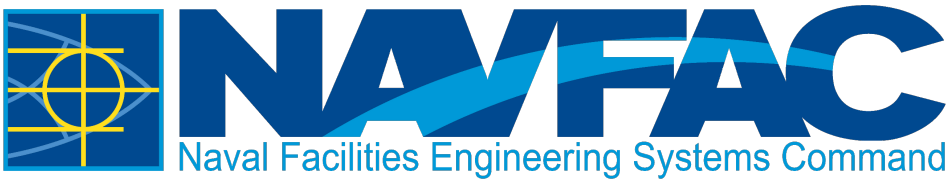

Naval Facilities Engineering Systems Command Hawaii

Contaminant Fate and Transport Model Technical Memorandum Red Hill Bulk Fuel Storage Facility

JBPHH, O‘ahu, Hawai‘i

June 26, 2023

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Red Hill Bulk Fuel Storage Facility
JBPHH, O‘ahu, Hawai‘i

June 26, 2023

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Table of Contents

Figures (compiled after References Section)

Charts

Tables

Acronyms and Abbreviations

%	percent
µg/L	micrograms per liter
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
CLN	connected linear network
CSM	conceptual site model
COC	constituent of concern
DLNR	Department of Land and Natural Resources, State of Hawai‘i
DOH	Department of Health, State of Hawai‘i
EAL	Environmental Action Level
EPA	Environmental Protection Agency, United States
ft	foot/feet
ft^2	square feet
ft/d	feet per day
gal	gallon
GWFM	groundwater flow model
JBPHH	Joint Base Pearl Harbor-Hickam
JP	Jet Fuel Propellant
Koc	organic carbon/water partitioning coefficient
LNAPL	light nonaqueous-phase liquid
mg/L	milligrams per liter
mgd	million gallons per day
(b)(9)	(b)(9)
RA	Regulatory Agency
(b)(9)	(b)(3)(b)(3)
SME	subject matter expert
SOW	Statement of Work
SGC	silica gel cleanup
SVMP	soil vapor monitoring point
TPH	total petroleum hydrocarbons
TPH-d	total petroleum hydrocarbons – diesel range organics
TPH-o	total petroleum hydrocarbons – residual oil range organics
U.S.	United States
VZM	vadose zone model

1.0 Introduction

This interim contaminant fate and transport (CF&T) model was performed as part of the Comprehensive Long-Term Environmental Action Navy (CLEAN) V Program under contract number N62742-17-D-1800, contract task order N6274222F0106. This document is the third of three technical memoranda, preceded by the Groundwater Flow Model (GWFM) and the Vadose Zone Model (VZM). These three memoranda represent the "best available" models for submittal to Regulatory Agencies (RAs) on June 30, 2023. The CF&T model is based on the preliminary best available GWFM and VZM results in June 2023. This deliverable is interim and best available and is therefore different from the final models that will be delivered to the Navy on September 30, 2024. The purpose of the best available models is to facilitate decision making during defueling of the Red Hill Bulk Fuel Storage Facility ("Facility").

The Facility is located along Red Hill ridge between South Hālawa Valley and Moanalua Valley on the island of O'ahu, Hawai'i. The study area is shown on Figure 1-1 (figures are compiled after Section 8.0 References). The Facility includes 20 steel-lined concrete underground storage tanks located in the unsaturated zone above the water table that store various fuels (e.g., jet, diesel) as described in the Red Hill Conceptual Site Model (CSM) report (DON 2019). Previous investigations have indicated evidence of petroleum hydrocarbons in the rock beneath the tanks and in the underlying aquifer. This aquifer supplies drinking water to the Navy, other military branches, and the community via water supply well (b)(9) ((b)(3)(b)(3) [(b)(3]), (b)(9) ((b)(3)), City and County of Honolulu Board of Water Supply (BWS) municipal water supply wells Hālawa Shaft, Moanalua Wells, and other wells.

On January 23, 2014, the Navy reported to the Hawai'i State Department of Health (DOH) a fuel release of an estimated 27,000 gallons of Jet Fuel Propellant (b)(3) from Tank 5 of the Facility's underground fuel storage tanks. The release occurred in December 2013 when placing the tank back in service following a 3-year tank inspection and refurbishment process.

The AOC in the Matter of the Red Hill Bulk Fuel Storage Facility (EPA Region 9 and DOH 2015) was issued in September 2015 following the aforementioned 2014 Tank 5 release. The AOC requires the United States (U.S.) Department of the Navy and Defense Logistics Agency to take actions, subject to DOH and U.S. Environmental Protection Agency (EPA) approval, to address potential future fuel releases and to implement infrastructure improvements to protect human health and the environment.

Sections 6 and 7 of the AOC Statement of Work (SOW) specifically call for environmental investigations to characterize the subsurface pursuant to addressing current and future environmental and risk concerns. Several completed and ongoing environmental investigations have been and/or continue to be conducted to fulfill the requirements of Sections 6 and 7 of the AOC SOW.

In 2018, an interim groundwater flow model was developed by AECOM under contract to the Navy to simulate groundwater flow in the area of the tanks (DON 2018, Appendix A). Further investigation—including but not limited to completing detailed geologic and geophysical logging, groundwater sampling, and monitoring of water levels, and modeling analysis—were conducted to build on the 2018 modeling. The resulting groundwater flow model was published in the March 2020 GWFM Report (DON 2020). This current work expanded previous modeling work, incorporating data and insights from the RAs and related

subject matter experts (SMEs). The goal of the 2020 GWFM Report was to improve on existing modeling, estimate capture zones of water supply wells, and serve as the flow modeling foundation for CF&T modeling as required by AOC SOW Section 7.2.2. According to the AOC SOW, development of the CF&T models is to occur after the GWFM is approved. On March 17, 2022, the Navy received a letter disapproving the GWFM Report (EPA Region 9 and DOH 2022), citing deficiencies identified by the RAs' respective SMEs.

After submittal of the 2020 GWFM Report, additional releases from the Facility were documented in May and November of 2021:

- **May 2021 Release:** On May 6, 2021, a (b)(pipeline near Red Hill Tanks 18 and 20 was damaged during a fuel transfer procedure. Fuel was released to the tunnel floor, and attempts were made to recover the fuel. It was later determined that fuel that was not recovered was pumped from a fire suppression retention system into a fire suppression recovery drain line and leach/holding tank. The fuel remained contained in that drain line and holding tank until the drain line was later damaged on November 20, 2021.
- **November 2021 Release:** On November 20, 2021, fuel was released from the fire suppression recovery drain line, traveled along the concrete tunnel floor toward Adit 3, and collected in a groundwater sump near Adit 3 (Adit 3 Sump). A portion of the fuel was recovered from the sump; the remainder of the fuel entered the soil and volcanic bedrock near (b)(3 from which some of the fuel entered the Joint Base Pearl Harbor-Hickam (JBPHH) Water Distribution System. (b)(3 ceased pumping and was isolated from the JBPHH Water Distribution System on November 28, 2021. Water supply wells BWS Hālawa Shaft and (b)(3) stopped pumping on December 3, 2021. Initial site characterization of the release areas has been completed (DON 2023b); additional characterization, monitoring, and remediation efforts continue (DON 2023a).

  Released fuel flowed along the Adit 3 Tunnel floor westward past the junction with the Pearl Harbor Tunnel and (b)(3 Fuel accumulated in a sump (Adit 3 Sump) approximately 750 feet (ft) west of the November 2021 release point. (b)(fuel was recovered from the Adit 3 Sump, connected piping, the fire suppression recovery drain line, and a Holding Tank/Leach Tank area outside Adit 3 including subsurface soil. The November 2021 release released fuel to the environment from the Adit 3 Sump, a Hume (French drain) line located immediately below the tunnel floor, and the Holding Tank and Leach Tank area. Fuel was observed in the water development tunnel of (b)(3 Upon confirmation that a fuel-like odor was present in drinking water in homes served by (b)(3 the supply well was shut off and isolated from the JBPHH Water Distribution System on November 28, 2021.

In response to these releases and associated potential risks, the U.S. Secretary of Defense made the decision to defuel and close the Facility (DoD 2022), which is scheduled to begin in fall of 2023 and be completed in 2024. Defueling refers to the removal of stored fuel and decommissioning of tanks and supply lines.

To assist in decision-making regarding defueling, the Navy developed the models described in this technical memorandum to provide preliminary, best-available CF&T simulations, based on the related interim

GWFM and VZM. The GWFM associated with the best available modeling submittal was designed to address deficiencies in the RAs' disapproval letter that could be addressed within the defueling timeframe. The CF&T modeling in this technical memorandum is based on the best-available GWFM, as documented in the *Groundwater Flow Model Technical Memorandum* (DON 2023c). The VZM is documented in the *Vadose Zone Model Technical Memorandum* (DON 2023d). The final modeling work will incorporate additional field work and analysis of data after June 2023 and be delivered September 30, 2024. The final modeling work will address RA comments from the 2022 review letter and comments received on the June 30, 2023 modeling work.

1.1 Study Objectives

The objectives of the three modeling components are to:

- GWFM: "…improve the understanding of the direction and rate of groundwater flow within the aquifers around the Facility," as expressed in AOC SOW Section 7.1 (EPA Region 9 and DOH 2015, Attachment A).
- VZM: inform source-term conditions for the CF&T model.
- CF&T Modeling: "…utilize the Groundwater Flow Model to improve the understanding of the potential fate and transport, degradation, and transformation of contaminants that have been and could be released from the Facility," as expressed in AOC SOW Section 7.2 (EPA Region 9 and DOH 2015, Attachment A).

Finally, the modeling results will be used to guide and inform the number and placement of groundwater monitoring wells required to adequately identify possible contaminant migration (AOC SOW Section 7.3) (EPA Region 9 and DOH 2015, Attachment A).

The specific objective of the CF&T model is to provide stakeholders with information that can be used to estimate the risk posed to potable water produced at (b)(3) and BWS Hālawa Shaft as well as other potential receptors by a range of hypothetical petroleum releases during tank defueling. One specific question to be addressed by the model is:

- What are the ranges of concentrations of petroleum fuel constituents likely to be in water from (b)(3) and BWS Hālawa Shaft following a hypothetical release?

The results of the modeling will be used to inform groundwater monitoring decisions, such as:

- How large might the footprint on the water table be?
- If light nonaqueous-phase liquid (LNAPL) from a fuel release reaches the water table, how long is it likely to persist?
- How long might soluble constituents be released to groundwater, and what might the concentrations of these constituents be over time?

2.0 Contaminant Fate and Transport Model

2.1 Approach

The CF&T model simulates the fate and transport of dissolved chemicals as they move with groundwater (advection) and as they attenuate through natural processes such as dispersion and degradation. Diffusion is assumed to be a negligible component of dissolved-phase transport due to relatively high groundwater velocities. CF&T modeling is based on the groundwater flow patterns simulated in the groundwater flow model. The GWFM Technical Memorandum (DON 2023c) provides an in-depth discussion of approach, calibration, sensitivity, and simulations to support the CF&T model. Typically, the flow and fate and transport models are developed in conjunction, so that interim CF&T results inform the flow model, which can then be modified to provide more accurate mass transport simulations. However, because of time constraints, this interim CF&T does not benefit from the full iterative process between the flow and CF&T models. The final models will reconcile, to the extent practicable, significant discrepancies among the three models, including the VZM.

CF&T modeling was conducted in three stages: historical simulations, hypothetical release simulations, and sensitivity analysis. Each of the three documented recent historical releases was simulated based on the information available. Analytical data for dissolved petroleum hydrocarbons in groundwater following each of the releases are often affected by many factors, including the potential for preferential pathways, pre-existing residual LNAPL sources in the unsaturated zone, water table fluctuations, and precipitation events. Where possible, groundwater monitoring data were used in the history-matching process to calibrate transport parameters dispersivity, effective porosity, and degradation. Source concentrations were also adjusted as necessary. In cases where matches to historical data were not achievable, the models can still be used as a tool to understand potential implications of mismatches between observed and simulated conditions, and to improve the underlying conceptual understanding of the hydrogeological system.

After final estimates of fate and transport parameters were established, a series of twelve hypothetical release scenarios were simulated. Four locations were selected: Tank 5, Tanks 18 and 20, RHMW(b and (b)(3 Adit3. At each location, a small ((b)(3) gallon [gal]), medium ((b)(3) gal), and large ((b)(3)(b)(3) gal) fuel release was simulated. These hypothetical release volumes were chosen to correspond with a release of 0.1%, 1%, and 100% of a single tank volume, respectively. Subsequently, a sensitivity analysis was performed to assess impacts on history matching and a range of potential outcomes.

2.2 Conceptual Site Model for Dissolved Phase Flow

This section provides a summary of the CSM for fate and transport of dissolved-phase chemicals. The CSM for geology and hydrogeology is summarized in the GWFM Technical Memorandum (DON 2023c).

The CF&T model used output from the VZM to establish boundary conditions (source terms) for different release scenarios. The source terms result from released petroleum fuel, which is a LNAPL. Some portion of LNAPL released at the ground surface is assumed to travel downward and form a lens at the water table. The size of the theoretical LNAPL lens is calculated by assumptions of average LNAPL lens thickness, average LNAPL lens saturation, and the volume of LNAPL that reaches the water table. These parameters are defined in the VZM Technical Memorandum (DON 2023d).

LNAPL is assumed to remain at the water table surface for the CF&T model. Although LNAPL can be forced below confining layers by large LNAPL heads at the site of a release, this process is not considered for this stage of interim modeling. Groundwater that migrates through the LNAPL lens dissolves soluble LNAPL constituents and transports these constituents downgradient within the saturated zone. The LNAPL composition and volume change over time as the LNAPL constituents dissolve out of the LNAPL at different rates. The transient source concentrations are established by the partitioning module of the VZM. Dissolution of constituents of concern (COCs) into the groundwater from LNAPL on the water table is the only mechanism currently considered for introduction of mass into the CF&T model.

In the current CF&T model, LNAPL depletion occurs only through dissolution into groundwater. Other LNAPL depletion mechanisms, including volatilization, adsorption, and biodegradation, may be considered in the future.

Constituents to be modeled include total petroleum hydrocarbons (TPH) in the diesel and oil range, designated as TPH-diesel range (TPH-d) and TPH-oil range (TPH-o). This selection was based on a weight-of-evidence evaluation supported by the frequency of detections of these chemicals, the likely presence of these chemicals based on historical usage of (b)(and (b)(as well as the presumed presence of residual weathered LNAPL in the vadose zone.

Most of the TPH detections at the Red Hill site have been in the diesel and fuel oil range. Chromatograms indicate that the initial LNAPL constituents composing these TPH fractions have been highly biodegraded, such that most of the TPH compounds detected are polar degradation products of the parent compounds. The specific degradation products and the biodegradation pathways responsible for degradation of the parent LNAPL have not been established at the site. Therefore, the CF&T model uses a simplifying assumption: TPH-d and TPH-o are assumed to solubilize from the LNAPL according to the average solubilities of each TPH fraction. These solubilized constituents are then assumed to be instantaneously converted to polar degradation products in groundwater. The mass of polar TPH compounds is assumed to be the same as the mass of the parent TPH-d or TPH-o that dissolved from the LNAPL.

The polar TPH-d and TPH-o compounds are assumed to undergo first-order biodegradation in the groundwater. A first-order degradation model is suitable at low concentrations because the concentrations are typically much less than the Monod half-saturation constant. Because polar compounds are much more soluble in water and do not adsorb onto organic carbon as readily as their parent compounds, the CF&T model assumes no adsorption of TPH-d and TPH-o onto soils. As a result, the TPH compounds migrate at the same rate as the groundwater in which they are dissolved. Volatilization is also not considered to be a significant attenuation mechanism during contaminant transport, which is a reasonable assumption for TPH in the diesel and oil ranges.

