BOARD OF WATER SUPPLY

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October 18, 2017

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and

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and

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Dear Messrs. Pallarino, Chang, and Manfredi:

Subject: Honolulu Board of Water Supply (BWS) Comments on the Groundwater Modeling Working Group (GWMWG) Meeting Held September 22, 2017 for Red Hill Administrative Order on Consent (AOC) Statement of Work (SOW) Sections 6 and 7

Thank you for the opportunity to participate in the fourth Red Hill groundwater modeling working group (GWMWG) meeting held on September 22, 2017. We observed that the half-day allotted for this meeting was insufficient for discussing the interim and final groundwater models. For example, there was no time to discuss how the Navy will simulate contamination and its migration in the interim model. Going forward, we suggest that the meetings be scheduled for a full day at a minimum. We acknowledge the efforts made by the Navy to provide meeting documents and slides prior to the start of the meeting. We ask that these materials be made available at least two days before each meeting. Being able to review such materials before the GWMWG meeting results in the meeting being more productive.

Our detailed comments and concerns from the September 22, 2017 GWMWG meeting about the Navy's stated plans for developing the interim and final 2018 groundwater flow and transport models follow. In summary, our key concerns are that the Navy modeling team:

- Has not provided a credible approach for evaluation of the risk to groundwater from the Red Hill Bulk Fuel Storage Facility (RHBFSF) tanks that is needed for the tank upgrade alternative selection and for the final models;
- Has provided only minimal information regarding how the interim transport model will be constructed, calibrated, and applied;
- Has not demonstrated an adequate understanding of the key hydrogeologic controls on groundwater flow in the Red Hill vicinity;
- Has not adequately addressed concerns raised by the BWS and United States Geological Survey (USGS) from the GWMWG meeting on August 22, 2017; and,
- Gave descriptions of the approaches for groundwater flow and transport modeling in the materials and discussions for this GWMWG meeting that are inconsistent with the approaches described in the groundwater model evaluation plan.

Detailed Comments from GWMWG Meeting Held on September 22, 2017

A. BWS's Key Concerns from the 3rd GWMWG Meeting Held on August 22 Meeting

At the beginning of the 4th GWMWG meeting on September 22, 2017, the BWS summarized our five major technical concerns from the previous 3rd GWMWG held on August 22, 2017. We restated these key points so that the Navy modeling team would try to address them during the next meeting. However, discussions during the 4th GWMWG meeting did not alleviate our major concerns, which we restate below with more detailed explanations in the expectation that the modeling team and AOC Parties will respond appropriately when we meet again on November 17, 2017.

1. There is a lack of important hydrogeologic data near the RHBFSF

   The most important data gaps are a) characterization of the spatial variability in the basalt hydraulic properties; b) identification of possible preferential flow paths through clinkers, lava tubes, or fractures; c) recharge rates; and d) hydraulic head gradients near the RHBFSF. We remain concerned that the Navy modeling team will overlook the importance of the uncertainties caused by these data gaps to their risk assessment or make unjustified simplifications about Red Hill hydrogeology to streamline and shorten the data analysis and modeling tasks. A key part of the Conceptual Site Model (CSM) that remains missing is a description of how the hydrogeology will be parameterized and the upper and lower boundaries for these parameters. According to the groundwater

model evaluation plan (DON, 2017), the Navy is following American Society for Testing and Materials (ASTM) 5981-96 (Calibrating a Groundwater-Flow Application), which states the parameterization and setting of boundaries should be completed before any model simulations are performed; however, the Navy's proposed approach appears to contradict the ASTM guidelines as they have yet to present the recommended ranges of parameter values and boundary settings.

