8. LNAPL Fate and Transport.

The following set of comments pertain to the contaminant transport aspect of the CSM and related modeling and evaluation approaches taken by the Navy's technical team. Conceptually, contaminant transport will depend on a suite of facets starting with the LNAPL migration that will occur following its release to the subsurface and the cumulative effects of multiple releases over time. While the LNAPL is mobile and moving in the environment, it poses a potential threat to receptors as a free-phase contaminant. Once the LNAPL ceases to move, the residual along the transport pathways presents a longer-term source of contaminants to groundwater that may be transported some additional distance within the aquifer system. Combined, these two aspects of fuel F&T represent the primary threat pathways to the sole-source groundwater resource. The Navy team's conceptualization of these processes would benefit from additional technical work and data collection to be more consistent with observed site data discussed in prior comment sections.

It is unclear how the Navy's current CSM will effectively represent LNAPL transport as indicated in Section 7.4 of CSM document that states: *"..to estimate LNAPL migration for current and potential future releases, including the fraction expected to be immobilized in the vadose zone, and the fraction expected to reach groundwater. The modeling effort will also include an assessment of the potential migration of LNAPL within the saturated zone."* The primary component of the Navy's LNAPL current modeling approach is a "*statistical LNAPL holding model*" that accounts for only the residualization of some fraction of an assumed LNAPL release within an assumed release geometry. This results in a source zone for the dissolved phase transport model that is rather arbitrary in nature since no active LNAPL transport calculations have been done to account for primary and preferential pathways, pore volume already occupied by past releases or infiltrating water, or the characteristics of different release rates. While perhaps useful for some general framing, this non-dynamic form of LNAPL modeling cannot determine critical aspects of risk determinations and potential mitigation approaches. The Navy team's CSM and contaminant fate and transport evaluation should be able to address questions, such as:

- What range of LNAPL releases might reach groundwater (and how quickly) as a function of release rates, locations, fuel types, and other characteristics? Transport in each area of the tank farm can reasonably be expected to behave differently based on the boring and barrel logging of the ridge. How do geologic distribution differences affect the transport outcomes?
- How do chronic low-rate releases behave in comparison to large-scale sudden events? How can the release event ranges be confidently bracketed and what are those ranges?
- Related, what is the fraction of residual capacity already taken up by pre-existing releases or infiltrating water, and how can that be determined from existing data? If it cannot be determined from existing data, what conservative assumptions might be made?
- How fast and how far might LNAPL travel as a function of various release scenarios and in what directions? The approach discussed by the Navy teams assumes a southwest direction that does not seem to comport well with observed detections of petroleum related compounds and depletion of natural attenuation parameters to the northwest.
- How can hydraulic capture be achieved for LNAPL containment in context with the

estimated LNAPL transport rates and under what kinds of pumping regimes?

- How far would an LNAPL release need to propagate to create potential detections at the Halawa Shaft and/or other groundwater resource areas and with what release volume and scenario could that occur?

As the regulatory agencies SME's LNAPL screening modeling shows, a release that exceeds the formation's residualization capacity, which is presently undefined in the CSM or by any correlative data, could potentially reach the water table zone at a rapid rate. This rapid downward transport may result in LNAPL gradients that exceed the shallow groundwater gradient resulting in LNAPL migration in unexpected directions and distances. This is an area that needs more development prior to submitting a revision to the fate and transport model, since the area covered by LNAPL plumes is the source zone for the dissolved phase transport model.

Defining specific LNAPL transport parameters will be a significant challenge in this environment. The Navy should consider what additional efforts can be taken to characterize these parameters. Unfortunately, core-scale testing in petrophysical labs (CSM Chapter 5.2.3) may be of limited value. As evidenced through the results of the API LNAPL Parameters Database compilation (API 4731, 2003), capillary centrifuge testing has also been shown to be suspect where residual saturation is over-estimated compared to field studies and other soil properties databases (e.g. U.S. Salinity Lab and others). It has also been observed in work at the IDPP OU1-C area in Honolulu that the residual saturations determined in the lab are unreliable and non-conservative. The Navy needs to develop an approach to better constrain the residualization capacity of the formation. Briefly, in situ samples collected by continuous coring in free-phase LNAPL zones generally test at or below residual saturation values in site areas of significant free product LNAPL. Since LNAPL cannot flow into a well if it is below residual in the formation, these lab-derived values conflict with site LNAPL observations. The same limitations may be expected for the Red Hill petrophysical testing program and we recommend the Navy team develop alternate bench and field testing and data collection methods to more realistically constrain these important LNAPL F&T parameters.