2.2.1 Historical Releases

December 2014

During refilling operations at Tank 5 following a scheduled tank-refurbishment project, a fuel release was discovered and verbally reported to DOH on January 13, 2014. A release of (b)(from Tank 5 was confirmed and reported to DOH in writing on January 23, 2014. The volume of fuel lost from Tank 5 was

estimated at 27,000 gallons. The following timeline of the 2014 release was compiled from sources described in the Red Hill CSM report (DON 2019, Section 4.5):

- Following a 3-year inspection and refurbishment completed in accordance with a process conducted every 20 years, Tank 5 was placed back into service on December 9, 2013, and the Navy commenced filling it with (b)(fuel.
- Alarms were activated when initially filling Tank 5 following the tank refurbishment.
- Operators observed an unscheduled fuel movement on January 11, 2014 and confirmed a 3/16-inch drop in fuel with manual gauges by January 13, 2014. Product from Tank 5 was drained.
- A fuel hydrocarbon seep was observed below Tank 5 on the evening of January 12, 2014 in the lower cross tunnel wall near the exterior of the material encasing the lower part of the tank. A sample showed that the liquid was (b)(fuel.
- The soil vapor monitoring points (SVMPs) under Tank 5 exhibited a sharp increase in hydrocarbon vapor concentrations from previously measured December 15, 2013 levels, and concentrations also increased significantly in nearby SVMPs at Tanks 3, 6, 7, 8, and 9.
- Subsequent analysis indicated faulty work by a contractor, specifically:
  - Defective workmanship in welding by the contractor was found in Tank 5.
  - Defective welds had not been discovered and corrected by the contractor due to poor inspection and ineffective quality control.
  - Seventeen unrepaired ¼-inch gas test holes drilled through the tank shell were found.

These, along with defective welds on patch plates that covered the gas test holes, were deemed the underlying cause of the release. As noted in the AOC Section 2 *Tank Inspection, Repair, and Maintenance Report* (NAVFAC EXWC 2016, Section 9-2.1.4): "When Tank was filled with fuel, the typical leak path was through defects in the seal weld, through the joint between a patch plate and the tank shell, and through the gas test hole."

May 2021

On May 6, 2021, a pipeline carrying (b)(near Red Hill Tanks 18 and 20 was damaged during a fuel transfer procedure. Fuel was released to the tunnel floor, and attempts were made to recover the fuel. It was later determined that fuel that was not recovered was pumped from a fire suppression retention system into a fire suppression recovery drain line and leach/holding tank. The fuel remained contained in the drain line and holding tank until the drain line was damaged on November 20, 2021.

November 2021

On November 20, 2021, fuel was released from the fire suppression recovery drain line, traveled along the concrete tunnel floor toward Adit 3, and collected in a groundwater sump near Adit 3 (Adit 3 Sump). Some of the fuel was recovered from the sump; the remainder of the fuel entered the soil and volcanic bedrock near (b)(3 from which some of the fuel entered the JBPHH Water Distribution System.

2.2.2 Key Assumptions

Key assumptions for the CF&T model are:

- The LNAPL lens forms at the water table and reaches its ultimate extent instantaneously.
- Once at the water table for each scenario, the LNAPL lens is assumed to be stable.
- The LNAPL lens contains only water and LNAPL (air is not present in the pore space below the air-LNAPL interface).
- The shape of the LNAPL lens is approximately circular, encompassing a number of model cells with an area corresponding to the computed area of the LNAPL lens from the VZM.
- Dissolved-phase concentrations in source cells will be initially diluted by the ratio of the source model cell thickness divided by the LNAPL lens thickness. For example, if the source concentration calculated by the VZM partitioning module is 10 milligrams per liter (mg/L), the LNAPL lens thickness is 2 ft, and the CFT model source cell thickness is 25 ft, then the concentration in the CFT model source cell would be set to 0.8 mg/L. (However, final source concentrations were established during model calibration).

$$Diluted\ Concentration = \frac{Concentration \times LNAPL\ Thickness}{Model\ Cell\ Thickness}$$

- TPH-d and TPH-o are the only two soluble constituents that dissolve from the LNAPL.
- Biodegradation, volatilization, and adsorption are conservatively assumed to not occur in the dissolved-phase contaminants.

2.3 Concentration Data for Calibration

The data used for model calibration consist of TPH-d and TPH-o groundwater concentration data collected using several different sampling methods, with groundwater samples analyzed by different analytical laboratories. The variable sample collection methods, differences in results between laboratories, and the different chemical nature of the TPH detected at each location make interpretation of the analytical data challenging. For this stage of CF&T modeling, the data have not been thoroughly analyzed to determine which specific concentrations could be related to the three known historical releases. Instead, the data are taken at face value without attempting to determine if specific breakthrough curves are consistent with the chemical nature of the historical releases. At a later stage, the specific chemical nature of the TPH data will be used to assess the possible association of TPH concentrations to the historical release events.

Nevertheless, some basic observations can be used to determine whether TPH data are likely to be associated with the three historical releases simulated. The observations include: 1) the timing of any observed increases and/or decreases in TPH concentrations, 2) the association of other chemicals with TPH at the time of significant concentration changes, and 3) the degree of degradation of the parent TPH as indicated by the difference in concentrations before and after silica gel cleanup (SGC). SGC removes polar compounds from the TPH fraction. These polar compounds are commonly present as by-products of parent TPH biodegradation, or are substances that are not associated with the parent petroleum. The concentration

before and after SGC can be used to determine the general degree of biodegradation, which can be useful for determining source locations and age, and chemical transport rates.

The interpretation of TPH data for the four wells used in this initial calibration (RHMW(b)(9) RHMW (b RHMW(b and (b)(3 are discussed below.

2.3.1 RHMW(b) TPH Data

Concentrations of TPH-d at RHMW01R increased by a factor of approximately 2–3 after the May 2021 release but prior to the November 2021 release at (b)(3 which is downgradient from RHMW(b)(The TPH-d detections continued to spike occasionally until mid-2022, when they largely returned to baseline (pre-May 2021) levels. TPH-o levels occasionally spiked, but the concentrations spikes are intermittent and separated by many non-detect results. Concentrations of 1-methylnaphthalene also increased slightly sooner than TPH-d, peaking at about 2–4 times baseline concentrations. The TPH-d SGC results indicate that most detected TPH following the May 2021 release is polar, suggesting significant degradation of the TPH-d, either at the source or during transport. Historically, TPH-d concentrations in RHMW01, screened at the same location but at a higher elevation, have been as high as 1,500 micrograms per liter (µg/L), although baseline concentrations hovered around 200–400 µg/L between 2010 and just prior to the May 2021 release.

The TPH concentration data from RHMW01R suggest that this well may have been impacted by (b)(from the May 2021 release based on the presence of 1-methylnaphthalene and TPH-d, which are both associated with (b)((b)(Most of the TPH-d detected in RHMW(b)(is polar, indicating that significant biodegradation of the TPH following the release has occurred. The TPH-d data from this well could be used for model calibration.

2.3.2 RHMW(b) TPH Data

Significant concentrations of naphthalenes, TPH-d, and TPH-o have been detected at RHMW02 since the well was installed in 20(b These constituents are associated with both (b)(and (b)(Concentrations of these constituents prior to the December 2013 release indicate impacts from undocumented historical releases in the area. Some of the historical concentrations exceed the concentrations detected in groundwater since 2014. More recent TPH data collected since 2014 suggest years of impacts at this location.

TPH-d, 1-methylnapthalene, 2-methylnapthalene, and naphthalene concentrations all show a slight increase after the November 2021 release event, although the concentrations are highly variable, and some concentrations were similar to concentrations prior to the November 2014 release, so the apparent concentration increase may simply represent concentration variability from factors unrelated to this release event.

Concentrations of TPH-d and TPH-o appear to have increased following the May 2021 release, with some fluctuation around the time of the later November 2021 release. Concentrations of naphthalene and 1-methylnaphthalene during this period remained relatively stable, while concentrations of 2-methylnaphthalene show a slight increase in mid- to late 2021. TPH-o concentration trends roughly mirrored the TPH-d concentration trends. The TPH-d SGC data indicate that the TPH-d found in RHMW(b)

since the beginning of 2021 is mostly polar compounds, with a possible increase in the non-polar compound fraction in late 2021.

The increase in TPH-d in mid-2021 and its subsequent decrease between early 2022 and early 2023 could be indicative of impacts from the May 2021 release, although the high background concentrations at this location render interpretation of the data difficult. The approximately 2-fold increase in 2-methylnaphthalene concentrations accompanying the TPH-d increase in mid-2021 suggests a possible new (b)((b)(source impacted the well. Although 2-methylnaphthalene is associated with many petroleum fuels, including (b)((b)(its increase in conjunction with the increase in TPH-d (which is indicative of kerosene-range petroleum fuels) suggests a new (b)((b)(source. Both the TPH-d and TPH-o data could be useful for model calibration, using the increase above background to indicate the contribution from the May 2021 release.

2.3.3 RHMW(b) TPH Data

TPH-d concentrations at RHMW(b have increased gradually between 2014 and 2020, then declined before increasing again following the May 2021 release. TPH-o concentrations follow a similar pattern, but with lower historical concentrations and a steeper increase since 2014. Naphthalene compounds have been detected in RHMW(b rarely since 20(b TPH-d concentrations increased following the May 2021 release, although the elevated concentrations are sporadic and interspersed by some non-detects. Concentrations of TPH-o also increased following the May 2021 release, and somewhat elevated concentrations remained through early 2023.

The lack of naphthalene compounds and the presence of significant TPH-o in RHMW(b is not consistent with a release of only (b)((b)(It is possible that residual LNAPL in the area of this well was mobilized during cleanup of the May 2021 release, and that this mobilized TPH-o mixed with some TPH-d that originated from the fresh release. Although the TPH-o in groundwater at RHMW(b is unlikely to be associated with the May 2021 release, the data are nevertheless useful for estimating rates of TPH-o migration under the assumption that the TPH-o was mobilized during the release cleanup. The TPH-d data could also be useful for calibration.

2.3.4 (b)(3)(b)(3)(b)(3) TPH Data

Very few detections of TPH or any naphthalene compounds occurred prior to the November 2021 release at (b)(3 Following the November 2021 release, significant detections of TPH-d and TPH-o occurred at this location. Much of the TPH-d was non-polar, suggesting that the impacts were associated with fresh (b)((b)(fuel. Elevated xylenes were also detected following the November 2021 release. Because xylenes rapidly biodegrade aerobically in both the vadose zone and groundwater, the presence of xylenes suggests a short travel path between the source and the groundwater. This short travel path is consistent with the fact that the release occurred immediately above (b)(3 Data from the pre-chlorination spigot is difficult to interpret and is still being analyzed. Although the (b)(3 data appear to be associated with the November 2021 release, the data are not particularly useful for model calibration because of the nearness of the release to the monitoring point.

2.3.5 TPH-o Breakthrough Sequence Following May 2021 Release

Although TPH-d is more closely related to (b)(than TPH-o is, the TPH-o data appear to show a clearer response to the May 2021 release, indicating potential mobilization of residual contamination during cleanup. Therefore, the TPH-o data were used for calibration of the model to this release event. Timing of the initial breakthrough and the peak TPH-o concentration are shown for the various wells on Chart 2-1 through Chart 2-6. RHMW(b and RHMW(b)(had only one detection or exceedance during this period; therefore, dates are the same for initial breakthrough and peak. Estimated groundwater velocities ranged from 2.5 to 52.4 feet per day (ft/d), as shown in Table 2-1. Although it is expected that groundwater velocity is variable along the travel paths between the release location and (b)(3 the timing of the detections and high variability in velocity does not lead to a clear sequence of breakthrough curves down the Red Hill ridge, particularly the timing of exceedances at the (b)(3 pre-chlorination spigot occurring well before detections occurred at RHMW(b and RHMW(b)(Peak concentration at the (b)(3 pre-chlorination spigot also occur prior to the peak at RHMW(b and RHMW(b)(Based on the available data, concentrations at RHMW(b are the most reliable, followed by RHMW(b) which may be also related to the May 2021 release. Other sporadic hits at RHMW(b)(and RHMW(b may be related but do not exhibit clear enough behavior for history matching. Because concentrations at the (b)(3 pre-chlorination spigot occur around the same times as those at RHMW(b) and RHMW(b it presents a conceptual inconsistency in the groundwater flow path that is currently unexplained. It is possible either that the detections are not related to the same source, or that some component of the TPH-o plume reached a preferential pathway that directed it to (b)(3 much faster than the remainder of the plume.

Table 2-1: Estimated Groundwater Velocities After May 6, 2021 Release

Parameter	RHMW(b	RHMW(b	RHMW0(b)(	RHMW(b	(b)((pre-chlorination spigot)
Date of breakthrough	6/4/2021	6/4/2021	11/10/2021	9/29/2021	7/8/2021
Date of peak concentration	8/26/2021	9/8/2021	11/10/2021	9/29/2021	8/5/2021
Distance from release (ft)	275	1,1(b	1,725	2,580	3,300
Total travel time for arrival (days)	29	29	188	146	63
Total travel time to peak (days)	112	125	188	146	91
Average groundwater velocity to breakthrough from release (ft/d)	9.5	38.1	9.2	17.7	52.4
Average groundwater velocity to peak from release (ft/d)	2.5	8.8	9.2	17.7	36.3

