Conceptual Site Model Development and Update Plan, Investigation and Remediation of Releases and Groundwater Protection and Evaluation, Red Hill Bulk Fuel Storage Facility

JOINT BASE PEARL HARBOR-HICKAM, O‘AHU, HAWAI‘I

Administrative Order on Consent in the Matter of Red Hill Bulk Fuel Storage Facility, EPA Docket Number RCRA 7003-R9-2015-01 and DOH Docket Number 15-UST-EA-01, Attachment A, Statement of Work Section 6.2, Section 7.1.2, Section 7.2.2, and Section 7.3.2

September 1, 2017
Revision 00

NAVFAC
Naval Facilities Engineering Command
NAVFAC HAWAII

Comprehensive Long-Term Environmental Action Navy
Contract Number N62742-12-D-1829, CTO 0053

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Revision 00

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Comprehensive Long-Term Environmental Action Navy
Contract Number N62742-12-D-1829, CTO 0053

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ACRONYMS AND ABBREVIATIONS

AOC	Administrative Order on Consent
BWS	Board of Water Supply, City and County of Honolulu
CF&T	contaminant fate and transport
CLEAN	Comprehensive Long-Term Environmental Action Navy
COPC	chemical of potential concern
CSM	conceptual site model
CTO	contract task order
CWRM	Commission on Water Resource Management
DLA	Defense Logistics Agency
DLNR	Department of Land and Natural Resources, State of Hawaiʻi
DOH	Department of Health, State of Hawaiʻi
DON	Department of the Navy, United States
DOT	Department of Transportation, State of Hawaiʻi
EDR	Existing Data Summary and Evaluation Report
EPA	Environmental Protection Agency, United States
ft	foot/feet
GPS	Global Positioning System
HGU	hydrogeologic unit
HSSM	Hydrocarbon Spill Screening Model
JP	Jet Fuel Propellant
LNAPL	light non-aqueous-phase liquid
NAP	natural attenuation parameter
NAPL	non-aqueous-phase liquid
NAVFAC	Naval Facilities Engineering Command
no.	number
NSZD	natural source-zone depletion
RCRA	Resource Conservation and Recovery Act
SAP	Sampling and Analysis Plan
SME	subject matter expert
SOW	scope of work
SSRBL	Site-Specific Risk-Based Level
SVEET	Soil Vapor Extraction Endstate Tool
TAMC	Tripler Army Medical Center
TGM	Technical Guidance Manual
TPH	total petroleum hydrocarbons
U.S.	United States
USGS	United States Geological Survey
VOC	total volatile organic compound
WP	work plan

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1. Introduction

This *Conceptual Site Model* (CSM) *Development and Update Plan* has been prepared for the Investigation and Remediation of Petroleum Product Releases and Groundwater Protection and Evaluation project at Red Hill Bulk Fuel Storage Facility ("the Facility"), Joint Base Pearl Harbor-Hickam, Hawai'i. The Facility is owned and operated by the United States (U.S.) Navy (DON; Navy) and is funded by Defense Logistics Agency (DLA).

The project *Work Plan / Scope of Work* (WP/SOW) (DON 2017a) presents the process, tasks, and deliverables that address the goals and requirements of Statement of Work Sections 6 and 7 of the *Administrative Order on Consent* (AOC) *In the Matter of Red Hill Bulk Fuel Storage Facility* (EPA Docket No: RCRA 7003-R9-2015-01; DOH Docket No: 15-UST-EA-01). The AOC was issued by the U.S. Environmental Protection Agency (EPA) Region 9 and State of Hawai'i Department of Health (DOH) (EPA Region 9 and DOH 2015) to the Navy/DLA in response to a release an estimated 27,000 gallons of Jet Fuel Propellant (JP)-8 from one of the Facility's 12.5-million-gallon underground fuel storage tanks (Tank 5) that was confirmed and reported to DOH on January 23, 2014. The bottoms of the Facility's 20 tanks are located approximately 100 feet (ft) above a major groundwater aquifer, which is used to feed both Navy and City and County of Honolulu drinking water sources.

The planning activities described in the project WP/SOW (DON 2017a) include the preparation of nine documents (including this *CSM Development and Update Plan*), referred to as derivative deliverables, that will address specific aspects of the planning process. The flowchart presented on Figure 1 shows the sequencing of the derivative deliverables; additional information on each of the other derivative deliverables is provided in the WP/SOW. The project study area and modeling domain are shown on Figure 2.

This *CSM Development and Update Plan* outlines how the existing CSM will be iteratively updated and refined for inclusion in the AOC Statement of Work Section 6 *Investigation and Remediation of Releases Report*. The refined CSM will identify characteristics of the study area that affect the nature and extent of contamination and the fate and transport of released fuel in the environment, and will support the feasibility evaluation of various remedial alternatives in response to the January 2014 leak and potential future fuel releases.

This Plan was prepared for DLA under Naval Facilities Engineering Command (NAVFAC) Hawaii, contract number (no.) N62742-12-D-1829, contract task order (CTO) no. 0053 of the Comprehensive Long-Term Environmental Action Navy (CLEAN) IV program.

1.1 Regulatory Guidance

An overview of the guidance and regulatory oversight for CSM development from the AOC parties and other industry standard sources is presented in the following subsections. The CSM will be prepared in general accordance with current guidance including but not limited to the following:

- *Standard Guide for Development of Conceptual Site Models and Remediation Strategies for Light Nonaqueous-Phase Liquids Released to the Subsurface,* ASTM E2531-06(2014) (ASTM 2014b)
- *Standard Guide for Developing Conceptual Site Models for Contaminated Sites,* ASTM E1689-95 (reapproved 2014) (ASTM 2014a)

- *Environmental Cleanup Best Management Practices: Effective Use of the Project Life Cycle Conceptual Site Model* (EPA 2011)
- *Evaluating Natural Source Zone Depletion at Sites with LNAPL,* Interstate Technology Regulatory Council (ITRC 2009)
- Light Non-Aqueous-Phase Liquid (LNAPL) Conceptual Site Model module in: *LNAPL Training Part 2: LNAPL Characterization and Recoverability – Improved Analysis* (ITRC 2008)
- Section 3.3 *Conceptual Site Models* in: *Technical Guidance Manual for the Implementation of the Hawaii State Contingency Plan* (TGM) (DOH 2016b)
- *Conceptual Site Model Tool,* NAVFAC Technology Transfer, Environmental Restoration website (URL: http://t2.serdp-estcp.org/t2template.html#tool=CSM&page=S1)

1.1.1 Parties to the AOC

In response to the January 2014 fuel leak, EPA and DOH negotiated an AOC with the Navy and DLA (EPA Region 9 and DOH 2015). The AOC includes Attachment A, the Statement of Work, which outlines the activities to be conducted and analyses to be performed. The AOC requires the Navy and DLA to take actions, subject to EPA and DOH approval, to address fuel releases and implement infrastructure improvements to protect human health and the environment. The Parties to the AOC (i.e., the Navy/DLA, EPA, and DOH) conducted Scoping Meetings to address the requirements of the AOC Statement of Work, resulting in 27 agreements and 8 action items for AOC Statement of Work Sections 6 and 7 (DON 2017a, Appendix A.1). The investigation is being conducted in accordance with the agreed-upon items.