Absent additional source zone characterization data, the LNAPL residual capacity will remain unconstrained along with other important elements to the LNAPL transport regime. As noted, this is one of several critical factors in the dynamic evaluation of LNAPL transport and potential risks to the groundwater system. Where measurements and data are absent, a greater degree of conservatism in the estimation approaches is necessary to allow for that uncertainty.

References:

API #4731, 2003. Light Non-Aqueous Phase Liquid (LNAPL) Parameters Database - Version 2.0 - User Guide.

Considerations on LNAPL Transport at the Navy Red Hill Facility, February 2018. G.D. Beckett, a presentation to interested Red Hill parties.

Conceptual Site Model, Investigation and Remediation of Releases and Groundwater Protection and Evaluation, Red Hill Bulk Fuel Storage Facility (dated July 27, 2018: "CSM Report")

Groundwater Protection and Evaluation Considerations for the Red Hill Bulk Fuel Storage Facility (dated July 27, 2018: "GPEC Report").

~~*Huyakorn, P.S., Panday, S., Wu, Y.S., 1994. A Three-Dimensional Multiphase Flow Model for Assessing NAPL Contamination in Porous and Fractured Media, 1. Formulation. Journal of Contaminant Hydrology, #16 (1994), pp 109-130.*~~

Nonaqueous-Phase-Liquid Dissolution in Variable-Aperture Fractures: Development Of A Depth-Averaged Computational Model With Comparison To A Physical Experiment. Detwiler, R.L., Rajaram, H., 2001. Water Resources Research, December 2001.

Neuman, S. P., 2005. Trends, Prospects and Challenges in Quantifying Flow and Transport Through Fractured Rocks. Hydrogeology Journal, March 2005, Volume 13, Issue 1, pp 124–147.

10. **LNAPL and Dissolved-Phase Plume Distribution**:

The LNAPL and dissolved-phase plumes are potentially more widespread and in alternate directions than the Navy team's CSM suggests. This has direct implications to the estimation of potential risks. The CSM will benefit by consideration of these observations as representative and then accommodate those implications through more thorough evaluations and possibly additional data collection/demonstration. Site specifically, there are multiple data sets that indicate there have been historic detections of interest to the west and northwest. For example, the dissolved-oxygen depletion shown in Figure 9.1 closely parallels the observed historic detections of TPHd in groundwater, as expected based on the mechanisms of degradation and transport. The CoC distribution, elevated temperature distribution (Figure 10.1), and other natural attenuation parameters also support this historic transport direction.

Much less is known with respect to the potential LNAPL distribution in the subsurface that is the source of these groundwater impacts. Simplified transport estimates suggest that for a wide range of general site parametric conditions, the expected downgradient extent of these compounds is typically less than 100-ft away from the LNAPL source zone, particularly when attenuation rates are high. Naphthenic compounds, due to their transport properties, are not generally highly transportable in aquifers. This suggests the possibility of distal LNAPL impacts relative to the Tank Farm from cumulative historic releases that have left their signature in the groundwater system. Naphthenic compounds are frequently detected at several outlying monitoring locations at low concentrations (commonly J-flagged), but detections of petroleum related compounds and depletion of natural attenuation parameters (NAPs) occur predominantly in the tunnel and northwest wells.

Commented [g1]: The detection frequency analysis was informative and compelling.