2. Groundwater head gradients are dynamic and very flat

   Partly because of the basalt's very high transmissivity, small differences in water levels can significantly change the direction and velocity of groundwater flow. Besides being relatively flat, hydraulic gradients near Red Hill are very dynamic (changing with time) because of the temporal variability in the large pumping rates at Red Hill Shaft and Halawa Shaft and because of the large temporal and spatial variations in recharge rates near and upgradient of Red Hill. To date, the Navy has yet to describe the water levels and hydraulic gradients that characterize the groundwater flow direction and velocity in this area. This characterization should include a discussion of the potential importance of measurement error in the water levels: transience in the water levels caused by natural processes such as barometric changes, recharge, and pumping; and, how assumptions about basalt hydraulic properties affect inferred groundwater flow directions. A key part of the CSM that remains missing is the error bars associated with the water levels that will be used for calibration targets. According to ASTM 5981-96 (Calibrating a Groundwater-Flow Application), which the groundwater model evaluation plan (DON, 2017) states that the Navy is following, calibration targets should be established before any model simulations are performed.

3. An uncertainty analysis is needed

   The RHBFSF stores an enormous amount of fuel above Oahu's sole-source aquifer and near to one of the BWS's most important drinking water supply points. As such, the continuing deterioration of the steel and concrete in the Red Hill tanks poses a risk to the drinking water supply for much of Oahu. Understanding this risk should be a necessary first step before the AOC Parties choose a tank upgrade alternative (TUA). Therefore, the interim model should estimate the risk by capturing likely outcomes of contaminant migration from Red Hill given the data gaps and uncertainties. The same is true of the final model.

   During the 3rd GWMWG meeting, BWS asked if the Navy modeling team will conduct an uncertainty analysis to quantify risk given the lack of data to characterize the site hydrogeology, the very flat hydraulic gradients, and the potentially important transience of the system. BWS was pleased to hear that Dr. Sorab Panday state that such an analysis would be valuable and would be conducted. Dr. Panday and the BWS discussed that the null-space Monte Carlo method is a proven approach for quantifying uncertainty, is documented in several USGS reports, and is often implemented using the PEST software (Watermark Numerical Computing, 2016).

BWS believes that the sensitivity analysis briefly discussed by the Navy's modeling team will not provide an estimate of risk to groundwater that is as defensible as the risk estimate from an uncertainty analysis. During the September 22nd meeting, BWS stated that the uncertainty analysis that includes the null-space Monte Carlo method is one of the most defensible ways to quantify the range of possible groundwater flow paths from Red Hill tanks to potential receptors given the uncertainty in important hydrogeologic variables and processes caused by the lack of data and information. Such an uncertainty analysis would describe the range of possible flow paths using "spaghetti" plots of particle tracks from Red Hill generated from the various reasonably calibrated flow models. These plots could then be used to estimate the risk to Oahu drinking water. The Navy's modeling team did not explain how their sensitivity analyses would be done, but the BWS believes that sensitivity analyses will describe variations in a single "spaghetti strand" and, unlike the uncertainty analysis, will not estimate the risk by evaluating all the strands.

4. Base case scenario for interim model should not have valley fill

   During the 3rd GWMWG meeting, BWS stated that, given the lack of data to characterize the three-dimensional geometry and hydraulic properties of valley fill, the base case or default assumption for the interim model should be there is no valley fill below the water table between Red Hill and Halawa Shaft. BWS suggests that an updated CSM define the valley fill characteristics (geometry below water table, hydraulic properties) as model calibration parameters and to provide upper and lower bounds for those parameters.

5. Use of freshwater heads instead of density-dependent flow

   During the 2nd and 3rd GWMWG meetings, BWS and Dr. Delwyn Oki from the USGS expressed concerns that the "freshwater head" approach proposed by the Navy's modeling team is an inappropriate simplification of the conditions near the ocean boundary and would introduce errors in groundwater flow paths. In response to this concern, the Navy's modeling team proposed to use a no-flow boundary to mimic the effects of the density-dependent flow. During this explanation of how the no-flow boundary would be implemented, Dr. Oki and BWS noted several major problems with the approach proposed by the Navy. Dr. Panday acknowledged these concerns but could not address them at the meeting and committed to revisiting the issue. To help address our concern with the Navy modeling team proposed "no-flow" approximations to represent the effects of density-dependent flow, BWS requested that comparisons be made between a model using the Navy's approach and a model that properly solves for density-dependent flow and uses the parameters from the Navy's calibrated model. During the 4th GWMWG meeting, BWS made it clear that the approach proposed by the Navy to use a no-flow boundary to represent the transition between fresh water and underlying seawater is contrary to the ASTM standard 5609-94 (Defining Boundary Conditions in Groundwater Flow Modeling), which, in the groundwater model evaluation plan (DON, 2017), the Navy states that they are following.