1.1.2 EPA

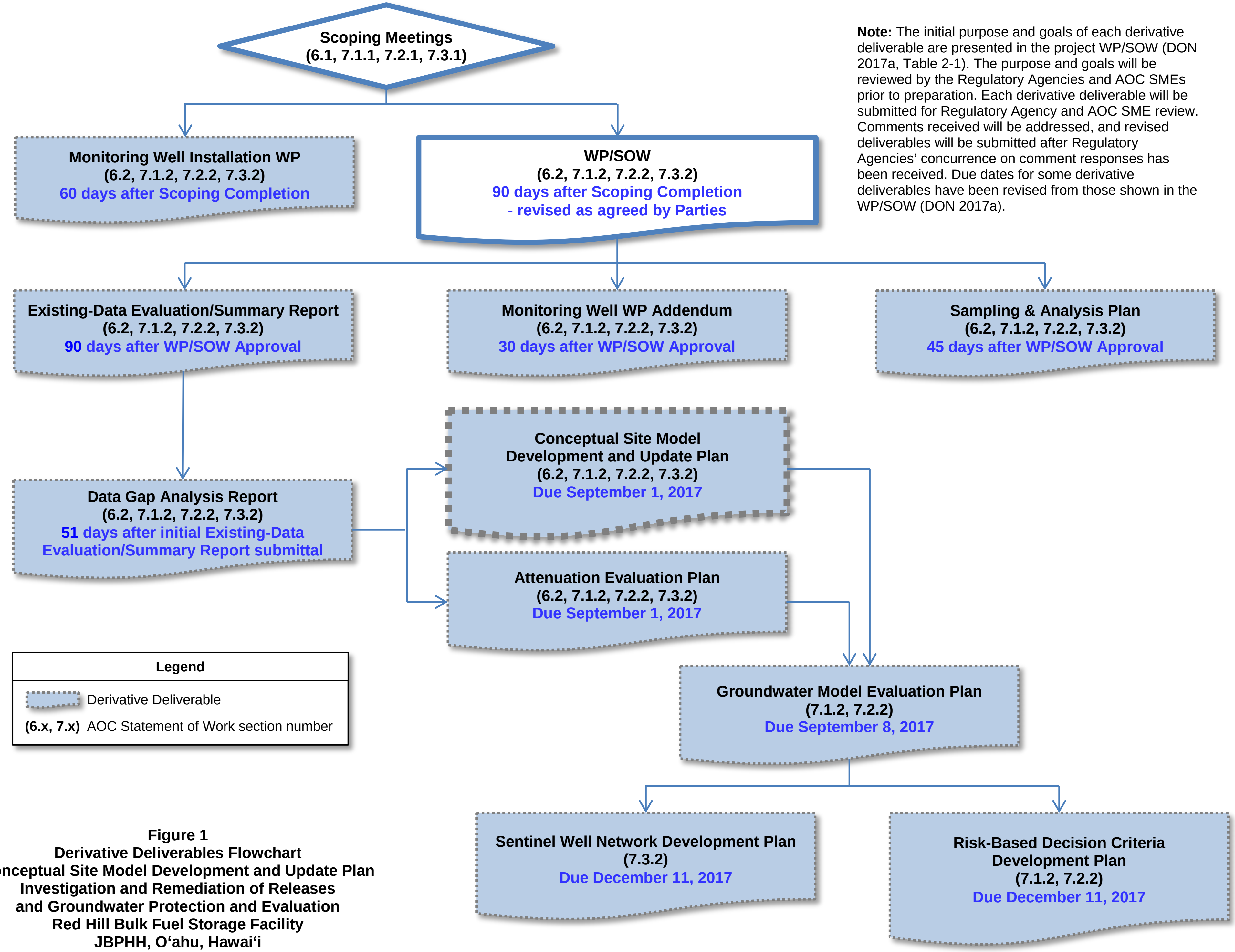
The investigation is being conducted in accordance with statutes and regulations promulgated under the Resource Conservation and Recovery Act of 1976 (RCRA). EPA guidance being used for the investigation includes *Guidance for Data Quality Assessment: Practical Methods for Data Analysis* (QA/G-9) (EPA 2000) and *Guidance on Systematic Planning Using the Data Quality Objectives Process* (QA/G-4) (EPA 2006).

1.1.3 DOH

The investigation is being conducted in accordance with statutes and regulations promulgated under Chapters 340E, 342D, and 342L of the Hawai'i Revised Statutes. DOH guidance being used for the investigation includes the TGM (DOH 2016b) and *Evaluation of Environmental Hazards at Sites with Contaminated Soil and Groundwater* (DOH 2016a).

1.2 PLAN ORGANIZATION

Section 2 identifies the purpose of developing and updating the CSM, Section 3 outlines the process for developing the CSM, and Section 4 identifies the CSM outputs. Section 5 outlines the process for updating and refining the CSM. Literature references cited in the text are compiled in Section 6.



Note: The initial purpose and goals of each derivative deliverable are presented in the project WP/SOW (DON 2017a, Table 2-1). The purpose and goals will be reviewed by the Regulatory Agencies and AOC SMEs prior to preparation. Each derivative deliverable will be submitted for Regulatory Agency and AOC SME review. Comments received will be addressed, and revised deliverables will be submitted after Regulatory Agencies' concurrence on comment responses has been received. Due dates for some derivative deliverables have been revised from those shown in the WP/SOW (DON 2017a).

Figure 1
Derivative Deliverables Flowchart
Conceptual Site Model Development and Update Plan
Investigation and Remediation of Releases
and Groundwater Protection and Evaluation
Red Hill Bulk Fuel Storage Facility
JBPHH, O‘ahu, Hawai‘i

