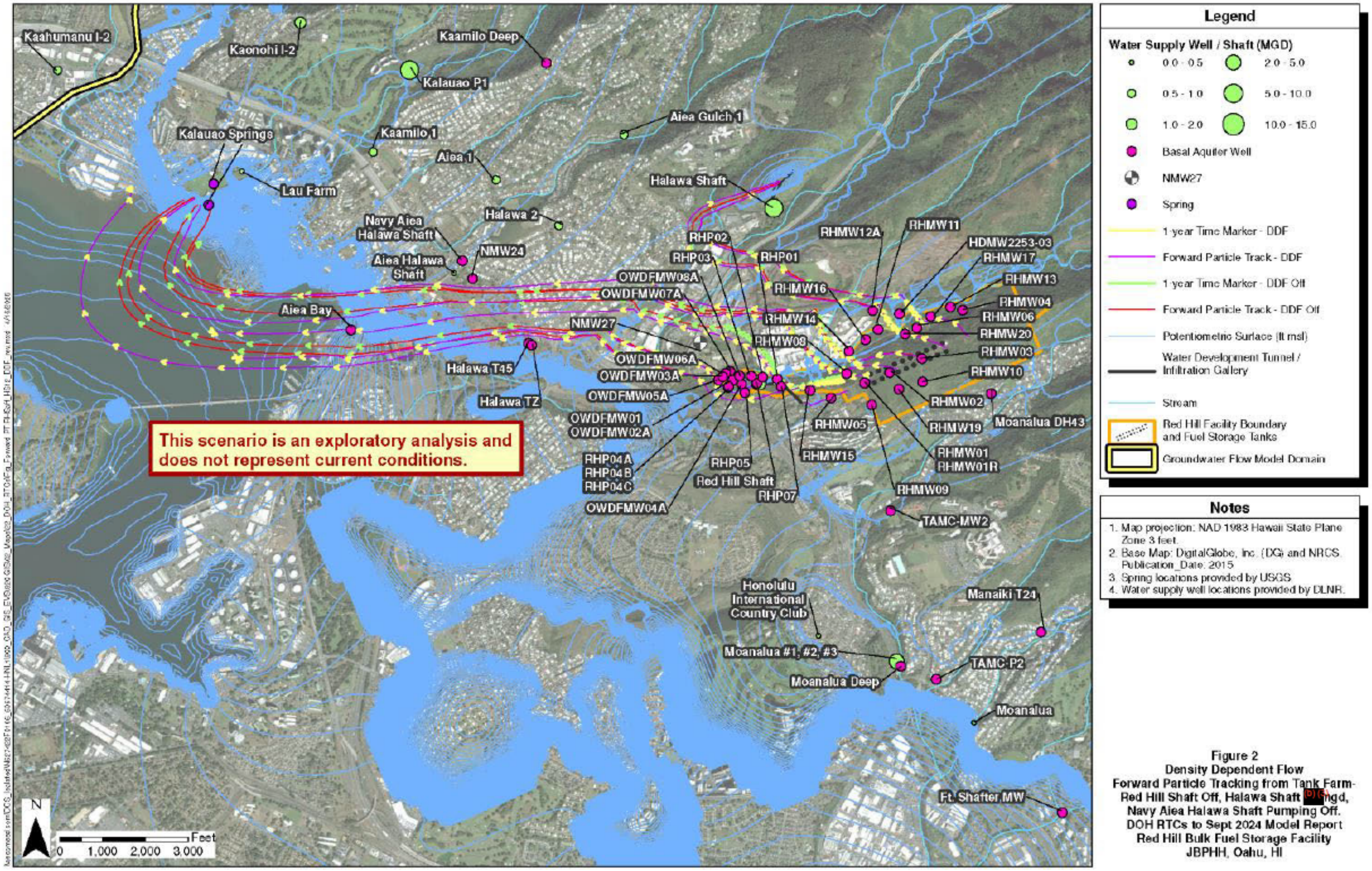

Figure 2
Density Dependent Flow
Forward Particle Tracking from Tank Farm-Red Hill Shaft Off, Halawa Shaft [redacted]mgd,
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Red Hill Bulk Fuel Storage Facility
JBPHH, Oahu, HI

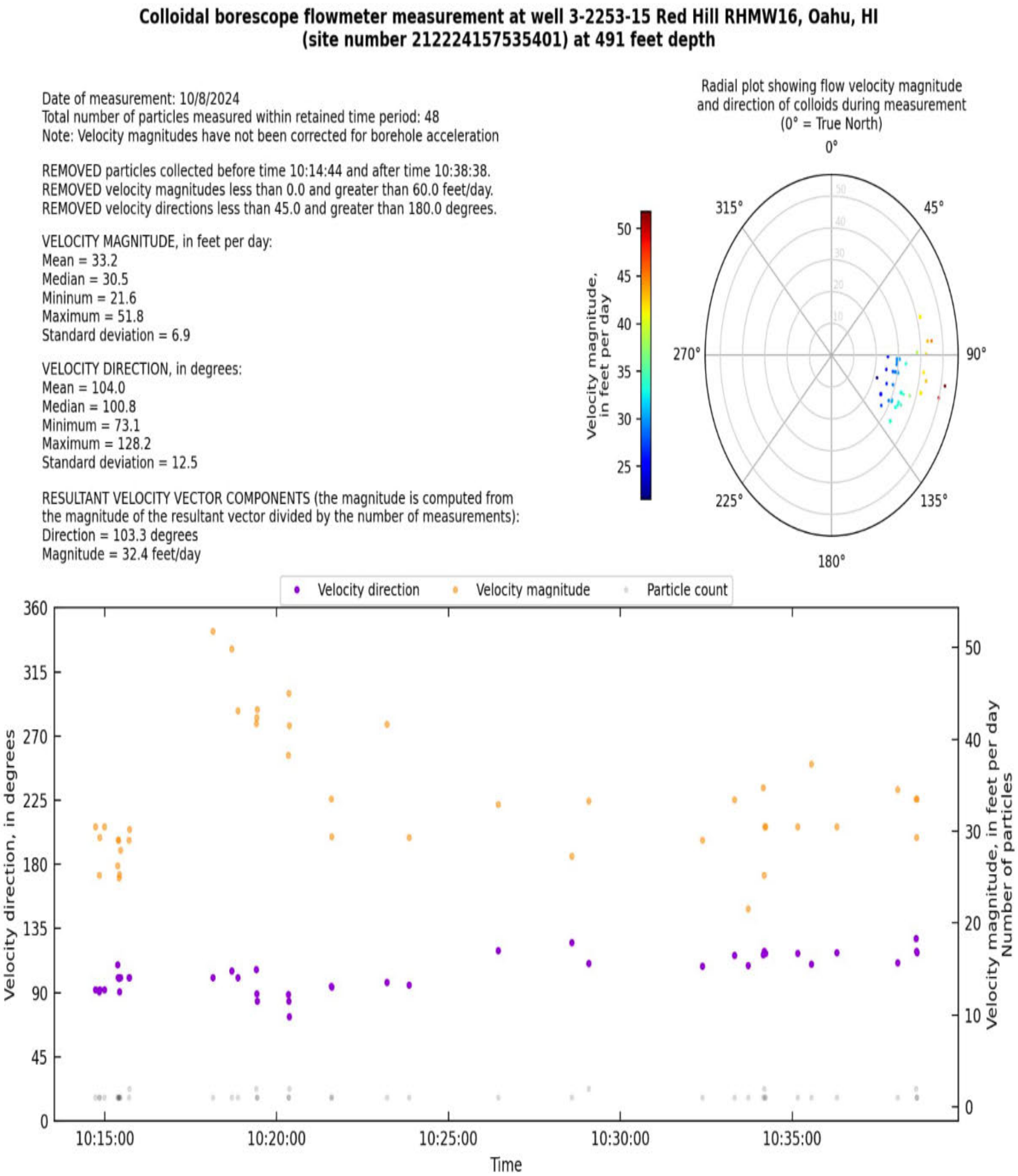

Figure 3-1
USGS RHMW16 Colloidal Borescope Results
DOH RTCs to Sept 2024 Model Report
Red Hill Bulk Fuel Storage Facility
JBPHH, Oahu, HI