B. Navy modeling team has yet to communicate a basic understanding of site hydrogeology

BWS has an overarching concern that the Navy modeling team has not yet communicated a basic understanding of the site hydrogeology in the GWMWG meetings and in the Navy's groundwater model evaluation plan (DON, 2017). Examples of our concerns are:

1. Hydraulic Properties of Basalt

   The Navy's groundwater model evaluation plan states that "In the Facility vicinity, the arithmetic mean, geometric mean, and median values of hydraulic conductivity for dike-free volcanic rocks were respectively 1700, 900, and 1200 feet/day (DON 2007)." However, these values are from a hydrogeologic study of Maui (DON, 2007; Rotzoll and El Kadi, 2007), not of the Red Hill vicinity. Factual errors like these in part drive our concerns about the Navy modeling team's grasp of the hydrogeology of Oahu's Moanalua and Halawa Valleys.

   BWS is concerned that the Navy modeling teaming will use a simplistic model to represent the basalt properties instead of focusing on the significant heterogeneities in basalt that act as preferential pathways. These include clinker zones, lava tubes, and fractures. A simplistic representation of basalt is typically appropriate for regional models addressing water supply issues, but it is not appropriate for risk assessments that focus on contaminant transport at the scale of hundreds to thousands of feet in which the preferential pathways are critical.

2. Hydraulic Head Data

   The Navy modeling team proposed to use a steady-state model calibration to average conditions in a period during 2015 for the interim model. The Navy modeling team stated this decision without presenting hydrographs from monitoring wells with water level data or discussing the transience in the calculated magnitude and direction of the hydraulic gradients. If the Navy groundwater modeling team uses a quasi-steady-state condition that has not been properly vetted, then the interim model could have biases and unknown errors in the model properties that will affect our understanding of the risk to groundwater but not be discovered until the Navy calibrates a model using transient water level conditions. The BWS is concerned that the decision for a steady-state calibration model seems to have been made out of expediency and not because it is an appropriate modeling approach for evaluating risk from groundwater contaminant transport. The Navy groundwater modeling team has not demonstrated from a risk assessment perspective why a steady-state calibration model should be used instead of a transient calibration model.

   Moreover, the task of developing calibration targets for a single steady-state calibration will introduce even more uncertainty into the model results than using transient calibration data. For instance, error bars for monitoring well water level and springs flow

calibration targets for a steady-state model will be much larger than the error bars associated with the point measurements for the same monitoring well water levels and spring flows for a transient model.

3. Recharge

The Navy groundwater modeling team stated that the recharge rates recently estimated by the USGS may be too high along Red Hill. The groundwater model evaluation plan states: "it appears that the low permeability of the thick saprolitic soil overlying the Red Hill ridge was not accounted for by the USGS study" (DON, 2017). The BWS is concerned that the Navy may be overlooking valuable information about ongoing recharge within Red Hill ridge and its saprolitic soil cover.