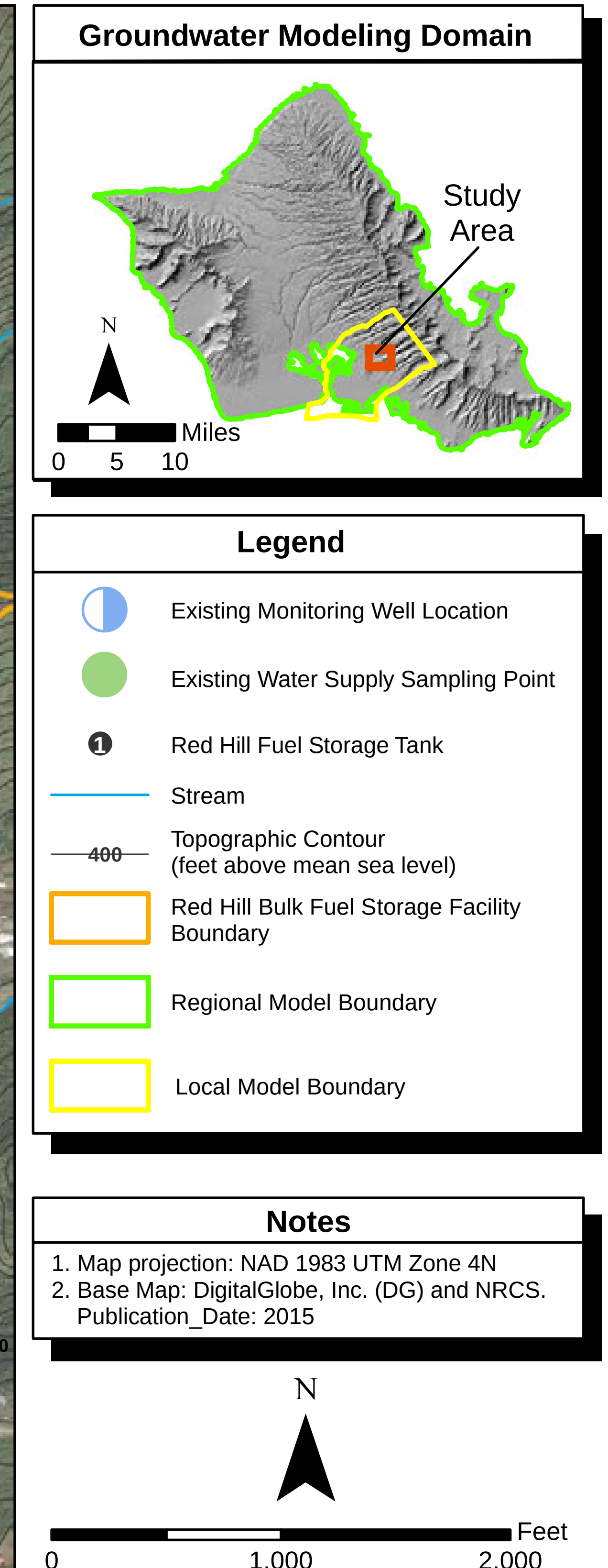


Figure 2
Current Study Area and Modeling Domain
Conceptual Site Model
Development and Update Plan
Investigation and Remediation of Releases and Groundwater Protection and Evaluation
Red Hill Bulk Fuel Storage Facility
JBPHH, O'ahu, Hawai'i

\\HONOLULU\Honolulu\Projects\NAVFAC PAC\CLEAN IV\60481245CTO 00053\900-Work\920 GIS\02_Maps\CSM Plan\Fig2_CSMPlan_CurStudyArea_v10.4.mxd 9/1/2017

2. Purpose of CSM

This *Conceptual Site Model Development and Update Plan* describes how the CSM will be developed and periodically updated to evaluate contaminant transport pathways and the potential for exposure of human and ecological receptors in support of the Investigation and Remediation of Petroleum Product Releases and Groundwater Protection and Evaluation project at the Facility. The CSM will be developed using an evidence-based approach to identify and evaluate the site-specific characteristics and processes that control the fate and transport of jet fuel (non-aqueous-phase liquid [NAPL]) and its constituent chemicals (petroleum hydrocarbons) from the source of the release (an underground fuel storage tank[s] at the Facility), through the vadose and saturated zones, and on to potential receptors (e.g., residential receptors exposed via the drinking water pathway).

The initial CSM will be developed prior to numerical groundwater modeling and will then be used as the basis for developing the numerical model. An iterative and collaborative process will be followed during development of the CSM to obtain input from Regulatory Agencies and AOC subject matter experts (SMEs). As new information is obtained, the CSM will continue to be refined interactively with the numerical modeling.

In assessing sources, contaminant migration/pathways, and exposure points, the CSM will evaluate and describe the following site characteristics and processes:

- Physical geologic and hydrogeologic nature of materials surrounding the Facility tanks and within the model boundaries
- Pathways and barriers to fuel migration
- Fuel and chemical of potential concern (COPC) sources in the model domain
- Fuel properties, volatilization, and dissolution
- Fuel weathering and biodegradation of both NAPL and dissolved-phase COPCs, and differentiating total petroleum hydrocarbons (TPH) using indicator compounds
- Vadose zone moisture and groundwater recharge
- Groundwater levels, hydraulic gradients, and flow directions
- Water-transmitting properties of basalt aquifer and aquitards
- Spatial and temporal distribution of COPCs in groundwater
- Fate and transport of dissolved COPCs
- Soil vapor data
- Potential exposure routes to receptors

The CSM will assess the exposure routes as potentially complete, potentially complete but insignificant, or incomplete, and will include assessments for hypothetical exposure pathways. The CSM will identify potential receptors of COPCs associated with the release. The CSM is also needed to support engineering analyses to evaluate remediation alternatives to address the fuel release. This CSM Plan describes how the lithology data will be used to estimate the probable NAPL migration direction, the fraction of NAPL that is expected to be immobilized in the vadose zone, and the fraction of released NAPL expected to reach the water table either as LNAPL or dissolved-phase contamination. The CSM will also provide a conceptual assessment of the potential NAPL degradation and movement incorporating the concepts for natural source depletion as described by the Interstate Technology Regulatory Council (ITRC 2009). The specific approaches, tasks, and procedures for this assessment are outlined in the *Attenuation Evaluation Plan* (DON 2017f).

2.1 IDENTIFICATION OF COPC TRANSPORT PATHWAYS

Previous investigations determined that the vadose zone and saturated zone beneath the Facility is composed of zones of high horizontal permeability, interconnected at the site scale; that low-permeability zones of unfractured basalt may form barriers to the movement of fluids through the vadose zone and groundwater flow; and that valley fill sediments are fine grained and have the potential to form low-permeability flow barriers. Additionally, dikes may present barriers and impound groundwater, but are known to be more prevalent to the northeast outside the model domain closer to the Ko‘olau ridgeline area (Izuka et al. 2016). Saprolite occurring beneath valley fill sediments also has the potential to form a low-permeability flow barrier, which could further impede the transfer of fluids or groundwater and limit recharge to the basal aquifer. Detailed description of how transport pathways will be integrated into the CSM is presented in Section 3.

2.1.1 Soil

Surficial soils are not expected to be a significant component of the CSM since releases are expected to occur at depth within the vadose zone. Valley fill sediments and saprolitic clay-rich soils have been identified at depth that are low in permeability and have the potential to restrict contaminant migration depending on the vertical and horizontal extent to which they occur.

2.1.2 Vapor

Vapor has been identified at the site and is currently monitored with a field meter for total volatile organic compounds (VOCs) within probes installed proximal to the tank bottoms within the interior tunnel. Exposure could be potentially complete within access tunnels at the site.

2.1.3 Vadose Zone

The Facility tanks are surrounded by rock in the vadose zone, which consists of layered basalt. The tank bottoms are approximately 100 ft above the groundwater table. A more detailed characterization of the geologic features in the vadose zone will be included in the CSM to better understand NAPL fate and transport mechanisms. Although fuel was released into the vadose zone, the NAPL has not been observed in any of the monitoring wells beneath the Facility or water supply wells in the area. As fuel migrates through the vadose zone, several processes reduce the contaminant mass:

- *Volatilization:* Fuel releases undergo evaporative weathering by losing volatile compounds to gas-filled pore space in the vadose zone.
- *Dissolution:* Compounds in fuels transfer from the NAPL into water that contacts the fuel.
- *Microbial degradation:* Indigenous microbial populations degrade petroleum fuels under both aerobic and anaerobic conditions.

In the Facility area, the vadose zone surrounding the fuel tanks is heterogeneous and composed of a series of complex alternating layers of basalt flows that vary from high to extremely low permeability. The spatial distribution of the interconnected pore space (effective porosity) is complex and controls the migration pathways. The CSM will better define the permeable pathways of higher effective porosity, as well as low-permeability barriers to NAPL movement, using geologic logs and data from existing reports, new wells, and geologic mapping. These data, along with heat temperature signal studies to assess biodegradation in the vadose zone, and JP-8 residual LNAPL saturation tests (performed in the lab) on core material from key zones (e.g., clinker), will aid in understanding how NAPL migrates from a release source and is distributed in the vadose zone.