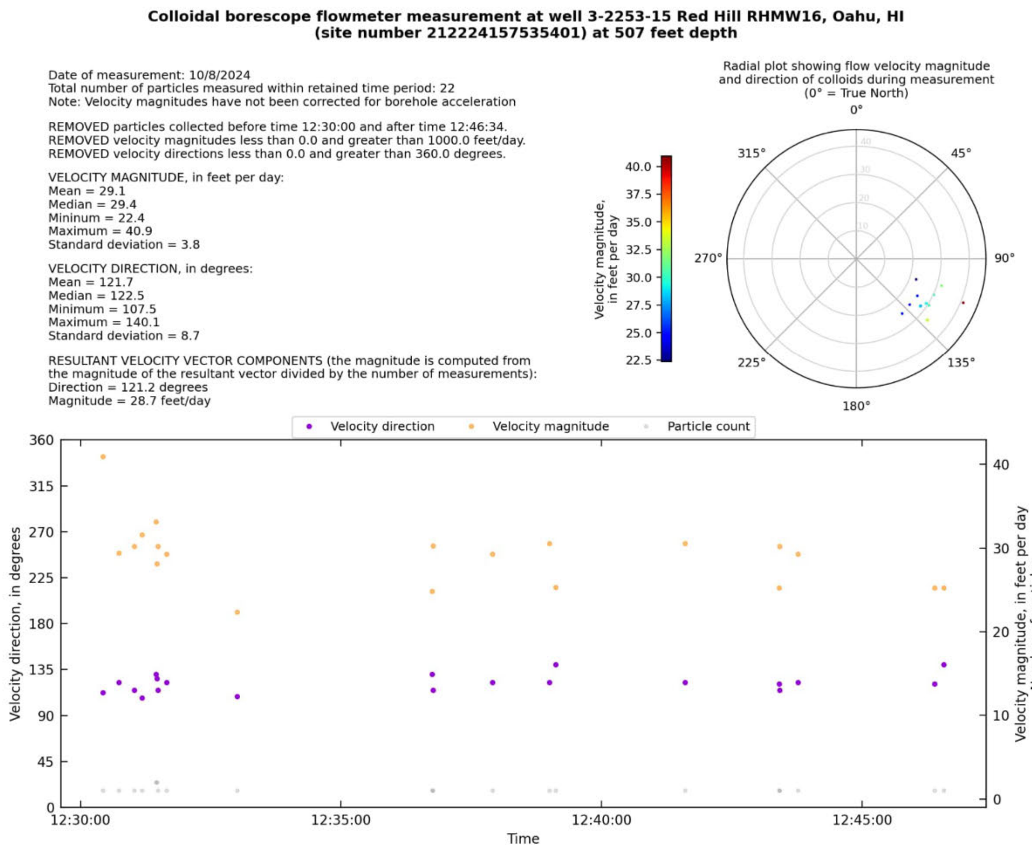

Figure 3-2
USGS RHMW16 Colloidal Borescope Results
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Red Hill Bulk Fuel Storage Facility
JBPHH, Oahu, HI

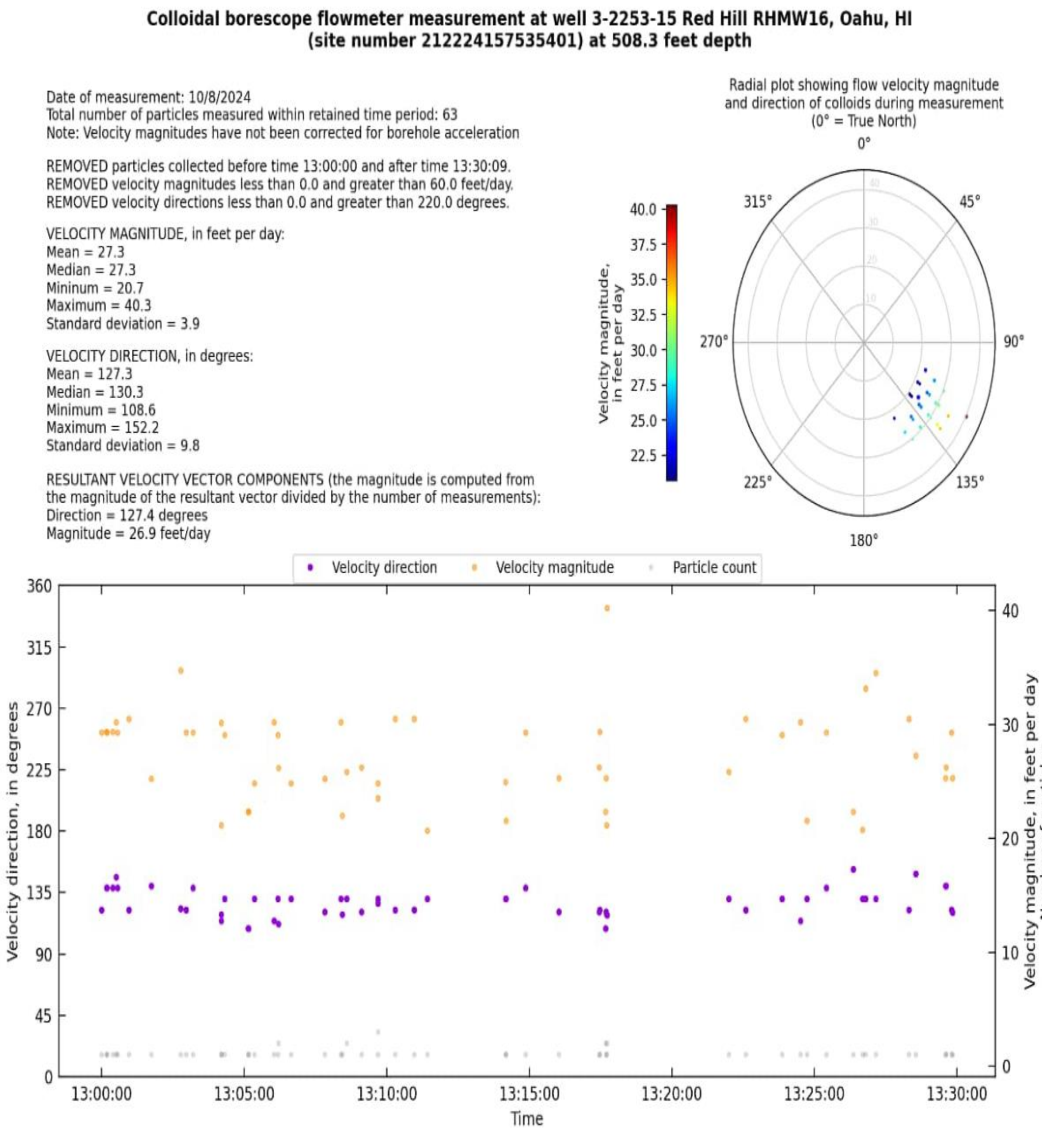

Figure 3-3
USGS RHMW16 Colloidal Borescope Results
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JBPHH, Oahu, HI

