REGION 9
SAN FRANCISCO, CA 94105

March 20, 2026

VIA ELECTRONIC MAIL ONLY

Rear Admiral Lester Ortiz
Navy Closure Task Force - Red Hill
850 Ticonderoga Street, Suite 110
Joint Base Pearl Harbor-Hickam, Hawai'i 96860, 5105

Subject: U.S. Environmental Protection Agency review of the *Draft Simulation of LNAPL Transport in the Vadose Zone, Red Hill Bulk Fuel Storage Facility, Joint Base Pearl Harbor Hickam, Hawaii, December 2025*

Dear Rear Admiral Ortiz:

Thank you for submitting the *Draft Simulation of LNAPL Transport in the Vadose Zone, Red Hill Bulk Fuel Storage Facility, Joint Base Pearl Harbor-Hickam Oahu HI* dated December 2025. The report documents the initial simulation of light nonaqueous-phase liquid (LNAPL) flow to characterize the potential distribution of LNAPL from releases.

U.S. Environmental Protection Agency (EPA) recognizes the simulation results depicted in the vadose zone (VZ) modeling report represent the initial stages in the development of a VZ model, which has appropriately commenced by representing a single phase "black oil" and conducting a range of sensitivity analyses regarding grid resolution and other model design and input alternatives. The comments provided below anticipate further development of the VZ model including multi-phase transport, which is critical to making comparisons between simulation results and historical data – particularly, vapor concentrations and groundwater concentrations. In addition, receipt of the model VZ input files enabled our contractor, SSPA, to conduct an efficient and thorough review without needing to transmit the very large output files and has positioned us ready to review later stages of the VZ modeling efforts in a similar manner.

EPA has completed a review of the VZ model and provides the following comments:

General Comments

1. In some of the realizations there appears to be an abrupt change in clinker content beneath the tanks and in other cases, between the tanks. It is unclear from the report figures if this is driven by the data, is an artifact of moving below or between the tanks, or is just an artifact of the

visualization. Our contractor is currently reviewing the actual model files to see if this apparent pattern is evident in the files. As a note: in previous work, SSP&A encountered some challenges obtaining realistic realizations when using SISIM together with the "raw" barrel log data, including defining a reliable vertical variogram. This was partially resolved when the raw barrel log data were supplemented or "filled in" to a common vertical spacing between the transition points marked in the original barrel logs, and this supplemented data set used. **Has the Navy team attempted this?**

2. **It is not entirely clear how the barrel log data were used in the realizations. Please clarify if they were used in the same manner as they were used in the GWFM – i.e. to help develop the variogram derived from the MrLavaLoba realizations, or if they were used in some other manner.** It is understood that the barrel log data do not possess the data quality of later stratigraphic logs, etc. However, they provide valuable information on material properties and proportions, particularly for purposes of vadose zone modeling and modeling LNAPL transport around the tanks.

3. One finding of the analyses completed so far seems to be that the simulation results are very sensitive to discretization, and that the coarser resolution simulations may not give realistic depictions of transport distances and also the extent of vertical migration. **Is this also a finding of the AECOM/GSI modeling team?** This has implications for the use of the VZ model moving forward, in terms of model design and execution timeframes, particularly when multiple phases are simulated.

4. The release volume for the May 2021 event (100 gallons) is inconsistent with other information and likely to be implausibly small. This is not necessarily demonstrated by the simulations presented in this VZ model report, because the outputs from those simulations are not compared to measured data such as vapor probe concentrations or groundwater concentrations. However, it is difficult to see how a release of this magnitude would have impacts at RHMW-3 and later at RHMW-2 that have been previously speculated to have results from the May 2021 release. **Thus, there appears to be an inconsistent interpretation of the volume and impacts of the May 2021 release across the Navy modeling work products that will lead to inconsistent analyses and understanding of contaminant fate and transport.**

5. There appear to be inconsistencies in some of the color-flood figures and the color scales presented in the reports. This makes comparison between modeled scenarios challenging. **We suggest using a single-color scale for figures for comparability – even if this means having to span orders of magnitude with the color scales and also checking that the figures are depicting the correct model outputs, color scales and color progressions**.

