BOARD OF WATER SUPPLY

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and

Ms. Roxanne Kwan
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Dear Mr. Shalev and Ms. Kwan:

Subject: Honolulu Board of Water Supply (BWS) Comments on the Red Hill Administrative Order on Consent (AOC) Statement of Work (SOW) Sections 6 and 7 Groundwater Modeling Working Group Meeting No. 8 Held February 12, 2018

The BWS offers the following comments on the above referenced meeting. Our comments focus on the development of the interim groundwater model and include previous concerns that we believe have not been adequately addressed. In order to help you better understand our comments on specific slides, we have included a copy of the Navy slide presentation from the February 12, 2018 meeting as Attachment A.

General Comments:

1. Insufficiently accurate approach to modeling basalt: The Navy's representation of the basalt as a single homogeneous unit is an inappropriate simplification of the actual physical aquifer system for the purpose of assessing risk of contaminant migration. Whether from publications or discussions during the groundwater modeling working group and AOC meetings, there is a substantial amount of field data that demonstrates basalt contains preferential flow paths caused by clinker

zones, lava tubes, fractures, faults, and other inhomogeneities in the vicinity of Red Hill. Numerous studies (Wentworth, 1945; Hunt, 1996; Oki, 2005) have shown that ignoring the spatial variability of the aquifer hydraulic properties often prevents inaccurate simulations of contaminant migration and hydraulic containment of contaminants. Oahu basalt aquifer properties have been represented as homogeneous in previous regional scale models of groundwater flow, but this representation is inadequate for the simulation of contaminant transport at smaller scales. Despite the scientific literature and the site-specific information, the Navy continues to model the basalt as a homogeneous material, leading to non-conservative predictions of contaminant migration rates and pathways because the preferential flow paths in the basalt aquifer have been ignored. The BWS urges the Navy to provide a more realistic and appropriately conservative representation of the basalt properties in their interim and final fate and transport models so that the risk from the Red Hill Bulk Fuel Storage Facility (RHBFSF) contamination to our drinking water supply is estimated in a scientifically defensible way.

Our comments are supported by a United States Geological Survey (USGS) report titled "Geohydrology of the Island of Oahu, Hawaii" that emphasizes the importance of appropriately representing the spatial variability in aquifer properties for risk evaluations involving contaminant transport. Hunt (1996) stated:

> "Rigorous analysis of some problems at the local scale may negate the presumption of homogeneity and require detailed drilling, borehole logging, and geological interpretation sufficient to define important conductive or confining zones. This is especially true of solute transport problems in which the arrival and concentration of solutes, being determined by travel times along particular flow paths, may depend more on the spatial distribution of conductive zones than on any average aquifer properties that may be assumed."

Our comments about aquifer property inhomogeneity and preferential flow paths within the area surrounding Red Hill area are based on site-specific observations. Clinker intervals and lava tubes were identified in the barrel logs for the Red Hill storage tanks (Pacific Naval Air Bases Contractors, 1942) and the logs for Red Hill Shaft (Macdonald, 1941; Stearns, 1943) and Halawa Shaft (BWS, 1943). Wentworth (1945) described many different examples of inhomogeneities that are likely very important preferential flow paths in Halawa Valley:

> 'In various quarries and in the transmission tunnels a'a clinker mounds 15 or 20 feet or more thick are not uncommon and irregularities of the dense masses are correspondingly greater. Many small lava tubes and several

large ones were encountered in the Inter-Halawa transmission tunnel. At one point a large tube, 15 to 30 feet wide and up to 8 or 10 feet high above the debris which partly filled it, crossed over the tunnel and was explored for two or three hundred feet inland."

2. Insufficiently accurate approach to modeling groundwater flow: The Navy's use of averaged water levels to reflect steady-state conditions is an over simplification of the actual physical aquifer system and is inappropriate for the purpose of assessing the risk to our water supply from migration of RHBFSF contamination. The Navy's choice to use averaged levels as calibration targets increased the error bars (or tolerance limits around each calibration target from the few tenths of a foot expected for errors in individual level measurements to roughly 2 feet at monitoring wells and 4 feet at pumping wells because each averaged groundwater level target now included the temporal variations caused by changing seasons and pumping rates. As a result, the Navy's interim model predictions of groundwater levels also have error bars that are too large to provide the accuracy necessary for assessing risk or understanding contaminant migration from future releases. Our specific concerns with the Navy approach to calibrating the interim model to averaged water levels are:

    - The Navy's groundwater flow models should be calibrated to groundwater levels with the smallest possible tolerance limits because a difference of a few tenths of a foot in groundwater levels changes the rate and direction of groundwater flow and contaminant migration in the highly permeable basalt aquifer. Given this sensitivity, developing a sufficiently accurate groundwater model for the RHBFSF requires calibrating to measured water levels using as small of a tolerance limit as possible, such as the few tenths-of-a-foot error that are principally associated with groundwater level measurements. Instead, the Navy has created tolerance limits of a few feet by averaging multiple water levels taken during different pumping rates and recharge conditions and using the averages in the model calibration. The tolerance limits used by the Navy are large enough such that their model can be considered to be calibrated even though it predicts hydraulic gradients and groundwater flow directions that directly contradict the groundwater levels observed along Red Hill Ridge in 2015 and 2016. During this meeting, Mr. Robert Whittier of the Hawaii Department of Health (DOH) and the BWS asked the Navy's contractors how they could explain why the interim model's predicted flow direction at Red Hill contradicted the observed Red Hill groundwater levels. More recently, in his letter to Ms. Grange at the DOH dated February 20, 2018 (Whittier, 2018), Mr. Whittier showed how the interim model's predicted groundwater levels create a hydraulic gradient from monitoring well RHMW04 to monitoring well OWDFMW01 where none exists

(Figure 1, reproduced below from Mr. Whittier's letter). The observed groundwater gradient is shown by the yellow line whereas the interim model's inaccurate and contradictory gradient is shown by the blue line. Note that the differences between observed levels (red bars) and model predicted levels (blue bars) are typically between 1 and 2 feet.

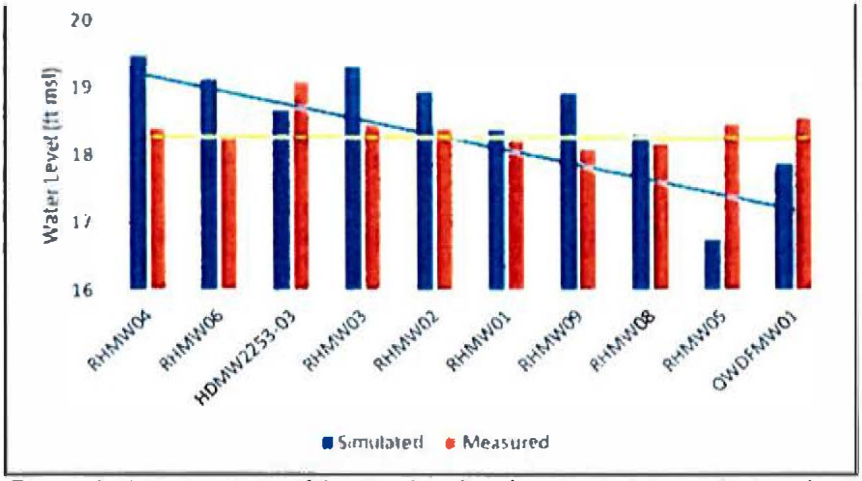

Figure 1. A comparison of the simulated and measured groundwater elevations in the RHMNW. RHMW07 is excluded from this graph since the water level in this well is very anomalous. The Red Hill Shaft (2254-01) is also excluded due to questions about the top of casing reference

- If groundwater levels in Halawa and Moanalua Valleys are essentially constant during a year or longer, and if the steady-state assumption is reasonable for the 2006, 2015, and 2017 calibration periods selected by the Navy, then the tolerance limit for the difference between measured and simulated water levels should be only a few tenths of a foot, not the two-foot tolerance limit adopted by the Navy consultants. If, on the other hand, groundwater level variations over time at the monitoring points support a two-foot tolerance limit, then the assumption of steady-state conditions is neither reasonable nor defensible given the basalt aquifer's high permeability and very small hydraulic gradients.

- The Navy has presented model results that have been calibrated to produce matches to averages of water levels measured for the years 2006, 2015, and 2017. The Navy, however, has not justified whether or not these average water levels reflect steady-state conditions. In the absence of any analysis of the field conditions (including pumping rates) during the calibration periods, the Navy's contention that the averages of the measured water levels represent steady-state conditions is only conjecture. The condition of steady-

state implies that the water levels and pumping rates remain nearly constant. If there are notable trends or fluctuations in either the set of measurements for the pumping rate or water levels, then the physical system should not be characterized as a steady-state system. The BWS recommends that the Navy consultants demonstrate that steady-state conditions are approximated by the averages of the pumping rates and water levels before assuming that such conditions exist using available measured water levels and pumping rates for 2006, 2015, and 2017.