The heterogeneous basalt formation is also present below the groundwater level. Information contained in geologic logs will be used to assess the nature and extent of low-permeability dense basalt layers, as well as high-permeability clinker zones that may create preferred flow pathways for groundwater and NAPL movement in the Facility source area. Understanding how these geologic features influence fluid migration will provide a foundation for setting up the numerical groundwater flow and contaminant fate and transport (CF&T) models.

2.1.4 Groundwater

Potential groundwater transport pathways will be identified based on the spatial and temporal trends of COPCs in groundwater from both historical and future sampling conducted at the site, and the results of groundwater flow and CF&T modeling.

The groundwater CSM will be based on all available data, including data collected by other agencies, and data collection activities described in the project WP/SOW (DON 2017a). Specifically, the groundwater CSM will evaluate the groundwater level data from site area wells to define hydraulic gradients during pumping and non-pumping conditions to improve the understanding of the direction and rate of groundwater flow within the aquifers around the Facility. The CSM will integrate these groundwater data with the geologic framework and other hydrogeologic data.

2.2 Identification of Potentially Complete Exposure Pathways

The presumed exposure pathways anticipated from the Red Hill Facility are outlined in the following subsections. The primary exposure route is the potential migration of a COPC plume to water supply systems pumping groundwater within the migration pathway of the plume. Soil, surface water, and vapor migration are also assessed.

2.2.1 Water Supply

Water supply wells near the Facility have been identified as transport mechanisms in potentially complete exposure pathways. Currently, it is presumed that the Navy’s Red Hill Shaft and ‘Aiea Halawa Shaft, and the City and County of Honolulu Board of Water Supply’s (BWS’s) Hālawa Shaft and Moanalua Wells, represent the most significant pathways to human receptors due to their known or suspected pumping influence on the aquifer beneath the Facility, the size of their drinking water distribution system(s), and location relative to potential downgradient groundwater flow direction relative to the Facility. Water supply wells identified within the groundwater flow modeling area are shown on Figure 3; additional detail is presented in the *Groundwater Model Evaluation Plan* (DON 2017g).

2.2.2 Onsite Human Receptors

Other potential receptors include construction and industrial workers at the Facility. Potential pathways to these receptors are from direct exposure to soil and vapor (inside and outside tunnels). While these pathways are considered potentially complete and will be assessed, they are not anticipated to be significant, for reasons that are discussed in Section 3.

3. CSM Development

A comprehensive CSM will be developed based on the site data detailed in this section. This CSM will continue to be refined as new data are obtained and will be based on the results of both the numerical and CF&T models as an iterative and collaborative process between the Navy and Regulatory Agencies and other SMEs.

All available information will be integrated with the new data being collected to develop the CSM. The CSM will then be used to develop and refine the numerical groundwater model. More detailed information and data are provided in the *Existing Data Summary and Evaluation Report* (EDR) (DON 2017b). Additional details of the work planned for numerical modeling are provided in the concurrently published *Groundwater Model Evaluation Plan* (DON 2017g) and *Attenuation Evaluation Plan* (DON 2017f).

Additional hydrogeologic and chemical data are currently being collected as described in the project WP/SOW (DON 2017a). Current efforts include plans for expanding the monitoring well network with multi-level groundwater monitoring systems that enable COPC sampling and hydraulic testing of up to seven levels within each well as deep as 300 ft below the water table. The wells will significantly improve understanding of the area's (vertical and horizontal) potential groundwater flow between the tank farm and the area's groundwater supply wells. Much of the data obtained during the investigation will be applicable and useful for refining and updating the CSM. The *Attenuation Evaluation Plan* (DON 2017f) describes additional data and analyses that will be useful for the groundwater CF&T modeling.

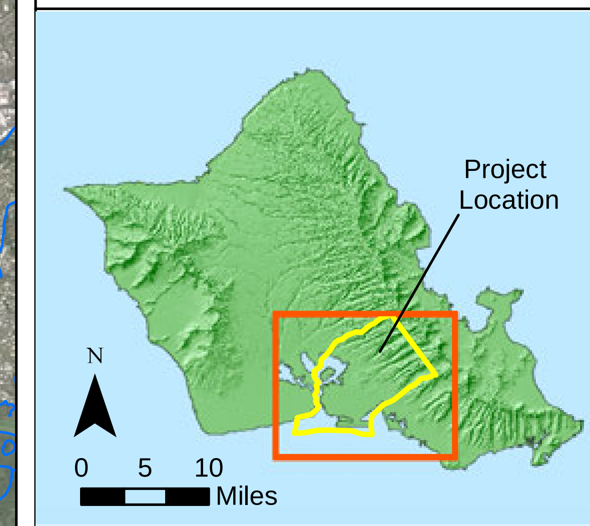
3.1 SUMMARY OF CURRENT DATA GAPS

The *Data Gap Analysis Report* (DON 2017d) described in detail the project data needs and data quality objectives. That report also described the data collection activities that were planned at that time to fill the project data needs. In reviewing that data gap analysis, the Regulatory Agencies requested that the Navy should identify only the data gaps that would remain following evaluation of data needs in consideration of existing data. To address that request, this section identifies and summarizes those remaining data gaps.

3.1.1 Groundwater Flow Directions and Rates

Eleven multi-level monitoring wells that will address multiple data gaps are now being planned at selected key locations to further define the spatial distribution of hydraulic heads (groundwater levels) and hydraulic gradients in the areas extending northward to Hālawa Shaft, near the Red Hill Shaft infiltration gallery, and in the area extending southward to the Moanalua and Tripler Army Medical Center (TAMC) wells (DON 2017e). These wells have the capacity to allow groundwater sample collection, water level data, and conduct hydraulic testing in up to seven packer-isolated discrete zones as deep as 300 ft below the water table. The surface water level can be measured with calibrated tape or transducer to ensure additional accuracy at the water table. Groundwater level elevation data are needed to represent non-pumping conditions as well as various combinations of pumping these wells. The additional multi-level monitoring wells will need to be completed with intake intervals that measure groundwater levels (hydraulic heads) to define the potentiometric surface, which will reflect horizontal hydraulic gradients at the water table. Additionally, the multi-level monitoring wells enable hydraulic head measurements from intervals deeper below the water table to measure the vertical hydraulic gradient at those locations, furthering understanding of vertical pumping effects.

Location Map



Legend

- Water Supply Well
- Model Area
- Red Hill Bulk Fuel Storage Facility Boundary
- Stream
- Red Hill Fuel Storage Tank

Notes

1. Map projection: NAD 1983 UTM Zone 4N
2. DigitalGlobe, Inc. (DG) and NRCS. Publication_Date: 2015

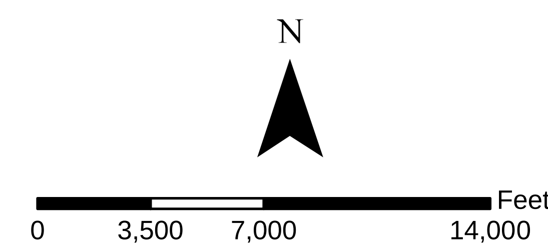


Figure 3
Water Supply Wells Within the Model Area
Conceptual Site Model
Development and Update Plan
Investigation and Remediation or Releases and Groundwater Protection and Evaluation
Red Hill Bulk Fuel Storage Facility
JBPHH, O'ahu, Hawai'i

\\HONOLULU\Honolulu\Projects\NAVFAC PAC\CLEAN IV\60481245\CTO 0053\900-Work\920 GIS\02_Maps\CSM Plan\Fig3_CSMPlan_SupplyWells_v10.4.mxd 9/1/2017

A synoptic water level study is being conducted to more accurately determine the measuring point elevations of all wells in the Red Hill groundwater monitoring network and address existing data gaps regarding datum uncertainty (USGS 2017). This survey includes primary water supply wells and monitoring wells in the area, including the BWS Hālawa Shaft, Navy Red Hill Shaft, Navy ‘Aiea Halawa Shaft, and the Moanalua wells. Data from this survey will allow more accurate determinations of hydraulic heads and hydraulic gradients using the available groundwater level measurements. Similar groundwater level data from additional monitoring well locations are needed to better define the direction and rate of migration of groundwater potentially impacted by COPCs from the Facility.