6. **Consider using Toughv3 dual domain or active fracture concept instead of heterogeneity for stability reasons due to unsaturated conditions.**

<u>Specific Comments</u>

Section 2.1 – LNAPL Hydraulic Conductivity and Relative Permeability

1. **Pg. 10 -** As LNAPL migrates through the environment, constituents leach and volatilize resulting in reductions in LNAPL viscosity and saturated hydraulic conductivity. **Please discuss how this process affects LNAPL transport over time and the implications of excluding it on transport simulations in anticipation of including it in future simulations.**

Section 3.0 – Numerical Model Development

2. **Pg. 13 - Please add a paragraph describing the problem formulation (i.e. the objective of the modeling and the questions it will answer) and how model outputs will be integrated with the ground water flow model.**

3. **Pg. 13 -** The report indicates: *"To account for this high variability, the rock properties specified in each model cell vary throughout the model domain in a manner that is statistically consistent with the field observations."* **Clarify whether or not the lithologic data collected from boring and barrel logs was directly incorporated into the model (see Comment #3 under General Comments)**

4. **Pg. 13 - Add a paragraph to Section 3 on Model evaluation that discusses the absence of model calibration and validation and associated uncertainties, implications for realizations and sensitivity analyses, and how this will be rectified in subsequent analyses using the multi-phase capabilities of TOUGHv3.**

Section 3.1 – Conceptual Site Model

5. **Pg. 13 - To better understand the tank/basalt interface and how tank construction may have altered local hydraulic properties, discuss tank construction, including: how were the lava tubes/voids filled?**

6. **Pg.13 -** The text indicates: "*Because the releases occurred deep beneath the surface, significant water wetting fronts that could affect LNAPL movement would not be expected to develop (but could be simulated in the future if deemed important)."* Given there is precipitation recharge at the site, it is not clear why wetting fronts would not occur at depth, encounter LNAPL, and thus influence LNAPL transport. **Please elaborate on why post-release precipitation recharge would not affect LNAPL migration.**

7. **Pg. 14 - The site CSM section should provide a general description of LNAPL transport through the vadose zone at Red Hill including the influences of weathered layers, perched ground water, groundwater recharge and residual NAPL from previous releases.**

8. **Pg. 14 - A cartoon figure illustrating the site conceptual model for LNAPL releases in cross-section and which depicts tanks, LNAPL bodies, and important processes/ features, should be included in the report.**

Section 3.3 - Model Domain and Grid Discretization

9. **Pg. 14 -** The report indicates: *"The model grid cells that represent the tanks are deactivated, so that the interior of the tanks are not included in any model."* **TOUGH3 no longer has "deactivation" capability, please clarify how this was accomplished.**

10. **Pg. 14 -** Illustrate/discuss how heterogeneity would also affect the hydraulic properties of a single cell, as it is never 100% clinker. i.e. increasing probability of clinker increases vertical anisotropy (and decreases in horizontal anisotropy). **How were the properties of each cell in the coarse and fine resolution grids determined?**

11. **Pg. 14 -** It's stated in Section 3.1 that rock types vary in as little as 10' horizontally and 1' vertically, yet a model grid of 25' X 25' X 2' is used. A smaller grid would be required to represent this heterogeneity at this scale - and this seems to be at least partly borne out by the grid sensitivity results. **Discuss the implications of using a grid that does not capture the scale of lithologic heterogeneity? Which properties are affected and what biases are introduced and how can any potential bias be mitigated?**

12. **Pg. 14 -** The report states "*The simulation results indicated that no LNAPL reached any of the deactivated portions of the model grids.*" as a justification of using the smaller model domain. However, Section 5.9 states "*The LNAPL travels further in the down-dip direction and reaches the water table near the edge of the model domain. In fact, the LNAPL reached the down-dip boundary of the model domain in this simulation*." **To ensure model results are not constrained by the model domains, future simulations should expand the activated portions of the model grid as necessary to accommodate simulations of lateral and vertical LNAPL flow.**