- The Navy's assignment of water levels to model layers and the placement of the model layers has not yet been properly explained or justified. Since August 2017, the BWS has asked the Navy on multiple occasions to show where model layers intersect the screened sections of the monitoring and pumping wells and where the model layers intersect the basalt zones identified on driller or geophysical logs. One of the BWS's concerns is whether calibration target wells have screens that span multiple model layers. An example is that the Navy has been using measured water levels in monitoring well HDMW2253-03 to estimate hydraulic gradients in the shallow aquifer (model layers 2 or 3) but this monitoring well is in reality a deep monitoring well that extends to a depth of 1,585 feet, is cased across the water table, and intersects intervals with groundwater levels that are much higher than those in the shallow aquifer, and so adds an inappropriate bias to predicted shallow groundwater levels in this area.

3. Saprolite Extent and Hydraulic Properties: The Navy's proposed extent of saprolite with low permeability along the Halawa Valley streams is not justified based on limited testing at a single well location. Furthermore, the Navy represents saprolite as a homogenous material without preferential flow paths, which is not consistent with previous reports by Hunt (1996), who indicates that preferential pathways are relevant and potentially significant in saprolite content:

   "Saprolite is a weathered material that has retained textural features of the parent rock. In basaltic saprolite, diverse parent textures and a variable degree of weathering impart a heterogeneous permeability structure with preferred avenues of water movement and retention. Miller (1987) measured saturated hydraulic conductivities of saprolite core samples and obtained values that ranged over five orders of magnitude from 0.001 ft/day to 100 ft/day. Miller (1987) further found that preferential flow occurs in channels between macropores and along joints."

The BWS advocates that assumptions regarding saprolite should be conservative relative to its impact on preventing contaminant migration from the RHBFSF to our water supply points until additional characterization of the saprolite shows otherwise. Until the Navy has data to show otherwise, their conceptual site model (CSM) should consider saprolite as a heterogeneous material that includes high-permeability preferential flow paths associated with remnant lava tubes or clinker zones.

The Navy should run the groundwater calibration model with and without any low-permeability saprolite in the stream valleys and compare the resulting calibration statistics and predicted groundwater levels. The BWS asked during at least two previous modeling working group meetings that the Navy follow the example of Oki (2005) and test whether the calibration results differed significantly with and without the presence of the low-permeability units in the stream valleys. The BWS noted that the Navy had agreed to do so in those meetings; however, the Navy contractor stated that they had not done so as of the last (February 12, 2018) groundwater modeling working group meeting.

4. Conceptual Site Model: The Navy has not yet provided a CSM that explains and is consistent with measured water levels, measured hydraulic gradients, and observed geologic features. Our previous comment letters have expressed significant concerns about the Navy's inability to support their CSM assumptions based on field data and the Navy's inability to explain measured vertical and horizontal gradients. The February 12, 2018 groundwater working group meeting did not provide any information to address BWS concerns that the Navy's CSM is inadequate and incomplete with regard to: a) describing a geological framework for modeling transport through basalt and saprolite; b) a groundwater flow system that accounts for the vertical hydraulic gradients in monitoring well RHMW11; c) spatial variability in recharge and possible influence on the shallow flow system; d) nature and extent of saprolite beneath valley fill and streams; and, e) boundary conditions controlling discharge to springs and the ocean.

5. Uncertainty Analysis: The Navy's modeling approach does not adequately account for important uncertainties in the driving forces, hydrogeologic framework, and hydraulic properties in Moanalua and Halawa Valleys. The Navy has not carried out the type of uncertainty analysis that the BWS has advocated since groundwater modeling working group meeting No. 3 in August 2017. There were no data presented in the February 12, 2018 groundwater modeling working group meeting that would give us reason to change our position.
Although it does provide some useful findings, the Navy's implementation of the American Society of Testing and Materials (ASTM) sensitivity methodology does

not provide an adequate framework for incorporating important uncertainties into the risk assessment of contaminant migration required by the AOC.