3.1.2 Thickness and Extent of Hydrogeologic Units

Geologic maps showing the thickness of the Caprock Hydrogeologic Unit (HGU) and elevation of the top of the Basalt HGU were published in recent USGS studies (Engott et al. 2015; Izuka et al. 2016). These maps are being used to estimate the extent and thickness of the HGUs in the model area. The data are being used to the update the groundwater flow model for most, if not all, of the model area. However, additional hydrogeologic data are needed to better define the depths of older alluvial sediment fill and saprolite in areas beneath North and South Hālawa valleys. Detailed borehole geologic logs of deep borings in those areas would reduce this uncertainty, resolving the hydraulic gradients and groundwater flow directions is of primary importance, and may reduce or obviate the need to collect additional geologic data to define the low-permeability materials in these valleys. The Navy is currently planning to install two new multi-level monitoring wells in South Hālawa Valley and two in North Hālawa Valley (DON 2017e). In addition to further define the valley fill and saprolite thickness in both valleys.

3.1.3 Preferred Pathways and Barriers

Hydrogeologic data will be collected from the planned new multi-level monitoring wells noted above (DON 2017e) and from the existing monitoring well network that will support further evaluation of geologic features that may act as preferred groundwater flow pathways or barriers. Comprehensively, these data will enable further definition the spatial distribution of clinker zones, paleo-channels, faults, dense low-permeability lava flows, and dikes in the primary area of interest for groundwater modeling. The two new multi-level monitoring wells in South Hālawa Valley and two in North Hālawa Valley will provide geologic data to further define the valley fill and saprolite thickness in both valleys that may act as barriers. Surface seismic studies are in the planning stage and will provide further data to augment the deep well geologic data to address this data gap.

3.1.4 Hydraulic and Physical Properties of Basal Aquifer

Installation of the new multi-level monitoring wells will include preparation of borehole geologic logs and collection of core samples for further characterizing the physical properties of the basal aquifer, from the water table to 300 ft below the water table. Furthermore, these wells allow for hydraulic testing from multiple discrete zones within the basal aquifer water column. Consequently, these wells will further address current data needs for calibrating the groundwater flow model and refining aquifer hydraulic properties, which include:

- Transmissivity
- Hydraulic conductivity
- Heterogeneity and anisotropy
- Storativity
- Specific yield

The existing 2007 groundwater model was calibrated using pumping test data from May 2006, when fewer monitoring wells were available near the Facility. Since 2007, the only new information relevant to aquifer hydraulic properties in the modeling area is the USGS data set collected in May 2015 while the BWS Hālawa Shaft was being pumped. Other wells in the Hālawa area were also being pumped during that time, but the pumping data for those wells appear to be incomplete. Variable pumping rates add further uncertainty in evaluating the data.

As requested by the Navy, the USGS is performing synoptic monitoring of approximately 25 monitoring wells (both within and outside the monitoring network) while the supply wells are pumped in sequence at controlled flow rates and continuously monitored (USGS 2017). Using these regional pumping test data, the groundwater model will be calibrated using an iterative process to reasonably match these data by adjusting the aquifer hydraulic properties in the model within the range of reported values from other studies. The flow model calibration will be complete when the refined model simulations reasonably match the time-series drawdown and recovery data, the measured hydraulic gradients, and groundwater level contour maps for non-pumping and pumping conditions. Data will be used to further understanding of groundwater flow and pumping effects exerted on the underlying basal aquifer.

3.1.5 Groundwater Recharge and Discharge Rates

Detailed maps of groundwater recharge rates from the recent USGS studies (Engott et al. 2015; Izuka et al. 2016), when made available by the USGS, will be used as direct input to the updated groundwater flow model for most, if not all, of the modeling area. However, a clay-rich saprolitic soil of substantial thickness is present at the Red Hill ground surface and extends throughout the Facility vicinity. This thick clayey soil cover probably reduces the recharge rates in the Red Hill area. Also, extensive building roofs and pavements create nearly impermeable coverage of the land surface in the light industrial area immediately north of the Facility which also reduces recharge rates locally. On the other hand, the Halawa Quarry and Hawaiian Cement plant operations have modified the natural watershed topography in a manner that likely increases local groundwater recharge rates. To account for such anthropogenic effects, which may not have been fully accounted by the recent USGS recharge studies, the local recharge rates need to be further evaluated. Plans being developed to address these data gaps include collection of data from studies to assess infiltration parameters specific to Red Hill (e.g., soil maps [units], weather stations, dual-ring infiltrometers.)

Natural groundwater discharge also occurs along the coast, and thus the model update needs to specify the rate of this flux. However, groundwater discharge rates are not estimated in the recent USGS reports (Engott et al. 2015; Izuka et al. 2016). Flow monitoring of larger springs in the Pearl Harbor area is being conducted by the USGS and the data are available from the USGS website, but total groundwater discharge flux out of the model area is not being measured. Updated estimates or groundwater recharge and discharge may become available from the USGS modeling studies currently underway. If not, however, these data gaps will need to be further evaluated during the modeling.

3.1.6 Nature and Extent of Contamination

Additional data are needed to better define the spatial distribution of COPC concentrations dissolved in groundwater surrounding the Facility. To fulfill these data needs, multi-level monitoring wells are planned to be installed and sampled for detailed groundwater quality analyses to characterize the spatial lateral and vertical distribution of COPC concentrations.

To provide data needed to estimate potential NAPL movement from the Facility fuel storage tanks, a detailed geologic model of Red Hill is being developed using all available borehole logs and "barrel" logs of the tank wall excavations. As further described in the Section 3.2, this geologic model will define the physical characteristics and geometry of the basalt flows and interbedded clinker zones underlying the Facility tanks and nearby. In addition, the planned installation of a new multi-level monitoring well (RHMW01R) adjacent to RHMW01 will involve drilling a core boring to 300 ft below the water table; the core will be used to prepared a detailed geologic log. Core samples from this boring will be inspected for the presence of LNAPL on site during drilling, then preserved and shipped for petrographic analyses. If no LNAPL is detected, then select core samples will be saturated in the lab to measure residual saturation representative of the geologic units. Details are presented in the *Monitoring Well Installation Work Plan Addendum 02* (DON 2017e).