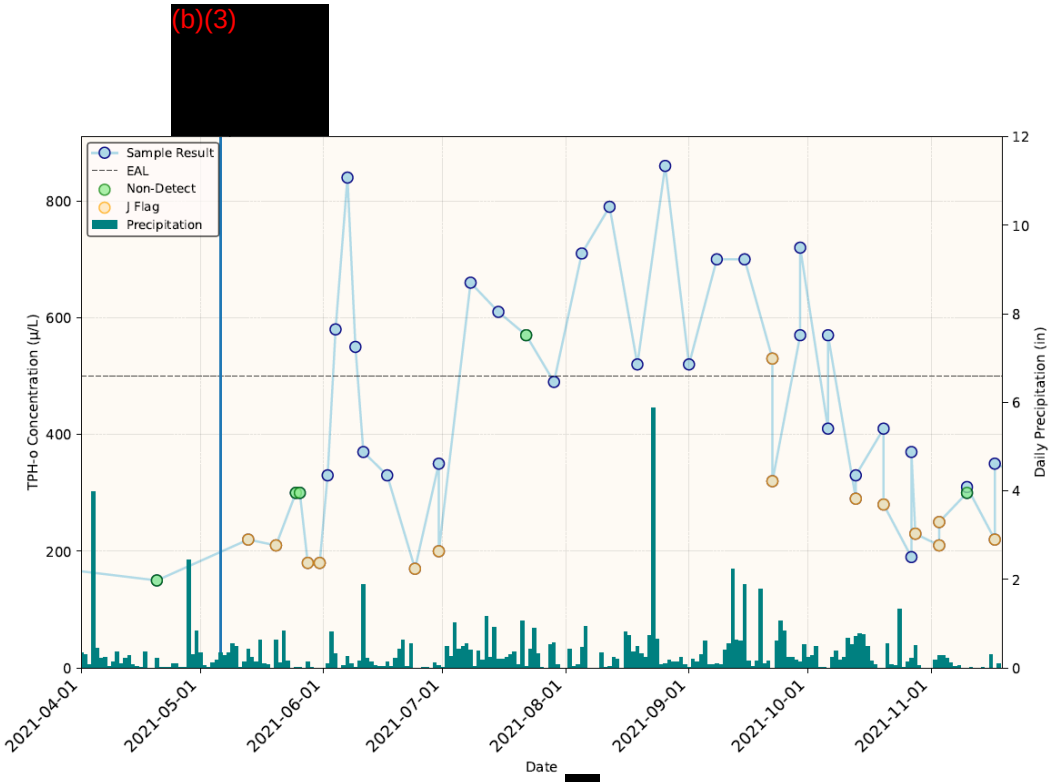


Chart 2-1: TPH-o Concentrations at RHMW(b) following the May 6, 2021 Release

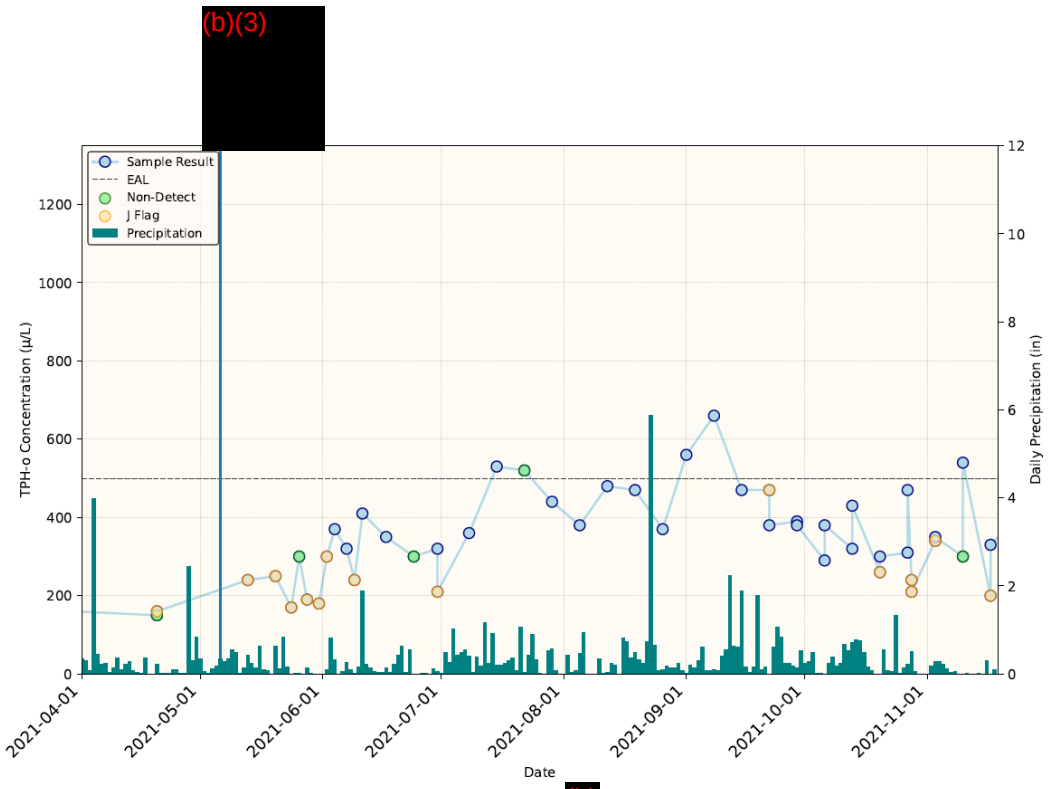


Chart 2-2: TPH-o Concentrations at RHMW(b) following the May 6, 2021 Release

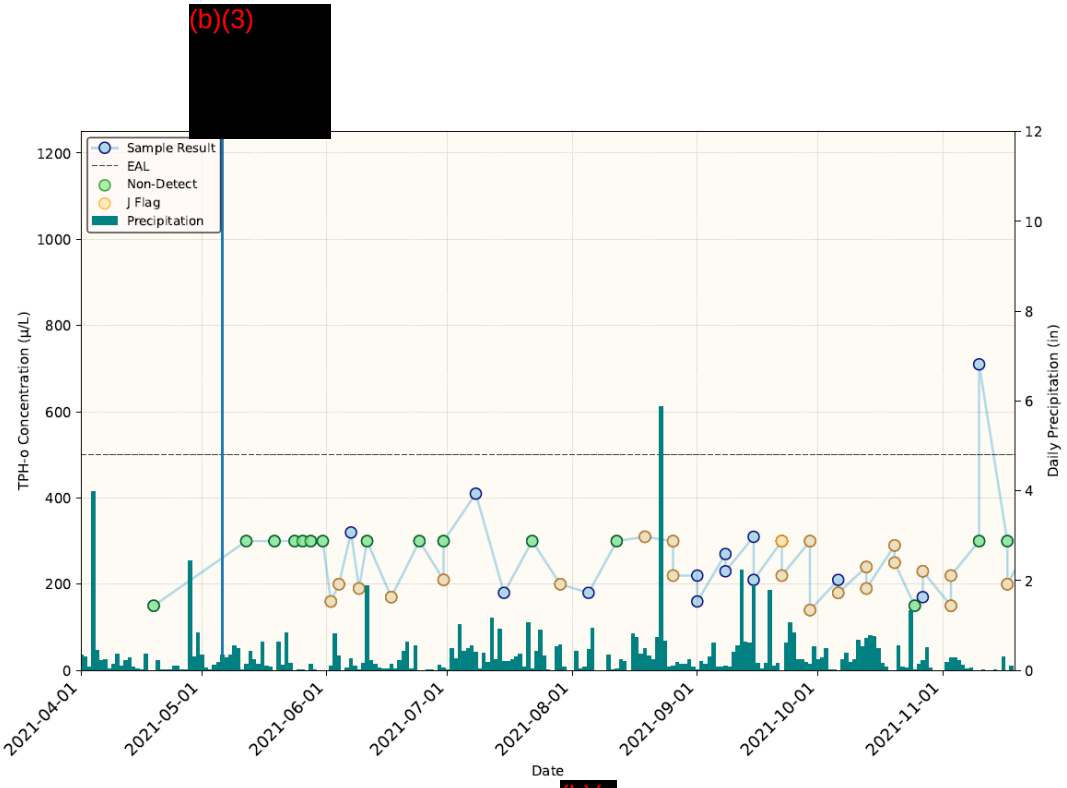


Chart 2-3: TPH-o Concentrations at RHMW(b)(following the May 6, 2021 Release

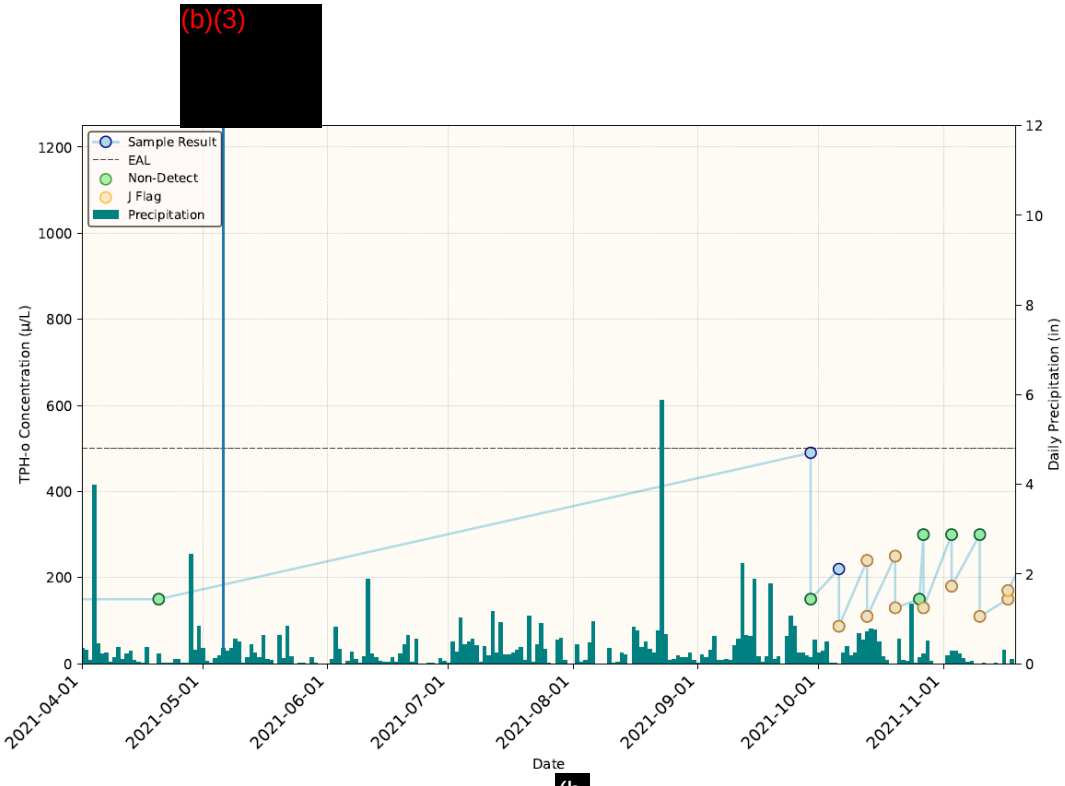


Chart 2-4: TPH-o Concentrations at RHMW(b following the May 6, 2021 Release

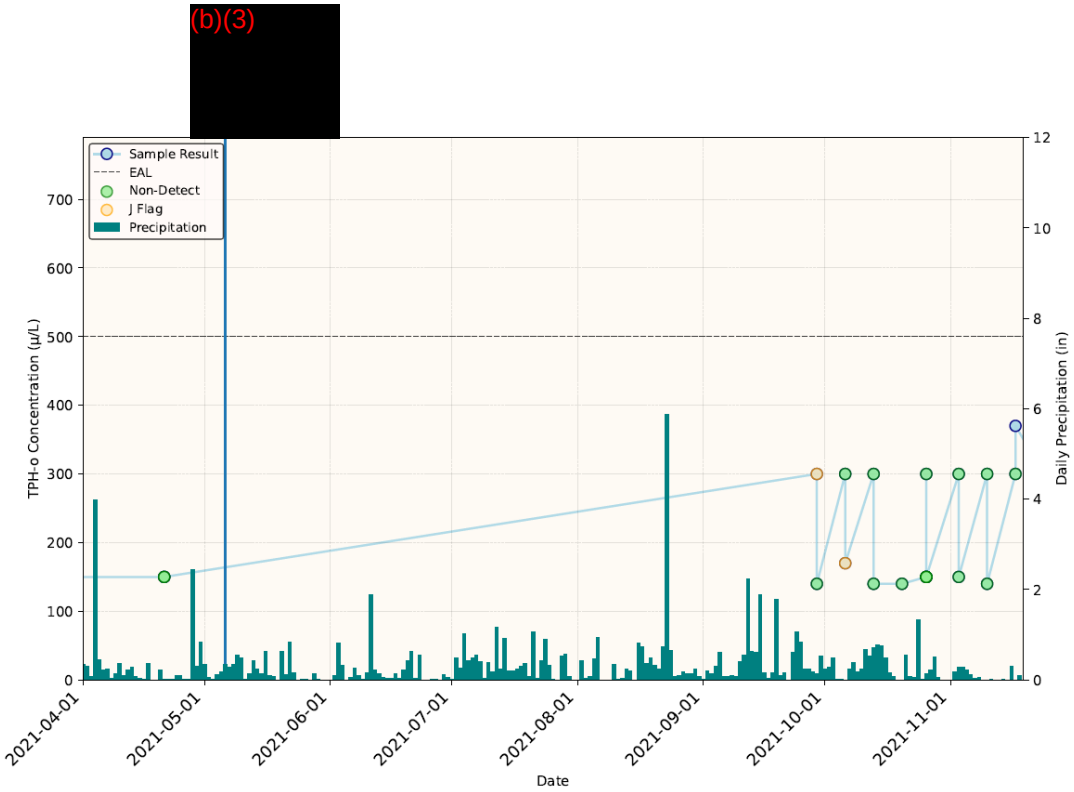


Chart 2-5: TPH-o Concentrations at (b)(3) (RHMW(b)(9)) following the May 6, 2021 Release

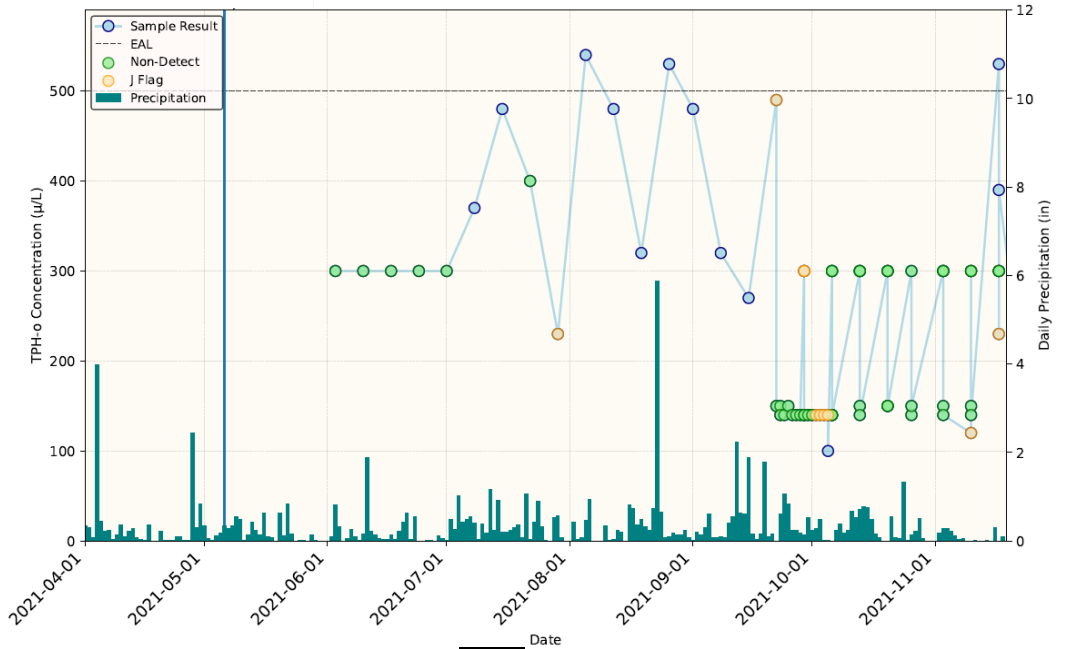


Chart 2-6: TPH-o Concentrations at (b)(3) Pre-Chlorination Spigot following the May 6, 2021 Release

2.3.6 TPH Data Limitations for Calibration

As noted above, use of the groundwater TPH data for CF&T model calibration is affected by several factors. Because the TPH data are used herein for model calibration uncritically, the model calibration based on these data should be viewed as preliminary. Further analysis of the TPH data is likely to result in changes to the rates of TPH transport and degradation, and to the magnitude and extent of the TPH concentrations simulated in the CF&T model.

Model Transport Parameters

Migration of COCs in groundwater depends on dispersion, effective porosity, and biodegradation rates. Because no adsorption is initially included in the CF&T model, organic carbon/water partitioning coefficients (Koc's) are not needed for the model. Similarly, Henry's constants are not needed because volatilization is assumed to be negligible.

Dispersion affects the degree of spreading of constituent concentrations. It is difficult to measure dispersivity at the field scale. While some methods are available to estimate dispersivity based on plume length or distances to measurement points, dispersivity values can range over 2–3 orders of magnitude (Gelhar, Welty, and Rehfeldt 1992). Dispersion coefficients were initially set based on the horizontal size of the model cells. In the area of the refined CF&T model grid, cells are 25 ft × 25 ft. The initial longitudinal dispersion coefficient was therefore set to 25 ft. The horizontal transverse dispersion coefficient was set at 1/10 the value of the longitudinal dispersion coefficient, and the vertical transverse dispersion coefficient was set to 1/100 the longitudinal value. Dispersion coefficients were adjusted during the CF&T model history matching. Dispersivity is generally used as a broad ranging tool that can account for heterogeneities and uncertainties in CF&T modeling. Final models are anticipated to use lower dispersion coefficients due to additional deconvolution of data, iterative calibration of the GWFM, and incorporation of the basalt heterogeneity based on geostatistical realizations.

Effective porosity is the volume of pore space that participates in storage and migration of dissolved chemical species, and is less than the total porosity of the medium (Panday 2022). Effective porosity affects the average advective velocity (seepage velocity) of the groundwater. In the absence of adsorption, chemicals migrate at this same average velocity. Effective porosity is highly variable throughout the site, and its magnitude at any location is not known with certainty. Therefore, the initial effective porosity was set to an initial value of 0.015, based on initial estimates of travel time from the tank farm to (b)(3 but was adjusted during calibration to obtain a reasonable match between simulated and observed concentrations.

Both TPH-d and TPH-o are composed of hundreds of compounds, each with a different biodegradation rate and biodegradation mechanism. In the CF&T model, the biodegradation therefore represents a "lumped" rate that reasonably represents the many compounds that compose each TPH type. The biodegradation rate was derived by history matching, so that no initial rate was specified for the CF&T model.

3.0 Historical Release Simulations

Simulations and history matching were conducted for the three historical releases, where transport parameters were calibrated to match observed concentrations. Simulations are discussed in the order by which they were calibrated. The May 2021 release offered the most information on groundwater velocities

and dispersivity; therefore, it was used to calibrate effective porosity and dispersivity. Calibrated values were carried forward to the simulation of the December 2013 release where the scaling factor on initial concentration of TPH-d was calibrated. Simulation of the November 2021 release was conducted last, and no parameters were calibrated based on the associated data. Concentrations of TPH-d related to this release were observed only within (b)(3 however, LNAPL was also observed within (b)(3

3.1 May 2021 Release

3.1.1 Simulation Approach

A relatively small volume of (b)(that was reported to have not been recovered ((b)(3gal) was assumed to have entered the subsurface. Results of the VZM indicated that it was not likely to have reached the water table as LNAPL. Additionally, no clear impacts of TPH-d, indicative of a fresh fuel release, were observed at the immediately downgradient well RHMW(b However, TPH-o concentrations measured at RHMW(b appear to show a breakthrough curve in the weeks and months following the release. While TPH-o is not expected to be a component of a (b)(release, it is suspected that post-release washing of the tunnel may have solubilized residual LNAPL in the unsaturated zone, sending a temporary slug to the water table and then downgradient toward (b)(3 For these reasons, simulation of the May 2021 release was conducted for TPH-o.