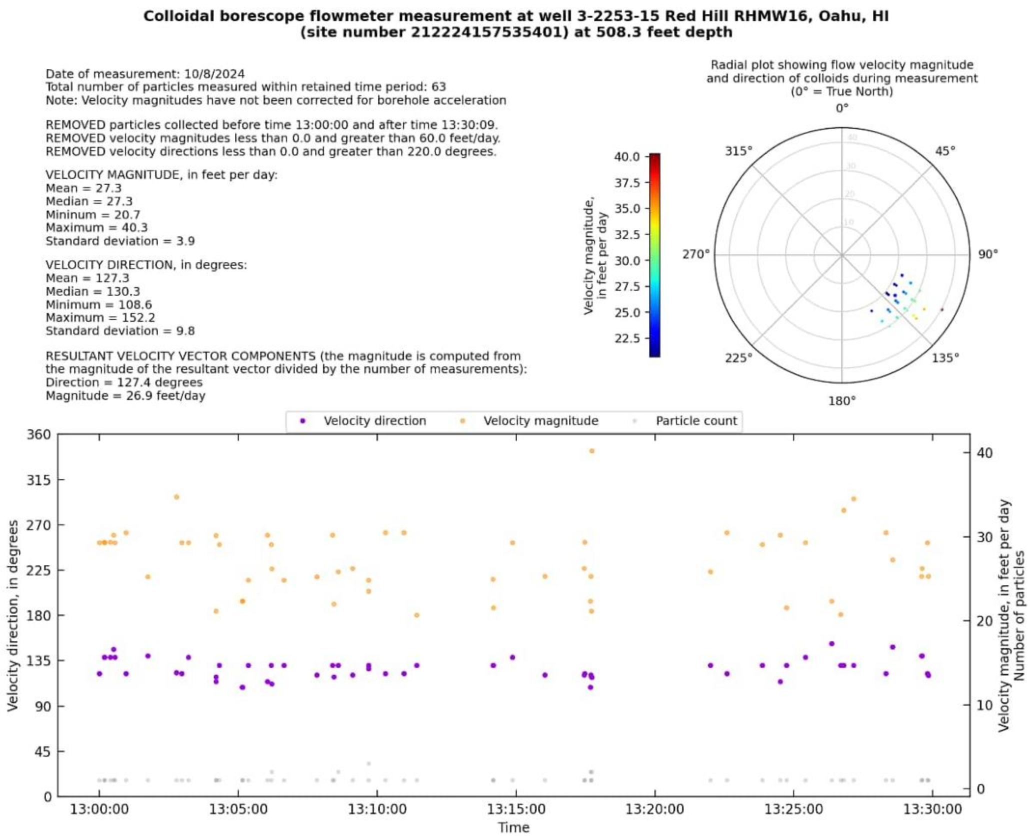

Figure 3-3
USGS RHMW16 Colloidal Borescope Results
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Red Hill Bulk Fuel Storage Facility
JBPHH, Oahu, HI

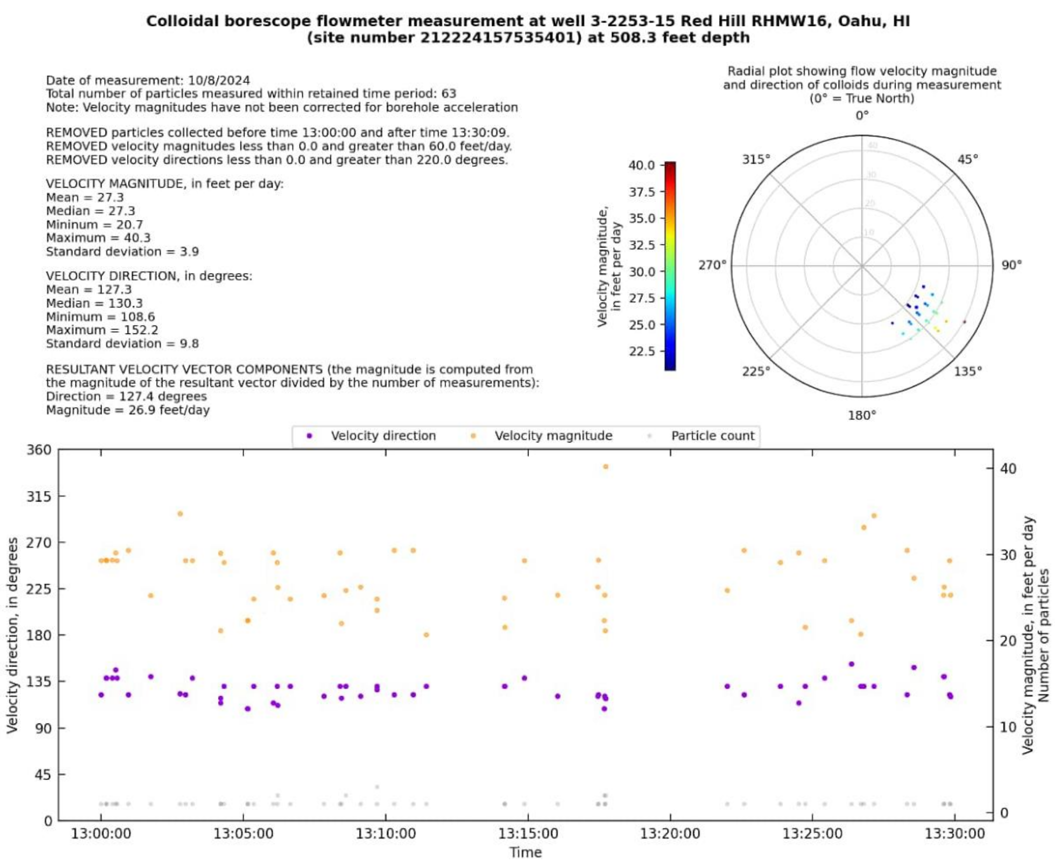

Figure 3-3
USGS RHMW16 Colloidal Borescope Results
DOH RTCs to Sept 2024 Model Report
Red Hill Bulk Fuel Storage Facility
JBPHH, Oahu, HI

<u>Attachment 1 –</u>

Cross-ridge Gradients

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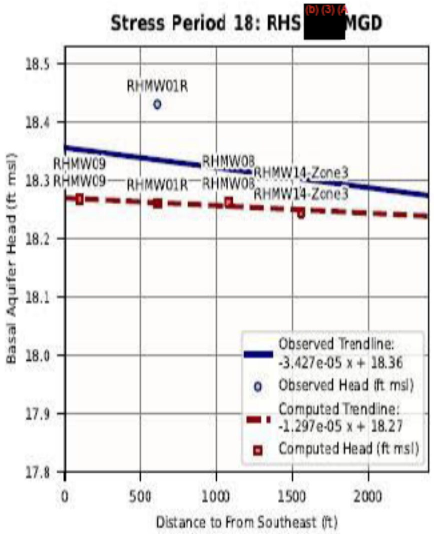
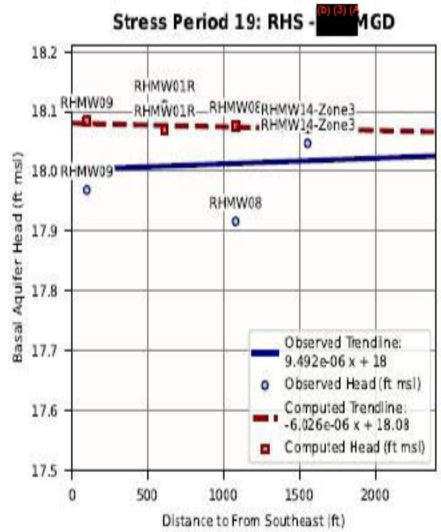
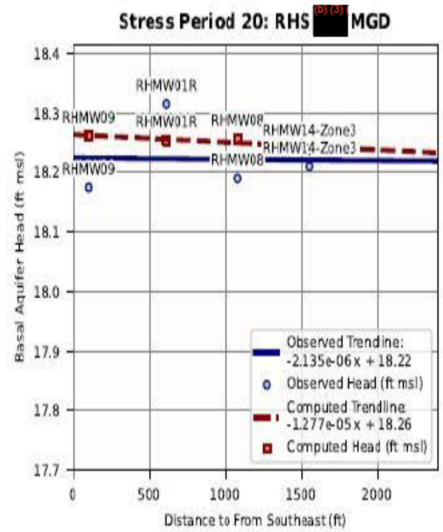
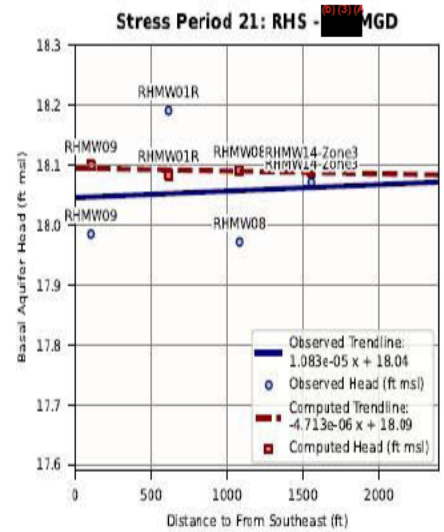
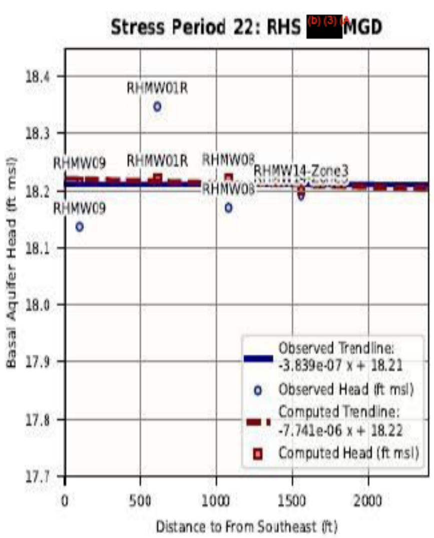
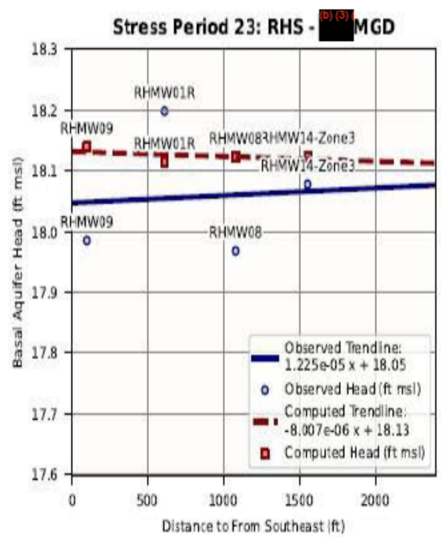