With regard to the CSM interpretations about the outcome of the 2014 Tank 5 release, perhaps one of the most fundamental is the estimated release volume of 27,000 gallons. The regulatory agency SMEs have not been able to find the specific release volume calculations nor the certainty bounds on that value. In our experience, release volume estimates have significant uncertainty that would affect the assumptions and conclusions in the CSM, particularly given that the release occurred during both filling and draining of Tank 5. We believe the particular details of the release estimate need to be more fully discussed in the CSM and the implications of that range considered in the evaluations. If the estimate is relatively certain, that should be documented with the appropriate background so that related interpretations are appropriately bounded.

Commented [g2]: Past release history & potential volumes are another matter of importance

The CSM and the underlying available data cannot (at present) reliably place the LNAPL source zone(s) in context with the observed groundwater contaminant distribution. The underlying cause for this gap is the absence of characterization around the Tank Farm. The product staining indications in historic angled-core sampling beneath various Red Hill USTs are useful, but none of those investigatory locations were intended to be sampled to groundwater. Further, it is unclear whether wells RHMW01 through RHMW03 are directly within an area of vadose zone contamination or not. At the time of their installation there were no gross indications of vadose zone fuel impacts, but groundwater was impacted, suggesting a complex relationship between release transport pathways and groundwater impacts. In other words, LNAPL impacts in the vadose and water table regions sourcing these impacts are not delineated by the available investigatory locations. This key uncertainty is not adequately discussed in the CSM, but affects all the related F&T discussions and framing.

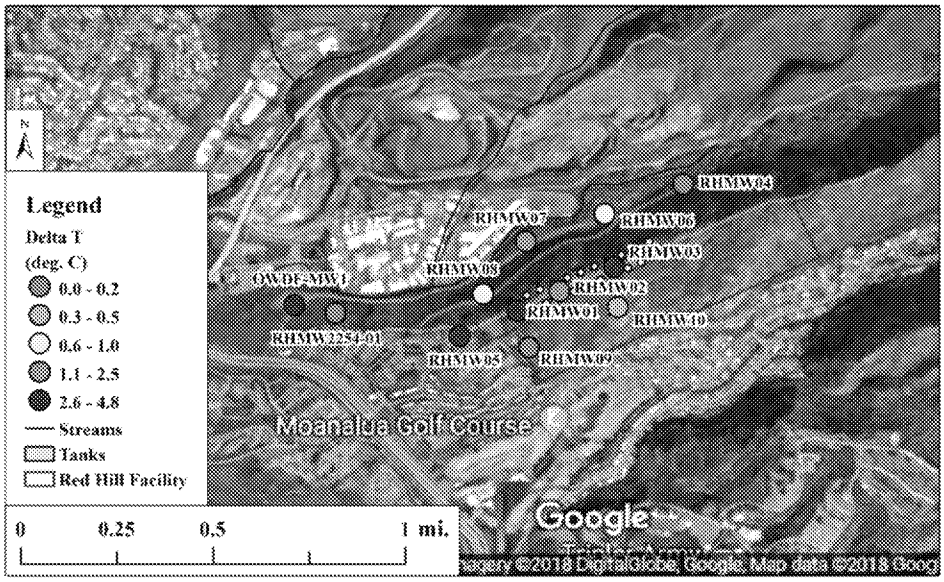

Figure 10.1 Net average temperature greater than the Red Hill Shaft (RHMW2254-01; in degrees Celsius). Like other MNA-related parameters, the elevated temperatures are generally along the Red Hill Ridge and to the west and north. Data source: USGS Synoptic Data, 2018.

The in situ vapor probe response around Tank 5 in the timeframe following the 2014 release can be interpreted as indicating that the primary vapor migration may have been to the northwest side of that tank and not in the direction of RHMW02 (see Figure 10.2 below). Actual LNAPL transport outcomes beneath Tank 5 in 2014 below the vapor probes is unknown; the conservative assumption based on this limited data is that transport was potentially to the northwest and is not represented with any certainty by the spatially limited monitoring well array.