The simulation for the May 2021 release was set up with a single steady-state flow stress period, with (b)(3 pumping at (b)(million gallons per day (mgd). The simulation was run from May 6 through November 20, 2021, for a total duration of 198 days. After this time period, the November 2021 release near (b)(3occurred, obscuring TPH data for comparison. Because the release of TPH-o in response to cleaning of the tunnel and solubilization of residual LNAPL in the unsaturated zone is not consistent with the conceptual model used for the vadose zone model, the release's size and location were estimated based on the reports of the release. The source was set as a constant concentration over an area of nine 25-ft × 25-ft model cells, as shown on Figure 3-1, assigned in the first active saturated layer of basalt (Layer 21). The location of the source was established as west of Tanks 18 and 20, based on reports of where fuel congregated in the tunnel following the release (as discussed at Special Purpose Meeting No. 27, May 31, 2023).

Several parameters were adjusted to better match TPH-o data, including source concentration, duration of the source, dispersivity in three model directions (longitudinal, transverse, vertical), and effective porosity. Degradation of TPH-o was considered to not be an important factor at the time scale of this simulation. In the history-matching process, TPH-o data from RHMW(b were considered the most reliable, with the clearest breakthrough curve. Data from RHMW02 also suggest an apparent breakthrough, with similar timing as that of RHMW(b Other locations with sporadic TPH-o detections and DOH Environmental Action Level (EAL) exceedances include RHMW(b)(RHMW(b)(and the (b)(3 pre-chlorination spigot. Detections at these locations could not be matched.

There are several reasons that TPH-o detections could not be readily matched at RHMW(b including potential inaccuracies in GWFM-simulated flow directions, preferential pathways and heterogeneity at a scale that cannot be modeled, or the detections stemming from different causes (i.e., detections at RHMW(b not related to the May 2021 release), or a combination of these and other factors. To facilitate matching of groundwater velocities, the location of RHMW(b was projected to the northwest, as shown on Figure 3-2,

which allows for comparison of the shape of simulated and observed breakthrough curves, although with different concentration magnitudes. Through this process, the initial concentration for this release was calibrated to a value of approximately 15,000 µg/L and kept active for a period of 70 days. Effective porosity was calibrated to a value of 3.7%. Dispersivity was calibrated to 42 ft in the longitudinal direction and 25 ft in the transverse direction. Vertical dispersivity was relatively insensitive and was therefore fixed at a ratio of 100:1 with longitudinal dispersivity resulting in a value of 0.42 ft.

3.1.2 Simulation Results

The simulated TPH-o concentrations after 120 days are shown on Figure 3-2. The plume color flood represents the maximum concentration across all layers at each cell location. Simulated and measured TPH-o concentrations are shown for RHMW(b and the projected location of RHMW(b in Chart 3-1 and Chart 3-2. At RHMW(b a brief peak of TPH-o was measured in early June 2021, then a gradual increase is observed beginning in early July peaking in early September. Similar timing of TPH-o detections occurs at RHMW(b Because the model assumes homogeneous properties, matching the timing of both curves is not possible. The best fit to the data biases the simulated concentrations at RHMW(b toward the early peak, while the simulated concentrations at the projected location of RHMW(b yielded a better match to the latter portion of the breakthrough curve. No significant detections were simulated at any other wells during the simulation. The simulated travel time for the plume peak to reach (b)(3 was 224 days; however, at that time the simulated concentration at (b)(3 had been diluted to approximately 7 µg/L.

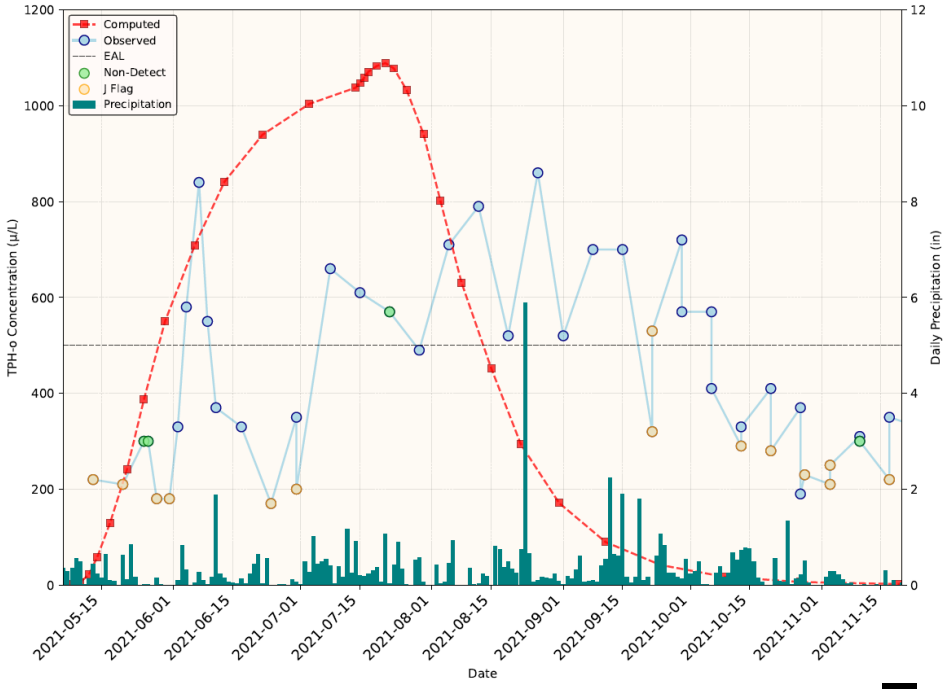


Chart 3-1: Simulated and Observed TPH-o Concentrations at RHMW(b)

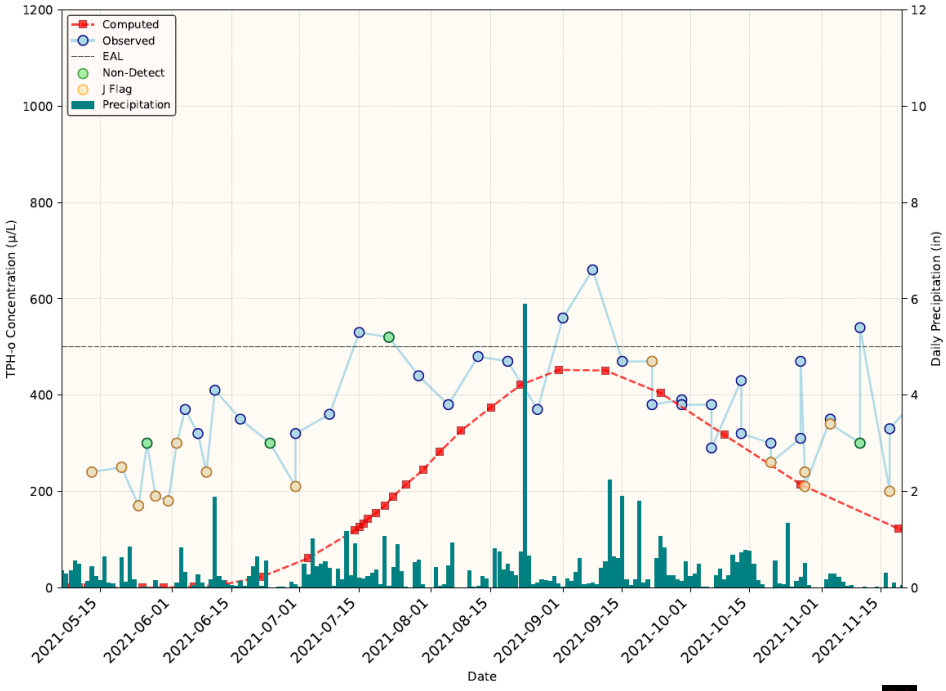


Chart 3-2: Simulated and Observed TPH-o Concentrations at RHMW(b)(6) Projected Location

3.2 December 2013 Release

3.2.1 Simulation Approach

The simulation for the December 2013 release was set up with two steady-state flow stress periods: initially with (b)(3 pumping at (b)(mgd beginning on January 13, 2014 lasting for 46 days, at which point (beginning February 28, 2014) the pumping rate at (b)(3 was increased to (b)(mgd. The second stress period lasted 122 days, ending on June 30, 2014. Transport parameters for effective porosity and dispersivity were assigned the values yielded through history matching during simulation of the May 2021 release, discussed in Section 3.1.1. Degradation of TPH-d was assigned a first-order decay rate of 0.14 per year, corresponding to a half-life of 1,808 days based on the median value from McHugh et al. (2022).

The source zone was assigned an area of 25,000 square feet (ft^2) based on VZM modeling, corresponding to 40 model cells of 25 ft × 25 ft. The location of the source term is shown on Figure 3-3, assigned in the first active saturated layer of basalt (Layers 17 and 18). The source concentration was kept constant throughout the simulation and was adjusted to match the highest concentrations observed at RHMW(b)(which is near the December 2013 release. The VZM indicated a source concentration of 2,550 µg/L; however, the maximum observed concentration at RHMW(b)(was approximately 5,000 µg/L. To achieve the measured concentrations at RHMW(b) the source concentration was adjusted to 22,727 µg/L, an increase by a factor of 8.9.

3.2.2 Simulation Results

The simulated TPH-d concentrations at the end of the simulation are shown on Figure 3-4. The plume color represent the maximum concentration across all layers at each cell location. Simulated and measured TPH-d concentrations are shown for RHMW(b)(RHMW(b) RHMW(b and (b)(3 (RHMW(b)(9) on Chart 3-3 through Chart 3-6. Simulated TPH-d concentrations at RHMW(b)(quickly rise and eventually level off at approximately 5,200 µg/L. The measured concentrations start around the peak of 5,200 µg/L, but then quickly drop off and stabilize between 1,000 and 2,000 µg/L, generally consistent with historical ranges. The simplifying assumption of a constant concentration source is conservative with respect to the observed behavior of the system. Additionally, no clear impacts from the release were observed at other monitoring wells. The simulated concentrations, however, do increase at the other three wells plotted, increasing to maximums of 1,400 µg/L at RHMW(b)(220 µg/L at RHMW(b and 42 µg/L at (b)(3

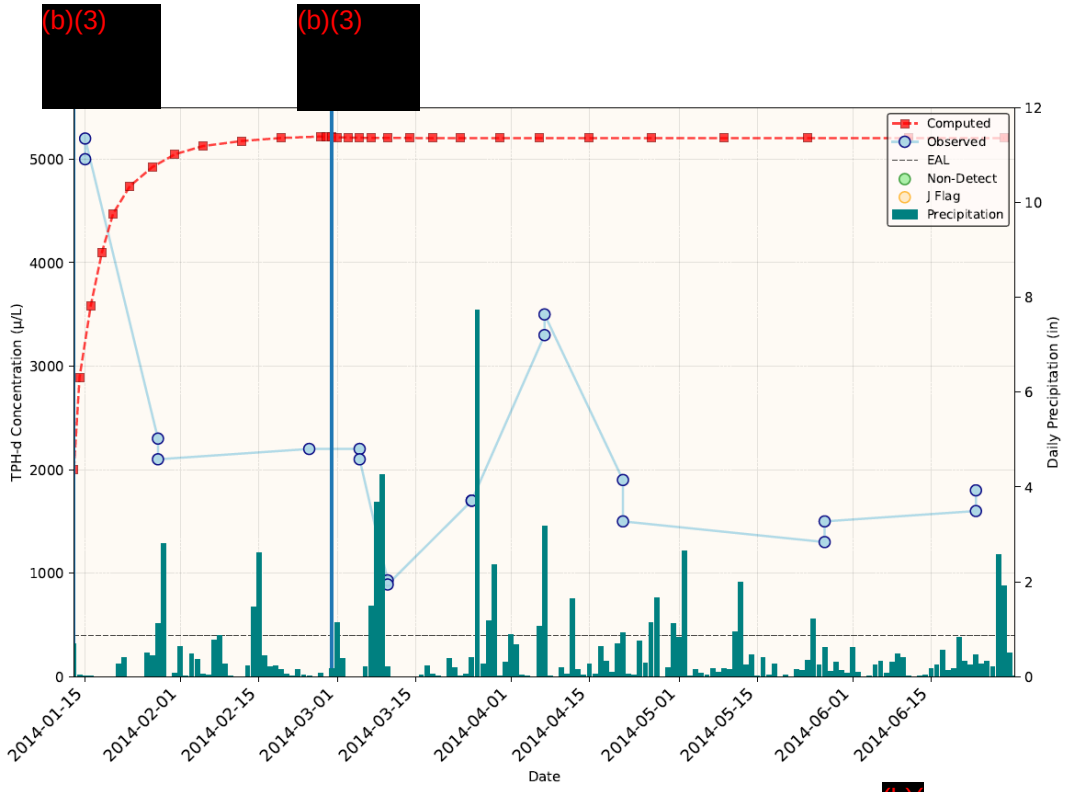


Chart 3-3: Simulated and Observed TPH-d Concentrations at RHMW(b)(3)

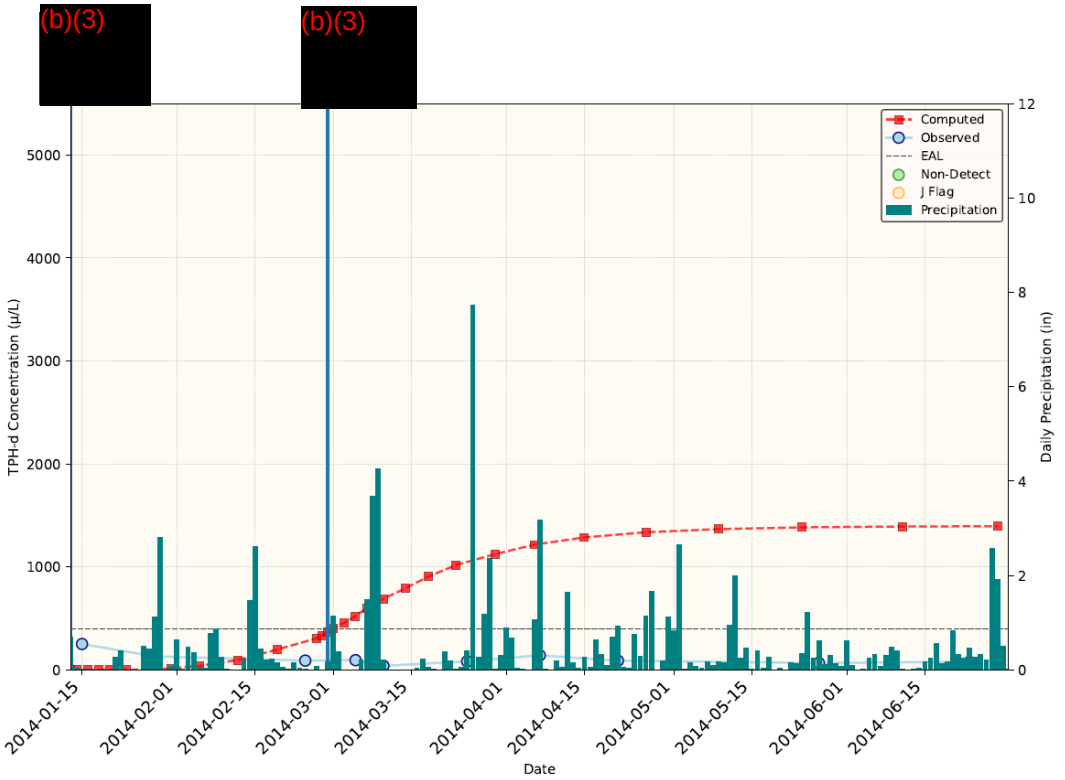


Chart 3-4: Simulated and Observed TPH-d Concentrations at RHMW(b)(3)