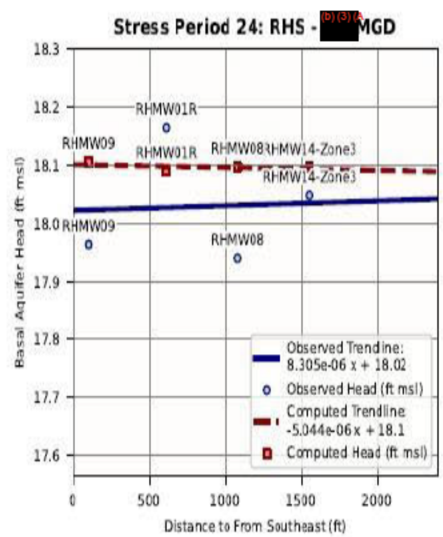


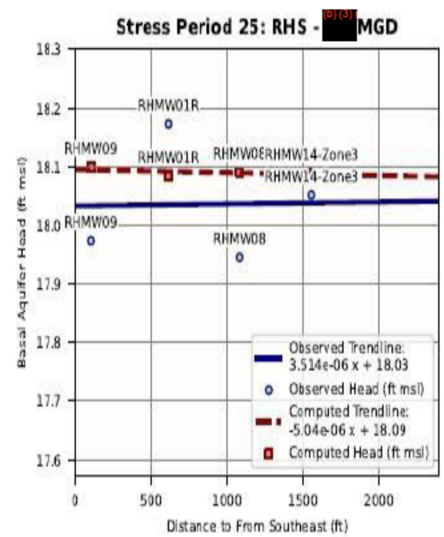


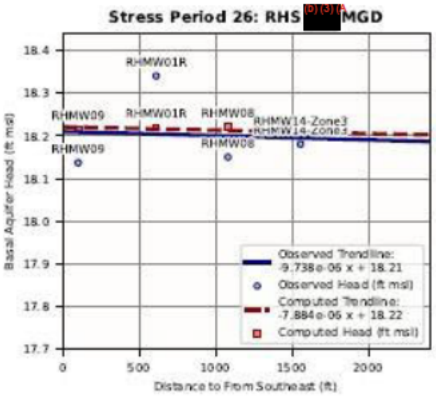


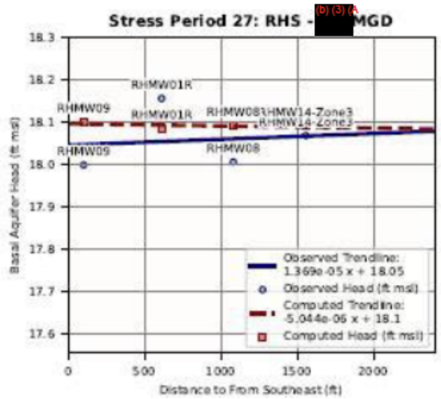









Stress Period 26: RHS [redacted] MGD
Basal Aquifer Head (ft msl)
Distance to From Southeast (ft)
RHMW01R
RHMW09
RHMW08
RHMW14-Zone3
Observed Trendline:
-9.738e-06 x + 18.21
Observed Head (ft msl)
Computed Trendline:
-7.884e-06 x + 18.22
Computed Head (ft msl)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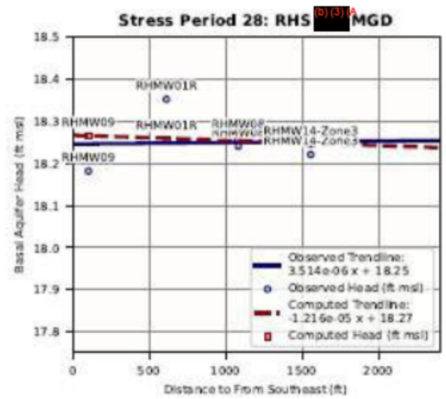
Basal Aquifer Head (ft msl)
Distance to From Southeast (ft)
RHMW01R
RHMW09
RHMW08
RHMW14-Zone3
Observed Trendline:
1.369e-05 x + 18.05
Observed Head (ft msl)
Computed Trendline:
-5.044e-06 x + 18.1
Computed Head (ft msl)


Stress Period 28: RHS [redacted] MGD
Basal Aquifer Head (ft msl)
Distance to From Southeast (ft)
RHMW01R
RHMW09
RHMW08
RHMW14-Zone3
Observed Trendline:
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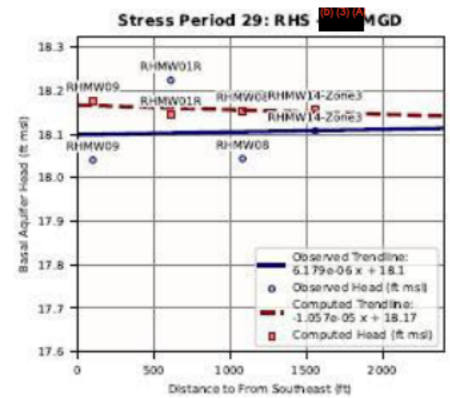
Observed Head (ft msl)
Computed Trendline:
-1.216e-05 x + 18.27
Computed Head (ft msl)


Stress Period 29: RHS - [redacted] MGD
Basal Aquifer Head (ft msl)
Distance to From Southeast (ft)
RHMW01R
RHMW09
RHMW08
RHMW14-Zone3
Observed Trendline:
6.179e-06 x + 18.1
Observed Head (ft msl)
Computed Trendline:
-1.057e-05 x + 18.17
Computed Head (ft msl)