Section 3.4 – **Boundary and Initial Conditions**

13. **Pg. 15 - A cross-sectional view of the model domain, oriented perpendicular to the ridgeline should be added to the report to visualize the distance from tanks to the atmosphere, tunnel, and water table.**

14. **Pg. 15 -** The text indicates: *"Although there have been many documented releases of LNAPL around the tank farm, the distribution of LNAPL from past releases is not known. Therefore, in these simulations, no LNAPL was assumed to be present in the subsurface before the releases."* Given Red Hill's period of operation, some of the LNAPL releases likely migrated into portions of the vadose zone where residual fuel from previous releases was already present. **Discuss how the presence of residual LNAPL in the vadose zone would affect the transport of later subsequent LNAPL releases.**

15. **Pg. 15 -** Moisture content values for all rock types were set to residual saturation values to avoid long simulation times (100+ years) required to achieve steady-state conditions. These long simulation times may make incorporating precipitation recharge into the model infeasible. **It is suggested that at least one model run include a significant amount of recharge to demonstrate proof of concept.**

16. **Pg. 15 - Please discuss the rates of simulated LNAPL transport in the vadose zone, how it varies during the modeled period, and the time required to achieve steady-state conditions in the formation.**

17. **Pg. 15 - It's assumed that LNAPL steady-state conditions precede steady-state moisture conditions. If so, is terminating the simulations once LNAPL has reached steady-state conditions an option to reduce run time?**

Section 3.5 Rock Properties and Distribution

18. **Pg. 16 -** The "calibrated" GWFM hydraulic properties (anisotropy) may not be directly applicable in the vadose zone or at these scales where there are likely higher contrasts in hydraulic properties between lithologies resulting in more circuitous/tortuous fluid migration than is simulated using regionally-derived parameters. For example: clinker typically has a loose upper section with a welded lower section acting as a vertical barrier, in Westbay wells located within the valley fill, vertical heads are similar within a block of basalt (AA, pahoehoe) but drop 10' crossing clinker. **Please discuss solutions or recommendations going forward to improve the characterization of hydraulic properties at this scale.**

19. **Pg. 15 -** Illustrate/discuss how heterogeneity would also affect the hydraulic properties of a single cell, as it is never 100% clinker. i.e. increasing probability of clinker increases vertical anisotropy (and decreases horizontal anisotropy). **How were the properties of each cell in the coarse and fine resolution grids actually determined?**

20. **Pg. 15 -** In many of the realizations the clinker appears to dip in the opposite direction from what the text indicates or is horizontal. For example, clinker should follow the dip within the same layer not cut through multiple layers. **Please review the figures to ensure consistency with the text.**

21. **Pg. 15 -** For this iteration of the vadose zone model it may be beneficial to initially use a homogenous basalt, this would also help in the sensitivity runs to better understand property effects. **The specific benefits of this exercise and how the runs would be structured should be discussed in advance**.

22. **Pg. 16 -** The text indicates "*Each realization contains between 25 and 42 percent clinker within the model domain for the 2014 release, and between 13 and 26 percent clinker for the 2021 release.*" **It is unclear why the two releases would have such different clinker distributions, please explain the bases for the differences.**

23. **Pg. 16 -** The text indicates: "*The clinker LNAPL residual saturation of 0.05 was chosen based on the assumption that clinker would not experience high LNAPL heads that could force large quantities of residual LNAPL into the clinker pores.*" Often clinker has a lower welded section with clay that could result in high residual LNAPL pooling. **Please discuss this uncertainty associated with weathered intervals and approaches to reducing it. Consider incorporating weathered units into the modeled lithologic sections based on a statistical analysis of the**

boring logs from the tank farm area.