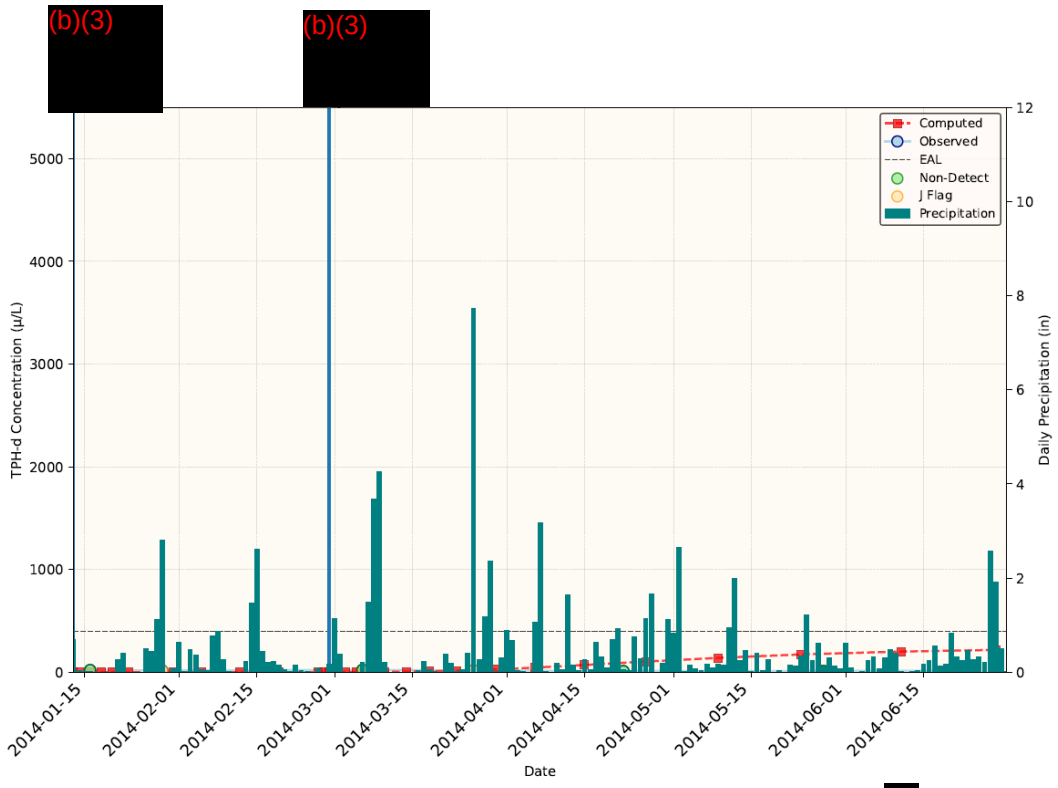


Chart 3-5: Simulated and Observed TPH-d Concentrations at RHMW(b

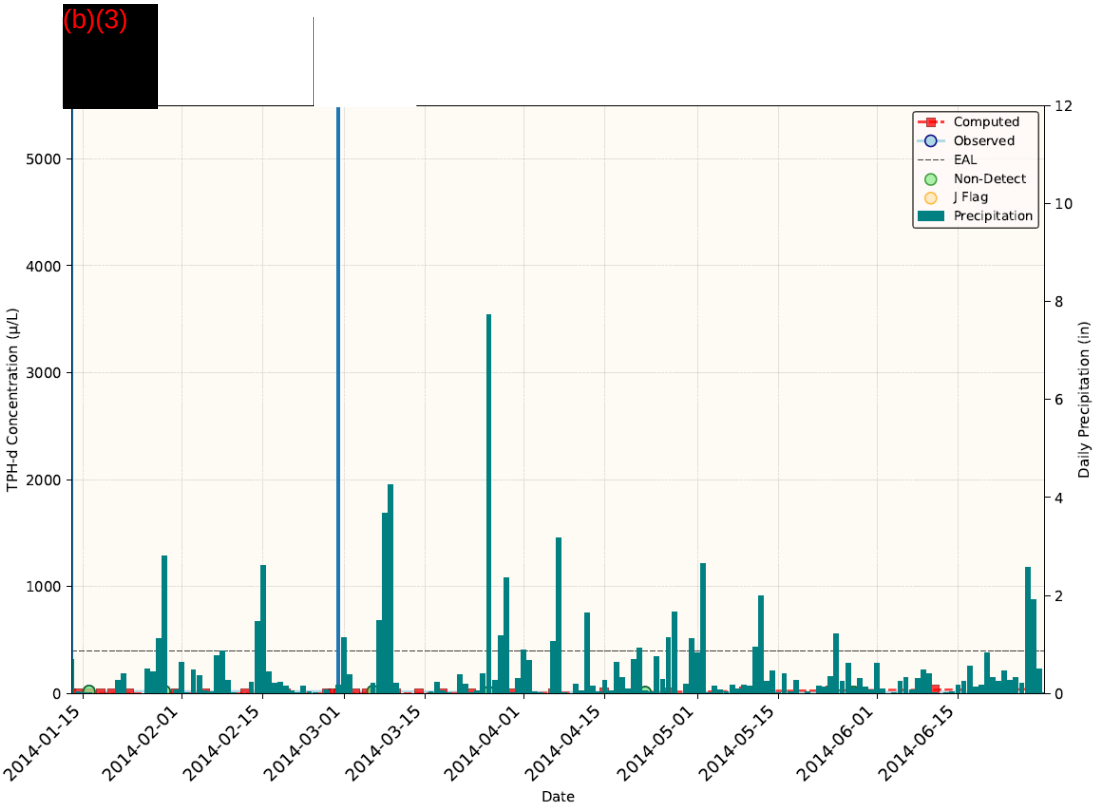


Chart 3-6: Simulated and Observed Concentrations at RHMW(b)(9)

3.3 November 2021 Release

3.3.1 Simulation Setup

The simulation for the November 2021 release was set up with four steady-state flow stress periods, as shown in Table 3-1. Transport parameters for effective porosity and dispersivity were assigned the values yielded through history matching during simulation of the May 2021 release. Degradation of TPH-d dissolved in groundwater was assigned a first-order decay rate of 0.14 per year, corresponding to a half-life of 1,808 days based on the median value from McHugh et al. (2022).

Table 3-1: Stress Period Setup for Simulation of November 2021 Release

Stress Period	Start Date	End Date	Duration (days)	Description
1	11/20/21 0:00	12/2/21 0:00	12.00	(b)(- (b)(3 mgd
2	12/2/21 0:00	12/2/21 12:00	0.50	(b)(b)(
3	12/2/21 12:00	1/29/22 14:00	58.08	BWS Hālawa Shaft (b)(
4	1/29/22 14:00	3/30/22 0:00	59.42	(b)(- (b)(mgd

The source zone was assigned an area based on VZM results that indicated an area of 21,000 ft^2, corresponding to 34 model cells of 25 ft × 25 ft. The location of the source concentration is shown on Figure 3-5, assigned in the first active saturated layer of basalt (Layer 10). The source concentration was kept constant throughout the first two stress periods. The VZM indicated a source concentration of 1,130 µg/L; however, the maximum observed concentration at (b)(3 was approximately 2,400 µg/L excluding one sample with a concentration of over 120,000 µg/L, possibly indicative of LNAPL in the sample. The same adjustment factor of 8.9 times from the December 2013 release simulation was applied to the VZM-generated source concentration, yielding a source concentration of 10,(b 7 µg/L.

3.3.2 Simulation Results

The simulated TPH-d concentrations at the end of the simulation are shown on Figure 3-6. The plume color represents the maximum concentration across all layers at each cell location. Simulated and measured TPH-d concentrations are shown for (b)(3 on Chart 3-7. Simulated concentrations at (b)(3 increase quickly to approximately 1,550 µg/L, but then quickly drop off once (b)(3 is turned off. Measured concentrations drop off more gradually, which may be attributable to the LNAPL observed within (b)(3 In the simulation, concentrations are quickly diluted from the connected linear network (CLN) representing (b)(3 Several wells at the Oily Waste Disposal Facility showed simulated detections of TPH-d; however, they did not result in measured detections at the corresponding times. It is possible that the LNAPL source was not as distributed in the groundwater after the release and was primarily located within (b)(3 Detections at RHMW(b) represent the most significant concentrations of TPH-d following the November 2021 release; however, they are within historical ranges for the well, suggesting that they are attributable to residual source in the area.

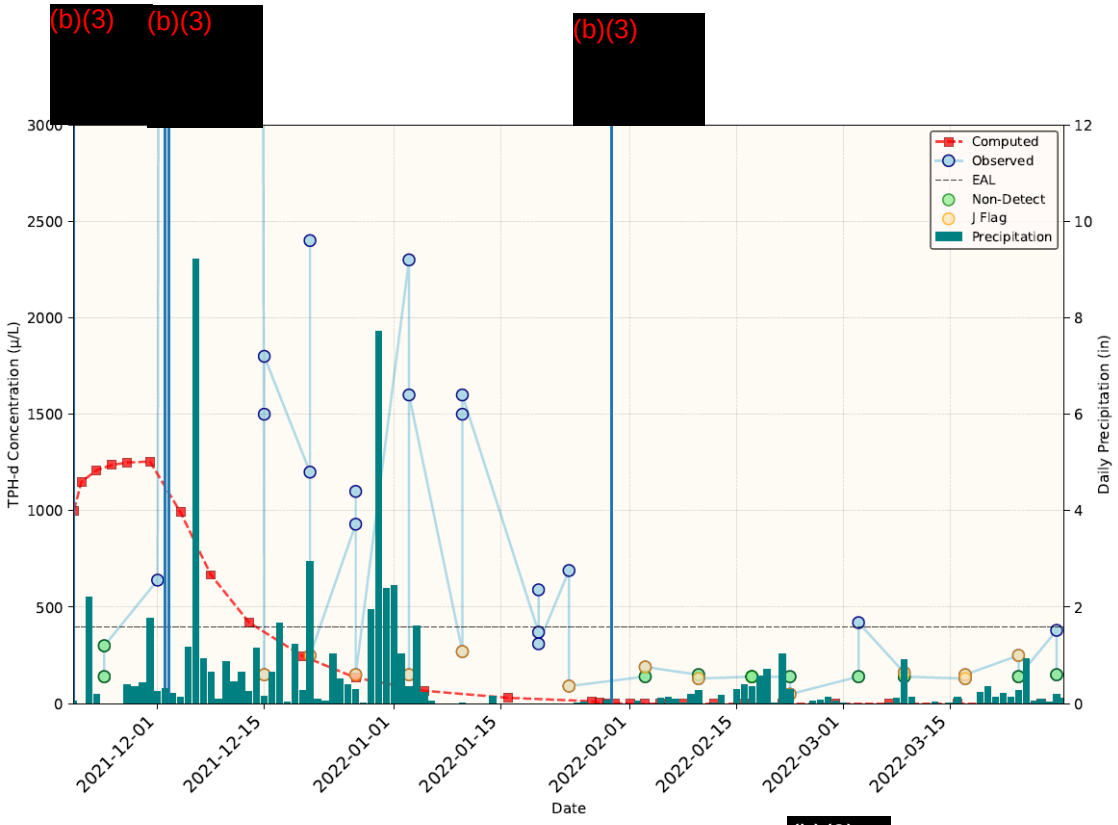


Chart 3-7: Simulated and Observed Concentrations at RHMW(b)(9)

4.0 Hypothetical Release Scenarios

Hypothetical release scenarios were simulated at four locations: Tank 5, Tanks 18 and 20, RHMW(b) and (b)(3) Adit3. The release location for Tanks 18 and 20 was shifted west down the tunnel as was done for the simulation of the historical release. Twelve hypothetical releases were simulated: three different-sized releases at each location (a small release of (b)(3) gal of fuel, a medium release of (b)(3) gal, and a large release of (b)(3)(b)(3) gal). Each simulation was conducted using a steady-state flow field with (b)(3) pumping at 4 mgd and BWS Hālawa Shaft and (b)(3) off. Simulations were run using a constant concentration source zone for a period of 5 years.

The size and concentration of the source zones were estimated with the VZM. An adjustment factor of 8.9 was applied to the concentration estimated using the VZM, consistent with the factor used in the history-matching process for simulation of the historical releases. The source zones for each of the 12 simulations are shown on Figures 4-1 through 4-4. In cases where the specified source zone radii extended into areas where valley fill and saprolite confine the basal aquifer, the source zones were truncated and redistributed to maintain the same area as defined. This is applicable to all four large releases scenarios. Based on results of history matching, effective porosity was set to 3.7%, and dispersivity was set to 42 ft in the longitudinal direction, 25 ft in the transverse direction, and 0.42 ft in the vertical direction. A first-order degradation half-life of 1,808 days used in the history-matching runs was also applied. Results of the VZM model along with the adjusted source concentrations for each scenario are presented in Table 4-1.

Table 4-1: Hypothetical Release Source Setup

Release Scenario Size	Release Location	Volume of LNAPL released (gal)	Average LNAPL Thickness in Lens (ft)	Average LNAPL Saturation in LNAPL Lens (dimension-less)	Volume of LNAPL Retained in Vadose Zone (gal)	Volume of LNAPL Reaching Water Table (gal)	Volumetric LNAPL Content at Water Table (dimension-less)	Area of LNAPL Lens (ft^2)	Radius of LNAPL Lens (ft)	TPH-d Conc. in LNAPL Lens[4] (mg/L)	TPH-d Conc. in 25-ft Model Grid Cell[5] (mg/L)	Adjusted TPH-d Conc. in LNAPL Lens[6] (µg/L)
Small	Tank 5	(b)(3)	2	0.3	(b)(3	(b)(3)	0.035	22,000	83.7	1.69	0.14	15,041
Small	Tanks 18 and 20	(b)(3)	2	0.3	(b)(	(b)(3)	0.031	26,000	91	1.69	0.14	15,041
Small	RHMW(	(b)(3)	2	0.3	(b)(3	(b)(3)	0.038	21,000	81	1.69	0.14	15,041
Small	(b)(/ Adit 3	(b)(3)	2	0.3	(b)(3	(b)(3)	0.039	20,000	80	1.69	0.14	15,041
Medium	Tank 5	(b)(3)	3	0.4	(b)(	(b)(3)	0.047	120,000	195	2.25	0.27	20,025
Medium	Tanks 18 and 20	(b)(3)	3	0.4	(b)(3	(b)(3)	0.041	130,000	203	2.25	0.27	20,025
Medium	RHMW(	(b)(3)	3	0.4	(b)(3)	(b)(3)	0.051	110,000	187	2.25	0.27	20,025
Medium	(b)(/ Adit 3	(b)(3)	3	0.4	(b)(	(b)(3)	0.053	110,000	180	2.25	0.27	20,025
Large	Tank 5	(b)(3)	5	0.5	(b)(	(b)(3)	0.059	5,700,000	1,300	2.82	0.56	25,098
Large	Tanks 18 and 20	(b)(3)	5	0.5	(b)(	(b)(3)	0.052	6,500,000	1,400	2.82	0.56	25,098
Large	RHMW(	(b)(3)	5	0.5	(b)(	(b)(3)	0.063	5,300,000	1,300	2.82	0.56	25,098
Large	(b)(/ Adit 3	(b)(3)	5	0.5	(b)(	(b)(3)	0.066	5,100,000	1,300	2.82	0.56	25,098

Notes:
1. Conc. = concentration
3. Volumetric LNAPL content at Water Table = the volume of LNAPL per unit total bulk volume within the LNAPL lens in the saturated zone (dimensionless).
4. TPH-d Conc. in LNAPL lens = the dissolved phase TPH-d concentration in groundwater within the LNAPL zone.
5. TPH-d Conc. in 25-ft Model Grid Cell = The groundwater concentration within the LNAPL lens, adjusted for the fact that the LNAPL lens thickness is smaller than the thickness of the 25-ft-thick CF&T model cell. The LNAPL lens concentrations are multiplied by the ratio of LNAPL lens thickness to CF&T model grid thickness to account for this dilution of the boundary condition concentration.
6. Adjusted concentration includes a multiplication factor on the TPH-d concentration of 8.9, which was derived from the history-matching process.

Importantly, these hypothetical releases are conservative and highly speculative. They are based on calibration to TPH data that are highly variable and that could be unassociated with the releases. In addition, the source area extents and concentrations are based on the simple heuristic model of vadose zone LNAPL releases, which do not account for the highly variable volcanic rock environment and that were developed without any LNAPL data following the historical releases for comparison. The CF&T model source zones are therefore highly uncertain and by necessity rely significantly on professional judgment.