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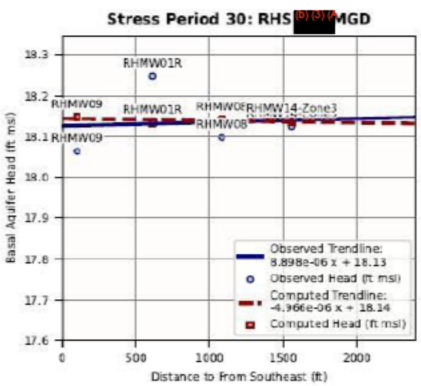

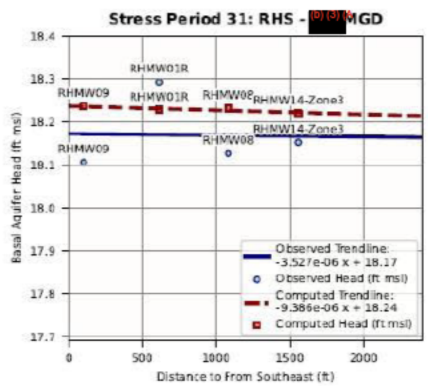

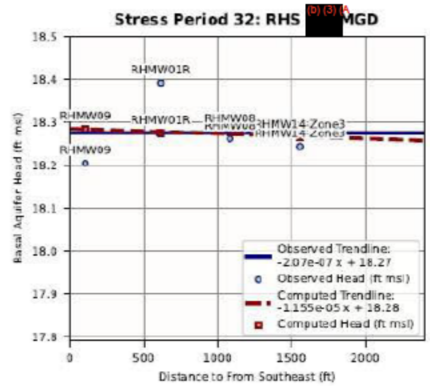

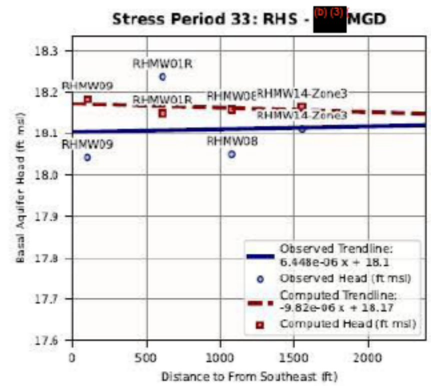

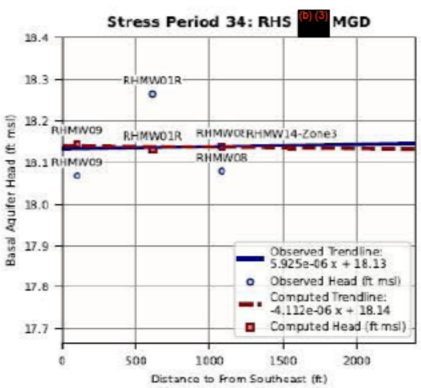

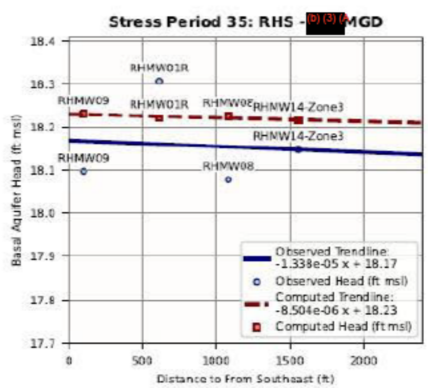

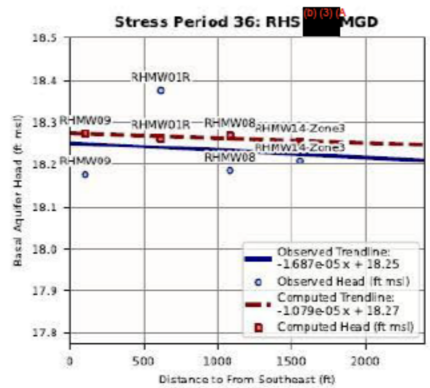

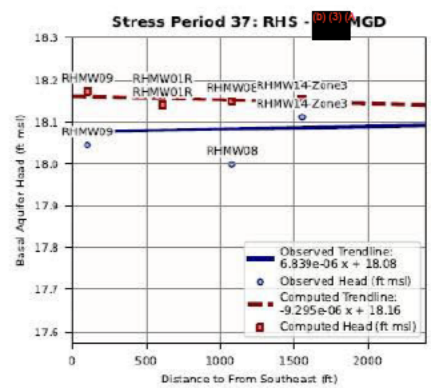

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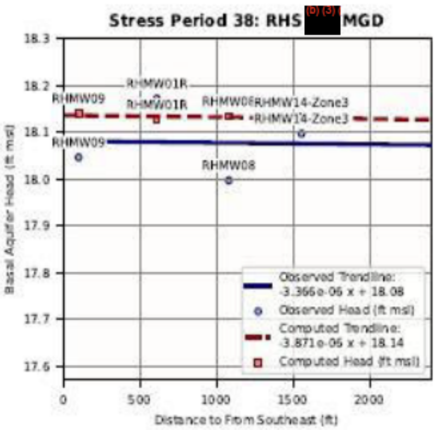