In terms of the depth of migration of LNAPL from the Tank 5 release in 2014, the primary analysis relied upon in the CSM is the thermal profile at RHMW02, with backup support from chemistry considerations. A net positive temperature profile indicates the effects of exothermic biologic reactions and is affected by a variety of subsurface factors. In general, that relationship can be useful to infer lateral distributions of LNAPL biodegradation (e.g., Figure 10.1 above) but is highly uncertain with respect to the LNAPL vertical distribution. In many cases, as shown in the example thermal profile in our August 15, 2018 presentation (Slide 28), the LNAPL vertical mass distribution cannot be inferred from the temperature profile. A review of data in the 2007 Red Hill investigation report (DON, 2007) shows that the rock cores were evaluated for evidence of petroleum contamination by checking for odor and by screening with a photo-ionization detector. No evidence of petroleum contamination was found. The groundwater temperature in RHMW03 ~~as~~ measured during sampling has remained unchanged at about 26.5 °C since first sampled in 2005 to the present, indicating that the temperature profile recently measured by the Navy likely existed when RHMW03 was first drilled. As a consequence, this locally-elevated temperature does not directly relate to the migration or distribution of LNAPL arising from the 2014 release but

relates (at least, predominantly) to past releases. Also, there has been no release of consequence since 2005 that would cause LNAPL to enter the zone indicated by the thermal anomaly in RHMW03. In summary, the Navy's contention that the thermal profiles in the tunnel wells show that the LNAPL is constrained above the water table is not supported by the available ~~physical evidence~~data. We believe the Navy technical team needs additional data to validate its interpretation of LNAPL transport around Tank 5 from the 2014 release, as it is a fundamental cornerstone to the remainder of the LNAPL F&T considerations. At a minimum, the Navy should include several Hawai'i or equivalent geology examples where the LNAPL source distribution has been definitively interpreted by this method and independently validated through subsurface data demonstrating that actual LNAPL source distribution (e.g., core sampling, downhole investigation, etc.). Alternatively, it would be useful to consider a site specific data collection program to verify the LNAPL source distribution around Tank 5 and possibly other key locations. By whatever approach, additional lines of evidence are needed to verify the assumptions relative to fate and transport of the 2014 release.

Commented [g3]: Known/reported

Lastly, CoC concentrations in groundwater at RHMW02 (and occasionally other locations) have been within the expected solubility ranges for jet, diesel and other fuels stored at the facility, suggesting that LNAPL may be in direct contact with the aquifer system somewhere in the vicinity. Robert Whittier, currently at DOH, visually observed LNAPL blebs at RHMW02 when this well was sampled using a bailer, indicating residual LNAPL in the vicinity of this well. Further indicating that LNAPL reached ~~the~~ groundwater, was the distinct increase in several CoCs at this location immediately following the 2014 release that can be interpreted as a breakthrough curve (Figure 10.3). While the Navy Team's interpretation is of simple coincident data scatter, these data could be interpreted as a new arrival of LNAPL to groundwater in the general vicinity of RHMW02 in the timeframe associated with that release. The CSM would benefit from examining these potential viable working hypotheses, though it is acknowledged that this is a spatially sparse data set.

Thi~~se~~ alternate interpretation of LANPL reaching the groundwater table following the 2014 release is consistent with site data and transport processes. The chemical analyte ratio methods used in the CSM to suggest otherwise are unbounded by site specific data of fuel compositional variability and analyte transformations. Further, we believe where chemical ratios use TPHd values, those values should also consider the native totals (without silica gel cleanup) because the parent hydrocarbons are predominantly derived from the original petroleum source(s). We also recognize the value of having both native and silica gel cleanup values for interpretation for various aspects of this investigation such as biodegradation and attenuation.

Lastly, the current deployment design for the in-situ sampling pumps below the water table within the existing monitoring wells precludes the sampling of LNAPL or any direct observation of an LNAPL plume, if present. Such measurements could however be accomplished in these wells periodically either by resetting these pumps or removing them to allow direct sampling of the top of the water table.