4.1 Tank 5 Hypothetical Release

Three hypothetical releases were simulated from the area around Tank 5, as shown on Figure 4-1. The small release of (b)(3) gallons of (b)(was simulated using a constant concentration of 15,041 µg/L. Results of simulated TPH-d concentrations are shown on Figure 4-5. The plume color flood represents the maximum concentration across all layers at each cell location at the end of the simulation. Generally, the plume migrated down Red Hill ridge toward (b)(3 and no groundwater with a concentration over 200 µg/L escaped capture by (b)(3 The threshold of 200 µg/L was selected because it is less than applicable EALs and in the range of typical detection limits in the data. The monitoring well with the highest simulated concentration of TPH-d was RHMW(b)(nearby the source zone with a concentration of approximately 3,400 µg/L. Other significantly impacted wells included RHMW(b) with a concentration of 1,900 µg/L, RHMW(b)(9 with a concentration of 1,100 µg/L, and RHMW(b)(9) with a concentration of 610 µg/L. All other wells yielded concentrations below 200 µg/L. The simulated concentration of water extracted from (b)(3 was 25 µg/L at the end of the simulation. TPH-d concentrations simulated at BWS Hālawa Shaft and (b)(3) were negligible.

The medium release of (b)(3) gallons of (b)(was simulated using a constant concentration of 20,025 µg/L. Results of simulated TPH-d concentrations are shown on Figure 4-6. The plume color flood represents the maximum concentration across all layers at each cell location at the end of the simulation. Generally, the plume migrated down Red Hill ridge toward (b)(3 and no groundwater with a concentration over 200 µg/L escaped capture by (b)(3 The monitoring well with the highest simulated concentration of TPH-d was RHMW(b) with a concentration of approximately 20,025 µg/L because it lies within the source zone. Other significantly impacted wells included RHMW(b with a concentration of 5,000 µg/L, RHMW (b)(with a concentration of 3,700 µg/L, and RHMW(b)(9) with a concentration of 1,700 µg/L. All other wells yielded concentrations below 200 µg/L. The simulated concentration of water extracted from (b)(3 was 75 µg/L at the end of the simulation. Concentrations simulated at BWS Hālawa Shaft and (b)(3) were negligible.

The large release of (b)(3)(b)(3) gallons of (b)(was simulated using a constant concentration of 25,098 µg/L. Results of simulated TPH-d concentrations are shown on Figure 4-7. The plume color flood represents the maximum concentration across all layers at each cell location at the end of the simulation. Generally, the plume migrates down Red Hill ridge toward (b)(3 and to the northwest of (b)(3 with a portion of the plume escaping the capture zone of (b)(3 Several monitoring wells are located within the same model cells as where the constant concentration source is specified, including RHMW(b)(9 RHMW(b)(RHMW(b RHMW(b RHMW(b) RHMW(b) RMHW(b) RHMW(b)(and RHMW(b)(RHMW(b) is also near the source zone and has a simulated concentration of over 22,000 µg/L. The most distal monitoring well to the northwest, RHMW(b)(9 reaches a maximum concentration of approximately 170 µg/L. RHMW(b)(9)

reaches a maximum concentration of approximately 1,500 µg/L. The simulated concentration of water extracted from (b)(3 was 930 µg/L at the end of the simulation. Concentrations simulated at BWS Hālawa Shaft and (b)(3) were negligible.

4.2 Tanks 18 and 20 Hypothetical Release

Three hypothetical releases were simulated from the area around Tank 18 and 20, as shown on Figure 4-2. The small release of (b)(3) gallons of (b)(was simulated using a constant concentration of 15,041 µg/L. Results of simulated TPH-d concentrations are shown on Figure 4-8. The plume color flood represents the maximum concentration across all layers at each cell location at the end of the simulation. Generally, the plume migrated down Red Hill ridge toward (b)(3 and no groundwater with a concentration over 200 µg/L escaped capture by (b)(3 The monitoring well with the highest simulated concentration of TPH-d is RHMW(b nearby the source zone with a concentration of approximately 5,000 µg/L. Other significantly impacted wells included RHMW(b with a concentration of 500 µg/L, RHMW(b)(with a concentration of 640 µg/L, RHMW(b)(with a concentration of 510 µg/L, and RHMW(b)(9) with a concentration of 270 µg/L. All other wells yielded concentrations below 200 µg/L. The simulated concentration of water extracted from (b)(3 was 35 µg/L at the end of the simulation. Concentrations simulated at BWS Hālawa Shaft and (b)(3) were negligible.

The medium release of (b)(3) gallons of (b)(was simulated using a constant concentration of 20,025 µg/L. Results of simulated TPH-d concentrations are shown on Figure 4-9. The plume color flood represents the maximum concentration across all layers at each cell location at the end of the simulation. Generally, the plume migrated down Red Hill ridge toward (b)(3 and no groundwater with a concentration over 200 µg/L escaped capture by (b)(3 The monitoring well with the highest simulated concentration of TPH-d was RHMW(b nearby the source zone with a concentration of approximately 14,000 µg/L. Other significantly impacted wells include RHMW(b) with a concentration of 1,500 µg/L, RHMW(b) with a concentration of 1,700 µg/L, RHMW(b)(with a concentration of 1,50 µg/L, RHMW(b)(9) with a concentration of 700 µg/L, RHMW(b)(9 with a concentration of 530 µg/L, and RHMW(b)(9) with a concentration of 200 µg/L. All other wells yielded concentrations below 200 µg/L. The simulated concentration of water extracted from (b)(3 was 1(b µg/L at the end of the simulation. Concentrations simulated at BWS Hālawa Shaft and (b)(3) were negligible.

The large release of (b)(3)(b)(3) gallons of (b)(was simulated using a constant concentration of 25,098 µg/L. Results of simulated TPH-d concentrations are shown on Figure 4-10. The plume color flood represents the maximum concentration across all layers at each cell location at the end of the simulation. Generally, the plume migrated down Red Hill ridge toward (b)(3 and to the northwest of (b)(3 with a portion of the plume escaping the capture zone of (b)(3 Several monitoring wells were located within the same model cells as the constant concentration source, including RHMW(b) RHMW(b RHMW(b) RHMW(b)(RHMW(b)(and RHMW(b)(The most distal monitoring well to the northwest, RHMW(b)(9 reached a maximum concentration of approximately 1,300 µg/L. RHMW(b)(9) reached a maximum concentration of approximately 4,200 µg/L. The simulated concentration of water extracted from (b)(3 was approximately 1,000 µg/L at the end of the simulation. Concentrations at (b)(3) were approximately 60 µg/L and increasing slightly after 5 years. Concentrations simulated at BWS Hālawa Shaft were negligible.

4.3 RHMW(b)(9) Hypothetical Release

Three hypothetical releases were simulated from the area around RHMW(b as shown on Figure 4-3. The small release of (b)(3) gallons of (b)(was simulated using a constant concentration of 15,041 µg/L. Results of simulated TPH-d concentrations are shown on Figure 4-11. The plume color flood represents the maximum concentration across all layers at each cell location at the end of the simulation. Generally, the plume migrated down Red Hill ridge toward (b)(3 however, the southern portion of the plume was not captured by (b)(3 continuing down the ridge to the southwest. The monitoring well with the highest simulated concentration of TPH-d is RHMW(b which is located in the source zone. The only other monitoring well significantly impacted is RHMW(b)(9) with a concentration of 636 µg/L. All other wells yielded concentrations below 200 µg/L. The simulated concentration of water extracted from (b)(3 was less than 1 µg/L at the end of the simulation. Concentrations simulated at BWS Hālawa Shaft and (b)(3) were negligible.

The medium release of (b)(3) gallons of (b)(was simulated using a constant concentration of 20,025 µg/L. Results of simulated TPH-d concentrations are shown on Figure 4-12. The plume color flood represents the maximum concentration across all layers at each cell location at the end of the simulation. Generally, the plume migrated down Red Hill ridge toward (b)(3 however, the southern portion of the plume was not captured by (b)(3 continuing down the ridge to the southwest. The monitoring well with the highest simulated concentration of TPH-d is RHMW(b which is located in the source zone. The only other monitoring well significantly impacted is RHMW(b)(9) with a concentration of 2,500 µg/L. All other wells yielded concentrations below 200 µg/L. The simulated concentration of water extracted from (b)(3 was approximately 2 µg/L at the end of the simulation, primarily due to some portion of the plume escaping capture. Concentrations simulated at BWS Hālawa Shaft and (b)(3) were negligible.

The large release of (b)(3)(b)(3) gallons of (b)(was simulated using a constant concentration of 25,098 µg/L. Results of simulated TPH-d concentrations are shown on Figure 4-13. The plume color flood represents the maximum concentration across all layers at each cell location at the end of the simulation. Generally, the plume migrates down Red Hill ridge toward (b)(3 with the southern portion of the plume migrating past (b)(3 to the southwest. Several monitoring wells are located within the same model cells where the constant concentration source is specified, including RHMW(b)(9 RHMW(b RHMW(b)(RHMW(b) and RHMW(b)(9) The simulated concentration of water extracted from (b)(3 was 9,963 µg/L at the end of the simulation. All other wells yielded concentrations below 200 µg/L. Concentrations simulated at BWS Hālawa Shaft and (b)(3) were negligible.

4.4 (b)(3) Adit 3 Hypothetical Release

Three hypothetical releases were simulated from the area around (b)(3 and Adit 3, as shown on Figure 4-4. The small release of (b)(3) gallons of (b)(was simulated using a constant concentration of 15,041 µg/L. Results of simulated TPH-d concentrations are shown on Figure 4-14. The plume color flood represents the maximum concentration across all layers at each cell location at the end of the simulation. The entire plume was captured by (b)(3 with no monitoring wells exceeding 200 µg/L. The simulated concentration of water extracted from (b)(3 was 1,925 µg/L at the end of the simulation.

The medium release of (b)(3) gallons of (b)(was simulated using a constant concentration of 20,025 µg/L. Results of simulated TPH-d concentrations are shown on Figure 4-15. The plume color flood represents the maximum concentration across all layers at each cell location at the end of the simulation. The entire plume was captured by (b)(3 with no monitoring wells exceeding 200 µg/L. The simulated concentration of water extracted from (b)(3 was 9,116 µg/L at the end of the simulation.

The large release of (b)(3)(b)(3) gallons of (b)(was simulated using a constant concentration of 25,098 µg/L. Results of simulated TPH-d concentrations are shown on Figure 4-16. The plume color flood represents the maximum concentration across all layers at each cell location at the end of the simulation. Most of the plume was captured by (b)(3 but the western portion flowed out of the (b)(3 capture zone then dilutes to below 200 µg/L approximately 1 mile to the west of (b)(3 The simulated concentration of water extracted from (b)(3 was 15,583 µg/L at the end of the simulation. Concentrations simulated at BWS Hālawa Shaft and (b)(3) were negligible.

5.0 Sensitivity Analysis

The impact of uncertainties, errors, and modeling assumptions was evaluated via a sensitivity analysis. A sensitivity analysis was conducted on various parameter changes. Each sensitivity simulation was evaluated for its impacts on the history matching, based on timing of concentration peaks, as well as the hypothetical simulation results. For these comparisons, parameter changes were incorporated into the simulation of the May 2021 release, as well as the medium release at Tanks 18 and 20. The medium release at Tanks 18 and 20 was selected because in the initial set of simulations it showed full capture but is the most likely to be sensitive to capture change based on parameter changes. The analysis was performed in accordance with ASTM International Standard Designation D5611-94 (2016). Each parameter was categorized as Type I, II, III, or IV sensitivity. Definitions for these parameter types are as follows:

- Type I Sensitivity—When variation of an input causes insignificant changes in the calibration residuals as well as the model's conclusions, then that model has a Type I sensitivity to the input. Type I sensitivity is of no concern because regardless of the value of the input, the conclusion will remain essentially the same.
- Type II Sensitivity—When variation of an input causes significant changes in the calibration residuals but insignificant changes in the model's conclusions, then that model has a Type II sensitivity to the input. Type II sensitivity is of no concern because regardless of the value of the input, the conclusion will also remain essentially the same.
- Type III Sensitivity—When variation of an input causes significant changes to both the calibration residuals and the model's conclusions, then that model has a Type III sensitivity to the input. Type III sensitivity is of no concern because, even though the model's conclusions change as a result of variation of the input, the parameters used in those simulations cause the model to become uncalibrated. Therefore, the calibration process eliminates those values from being considered to be realistic.
- Type IV Sensitivity—If, for some value of the input that is being varied, the model's conclusions are changed but the change in calibration residuals is insignificant, then the model has a Type IV sensitivity to that input. Type IV sensitivity can invalidate model results because over the range of

that parameter in which the model can be considered calibrated, the conclusions of the model change. A Type IV sensitivity generally requires additional data collection to decrease the range of possible values of the parameter.

A summary of the changes to each simulation, model calibration, basalt parameters, particle tracking results, and sensitivity type characterization is presented in Table 5-1.

The sensitivity Scenario 1 corresponds to a sensitivity scenario from the GWFM Technical Memorandum (DON 2020), where recharge was scaled proportionally with precipitation over the previous 2 years. In the 2023 GWFM, this resulted in a Type IV sensitivity because some particle tracks from the tank farm were not captured. For that reason, this scenario was carried over to the CF&T sensitivity analysis. For simulation of May 2021 release, timing of the breakthrough curves at RHMW(b and RHMW(b) (projected location) was similar to the base scenario; however, concentrations were slightly lower at RHMW(b)((projected location) due to flow paths in this model slightly more in the northwest direction. Simulation of the medium hypothetical release at Tanks 18 and 20 showed most of the plume captured, but a small portion from the upper tank farm escaping to the northwest. The plume attenuated to below 200 µg/L prior to reaching RHMW(b)(Because this parameter change did not affect calibration, but did change the conclusions of the predictive simulations, it was characterized as a Type IV sensitivity.

The sensitivity Scenario 2 corresponds to simulations with twice the dispersivity as the base simulations. For simulation of May 2021 release, timing of the breakthrough curves at RHMW(b and RHMW(b)((projected location) was similar to the base scenario; however, concentrations were slightly lower at RHMW(b Simulation of the medium hypothetical release at Tanks 18 and 20 showed some concentrations of TPH-d escaping capture to the northwest. Because this parameter change affected both calibration and conclusions of the predictive simulation, it was characterized as a Type III sensitivity.

The sensitivity Scenario 3 corresponds to simulations with half the dispersivity as the base simulations. For simulation of May 2021 release, timing of the breakthrough curves at RHMW(b and RHMW02 (projected location) was similar to the base scenario; however, concentrations were slightly higher at RHMW(b and significantly lower at RHMW(b)((projected location). Simulation of the medium hypothetical release at Tanks 18 and 20 yielded similar results to the base simulation with full capture achieved by (b)(3 Because this parameter change affected calibration, but not conclusions of the predictive simulation, it was characterized as a Type II sensitivity.

The sensitivity Scenario 4 corresponds to simulations with twice the porosity as the base simulations. For simulation of May 2021 release, it achieved a better match to the data at RHMW(b compared to the base but showed late breakthrough and lower concentrations at RHMW(b)((projected location). If it were determined that the concentrations at RHMW(b) were not related to the May 2021 release, the doubled porosity value of 7.4% would be considered a reasonable value for calibration. Simulation of the medium hypothetical release at Tanks 18 and 20 yielded similar results to the base simulation with full capture achieved by (b)(3 Because this parameter change affected calibration but not conclusions of the predictive simulation, it was characterized as a Type II sensitivity.