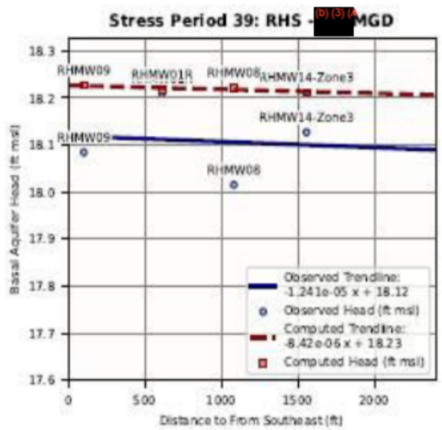

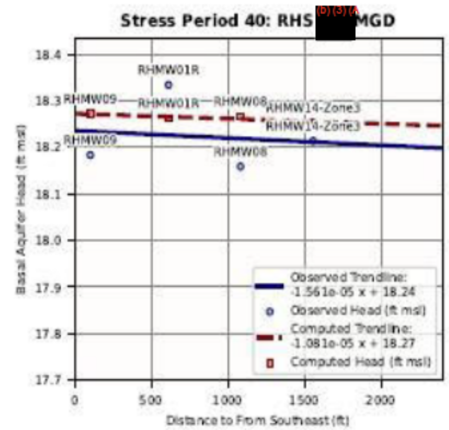

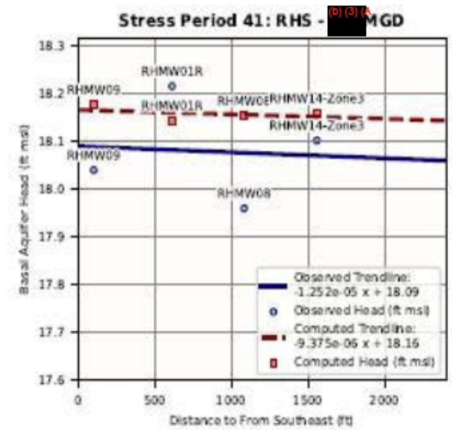

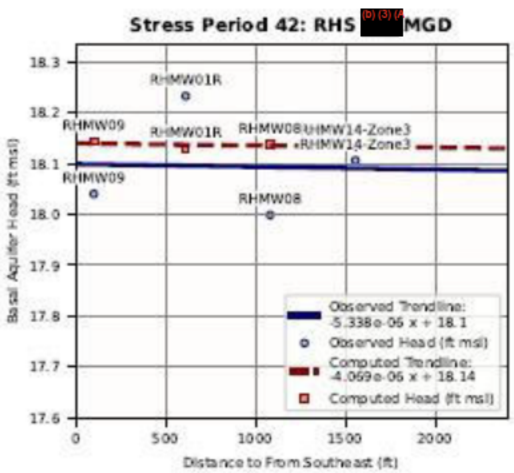

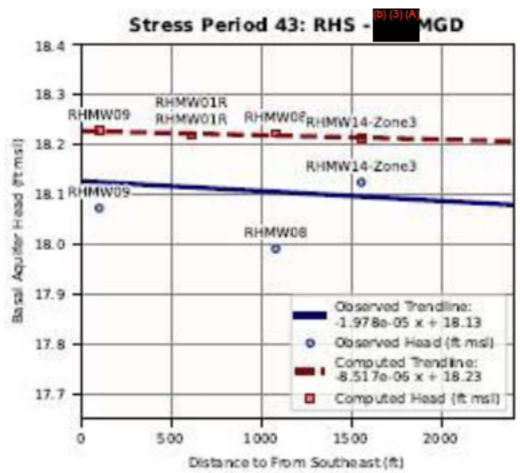

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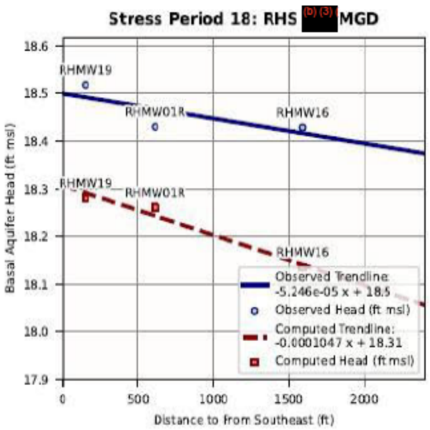

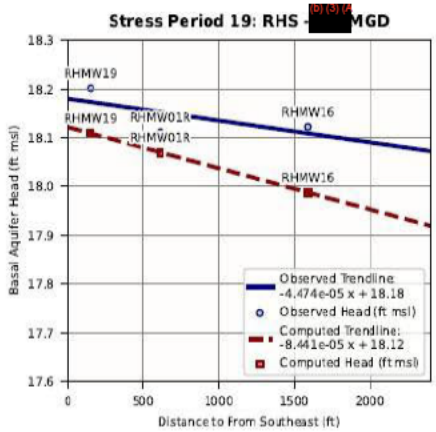

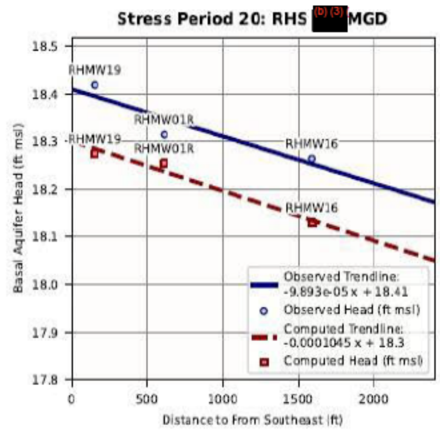

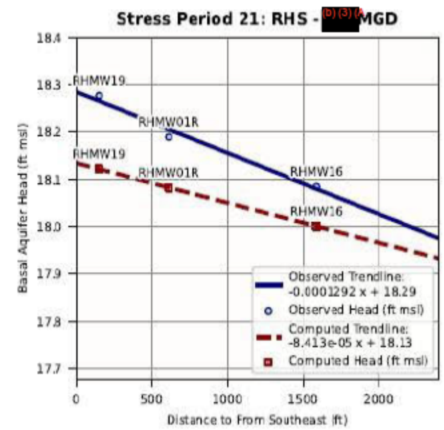

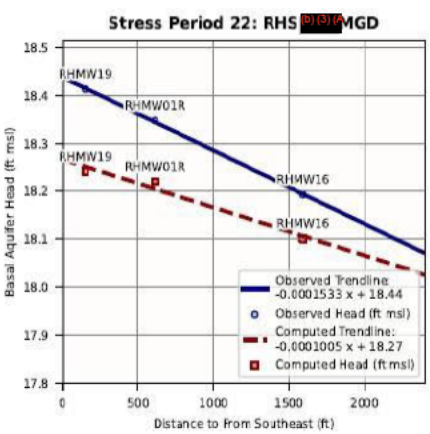

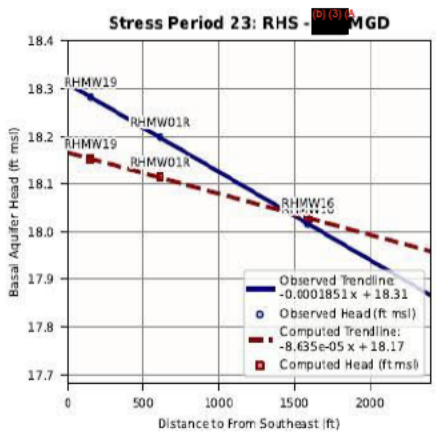

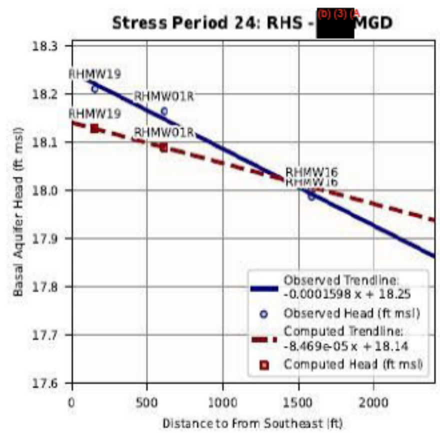

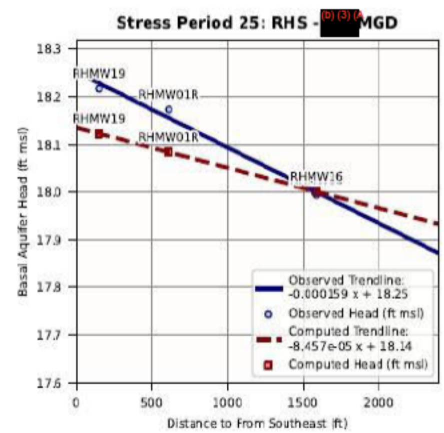

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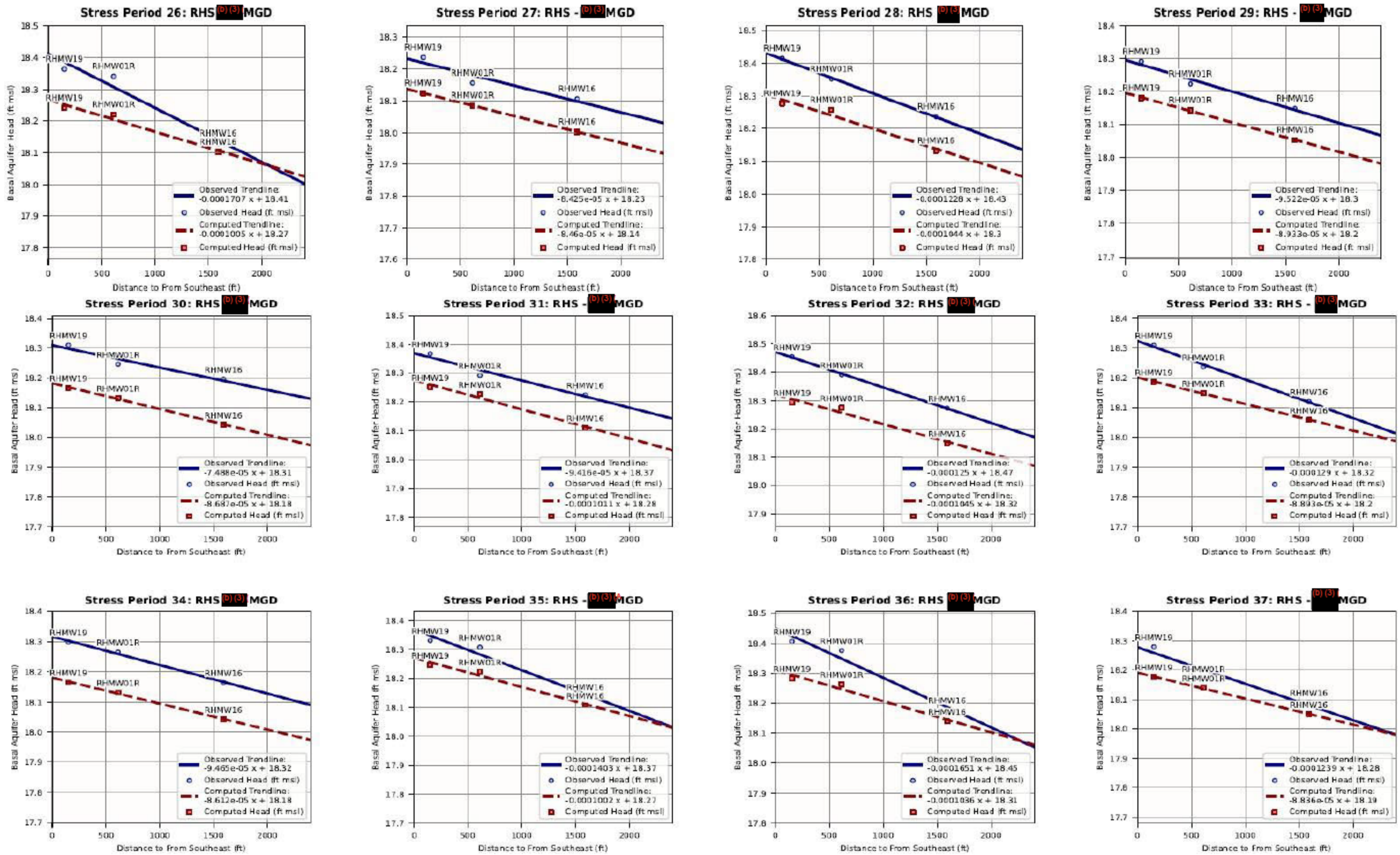