Section 3.6 - LNAPL Properties

24. **Pg. 17 -** JP-5 & JP-8 are simulated as two different releases, but to fully evaluate historical releases from Red Hill and potential extent of LNAPL impacts, **the Black Oil Model should be run for marine diesel and Navy special fuel oil, including sensitivity runs.**

Section 4.1 - January 2014 Release

25. **Pg. 17 -** The text indicates: *"To simulate this LNAPL release, 27,000 gallons of LNAPL was "injected" into model cells around the circumference of Tank 5, at approximately 26 ft above the tank bottom (150 ft msl)."* Is it possible that the fuel leaked out only on one side of the tank? **Recommendation: perform runs that assume releases are from one side of the tank (e.g. up-dip, down-dip) as opposed to uniformly released around the circumference of the tank.**

26. **Pg. 17 -** The text indicates: *"In each of the 20 source cells, approximately 195 gallons of LNAPL per day were injected over a period of 7 days."* **What is the basis for picking 7 days?**

27. **Pg. 19 -** The text indicates: *"Several conclusions can be made from the 2014 simulation results shown on Figure 4 through Figure 8. First, very little LNAPL flows up-dip from the release points. In fact, LNAPL does not flow even into the first up-dip cell from the LNAPL release source cells, as seen on Figure 6. LNAPL flows in the downdip or cross-dip direction almost entirely. This observation can be explained by the strong tendency of LNAPL to flow in the direction of the gravity gradient, and to spread laterally based on preferential flow in the clinker layers. In addition, the rate of the simulated LNAPL release did not result in any significant elevated pressure at the release cells, so that a significant hydraulic head of LNAPL and associated steep hydraulic gradients that could have forced LNAPL to flow up-dip did not develop."* It's observed that a more rapid release could produce up-dip migration. Soil vapor data collected after the 2014 release suggests this may have occurred. **Please conduct a sensitivity analysis to evaluate up-dip LNAPL transport potential by varying release volumes and rates.**

Section 4.2 – May 2021 Release

28. **Pg. 20 -** The text indicates: "*The Navy reported that most of the fuel was recovered and estimated that less than 100 gallons of fuel entered the environment."* Soil vapor data suggest a much larger release occurred. **As the vadose model progresses to include vapor and dissolved-phase contamination, the release volume should be increased until the simulated vapor footprint approximates the one observed post-incident.**

Section 5.0 - Sensitivity Studies

29. **Pg. 20 -** Evaluate the sensitivity of the model results to different release volumes. To constrain the range of volume of LNAPL released. **Consider historical releases documented in the site assessment work plan** (AECOM Technical Services Inc, *Draft Final Tank Closure Plan; Supplement 3: Phase 1 Closure Site Assessment*, July 2025).

30. **Pg. 20 - Please evaluate the model's sensitivity to a reasonable range of residual water saturation values for the various rock types.** If model predictions are sensitive to this parameter, consider determining residual saturation for different rock types empirically through lab centrifuge testing of cores.

31. **Pg. 21 - The title of Figure 12 is incorrect**; it should read 1 x 10^{-6} not 0.001. **Please use the same scale but add new colors for NAPL saturation values 0.000001 – 0.001 generated during Run 1.**

32. **Pg. 21 -** There are multiple errors in cross-section color representations that do not match maximum residual values presented in Table 8. **Please correct**.

Section 5.1 – Minimum Saturation Value

33. **Pg. 21 -** The text indicates: *"Unsurprisingly, the lower value of Smin results in a larger LNAPL footprint than the default Smin value of 0.001. With the lower Smin value, the LNAPL plume footprint is approximately 50 ft longer in the downdip direction."* **It should be acknowledged in the text that the extent of LNAPL migration is the same in both cases and differences shown in Figure 12 reflect changes in visual resolution not numerical results.**

34. **Pg. 21 -** The text indicates the 0.00001 saturation threshold LNAPL presence in a grid cell corresponds to 17 mL of LNAPL per cell. While there is likely broad agreement this volume of LNAPL is insignificant, it's not clear this conclusion can be extended to the 0.001 saturation value. The 17 liters/cell associated with the higher saturation value, when taken in aggregate, potentially represents a significant volume of LNAPL that is unaccounted for by the model output. **Please provide additional discussion and support for an appropriate minimum LNAPL saturation value for simulating transport.**