Table 5-1: Sensitivity Analysis Results

Sensitivity Scenario	Parameter Change	History Matching May 2021 Release		Hypothetical Releases Tanks 18 and 20 Medium Release			Sensitivity Type
		Match at RHMW(b	Match at RHMW02 (projected location)	Full Capture by (b)(	Maximum TPH-d Concentration at RHMW(b (µg/L)	Maximum TPH-d Concentration at (b)((µg/L)	
0	Base	Slightly early peak	Slightly late peak	Yes	14,723	1(b	—
1	GWFM Sensitivity Scenario 2 (scaled recharge)	Slightly early peak	Slightly late peak	No, Small portion of plume from upper tank farm escapes capture	14,235	125	IV
2	Dispersivity × 2	Earlier peak	Slightly late peak	No	14,307	94	III
3	Dispersivity ÷ 2	Slightly early peak	Slightly late peak	Yes	15,178	88	II
4	Porosity × 2	Good match	Late peak	Yes	14,622	96	II
5	Porosity ÷ 2	Early peak	Slightly early peak	Yes	14,754	110	II
6	Degradation Rate × 2	N/A	N/A	Yes	14,662	96	II
7	Degradation Rate ÷ 2	N/A	N/A	Yes	14,754	110	II
8	10th Percentile LNAPL Radius (97 ft)	N/A	N/A	Yes	7,423	59	II
9	90th Percentile LNAPL Radius (713 ft)	N/A	N/A	No	20,025	527	IV

Note:
N/A – Not Applicable

The sensitivity Scenario 5 corresponds to simulations with half the porosity as the base simulations. For simulation of May 2021 release, it showed very early breakthrough at RHMW(b and slightly early breakthrough at RHMW(b (projected location). Simulation of the medium hypothetical release at Tanks 18 and 20 yielded similar results to the base simulation with full capture achieved by (b)(3 Because this parameter change affected calibration but not conclusions of the predictive simulation, it was characterized as a Type II sensitivity.

The sensitivity Scenario 6 corresponds to a simulation with twice the degradation rate as the base simulations. Degradation was not included in the May 2021 simulations; therefore, this parameter change was conducted only for the hypothetical release scenario. Simulation of the medium hypothetical release at Tanks 18 and 20 yielded similar results to the base simulation with full capture achieved by (b)(3 Because this parameter change is not applicable to history matching and conclusions of the predictive simulation did not change, it was characterized as a Type II sensitivity.

The sensitivity Scenario 7 corresponds to a simulation with half the degradation rate as the base simulations. Degradation was not included in the May 2021 simulations; therefore, this parameter change was conducted only for the hypothetical release scenario. Simulation of the medium hypothetical release at Tanks 18 and 20 yielded similar results to the base simulation with full capture achieved by (b)(3 Because this parameter change is not applicable to history matching and conclusions of the predictive simulation did not change it was characterized as a Type II sensitivity.

The sensitivity Scenario 8 corresponds to a simulation with the 10th percentile LNAPL radius of 97 ft from the VZM sensitivity analysis, but same specified concentration of TPH-d. This parameter change was only applicable to the hypothetical release scenario. Simulation of the medium hypothetical release at Tanks 18 and 20 yielded similar results to the base simulation with full capture achieved by (b)(3 Because this parameter change is not applicable to history matching and conclusions of the predictive simulation did not change, it was characterized as a Type II sensitivity.

The sensitivity Scenario 9 corresponds to a simulation with the 90th percentile LNAPL radius of 713 ft from the VZM sensitivity analysis, but same specified concentration of TPH-d. This parameter change was only applicable to the hypothetical release scenario. Simulation of the medium hypothetical release at Tanks 18 and 20 showed some plume escape capture of (b)(3 to the northwest, but it attenuated to below 200 µg/L well before reaching water supply wells such as (b)(3) and BWS Hālawa Shaft to the northwest. Because this parameter change is not applicable to history matching but conclusions of the predictive simulation did change it was characterized as a Type IV sensitivity.

5.1 Sensitivity Analysis Summary

The sensitivity analysis conducted on the CF&T model was used to evaluate several assumptions and their impacts on both history matching and hypothetical medium at Tanks 18 and 20. Nine scenarios were analyzed in comparison to the May 2021 release simulation described in Section 3.1. Of the nine scenarios, only 1 (Scenario 1) was able to achieve an acceptable calibration; however, a small portion of the plume from the upper tank farm escaped capture to the northwest. Two of the additional scenarios investigated yielded results of the hypothetical medium release at Tanks 18 and 20 that showed portions of the plume

escaping capture from (b)(3) Those scenarios included Scenario 2 with twice the dispersivity, and Scenario 9 with the 90th percentile LNAPL radius from the VZM sensitivity analysis. In both of those cases, TPH-d concentrations attenuated to below 200 µg/L well before reaching water supply wells to the northwest such as BWS Hālawa Shaft and (b)(3)

6.0 Summary and Conclusions

The interim CF&T model documented in this technical memorandum uses the interim best available GWFM (DON 2023c) to perform history matching and predictive simulations of fuel releases at the Facility. The CF&T models use the model code MODFLOW-USG Transport (Panday 2022) to simulate source terms, advection, dispersion, and degradation of TPH in the area of the Facility. The interim GWFM was used to set the advective flow field. Size, locations, and concentrations of the source zones were defined by the VZM (DON 2023d). Other parameters were adjusted during the history-matching process.

Three known historical releases in December 2013, May 2021, and November 2021 were simulated for history matching. Of those three simulations, the May 2021 release offered the most information on groundwater flow, as a breakthrough curve of TPH-o appeared to move from the release to RHMW(b (Chart 2-1) to RHMW(b (Chart 2-2). The December 2014 release near Tank 5 showed briefly elevated concentrations only at nearby RHMW(b and the November 2021 release showed elevated concentrations of TPH only at (b)(3 which also corresponded to the observed presence of LNAPL in (b)(3 Several model parameters including dispersivity, initial concentration, and effective porosity were calibrated to THP-o data at RHMW(b and RHMW(b following the May 2021 release. Although the plume orientation is unknown, model simulations yielded concentrations at RHMW(b too low, and it was assumed that the flow path from the GWFM is slightly to the northwest. At this stage, iterative recalibration of the GWFM and CF&T model was not performed; therefore, the location of RHMW(b was projected to the northwest closer to the centerline of the simulated flow path from the release location for better calibration of transport parameters. Model parameters were calibrated with PEST software (Doherty 2015). Calibrated model parameters were carried forward for predictive simulations of 12 hypothetical releases.

Significant conclusions from this CF&T modeling study include:

- Significant uncertainties exist in the history matching process for CF&T.
- Data from the December 2013 and November 2021 release yielded little information regarding groundwater flow and contaminant transport.
- History matching for the May 2021 release:
  - Only 100 gallons of fuel were reported to have not been recovered after the release, which would not have been expected to arrive at the water table or be picked up by the monitoring well network.
  - Data from the May 2021 release show apparent breakthrough of TPH-o at RHMW(b and RHMW(b(

- TPH-o is not a component of the (b)(jet fuel spilled. It is assumed that water used during cleaning of the tunnel around the release may have solubilized residual fuel contamination in the unsaturated zone.
- The timing of both breakthrough curves is similar, which may be attributable to heterogeneity and preferential pathways.
- Several other wells also showed sporadic EAL exceedances following the release with similar timing, including RHMW(b)(RHMW(b)(and the pre-chlorination spigot from (b)(3 The simultaneous timing of many of these releases may suggest another cause rather than the May 2021 release.
  - Simulated flow paths from the GWFM did result in breakthrough at RHMW(b)
- Hypothetical releases:
  - Fate and transport of TPH-d for 12 hypothetical releases was simulated with small ((b)(3) gal), medium ((b)(3) gal), and large ((b)(3)(b)(3) gal) releases at four locations: Tank 5, Tanks 18 and 20, RHMW(b and (b)(3 Adit3.
  - Source term inputs for each hypothetical release were defined by the VZM; however, source concentrations were adjusted based on results of history matching.
  - All small-release scenarios resulted in full capture by (b)(3 with concentrations of TPH-d ranging from < 1 to 35 µg/L except the release at RHMW(b where the southern portion of the plume escaped capture and continued to the southwest.
  - All medium-release scenarios resulted in full capture by (b)(3 with concentrations of TPH-d ranging from 2 to 9,116 µg/L except the release at RHMW(b where the southern portion of the plume escaped capture and continued to the southwest.
  - All large releases were only partially captured by (b)(3 however, all were attenuated to below 200 µg/L prior to reaching water supply wells to the northwest, including BWS Hālawa Shaft and (b)(3)
- Sensitivity Analysis:
  - Nine sensitivity analysis scenarios were analyzed that included a Type IV sensitivity scenario from the GWFM, variations to dispersivity, degradation rate, and effective porosity, and LNAPL radii corresponding to the 10th and 90th percentile size from the VZM sensitivity analysis.
  - Each scenario was conducted for the May 2021 release, for comparison of history matching, and the hypothetical medium release at Tanks 18 and 20. The hypothetical release at Tanks 18 and 20 represents the scenario with greatest risk to the water supply wells to the northwest, and is the farthest from (b)(3 making it more sensitive to changes in plume capture.
  - The sensitivity scenario with scaled recharge from the GWFM, which resulted in a Type IV sensitivity and did not require unrealistic parameters to calibrate, resulted in similar history matching to the base scenario. Conclusions of the predictive hypothetical release changed

slightly, showing a small portion of the plume escaping capture to the northwest; however, the plume attenuated to below 200 µg/L prior to reaching RHMW(b)(

– All other model runs except an increase in dispersivity by a factor of two and the 90th percentile LNAPL radius of 713 ft resulted in full capture by (b)(3

- The two exceptions attenuated to below 200 µg/L prior to reaching water supply wells to the northwest including BWS Hālawa Shaft and (b)(3)
- Only the 90th percentile LNAPL radius scenario was characterized as a Type IV sensitivity. This input assumption is not a factor in history matching, but its input changes the conclusions of the predictive results.

7.0 Limitations

This CF&T modeling work is intended to provide insights into the migration of fuel from historical and hypothetical future releases of fuel from the Facility during defueling. While these insights can be useful in preparation for defueling and decision making in the event of a release, certain limitations must be recognized when using models and interpreting results. Many assumptions are made to support this modeling project. Each assumption comes with inherent uncertainty. There are many sources of error and uncertainty in models. Model error commonly stems from practical limitations of grid spacing, time discretization, parameter structure, insufficient calibration data, and the effects of processes not simulated by the model. These factors, along with unavoidable error in observations, result in uncertainty in model predictions.

The GWFM is a simplified representation of reality with the assumption of uniform basal aquifer parameters including orientation of anisotropy. Limitation of the GWFM itself are discussed in the GWFM Technical Memorandum (DON 2023c). While reasonable calibration was achieved fitting simulated groundwater levels to observed levels, complex small-scale geological heterogeneities and preferential flow paths will have impacts on contaminant transport as a scale that cannot be modeled, both in space and time.

Inputs from the VZM also represent significant uncertainties, as discussed in the VZM Technical Memorandum (DON 2023d). Key uncertainties in this modeling are related to the geology and parameters selected to quantify LNAPL and groundwater flow through the unsaturated zone. These parameter inputs are generally bound by sensitivity analysis because data with respect to LNAPL flow throughout the vadose zone at the Facility are sparse.

History matching and calibration of the CF&T models carry inherent uncertainties from the outset, including compounding errors in the GWFM and interpretations of TPH data at the site. Of the three documented releases, the December 2013 release and November 2021 release show only very localized and short-term impacts. The May 2021 release appears to show breakthrough curves at two wells for TPH-o, RHMW02 and RHMW(b suggesting that residual contamination from the vadose zone may have been solubilized during cleaning of the tunnel following that event. Nearly simultaneous occurrences and EAL exceedances of TPH-o occur at several other wells from this event, including the (b)(3 pre-chlorination spigot. All these occurrences cannot be replicated through model simulations and may not be related to the same source. Significant uncertainty is also conveyed with deconvolution of TPH data and attributing them

various sources such as the three documented historical releases or other causes such as laboratory changes, sampling methods, background aqueous-phase contamination, and mobilization of residual contamination through precipitation events and fluctuations in the water table.

Calibration of transport parameters such as effective porosity and dispersivity can lead to a high degree of non-uniqueness, particularly in cases such as this where a limited number of monitoring wells show responses. Often, the result of such calibration is high dispersivity values that can conceal uncertainties and errors in the input assumptions. The basal aquifer at the site contains significant heterogeneity, leading to local variations in groundwater velocity. Heterogeneity of the basal aquifer is not incorporated at this stage and is represented with uniform hydraulic parameters under the assumption of equivalent porous media. Dispersivity is used as a parameter to represent these local variations in groundwater velocities. In the next stages of modeling, as uncertainties are further clarified and heterogeneity is incorporated in greater detail, it is anticipated that the use of dispersivity as a tool to account for uncertainty will be reduced. In the CF&T model, the predictions of TPH concentration carry uncertainty, and the values predicted should be interpreted as such. Predictions of TPH concentrations are more indicative of qualitative likelihoods of TPH impacts to water supplies. For example, the simulations of different release scenarios might be interpreted as indicating a high, moderate, or low probability of an impact at a location. However, the possibilities of unknown preferential flow paths mean that TPH detections at water supply locations could occur even if the simulation results suggest that the likelihood of an impact is low.

8.0 References

ASTM International (ASTM). 2016. *Standard Guide for Conducting a Sensitivity Analysis for a Groundwater Flow Model Application*. D5611-94(2016). West Conshohocken, PA.

Department of Defense, United States (DoD). 2022. *Defueling Plan, Red Hill Bulk Fuel Storage Facility, Oahu, Hawaii*. Prepared by Secretary of the Navy (SECNAV), in Coordination with Director, Defense Logistics Agency (DLA), on Behalf of DoD. June 30, 2022.

Doherty, J. 2015. *PEST: Model-Independent Parameter Estimation and Uncertainty Analysis*. Brisbane, Australia: Watermark Numerical Computing. http://pesthomepage.org/.

Department of the Navy (DON). 2018. *Groundwater Protection and Evaluation Considerations for the Red Hill Bulk Fuel Storage Facility, Joint Base Pearl Harbor-Hickam, O'ahu, Hawai'i; July 27, 2018, Revision 00*. Prepared by AECOM Technical Services, Inc., Honolulu, HI. Prepared for Defense Logistics Agency Energy, Fort Belvoir, VA, under Naval Facilities Engineering Command, Hawaii, JBPHH HI.

———. 2019. *Conceptual Site Model, 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; June 30, 2019, Revision 01*. Prepared by AECOM Technical Services, Inc., Honolulu, HI. Prepared for Defense Logistics Agency Energy, Fort Belvoir, VA, under Naval Facilities Engineering Command, Hawaii, JBPHH HI.

———. 2020. *Groundwater Flow Model Report, Red Hill Bulk Fuel Storage Facility, Joint Base Pearl Harbor-Hickam, O'ahu, Hawai'i; March 25, 2020, Revision 00*. Prepared by AECOM Technical Services, Inc., Honolulu, HI. Prepared for Defense Logistics Agency Energy, Fort Belvoir, VA, under Naval Facilities Engineering Command, Hawaii, JBPHH HI.

———. 2023a. *Quarterly Release Response Report, Red Hill Bulk Fuel Storage Facility, JBPHH, O'ahu, Hawai'i*. Prepared for NAVFAC Hawaii by AECOM Technical Services, Inc. DOH Facility ID No. 9-102271; DOH UST Release ID Nos. 140010, 210012; DOH HEER Release Incident Case Nos. 20210507-0852, 20211120-2330. JBPHH HI: Naval Facilities Engineering Systems Command, Hawaii. March 22.

———. 2023b. *Site Characterization Report, November 2021* (b)(*Release in Adit 3, Operable Unit 1, Red Hill Bulk Fuel Storage Facility, JBPHH, O'ahu, Hawai'i*. Working Draft. JBPHH HI: Naval Facilities Engineering Systems Command, Hawaii. March.

———. 2023c. *Groundwater Flow Model Technical Memorandum, Red Hill Bulk Fuel Storage Facility. JBPHH, O'ahu, Hawai'i*. Prepared for NAVFAC Hawaii by AECOM Technical Services Inc. May 17.

———. 2023d. *Vadose Zone Model Technical Memorandum, Red Hill Bulk Fuel Storage Facility. JBPHH, O'ahu, Hawai'i*. Prepared for NAVFAC Hawaii by AECOM Technical Services Inc. May 17.

Environmental Protection Agency, United States, Region 9; and Department of Health, State of Hawaii (EPA Region 9 and DOH). 2015. *Administrative Order on Consent 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*. September.