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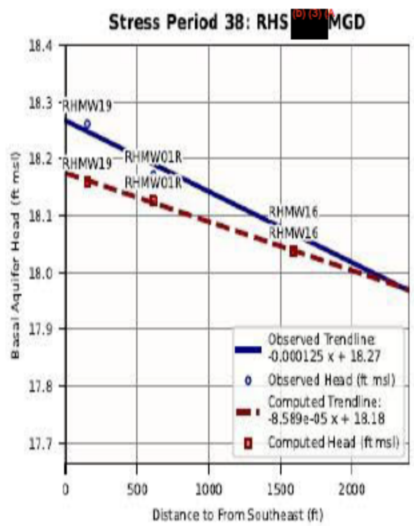

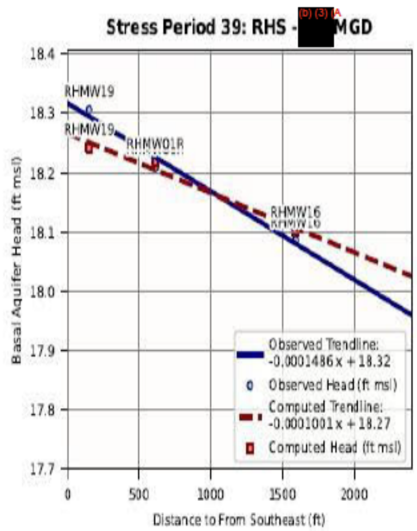

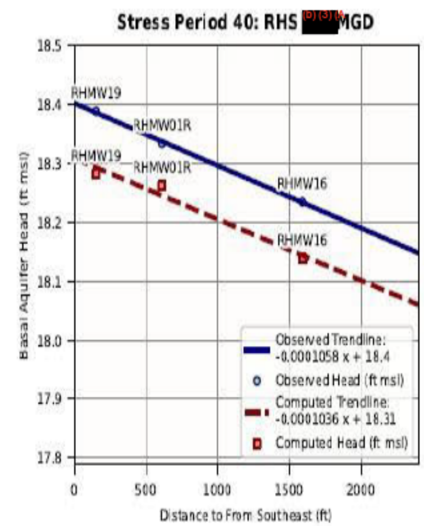

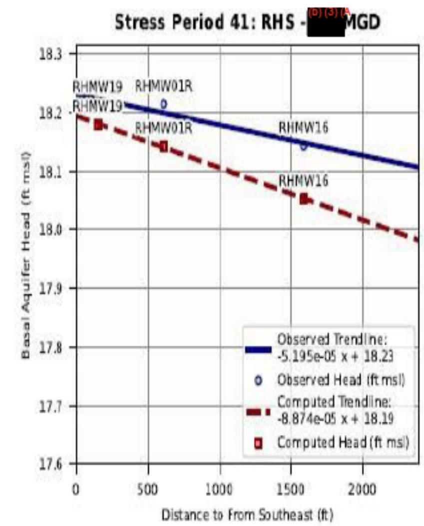

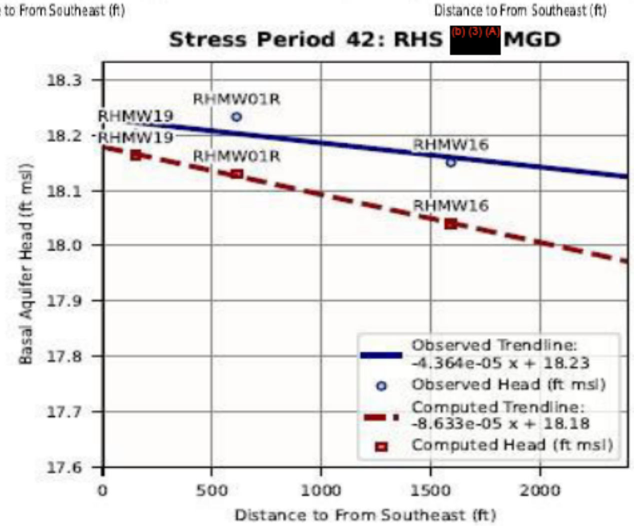

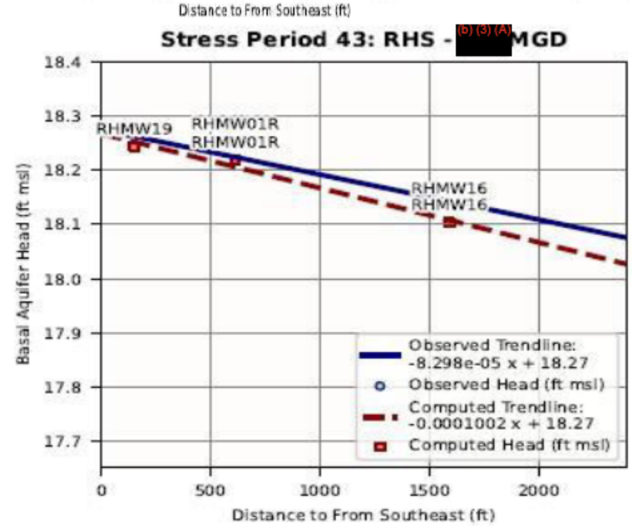

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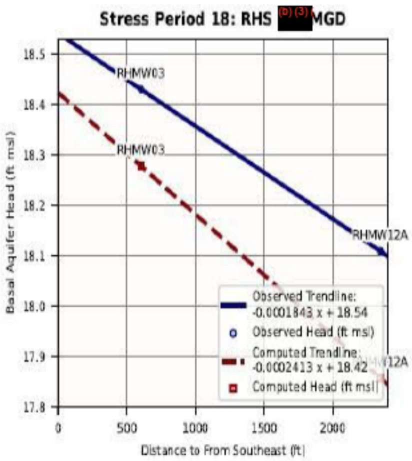