Section 5.2 – Basalt Heterogeneity

35. **Pg. 22 -** The report indicates the massive aa'/pahoehoe basalt K value of 13 ft/day used in the VZ model is consistent with the paramerters of the GWFM. However, the GWFM model assigned a calibrated value of 9,310 ft/d for an undifferentiated basalt (clinker and massive units combined). Furthermore, the basalt porosity also differed, 7% in the vadose zone model and 4% in the GWFM. **Please explain the apparent discrepancies.**

36. **Pg. 22 -** The report indicates: ***"****Therefore, the massive aa/pahoehoe retains very little LNAPL. The permeability of massive aa/pahoehoe translates into a saturated hydraulic conductivity of 13 ft per day (4.5 × 10-3 centimeter per second). Although this value is three orders of magnitude less than that of the clinker, it is still comparable to the hydraulic conductivity of a fine- to medium-grained sand, so the massive aa/pahoehoe readily transmits fluids, although at much slower rates than clinker."* Based on the texture and effective porosity of massive aa', the assignment of 13 ft/day hydraulic conductivity value (equivalent to a fine- to medium-grained sand) appears to significantly overestimate the actual conductivity of these units. This assumption leads to more diffuse LNAPL transport through the vadose zone with shorter

transport distances. **To ensure the hydraulic conductivity assignments used in the VZ model accurately characterize the lithologies present, EPA asks Navy to revisit and further support the K values selected.**

37. **Pg. 22 - A way to address the extreme conductivity contrasts and model instability, is to take Run 3 (homogeneous basalt) but vary horizontal and vertical anisotropies to represent increasing clinker content.**

Section 5.9 – Combination of Finer Horizontal Grid Size and Source Below Tank 5

38. **Pg. 25 -** The text indicates: *"This final sensitivity study indicates that there are combinations of model parameters that can cause LNAPL to reach the water table in LNAPL simulations. This observation suggests that a wide range of model parameter sets should be explored to inform field investigations designed to locate and characterize LNAPL at the site."* These results suggest that the 25' cell grid is likely too coarse for these simulations and that without greater conceptual understanding of the tank/basalt interface it may be very difficult to reduce prediction uncertainty. **EPA recommends using a finer resolution grid and improving the characterization of lithology/heterogeneity of formation surrounding tanks.**

Section 6.1 – Interpretation of Simulation Results

39. **Pg. 25 -** The text indicates: *"However, because there is no LNAPL field data for calibration and travel distances are relatively short, the actual distribution is likely affected by the local dip in this specific area, which may differ from the regional dip. The local dip can vary significantly at any particular location, such that the directions of flow may vary from those simulated."* EPA agrees with this statement and notes the uncertainty it introduces into the analysis and results. **EPA suggests reviewing barrel and boring logs to characterize the local dip and azimuth of lava flows beneath the tank farm and in the vicinity of the 2014 release, and to compare with model assumptions.**

40. **Pg. 25 -** The text indicates: *"As seen on Figure 11, the simulations indicate that very little migration of LNAPL occurred following the 2021 release (though petroleum constituents may have been transported in other phases or media). The limited migration is due to the relatively small LNAPL volume released."* The volume of this release appears underestimated as a larger mass would be required to generate the level of contamination observed in other phases (e.g. soil vapor concentrations) after the 2021 release. **The volume of the May 2021 release should be re-examined and reconciled with field data collected after the incident occurred.**

41. **Pg. 25 - Additional scenarios to consider include** (a) more analyses varying hydraulic properties (anisotropy, porosity) with homogeneous basalt to understand general principles; (b) varying release volumes and locations; and (c) ranging LNAPL properties over the entire range of materials stored – i.e., not just JP-5 & JP-8.

If you have any questions regarding this letter, please contact me at russi.tonya@epa.gov or (415) 972-3706.

Sincerely,

/s/
Tonya Russi
Red Hill Project Coordinator
U.S. Environmental Protection Agency, Region 9

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