UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION IX
75 Hawthorne Street
San Francisco, CA 94105

STATE OF HAWAII
DEPARTMENT OF HEALTH
P. O. BOX 3378
HONOLULU, HI 96801-3378

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Captain Marc Delao
Regional Engineer
Navy Region Hawaii
850 Ticonderoga St. STE 110
Joint Base Pearl Harbor Hickam, Hawaii 96860

Subject: Comments on Vadose Zone Modeling for the Red Hill Administrative Order on Consent ("AOC") Statement of Work ("SOW")

Dear Captain Delao:

The U.S. Environmental Protection Agency ("EPA") and Hawaii Department of Health ("DOH"), collectively the "Regulatory Agencies", are providing comments on the proposed vadose zone modeling of Light Non-Aqueous Phase Liquid ("LNAPL") under development by the U.S. Department of the Navy ("Navy") and Defense Logistics Agency ("DLA") to satisfy requirements for Sections 6 and 7 of the Red Hill AOC SOW.

The Regulatory Agencies agree with the Navy that the complexity of this environment makes deterministic vadose zone modeling impractical. However, the AOC SOW states that the Navy is to develop models to evaluate the fate and transport of contaminants in the subsurface, and an assessment of the risk to the groundwater resources that may be posed by the Red Hill Bulk Fuel Storage Facility ("Facility"). Currently the Navy has only submitted to the Regulatory Agencies a statistical holding model for estimating capacity of the formation to contain releases. This holding model does not address this intent, and it is not conservative or realistic if utilized as a predictor of the potential consequences from future releases. The Regulatory Agencies' understanding is that the holding model is being used an initial assessment of the vadose zone holding capacity, primarily for the purposes of assessing natural source zone depletion.

The Navy has recently proposed using a homogeneous LNAPL Equivalent Porous Media ("EPM") model to simulate how releases, like the 2014 release from Tank 5, move in the vadose zone around the Facility. The Regulatory Agencies believe an EPM model can potentially facilitate a general understanding of how releases from the Facility will tend to move in environments like those found at Red Hill. This information may help refine the Navy's

Conceptual Site Model ("CSM"), articulate the possible fate of the 2014 release given the available data, and improve a generalized understanding of the subsurface. However, the Navy should provide a technical rationale for employing an EPM model to supports its application in this case, if it will be incorporated into the CSM submitted to the Regulatory Agencies. Ultimately, all modeling efforts under section 7.2 of the Red Hill AOC SOW will need to carefully incorporate or conservatively account for site heterogeneity.

Neither the holding model nor the proposed EPM model can identify preferential pathways or determine their effect on the transport of product through the vadose zone, but an EPM model is generally more representative than the holding model for simulating the consequences of future releases because it incorporates more of the surrounding environment's physical properties. The Navy's proposed EPM model should provide insights for the Investigation and Remediation of Releases Report and the CSM, however it will not provide conservative inputs to the saturated zone contaminant fate and transport model. Satisfactory inputs for the saturated zone model should be developed after further technical discussion with the Regulatory Agencies. As stated in the Red Hill AOC SOW, the contaminant fate and transport model report will utilize the groundwater flow model to improve understanding of the potential for contaminant fate and transport in groundwater.

Because the proposed LNAPL model does not adequately account for the role of preferential pathways as a conduit for the migration of potential future releases to sensitive receptors, uncertainty related to the role of preferential pathways should be weighed heavily during risk-based decision making. Appropriate engineered and/or institutional controls are likely necessary to account for the uncertainty.

Our contractors have provided some technical concerns and suggestions regarding the Navy's LNAPL modeling proposal. The memo is enclosed for your consideration. Please contact us if you have any questions or concerns.