3.1.7 Source Area Extent, Mass Loading, and Natural Attenuation Rates

Extent of the source area, COPC mass loading rates, and site-specific values for natural attenuation rates of the COPCs are uncertain. Site-specific values for COPC sorption and degradation rates are not currently available. For the 2007 model (DON 2007), regional studies provided the basis for estimating values for all these parameters. For the current project, natural attenuation rates will be evaluated following natural source-zone depletion (NSZD) concepts and multiple lines of natural attenuation evidence based on existing data augmented by new data to be collected, including:

- Historical records of Facility construction and reported releases
- Detailed analyses of composition and equivalent carbon fractions of dissolved TPH
- Natural attenuation of petroleum fuels and dissolved COPC compounds
- Groundwater chemical analyses of natural attenuation parameters (NAPs)
- Microbial analyses and in-situ COPC degradation with bio-trap and stable isotope probing
- Carbon dioxide measurements using carbon traps
- Soil vapor analyses
- Estimates of site-specific recharge
- Vertical temperature profiles of the vadose and saturated zones
- Petrographic studies
- Solute transport modeling parameter estimation by history matching time-series data

Details of the plans to evaluate natural attenuation are presented in the *Attenuation Evaluation Plan* (DON 2017f).

3.2 FACILITY AND SOURCE INPUTS

Information on the Facility history, tank construction, previous investigations, and the 2014 Tank 5 release will be compiled from investigation reports, the Red Hill *Groundwater Protection Plan* (DON 2014b), the State Senate Red Hill Task Force report (RHSF Task Force 2014), and the Tank 5 Release Response Reports (DON 2014a). The compiled information will be synthesized to present a historical summary of the site and the release that resulted in the current investigation. This information will be used to provide input the CSM at the initial release(s) site(s) regarding the nature and locations of the release(s).

Kerosene-based jet fuels stored at the facility have included JP-5, JP-8, and F-24. In January 2014, the Navy reported that JP-8 fuel was released from Tank 5. Although these jet fuels are all kerosene-based, the fuel's exact composition of aliphatic and aromatic hydrocarbons will vary depending on the crude oil source used to refine the fuels (ATSDR 2017). The *Attenuation Evaluation Plan* (DON 2017f) outlines planned source studies on the fuels involving detailed hydrocarbon analysis and carbon fractionation analysis. The insight into compositional changes in the fuel may inform some elements of the CSM within both the vadose zone and the saturated zone.

3.3 GEOLOGIC FRAMEWORK INPUTS

The CSM geologic framework will integrate all available data to define the physical characteristics and geometry of geologic units, including rock type, fracture aperture, pore space, thickness, and lateral continuity. The CSM will characterize the spatial distribution of higher- and lower-permeability units (e.g., clinker zones, massive basalt flows, fractures, saprolite) at the Facility. Sources of information for constructing the geologic framework include:

- *Document and Literature Search:* Review available geologic literature, maps (old and new), photographs (old and new), aerial imagery (old and new), drilling and boring logs, and rock cores.
- *Field Geological Survey:* Map visible outcrops and visual evidence of other geologic features such as dikes and large fractures. This may allow for structural mapping to identify the locations of major rock types and features. Map dips and strikes of bedding, fractures, dikes, faults, and potential preferential pathways to the extent possible. Measure thicknesses of individual flow units at available rock outcrops. Identify trend and plunge of any visible linear features. Survey all mapped features using Global Positioning System (GPS) survey techniques to determine horizontal and vertical coordinates. Use a GPS receiver and a field data collection system to compile, in a time-efficient manner, numerous geologic structure measurements taken during mapping.
- *Detailed Logging of Rock Cores:* Indicate rock type of all rock cores, note all fractures, and describe the physical properties including aperture, type of infilling, amount of infilling, surface shape of joint, roughness of surface. Augment the logging with borehole geophysical surveys to provide further assessment.
- *Construct Detailed Geologic Cross Sections:* Integrate log, rock core, and field data. Correlate geologic units/bedding across the site, if possible. Integrate available geophysical data into cross-sections.
- *Construct Subsurface Geologic Maps and Cross Sections:* Integrate data from previous studies, rock and geophysical boring logs, barrel logs, surface mapping, and seismic investigation to identify subsurface layers that may act as pathways or barriers to COPC transport in both the vadose and saturated zones. Particularly focus on defining alluvium and saprolite depth in valleys within the model area.
- *GIS Integration of Subsurface Data:* Integrate data into a comprehensive GIS framework from rock boring and barrel logs, surface mapping, cross sections, seismic investigation, COPC data, and previous studies to identify subsurface layers that may act as pathways or barriers to COPC transport in both the vadose and saturated zones.

3.3.1 Subsurface Boring and Barrel Logs

Available boring and barrel logs from the study area (i.e., Hālawa Valley, Red Hill, Moanalua Valley) will be compiled from available sources including Navy, BWS, State of Hawai‘i Department of Land and Natural Resources (DLNR) Commission on Water Resource Management (CWRM), State of Hawai‘i Department of Transportation (DOT), and United States Geological Survey (USGS), as identified in the EDR (DON 2017b) and the *Data Gap Analysis Report* (DON 2017d). The logs will be evaluated to characterize subsurface geology and support the development of geologic cross sections of subsurface vadose zone lithology, which in turn will support characterizing the fate and transport of NAPL in the vadose zone.

Currently, the planned installation of monitoring well RHMW01R adjacent to RHMW01 will involve conducting additional intrusive investigation activity in the immediate vicinity of the fuel tanks and source area. Details for the drilling of RHMW01R are described in the *Monitoring Well Installation Work Plan Addendum 02* (DON 2017e) This well will be completed as a multi-level groundwater monitoring system that will enable the COPC sampling and hydraulic testing of up to seven levels within the well to depth of 300 ft below the water table. This well will also feature soil vapor sampling ports within the vadose zone. The *Monitoring Well Installation Work Plan Addendum 02* (DON 2017e) also includes plans to drill 11 new (not including RHMW01R) similar multi-level groundwater monitoring wells in strategic locations between the Facility and identified potential water supply wells both within and outside the Facility.

3.3.2 Geologic Mapping

As described in the project *Sampling and Analysis Plan* (SAP) (DON 2017c), geologic mapping will be conducted in the study area to map visible outcrops and evidence of other geologic features, such as dikes and large fractures, which may allow for mapping to identify the locations of major rock types and rock structure features. Prior to field mapping, a document and literature search will be conducted to obtain available information, and geologic reports on the nature of the rocks and geology in the study area will be obtained, along with any existing geologic maps. Available geophysical and subsurface geologic and hydrologic data (i.e., from well borings) will be incorporated into the construction of geologic cross sections and maps of the study area. The cross sections and maps will support building a geologic framework model.

3.4 Source and Vadose Zone Inputs

Together with the geologic framework, the CSM will incorporate information about tank construction and fuel storage history as well as fuel weathering processes, to improve the understanding of NAPL movement, retention, and degradation mechanisms. For example, the CSM will describe how NAPL releases would likely move from a tank leak point by characterizing the spatial distribution of interconnected pore spaces (e.g., clinker zones) and low-porosity, low-permeability lava beds, and, if present, perched water. The CSM will also assess lateral spreading and retention of NAPL, including the effect of capillary moisture in smaller pore spaces such as small water-filled fractures in massive basalt layers. In summary, these CSM components will provide a basis for estimating the extent and volume of NAPL movement that could be retained in the vadose zone.

Detailed data will be extracted from the geologic framework described in Section 3.3. The porosity and permeability of each different hydrogeologic unit will also be estimated or described qualitatively based on the detailed geologic descriptions from the barrel logs, boring logs, and published reports from other hydrogeology investigations of the basalt. The data will be evaluated and used to estimate the abundance, thickness, and locations of permeable layers or zones. This information will be used to estimate likely directions and locations where NAPL could migrate if released from a tank.