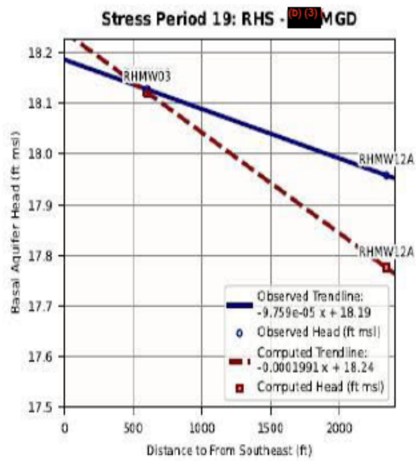

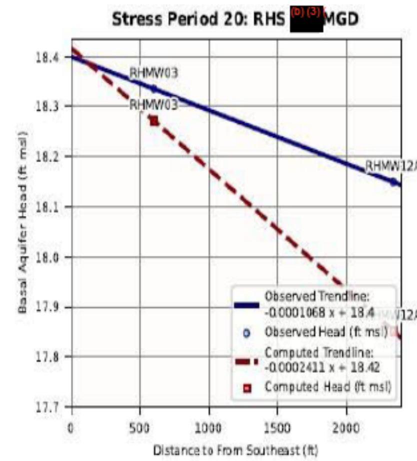

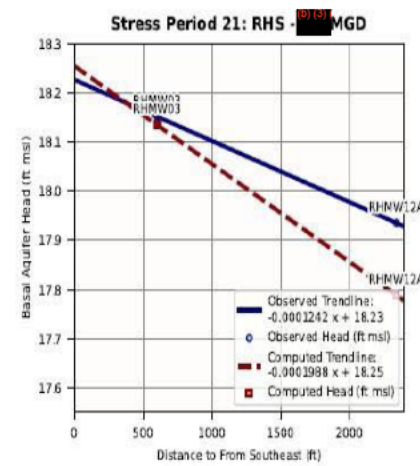

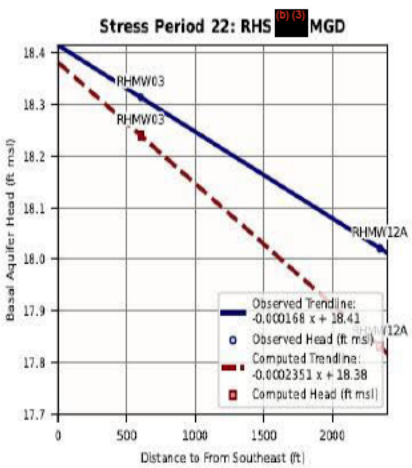

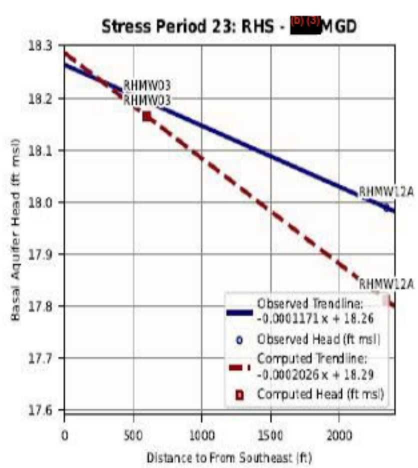

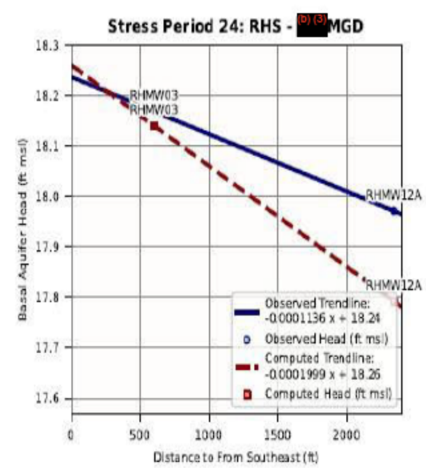

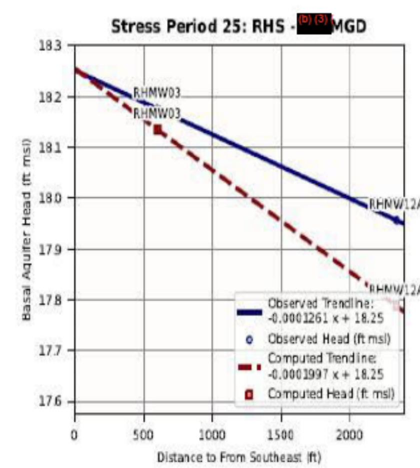

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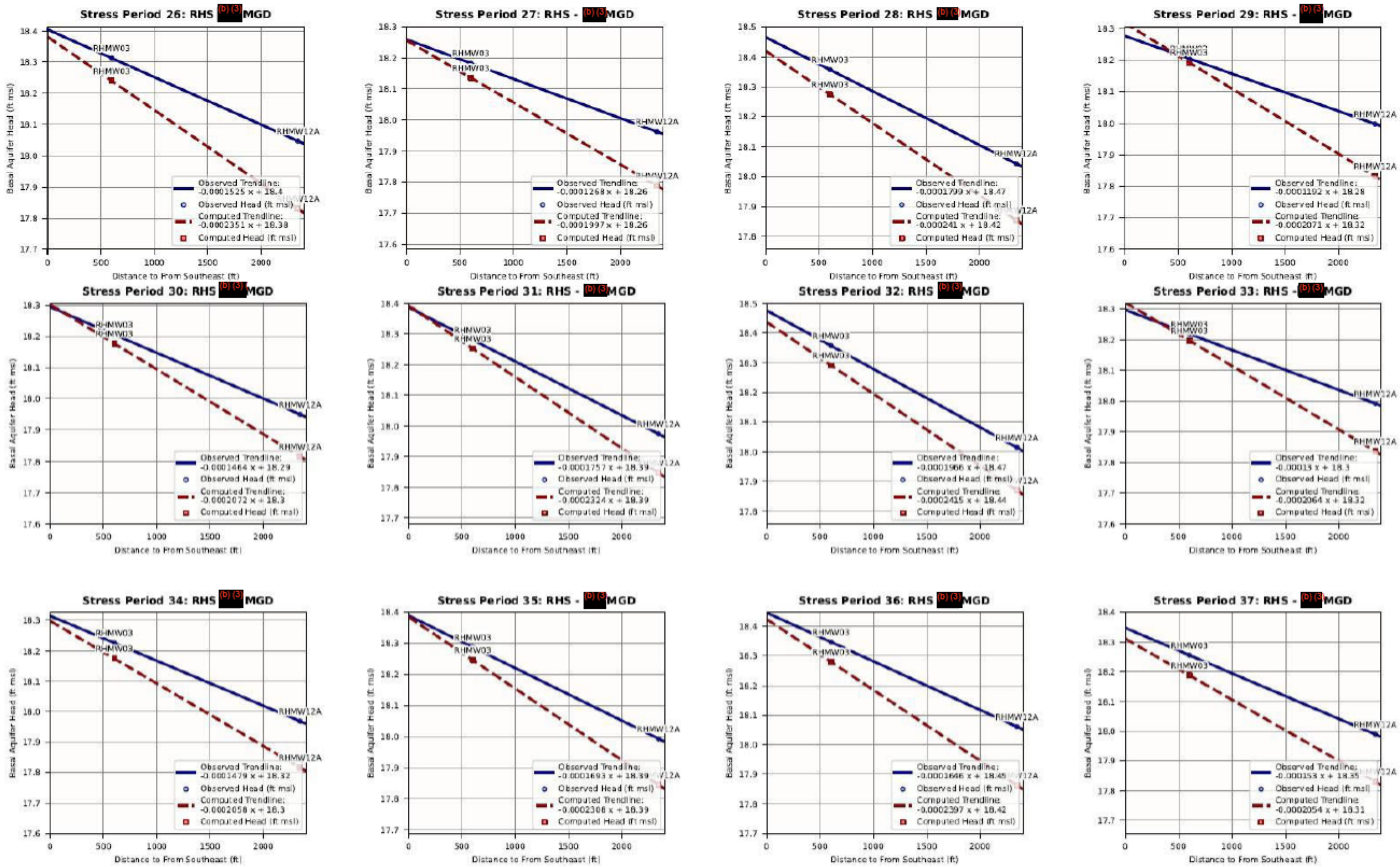

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