Sincerely,

Omer Shalev
Project Coordinator
EPA Region 9 Land Division

Roxanne Kwan
Interim Project Coordinator
DOH Solid and Hazardous Waste Branch

Enclosure: Aqui-Ver Memo to Regulatory Agencies dated June 18, 2019

cc: Commander Darrel Frame, Navy (via email)
Mr. Cory Waki, Navy (via email)
Ms. Tracy-Joy Saguibo, Navy (via email)

Date: June 18, 2019

To: Ms. Fenix Grange, Ms. Lene Ichinotsubo &Mr. Robert Whittier, Hawaii DOH
Mr. Omer Shalev, Ms. Lyndsey Tu & Mr. Steven Linder, USEPA Region 9
Dr. Matthew Tonkin, S.S. Papadopulos & Assoc., Inc.
Dr. Donald Thomas, Director, Center for the Study of Active Volcanoes, University of Hawaii, School of Ocean and Earth Science and Technology

From: G.D. Beckett, **AQUI-VER, INC.** (AVI) with Input from the Regulatory SME Team

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REVIEW OF LNAPL MODELING PROPOSED BY THE U.S. NAVY RED HILL BULK FUEL STORAGE FACILITY TECHNICAL TEAM

ADMINISTRATIVE ORDER ON CONSENT SECTIONS 6 & 7

OVERVIEW

In March 2019, the Navy technical team working on AOC Section 6 and 7, AECOM and Groundwater Services, Inc. (GSI; collectively the "Navy team") proposed performing potential multiphase numerical transport modeling to estimate how far, fast, and in what direction fuels (a.k.a., LNAPL) might travel as a result of various release scenarios; the initial suite of release conditions will be reflective of the 2014 Tank 5 release. This modeling was proposed to address regulatory concerns that the LNAPL holding model approach was incapable of providing reliable information regarding the behavior and fate of such releases and the associated potential risks to the groundwater resource.

The sufficiency of any modeling approach to assist in risk-based decision making depends on its reliability, technical quality and reasonable conservatism. Reliability in this case means that the modeling results can be trusted to reasonably predict release outcomes in this specific environment. Technical quality means that the scientific framework and parameter assignments are robust and adequately represent the range of site conditions relative to the groundwater protection questions being addressed. Reasonable conservatism means consideration of subsurface conditions, such as fast-track transport features, that could result in higher risk to the groundwater system than would average conditions.

The purpose of this summary memo is to assess these aspects of the Navy's proposed LNAPL modeling and respond to their request for regulatory comments. Notwithstanding the comments that follow, we believe the proposed LNAPL modeling is a step in the right direction toward ascertaining LNAPL behavior in the environment. Our summary position is that the Navy team needs to do a more thorough job in defining the model framework and parameter distributions in order to meet the goal of informing groundwater protection decisions. The LNAPL modeling as currently proposed is unlikely to be useful in that regard because of its simplifications in structure, parameterization, and overall approach.

THE NAVY'S PROPOSED MODEL

The Navy team has proposed using a lumped homogeneous three-dimensional (3-D) groundwater flow model modified to account for active LNAPL transport using the Richards unsaturated flow equations. In simple terms, this means the active mobile fluid in the model is LNAPL, while pore water is fixed and the air-filled pore space is the fraction of the total through which LNAPL can migrate (air-phase is passive). We agree that this will simplify the computational requirements of solving for full multiphase flow where water, LNAPL and vapor can all move in response to changes in the system (like a release). Further, the proposed model is a lumped homogeneous framework assumed to be reflective of an equivalent porous medium (EPM), as discussed further below.

As it is presently proposed, the Navy' LNAPL modeling is unlikely to be useful in groundwater protection decisions because of its simplifications in structure, parameterization, and overall approach. These simplifications are likely to generate unreliable and non-conservative results. The proposed modeling is, however, a framework and concept that we believe can serve those groundwater protection goals with additional technical evaluations. Several specific areas of concern are discussed below, while noting that most of them are interrelated

As background, most common fluid flow simulation models were developed using equations that assume Darcy's law and its transient form is applicable at the scale of interest and that migration occurs under laminar flow conditions within distributed porous media (i.e., via primary porosity connected pore space). Porous media are typically soils or other porous materials with relatively narrow variability in the primary porosity and permeability characteristics such that each individual hydrostratigraphic unit (HSU) can be described by a uniform set of parameters. A homogeneous lumped model has only one HSU and lumping assumes that the central tendencies of the hydrogeologic transport system are adequately represented by this significant simplification.