Inputs to the CSM that address NAPL release, migration, attenuation, and retention in the vadose zone include the following information:

- Tank 5 release history, tank construction, fuel types, leak rates, and volume estimates
- JP-8 or similar fuel composition fingerprinting
- Studies of natural attenuation and degradation of dissolved-phase constituents of jet fuel
- Evaluation of retention and migration of NAPL at a macro-scale (i.e., structural geometry of high- and low-permeability layers, ponding on low-permeability units, perched water horizons) in the context of the geologic framework as noted in Section 3.3
- Evaluation of residual NAPL at a micro-scale (e.g., pore, micro-fractures retention) including residual LNAPL in situ (performed in the lab) on core material from key zones (e.g., clinker) where residual NAPL is identified, and/or JP-8 or similar fuel introduced to rock core types to assess residual capacity of the rock types
- Heat temperature signal studies to assess biodegradation-generated heat in the vadose zone
- Soil vapor concentrations from monitoring the portions of well screens exposed above the water table, multi-level well vapor sampling ports, and sub-tank vapor probes that include oxygen, carbon dioxide, methane, and VOCs to assess biodegradation in the vadose zone
- Carbon trap deployment to assess biodegradation in the vadose zone
- Soil Vapor Extraction Endstate Tool (SVEET) (Truex et al. 2013) modeling of vadose zone volatilization/leaching, and Hydrocarbon Spill Screening Model (HSSM) (Charbeneau, Weaver, and Lien 1995) modeling of vertical fluid transport velocities using correlations between precipitation and water level and soil vapor data that integrate infiltration parameters for Red Hill (e.g., soil maps [units], weather stations, dual-ring infiltrometers)

3.5 SURFACE WATER AND RECHARGE INPUTS

Groundwater recharge from direct infiltration of precipitation and streambed seepage are important components of the CSM for groundwater and surface water. The principal surface water features in the primary area of interest include North Hālawa Stream, South Hālawa Stream, and Moanalua Stream. Where the water table lies below the streams, as is the case in the Facility area, in addition to recharge from precipitation, it is important to account for interactions between groundwater and surface water. The streams in the Facility area do not receive groundwater discharge. Rather, streambed seepage causes groundwater recharge. The relationships between surface water and groundwater will be integrated within the CSM. Supplemental data used to quantify infiltration parameters for Red Hill (e.g., soil maps [units], weather stations, dual-ring infiltrometers) will be integrated into the CSM.

Detailed maps of groundwater recharge rates from recent USGS studies (Engott et al. 2015; Izuka et al. 2016) will be used as inputs to the CSM and groundwater model. North of the Facility, the Halawa Quarry and Hawaiian Cement plant operations have modified the natural watershed topography and likely changed groundwater recharge rates in the area. A number of monitoring wells in the South Hālawa Stream Valley and to the north have encountered perched water, which is an indication of local groundwater recharge. The CSM will describe the perched water locations and depths (elevations), which have previously been reported for monitoring wells at the Hālawa Correctional Facility, Oily Waste Disposal Facility, and Well RHMW08.) Data for water usage and discharges at the cement plant will be important to evaluate the local hydrologic budget of that area, and will be used to refine the estimated recharge rates.

A more detailed conceptual model of the water balance (hydrologic budget) at the cement plant, crushing facility, and quarry will be developed to better estimate groundwater recharge rates in that area. After receiving a geospatial data set of revised recharge rates from the USGS (based on the USGS reports by Engott et al. 2015 and Izuka et al. 2016), those data will be used to prepare a detailed recharge rate map for the entire model area. That groundwater recharge rate map will be revised as needed to adjust the rates in the area surrounding the Facility to reflect the current land surface features and soils. The results of this local water balance analysis will be incorporated into the water balance for the entire model area, and the refined groundwater recharge rates will be input to the numerical groundwater model.

3.6 HYDROGEOLOGICAL INPUTS

In conjunction with the geologic framework, other hydrogeological factors will be evaluated and incorporated into the CSM to define groundwater flow directions and rates. Data have been collected at various temporal scales including a long-term synoptic monitoring over a 4-month period, historical water level surveys, and water level data collected in the monitoring well network during quarterly and sometimes monthly intervals. To address COPC migration in groundwater, the CSM will describe groundwater flow in the Facility area as well as the areas surrounding potential receptors and other pumping wells. Accordingly, the CSM will provide the conceptual hydrogeologic basis for the numerical groundwater modeling. For modeling, specific hydrogeologic information is needed, including:

- Hydrogeologic unit characteristics:
  - Basalt, caprock and valley fill geometry, and water transmitting and storage properties
  - Perched water zone areas, genesis, and potential effects on contaminant migration
  - Geologic structures that may affect groundwater flow
  - Preferred pathways for groundwater flow (e.g., clinker paleochannels)
- Hydraulic heads, vertical and horizontal gradients, and groundwater flow:
  - Synoptic monitoring data to evaluate pumping and non-pumping conditions
  - Time-series hydrographs and potentiometric maps
  - Installation of multi-level wells that allow vertical hydraulic testing in discrete zones to depths of 300 ft below the water table
- Other geologic structures that may affect groundwater flow:
  - Hydrogeologic features along model perimeter boundaries:
    - Valley fill depth, genesis, lithology, and water-transmitting properties along northwest and southeast model boundaries
    - Basalt depth, lithology, and water-transmitting properties along the east model boundary

    - Caprock depth, lithology, and water-transmitting properties along the west model boundary
    - Saprolite depth, lithology, and water-transmitting properties
  - Barriers to groundwater flow (e.g., dikes in "dike-free" area depicted on Izuka et al. [2016, Figure 32])
- Water balance for groundwater model domain:
  - Groundwater flow rates (mass flux rates) along each perimeter boundary
  - Groundwater recharge and discharge locations and rates
  - Pumping well locations, withdrawal rates, and seasonal changes

3.7 GROUNDWATER COPC DATA INPUTS

Water chemistry analyses of samples collected quarterly (or more frequently) from the Red Hill groundwater monitoring network will be a key input to the CSM. Time-series plots of COPC concentration data from the Red Hill groundwater long-term monitoring reports will be used in conjunction with water level measurements and precipitation records to evaluate mass loading, groundwater recharge, and attenuation processes. Spatial and temporal distribution of COPC concentrations in the monitoring wells will support defining the nature and extent of contamination, and will also assist in characterizing groundwater flow and solute transport for the CSM.

Spatial and Temporal Trends in the Dissolved Plume. A necessary component to evaluating COPC plume trends is the plotting of COPC concentrations over time at each monitoring location, as well as the spatial graphing of contaminant concentrations versus distance downgradient along the plume flow path at each relevant monitoring location over multiple sampling events. The trend evaluation will consider shorter variances that may be due to seasonal variation or recharge events, and longer-term effects that are more typically aligned with natural attenuation processes. The geologic framework within the groundwater aquifer will also be considered, since factors such as rock characteristics, hydrological barriers, variable permeability zones, and structural geometry may impede or facilitate plume migration rates. Data that have been and continue to be collected within the Facility groundwater network since 2007 will provide the basis for the trend analysis. In addition to primary COPC data, the trend analysis will include plots of diagnostic parameter concentration ratios to better to correlate changes with degradation.