There is ample evidence of recharge within the ridge, including historical and present-day seepage into the upper and lower Red Hill tunnels, even with the grouting of the tunnel ceiling and walls, and the extensive water collection system that sends water to the oil-water treatment system. The rate of recharge can be quite large based on the image of a worker standing knee deep in water while excavating a Red Hill tunnel in its recent historical video (see minute 1:40 in https://www.youtube.com/watch?v=0Bx81rD206A&feature=youtu.be). The Navy should quantify the subsurface water flux, e.g., the water flux onto the tunnel ceilings, rather than focusing on the saprolitic soil because it is easy to see there is a significant amount of inflow into the Red Hill Ridge's interior based on what has been observed historically and what is currently observed in each RHBFSF tunnel. As part of the CSM, the Navy modeling team should provide a water budget for the Red Hill groundwater system, explain any concerns with the USGS recharge rates, and describe how they plan to parameterize recharge for the interim and final groundwater models.

4. Density-dependent flow

The Navy groundwater modeling team proposed to ignore density-dependent flow to reduce model run time. During the 3rd GWMWG meeting, the Navy groundwater modeling team could not answer USGS and BWS concerns about the Navy's proposed approach to use fresh-water head boundary conditions. During the 4th GWMWG meeting, the Navy groundwater modeling team could not answer concerns raised by the USGS and BWS about a proposed approach to use no-flow boundary conditions to represent the freshwater-seawater interface. In the 4th GWMWG meeting, it became readily evident that the Navy groundwater modeling team was unware of the measured groundwater levels near the caprock and that they would have to rethink how they will define and parameterize these boundary conditions.

5. Transport

The Navy groundwater modeling team has not yet presented a conceptual plan to model transport. Key parameters such as source terms, biodegradation rates, porosity, and dispersivity values have yet to be presented. Equally important is the conceptualization of the migration distance, directions, and rates that fuel released from the RHBFSF can travel within the vadose zone located between the release points and the groundwater surface (water table).

C. How Can Proposed Interim Modeling Approach Properly Assess Risk to Aquifer?

During the third GWMWG meeting, the Navy groundwater modeling team stated that they will create an interim flow and transport model for the Red Hill groundwater flow system that is intended to provide input information for the tank upgrade alternative (TUA) study. Given that proposed TUAs span a wide range of risks of fuel release, the interim modeling should directly and defensibly evaluate the risk that groundwater contamination from Red Hill can migrate to Halawa Shaft and other water supplies. Otherwise, how will the Regulatory Agencies be able to make a defensible TUA choice? From the BWS's perspective, if the risk of Red Hill contaminant migration to Halawa Shaft (or other water supplies) is significant, then a TUA with a low risk of release should be chosen. We hope that the Regulatory Agencies share this same perspective.

The Navy's proposed steady-state approach replaces numerous individual groundwater level measurements with a single average for each well location. Similar averaging must be applied to the time-varying pumping rates and spring discharges. This means the averaged calibration targets for water levels and spring flow will each represent a composite value that will have much larger error bars than would the individual values used to create each averaged target. Instead of estimating aquifer properties by calibrating the groundwater model to many different hydrologic conditions represented by the changes in pumping and recharge over time, the Navy's approach is to create a single and hypothetical condition based on averages and then presume that the hypothetical condition represents steady-state conditions that are important for understanding risks from contaminant migration.

The BWS has concerns with the steady-state approach for several reasons. First, the assumption that average conditions represent steady-state conditions is not necessarily true. Steady-state conditions require that the total inflows into (recharge, lateral flows) the groundwater model domain perfectly balance the outflows (pumping, springs, lateral flow) from the groundwater domain so that the water levels and flows do not change over time. This means there is no change in the amount of water stored in the aquifer. The period over which the water levels are being averaged is, by definition, not steady-state if the inflows and outflows are changing or if the amount of water stored in the aquifer is changing. If the Navy wishes to force the steady-state assumption, then BWS recommends that the Navy evaluate the aquifer properties and their estimates of recharge and boundary condition choices from their "steady-state" interim model calibration by using them to simulate other hydrologic data sets from other years.