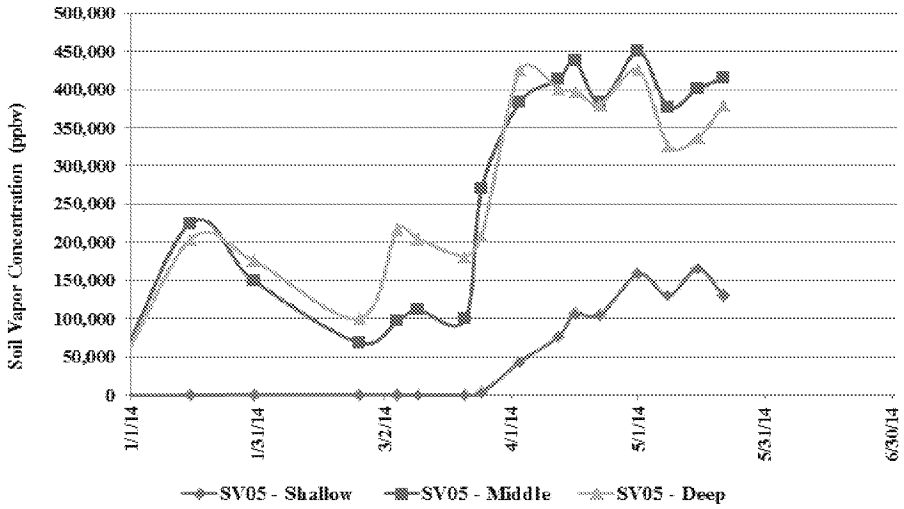

Figure 10.2 Soil vapor probe readings beneath Tank 5 following the January 2014 release. The deep probe is toward the outside of the tank corridor and the shallow probe closest to the tunnel. These data can be interpreted as initial release migration to the northwest of this Tank; note the shallow probe has low level detections that are not visible on a linear plot.

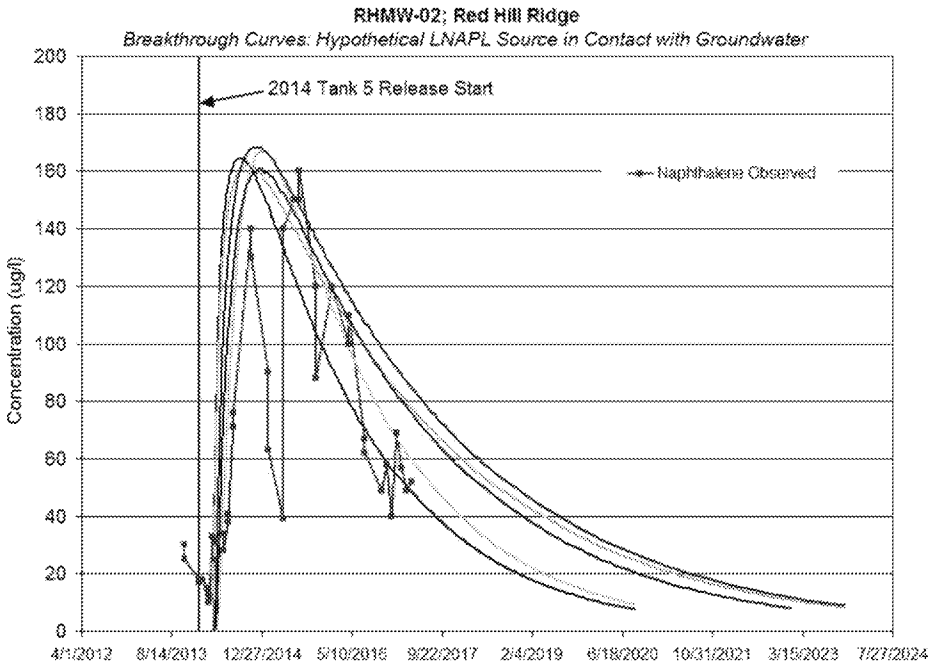

Figure 10.3 Observed naphthalene concentrations following the 2014 Tank 5 release and a family of conceptual contaminant transport breakthrough curves matching those data. Other interpretations are viable, as is the possibility of LANPL contacting groundwater near RHMW02 following that release.

References

Department of the Navy (DON), 2007. *Red Hill Bulk Fuel Storage Facility Final Technical Report, Pearl Harbor, Hawaii*. 12 Prepared by TEC Inc., Honolulu, HI. Pearl Harbor, HI: Naval Facilities Engineering Command, 13 Pacific. August