Typical Darcian flow models are generally applicable to fluid movement in clastic sedimentary sequences, but may not be applicable in more complex setting like Red Hill. In settings such as Red Hill, secondary porosity features such as connected fractures can be crucial controls to fluid migration. A number of flow models have been developed that can represent the non-Darcian migration of fluids within secondary porosity features and within rock settings dominated by such features. However, the application of such codes in site-specific settings is often hampered by (a) the lack of knowledge regarding the distribution and character of the secondary porosity features and (b) the computational demand that such non-Darcian models often required. For this reason, fluid migration in settings that are dominated by secondary porosity features is often simulated using models that assume Darcian flow using an equivalent porous media (EPM) assumption. That means the complexity of the actual flow system is assumed to be adequately represented by an EPM without neglecting critical behaviors that will influence the estimation of risks to area receptors. If the EPM assumption can be justified that enables the simulation of fluid migration in this complex setting to be completed using any number of common models.

Given the background above, there are two distinct issues to consider with regard to the Navy team's proposed 3-D LNAPL model. First, is the assumption of an EPM system technically supported and will it account for the scale and behavior of fast-track geologic features known to be present within the subsurface system? Second, is the assumption of a lumped homogeneous system appropriate to this complex hydrogeologic setting, and related to that determination, how should the model be parameterized?

Limitations of the Modeling Approach

The Navy's proposal to use the MODFLOW-USG model, modified with the unsaturated flow equations, to simulate fluid migration at the Red Hill site rests upon the EPM assumption. In essence, the EPM assumption is that at the scale of interest the behavior of the fluid within the host media can be reasonably approximated using the transient forms of Darcy's law. Thus, the potential applicability an EPM modeling approach depends on the relationship between the scale of interest at the site and the character (occurrence, frequency, apertures, connectivity, etc.) of secondary porosity features. Therefore, to provide support that an EPM approach is reasonable, it is typical in scientific literature that the character of the host rock is demonstrated to be reasonably approximated at relevant scales using an EPM. This has not yet been demonstrated at Red Hill. The agencies have noted in past comments that aspects of the fractured and void-influenced system need to be quantified as an initial basis to understand the scale and behavior of LNAPL and associated contaminant transport in this system (e.g., ITRC Fractured Rock Guidance, 2017; NAP 2015).

This geologic system, with fractures, voids, and inter-flow complexities is not what would typically be considered of an EPM system. The EPM assumption becomes less valid as the variability of those geologic features becomes more pronounced. This is further complicated by the lack of high density characterization data that could constrain the scale where an EPM approach might be applicable. If the scale of critical transport processes is smaller than the scale where an EPM approximation is appropriate, then different model approaches would be necessary (e.g., discrete fracture/void network model [DFN] or others).

The LNAPL model is also proposed as a homogeneous "lumped" model; this is a distinct assumption that has nothing to do with the EPM model itself. This essentially assumes that the complex geologic setting can be simplified and represented as a "sand box" type of continuum. Flow and transport will occur as a function of the release character, geologic parameters, gravity and other factors, but it will not be influenced by the vast differences between each geologic unit (clinker, massive basalt, void features, lave tubes, etc.). At best, the lumped model may represent central tendencies of transport if the parameterization is suitable, but it will not predict reasonable and conservative end-members. It is inherently non-conservative by the constraints of the homogeneity assumption. LNAPL migration beneath the release will be predominantly downward with little lateral migration, the water table impacts will be smaller than could actually occur in a more distributed release, and other critical risk aspects may be under-represented.

Limitations of the Model Parameters

If it can be demonstrated that the character of the void/fracture structure at Red Hill can be reasonably approximated at relevant scales using an EPM assumption, it is then necessary to develop parameters for the distributed porous media model that reasonably represent the movement of fluids through the host rock. A distributed porous media model, such as MODFLOW-USG[1], uses hydraulic conductivity and mobile porosity as input parameters to describe the potential for fluid migration. When simulating migration in settings such as Red Hill, these parameters are "surrogates" for the integrated properties of the actual features through which most migration may occur (i.e., clinker, fractures, and inter-flow boundaries). The values for these "surrogate" parameters are generally derived through a process that includes quantifying the frequency of occurrence, aperture, interconnection, feature distribution density, and other characteristics of the combined (primary and secondary) fluid migration features. This process has not yet been documented at Red Hill.