Specific Comments

- Slides 9 to 11: If the Navy is assuming steady state conditions, then pumping rates and water levels should be relatively constant during the period of measurement. The BWS is concerned that the Navy did not present any data to justify their assumptions of steady-state conditions. Also, the BWS is concerned that the time-period used to average the water levels is different than the time period used to average the pumping rates. The Navy was not able to answer BWS questions regarding the temporal variability in either the water levels or the pumping rates during the February 12, 2018 groundwater modeling working group meeting, and we wish to remind the Navy of their agreement to provide this information to the BWS.

- Slides 12 to 14: The BWS has questions about the selection of the location and water levels assigned to the control points along the northeast boundary. These control points appear to produce hydraulic gradients in the vicinity of the northeast model boundary that are different than hydraulic gradients produced by several previous groundwater models. The BWS urges the Navy to check the assumptions and the model sensitivities associated with the control points as they may have an important impact of groundwater flow directions.

- Slide 19: The Navy uses different rationales to establish the range of values for different interim model parameters tested during the calibration process resulting in ranges that are too small for several important parameters. For instance, based on BWS's understanding of the process, the Navy selected several parameters such the basalt hydraulic conductivity anisotropy of 3 to 1 and the hydraulic conductivity value for saprolite based on expert option whereas hydraulic conductivity values for the basalt were determined from the Parameter Estimation Software (PEST) (Watermark Numerical Computing, 2016) simulations. The Navy is not adequately investigating and documenting the full ranges that are reasonable for model parameters that can lead to equally good fits to the measured water levels and thus are not adequately investigating important uncertainties.

- Slide 19: The Navy did not answer several important questions about the model calibration process during the February 12, 2018 groundwater modeling working group meeting. Among these key questions is how did the Navy establish acceptable calibration criteria? Which water levels were used? What calibration

criteria and weighting factors were used? For instance, the Navy could not provide information about which calibration targets were based solely or primarily on real observations and which targets were based on projected ("made-up") water levels. We remind the Navy that they agreed during the February 12, 2018 groundwater modeling working group meeting to provide the BWS with this information.

- Slides 25 to 30: The BWS is not convinced that the results shown support a conclusion that the groundwater model has been properly calibrated. Slides 27 through 30 show clustering of water level residuals with similar biases. For instance, measured water levels in the northwest are predominantly underpredicted whereas the measured water levels in the southeast are predominantly overpredicted. Slide 25 shows that the groundwater model does an inadequate job of matching water levels near the springs and the coastline. The BWS believes that the lack of groundwater model calibration may be caused by an oversimplification of the coastal boundary and/or vertical discretization which impacts the simulation of observed vertical gradients. Figure 26 shows a root mean square error (RMS) for the residuals (differences between observed and predicted heads) of 1.2 feet for heads in the vicinity of Red Hill with water levels between 12 and 25 feet above mean sea level. Such a large RMS suggests that the hydraulic gradient may not be properly represented between target wells. Moreover, the calibration process included calibration targets that were not measured but rather estimated or projected by the Navy consultants. The BWS urges the Navy reconsider their approach to both establishing the groundwater model calibration objective and explain how the groundwater model was calibrated.

- Slide 25: If the Navy's model cannot properly represent flow along the coastal boundary, then the model could be underestimating flow rates in the vicinity of Red Hill. An underestimate of groundwater flow rates could have significant repercussions when evaluating the risk of contaminants reaching the receptor wells.

- Slides 34 and 35: The relationship between changes in the pumping rates in Red Hill Shaft and the changes in measured water levels appears to be out of phase. Please check to make sure that the timing of the changes in the pumping rate is accurately shown.

- Slides 52 to 115: The BWS does not believe the numerous particle tracking results are based on appropriate assumptions and model parameters. In future meetings, the BWS recommends that the Navy spends more time on presenting

field data and explaining the development of appropriate modeling tools and less time on presenting results from predictive model scenarios. Much of the information in slides 52 to 115 could have been consolidated into significantly fewer slides.

We continue to ask that the Navy distribute meeting handouts and other information documents two weeks prior to the start of each meeting to ensure subject matter experts, the BWS, and other stakeholders are afforded the opportunity to thoroughly review the materials ahead of time. We also request that the Navy and its contractors provide copies of all materials disclosed at the meeting that they committed to share with subject matter experts.

Thank you for the opportunity to comment. If you have any questions, please feel free to call Erwin Kawata at 808-748-5080.

Very truly yours,

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Attachment A

Navy Slide Presentation dated February 12, 2018