Site-specific groundwater data (NAPs) and microbial analyses including bacterial population counts and deploying biotraps for stable isotope probe analysis, as described in the *Attenuation Evaluation Plan* (DON 2017f), will provide data to assess biodegradation within the dissolved plume.

3.8 GROUNDWATER FLOW MODELING

Following CSM development, numerical groundwater modeling will be used to further quantify the groundwater flow system and improve understanding of groundwater flow. Numerical modeling may also serve to refine the CSM. Details of the planned technical approach are described in the *Groundwater Model Evaluation Plan* (DON 2017g). Initial submittal of the *Groundwater Flow Modeling Report* (AOC Statement of Work Section 7.1.3) is scheduled concurrent with initial submittal of the *Investigation and Remediation of Releases Report* (AOC Statement of Work Section 6.3) (EPA Region 9 and DOH 2015).

3.9 Contaminant Fate and Transport Modeling

All available data will be evaluated to develop the CSM for CF&T modeling, including new chemical data to be collected as part of the project WP/SOW (DON 2017a) and the *Attenuation Evaluation Plan* (DON 2017f). With the numerical groundwater flow model set up and calibrated consistent with the CSM, the CF&T modeling will utilize available information for predictive simulations of COPC migration and concentrations for assessing health effects to potential receptors, as described in Section 3.10. Initial submittal of the *Contaminant Fate and Transport Modeling Report* (AOC Statement of Work Section 7.2.3) is scheduled 6 months following initial submittal of the *Investigation and Remediation of Releases* and *Groundwater Flow Modeling* reports. Interim results of the CF&T modeling effort will be used to estimate NAPL 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 NAPL within the saturated zone.

3.10 Exposure Routes and Receptor Assessment

Exposure routes and receptors will be identified in accordance with the DOH TGM (DOH 2016b) to develop a schematic pathway exposure model. Pathway components will include:

- Release source (i.e., Facility fuel storage tank[s])
- Type of contaminated media (i.e., groundwater)
- Migration pathways (e.g., potable water, volatilization)
- Exposure route (e.g., ingestion, inhalation)
- Current and future human receptors (e.g., offsite residents, onsite industrial and construction workers)

A preliminary risk assessment conducted as part of a previous Facility investigation concluded that there were no significant pathways for ecological receptors (DON 2002). Each identified exposure route will be assessed as potentially complete, potentially complete but insignificant, or incomplete in accordance with the following criteria:

- *Potentially complete:* exposure pathways that include all of the following elements:
  - Sources and type of chemicals present
  - Affected media
  - Chemical release and transport mechanisms
  - Known and potential routes of exposure
  - Known or potential human receptors
- *Potentially complete but insignificant:* exposure pathways identified as potentially complete but not likely to pose a potential for adverse effects to human health
- *Incomplete:* exposure pathways that are not complete and therefore will not affect human health

At present, human exposure to drinking water via groundwater intake to water supply wells and their distribution system and vapor intrusion are considered to present the only potentially complete exposure pathways, but all pathways will be iteratively re-evaluated if new data suggest additional potentially complete pathways. The vapor intrusion pathway for nearby residents will be evaluated by screening new data against DOH vapor intrusion hazard Environmental Action Levels (EALs) (DOH 2016a). A Tier 2 risk assessment conducted for a previous Facility investigation found that under the conditions then measured, the soil vapor to indoor air pathway posed negligible risk to industrial and residential receptors (DON 2007).

Information derived from natural attenuation studies described in the *Attenuation Evaluation Plan* (DON 2017f) will be used to refine the exposure assessment as applicable. The refined exposure assessment will provide the basis for deriving Site-Specific Risk-Based Levels (SSRBLs) for specific areas based on DOH EALs and other criteria (e.g., attenuation, solubility). Development of these SSRBLs will be described in the forthcoming derivative deliverable *Risk-Based Decision Criteria Development Plan* (Figure 1). The SSRBLs will consider multiple future scenarios that have variable release volumes and tank locations to address future vulnerability under AOC Statement of Work Section 8 (EPA Region 9 and DOH 2015).

4. CSM Outputs

The CSM will define transport and exposure pathways, present a pictorial CSM and schematic pathway exposure model, and describe current site conditions in narrative format.

4.1 Graphical Model

A graphical CSM of the project vicinity will be presented on a figure depicting the relationship between the contaminant source and receptors through consideration of potential or actual migration and exposure pathways. The graphical model will include all of the key elements of a CSM including the sources, transport pathways, exposure points, and receptors. Diagrams will also be used to illustrate the CSM attenuation processes acting on the petroleum fuel and COPCs dissolved in groundwater. The graphical CSM will depict these elements in a stylized and concise pictorial format suitable for briefings to regulators and other stakeholders.

The graphic CSM model will be supported by 3D visualization of integrated site data (as described in Section 3), with detailed renderings of subsurface cross sections and subsurface COPC data.

4.2 Schematic Pathway Exposure Model

The exposure pathway assessment will be presented in a schematic model in the initial CSM technical memorandum. The general format will follow that presented in Section 3.3 *Conceptual Site Models* of the DOH TGM (DOH 2016b). The assessment will be revisited in subsequent updates to the CSM if newly acquired data (e.g., results of groundwater monitoring results or natural attenuation studies) suggest revision of potentially complete, insignificant, or incomplete pathways.

4.3 Narrative Model

The narrative model will synthesize information acquired from the CSM inputs identified in Section 3 to describe conditions in the study area and at the site and present historical information affecting the current environmental condition of the study area and site. The narrative will characterize the source of contamination and identify potential migration pathways and environmental receptors. The narrative model will provide a more in-depth presentation of how the physical environment and contaminant transport (groundwater flow, NAPL migration in the vadose zone, COPC transport in groundwater) could result in exposure to potential human receptors.

5. Updates and Refinement

The CSM will be maintained and updated throughout the duration of the project. An iterative and collaborative process between the Navy and Regulatory Agencies and SMEs will be employed to accommodate additional site information and refine the CSM. Information that will be used to maintain and update the CSM includes, but is not limited to, the following:

- Additional COPC data and associated chemical data in various media (e.g., vapor, groundwater, subsurface NAPL, NAPs, and general groundwater chemistry)
- Data from additional monitoring wells and borings (e.g., subsurface geology, groundwater levels)
- COPC contamination summary figures with areas above project action levels
- Modifications to the direction of groundwater levels or flow directions, based on new information to be collected or insights gained from numerical modeling iterations
- Collection of additional geologic data that enable refinement of cross sections depicting the site subsurface geology
- Collection of additional COPC data that further the understanding of the lateral and vertical extent of contamination
- Identification of existing buildings, structures, and infrastructure changes that might affect subsurface conditions or preferential pathways (e.g., addition of underground piping), roads, surface water bodies, neighboring property operations and land uses, geographical features)
- A change in surrounding land use that changes exposure pathways or potential receptors
- Advanced evaluations of environmental risk for existing and potential future scenarios

5.1 PROCESS

The initial CSM will be presented in a technical memorandum. Updates to the CSM will be reported periodically in *Groundwater Model Progress Reports*. The CSM will also be updated in the project *Investigation and Remediation of Releases Report*, scheduled for publication in December 2018.

5.2 NOTIFICATIONS

The Navy will notify the AOC Parties when the CSM has been updated. The notification will include a summary of what modifications and refinements have been made to the CSM.

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