There are many groups of parameters in the proposed model, some of which (like fluid properties) are likely representative and/or relatively insensitive. Many of the remainders have high uncertainty and potentially non-conservative ranges, particularly as applied in a homogeneous EPM model. The lithologic capillary properties were taken from literature values for sand. Although the Navy team suggests the capillarity has low sensitivity that will not likely be true once LNAPL contacts the water table region. Capillary properties control how much LNAPL enters the pore space for a given pressure, and in turn, that controls the relative permeability toward the LNAPL; the more LNAPL that intrudes (i.e., higher saturation), the exponentially greater its ability to migrate. In hard rock settings, capillarity is controlled by void apertures, their density, continuity, roughness and other factors. These properties are expected to vary widely between the different lithologic zones present beneath the Tank Farm and the assumption of these values from a literature-based sand is non-conservative and inapplicable, as is the assumption of homogeneity.

The LNAPL residual saturation values cover a wide range where the end-members are likely too broad. On the high-end, we have noted that the petrophysical testing methods used by the Navy team have been shown to result in significant overestimates of residual capacity (i.e., they are unreliable and non-conservative). At the lower end, the LNAPL residual saturation of 0.13% is likely too small to be relevant. For perspective, that value would imply a vadose zone LNAPL holding capacity of about 75,000 gallons over the entire 20-acre Tank Farm area. That total release volume is less than those reported in Navy tank and inventory documents (e.g., BWS Comments, 2015; Draft QRVA, 2018).

<u>No Background LNAPL Conditions</u>

The proposed LNAPL model has no accounting for the likely residual mass in-place in the vadose and water table zones. Those will result in smaller modeled LNAPL migration than is probable under real conditions, particularly when coupled with the homogeneous and EPM aspects discussed above. While estimates of residual in-place are difficult to derive given the spatially sparse characterization data, it is a critical component to risk characterization at this site and needs further technical development. This could possibly be a set of conceptual working models that are hinged on different bounding conditions regarding the tank release history combined with available environmental data.

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[1]*MODFLOW-USG does implement some features that are non-Darcian, such as the Connected Linear Network (CLN) package that can simulate flow in conduits. However, although the simulation code has this capability, there remains the difficulty of obtaining information on the occurrence, orientation, and other characteristics of discrete conduits that would be simulated using the CLN package.*

Limitations in Consistency Criteria

The Navy team has proposed model consistency criteria that will form the basis of eliminating certain model runs and their parameter suites from further consideration. Two of the key factors are vapor responses and LNAPL responses. Basically, if vapor and/or LNAPL appear in the model in areas where the corresponding field data do not concur, then that particular model will be eliminated. As part of the model framework above, there is an anisotropy related to the dip of the lava flows at 2.9° at a compass direction of 214°. While those values are consistent with area measurements, the resultant direction of flow and transport they imply may not be valid. The distribution of the dissolved-phase plume over time has a potential bias toward the northwest, the same direction in which groundwater flow is suggested to often move under a range of conditions (per Robert Whittier's evaluations). The vapor response data beneath Tank 5 following the 2014 release also suggested a possible northwest transport direction for part of that release. Because of these observations and the absence of 2014 plume characterization data that constrain its fate and subsurface location, the proposed consistency criteria may not therefore be reflective of the underlying transport conditions. The Navy team's interpretations of thermal profiles at RHMW02 and RHMW03 as indicating the depth of LNAPL transport are unconstrained by confirmatory subsurface data and are non-unique; i.e., they do not adequately constrain the position of LNAPL around Tank 5 or elsewhere. Regardless, the EPM and homogeneity assumptions alone make comparison to site data difficult at best, which may result in elimination of risk-conservative LNAPL transport scenarios.

CITATIONS

2018, ABS Consulting et al. *Quantitative Risk and Vulnerability Assessment Phase 1 (Internal Events without Fire and Flooding).* October 9, 2018.

2017, Interstate Technology Regulatory Council (ITRC). *Characterization and Remediation of Fractured Rock.*

2015, The National Academies Press (NAP). *Characterization, Modeling, Monitoring, and Remediation of Fractured Rock.*

2015, Board of Water Supply (BWS). *Comments on the Proposed Administrative Order on Consent (AOC) and Attachment A, Statement of Work (SOW) on the Red Hill Bulk Fuel Storage Facility.* July 2015. Table 1.