Another BWS concern with a steady-state calibration is that it will not provide any information about the storage properties of the basalt aquifer. Storage properties are necessary for understanding how quickly changes in pumping rates (such as those expected when a fuel release occurs and those for remediation design) affect groundwater flow directions and rates. The BWS supports the transient calibration approach described by Dr. Oki during the third GWMWG meeting. Dr. Oki and the BWS pointed out that a transient calibration will provide a way to estimate, or at least bound, the storage properties. A transient calibration run over a sufficiently long-time period will also test the choices of recharge rates and other boundary conditions. Thus, the steady-state calibration approach proposed by the Navy groundwater modeling team will not be able to investigate potentially important dynamics that could be critical to characterizing the groundwater flow system.

Yet another BWS concern is that the Navy's approach for model calibration is contrary to ASTM 5981-96 (Calibrating a Groundwater-Flow Application), which the groundwater model evaluation plan (DON, 2017) states the Navy is following. In order to help address the problem of non-uniqueness, ASTM 5981-96 recommends calibrating to data collected from multiple distinct hydrological conditions. At Red Hill, the primary site conditions that will create distinct hydrological conditions are different pumping rates and recharge rates, which exist in the transient data, but are lost when averaged and used in a steady-state simulation.

Given the large uncertainties about how hydraulic conductivity, storage properties, and recharge vary across the RHBFSF and its vicinity, the BWS fully supports the recommendation for a constrained uncertainty analysis made by Dr. Panday during the third GWMWG meeting. The BWS believes that the Navy modeling team should revise their modeling approach to instead yield defensible estimates of the risk from RHBFSF fuel releases of various magnitudes to our water supplies that will be useful and appropriate for the TUA selection process.

D. Interim Model Will Incorporate Little to No Data from New Monitoring Wells

There are insufficient data currently available about groundwater flow paths and aquifer properties in Halawa Valley between the RHBFSF and the BWS Halawa Shaft to build a credible groundwater flow and transport model. A considerable amount of additional field data about geology, groundwater levels, groundwater chemistry, and hydraulic properties are needed to:

- Develop a CSM for current and future Red Hill contamination;
- Construct a numerical model that defensibly simulates groundwater flow and transport, and,
- Quantify uncertainty in the contaminant migration predictions.

The BWS has repeatedly recommended such data be collected and welcomes the Navy's proposed new monitoring wells in Halawa Valley. However, given the impending deadline for the interim model and the fact that drilling of the first off-Site well has only just begun, it appears that little to no new data from Halawa Valley will be used in constructing and calibrating the

Navy's interim groundwater model. The new monitoring wells and associated aquifer testing will provide some of the data needed to better understand groundwater flow and solute migration in this critical area. If few to no new data will be ready in time for the interim groundwater model, then the Navy should use a constrained uncertainty analysis to evaluate the effects of all the likely properties and stresses in this area on the risk of contaminants migrating from the RHBFSF to Halawa Shaft and other water supply points.

E. MODFLOW-USG Transport Code is Unverified and Proprietary

Dr. Panday proposed to use his currently USG transport code to simulate migration of groundwater contaminants for the Navy's interim and final groundwater models. The BWS has concerns about using an unverified and proprietary modeling code for the high-risk, high profile RHBFSF project.

According to Dr. Panday, the USG transport code has been applied to only two projects, for which there are no final reports available for review, and the source code and documentation were to be made available in September 2017. As of this writing, neither the Navy nor Dr. Panday have made the source code and documentation available.
BWS is not comfortable with the Navy planned use of Dr. Panday's USG transport code. As part of the next GWMWG meeting, we ask that the Navy provide the USGS, BWS, and other interested parties the source code for the transport code, a hard copy of the code documentation, communication from the authors of GMS to confirm whether or not the transport code is fully functional in GMS, communication from the USGS regarding their involvement with the development or verification of the transport code, communication for the USGS regarding their plans for developing a transport code for MODFLOW-USG, electronic copies of reports that have used Dr. Panday's transport code, and a list of references that have provide a third-party verification of the accuracy of the USG transport code.

Thank you for the opportunity to comment. If you have any questions, please feel free to call Erwin Kawata, Program Administrator of our Water Quality Division at 808-748-5080.

Very truly yours,

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