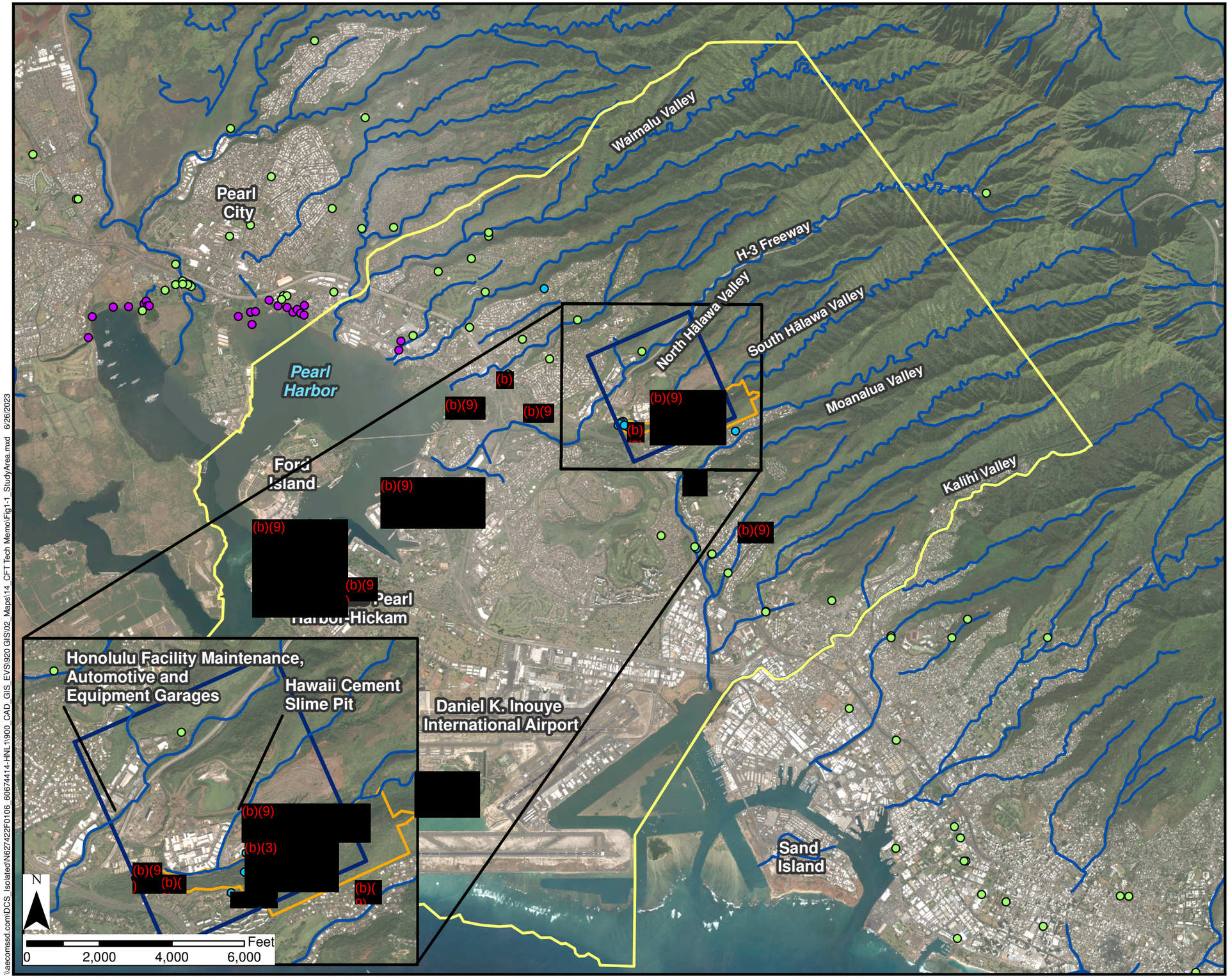
———. 2022. *Subject: Disapproval of the Groundwater Flow Model Report*. Letter from: Gabriela Carvalho, Red Hill Project Coordinator, US Environmental Protection Agency Region 9; and Roxanne Kwan, Interim Red Hill Project Coordinator, State of Hawaii Department of Health; to: CAPT Gordie Meyer, CEC, USN Regional Engineer, Navy Region Hawaii. March 17.

Gelhar, Lynn W., Claire Welty, and Kenneth R. Rehfeldt. 1992. "A Critical Review of Data on Field-Scale Dispersion in Aquifers." *Water Resources Research* 28 (7): 1955–74. https://doi.org/10.1029/92WR00607.

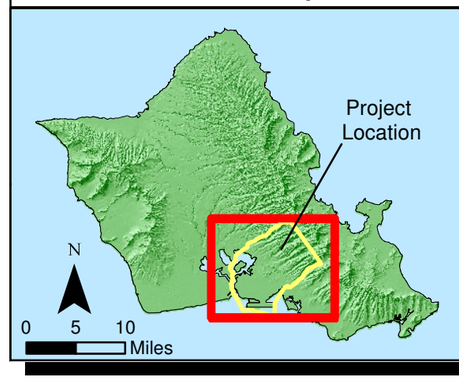
McHugh, T. E., L. M. Beckley, G. E. Devaull, and M. A. Lahvis. 2022. "Long-Term Assessment of Petroleum Hydrocarbon Attenuation at Petroleum Release Sites in California." *Groundwater Monitoring & Remediation* 42 (3): 75–85.

Naval Facilities Engineering Command, Engineering and Expeditionary Warfare Center (NAVFAC EXWC). 2016. *Red Hill Facility Tank Inspection, Repair, and Maintenance Report, Administrative Order on Consent (AOC) Statement of Work (SOW), Section 2.2*. Site Specific Report SSR-NAVFAC EXWC-CI-1655. October 11.

Panday, S. 2022. *USG-Transport Version 1.10.0: The Block-Centered Transport Process for MODFLOW-USG*. GSI Environmental. http://www.gsi-net.com/en/software/free-software/USG-Transport.html.



Location Map



Legend

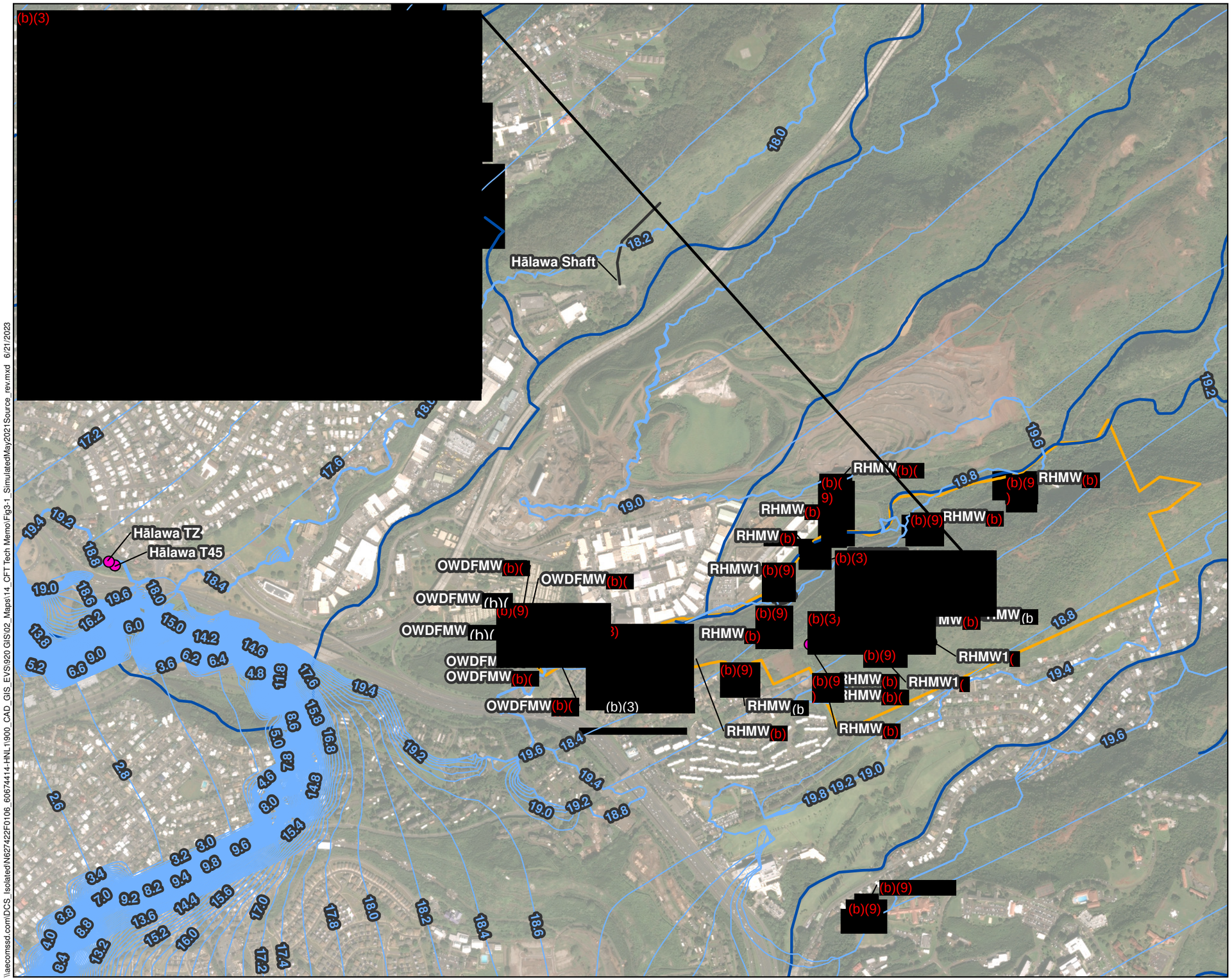
- Supply Well / Shaft
- Monitoring Well
- Spring
- Stream
- Red Hill Facility Boundary and Fuel Storage Tanks
- Nested Grid
- Groundwater Flow Model Domain

Notes

1. Map projection: NAD 1983 Hawaii State Plane Zone 3 feet.
2. Base Map: DigitalGlobe, Inc. (DG) and NRCS. Publication_Date: 2015
3. Spring locations provided by USGS.
4. Water supply well locations provided by DLNR.

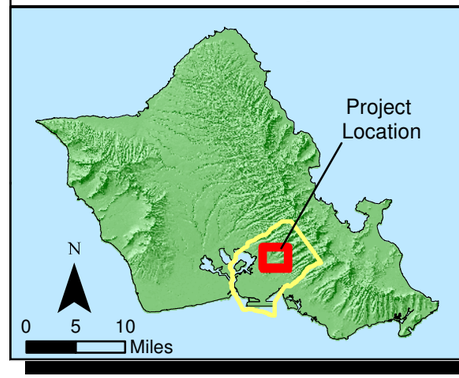
Figure 1-1
Groundwater Flow Model Domain and Study Area
CF&T Technical Memorandum
Red Hill Bulk Fuel Storage Facility
JBPHH, O'ahu, HI

\\aecomssd.com\DCS_Isolated\N6274422F0106_60674414-HNL11900_CAD_GIS_EVS\920 GIS\02_Maps\14_CFT Tech Memo\Fig1-1_StudyArea.mxd 6/26/2023



\\aecomssd.com\DCS_Isolated\N627422F0106_60674414-HNL1\900_CAD_GIS_EVS\920 GIS\02_Maps\14_CFT Tech Memo\Fig3-1_SimulatedMay2021Source_rev.mxd 6/21/2023

Location Map



Legend

- Source Zone
- Monitoring Well
- Potentiometric Surface (ft msl)
- (b)(Water Development Tunnel
- Stream
- Red Hill Facility Boundary
- Groundwater Flow Model Domain

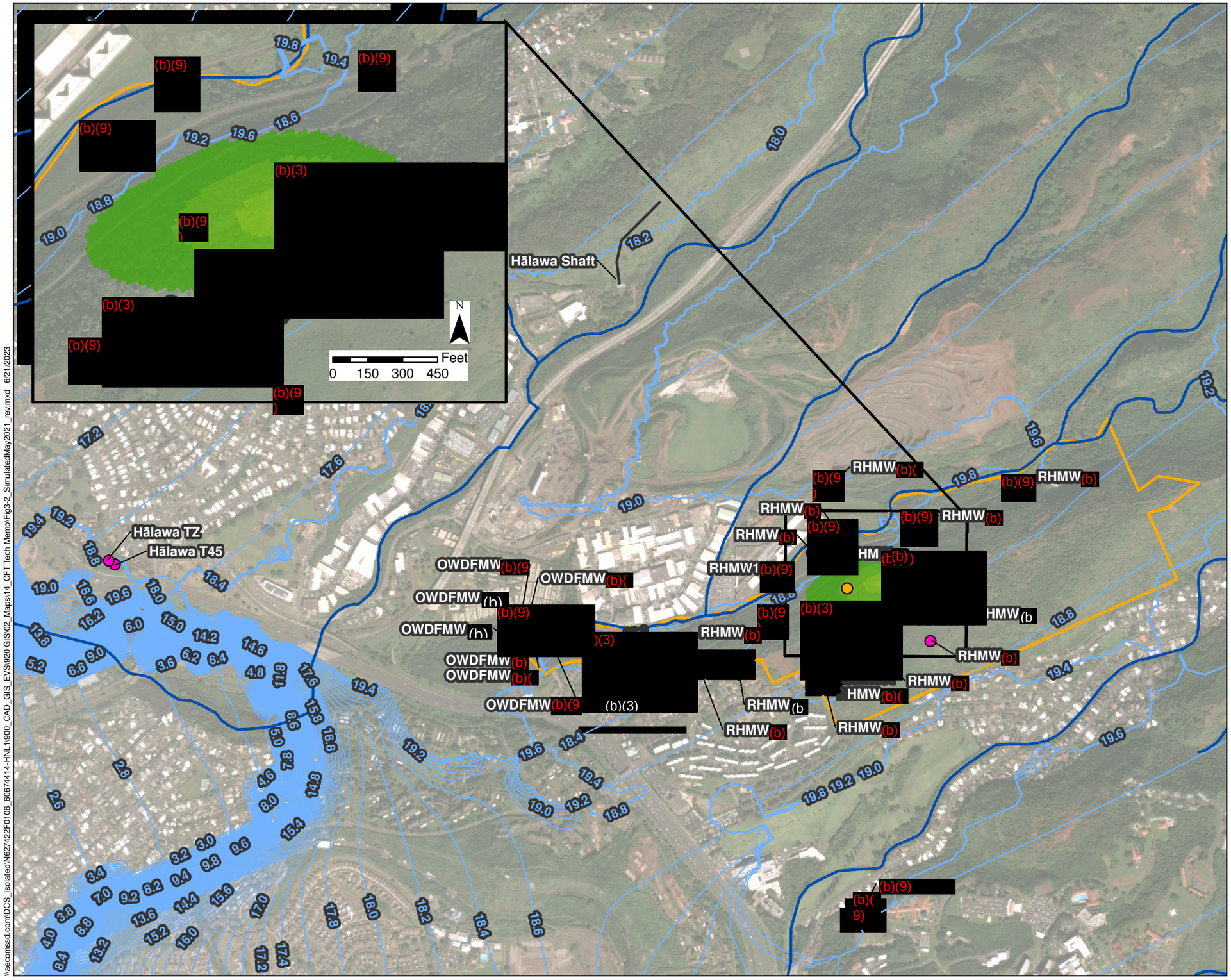
Notes

1. Map projection: NAD 1983 Hawaii State Plane Zone 3 feet.
2. Base Map: DigitalGlobe, Inc. (DG) and NRCS. Publication_Date: 2015
3. Spring locations provided by USGS.

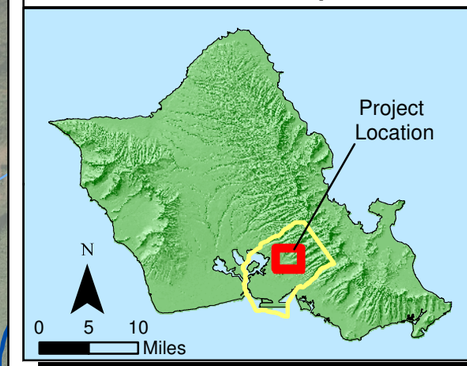
N

0 500 1,000 1,500 Feet

Figure 3-1
Simulated May 2021
Release Source Zone
Red Hill Bulk Fuel Storage Facility
JBPHH, O'ahu, HI



Location Map



Legend

Simulated TPH-d Concentrations (µg/L)

- 200 to < 400
- 400 to < 600
- 600 to < 800
- 800 to < 1,000
- 1,000 to < 2,000
- 2,000 to < 3,000
- 3,000 to < 4,0000
- 4,000 to < 5,000
- 5,000 to < 10,000
- > 10,0000

- Source Zone
- Monitoring Well (not in the basal aquifer)
- Projected Monitoring Well
- Potentiometric Surface (ft msl)
- (b)(Water Development Tunnel
- Stream
- Red Hill Facility Boundary
- Groundwater Flow Model Domain

Notes

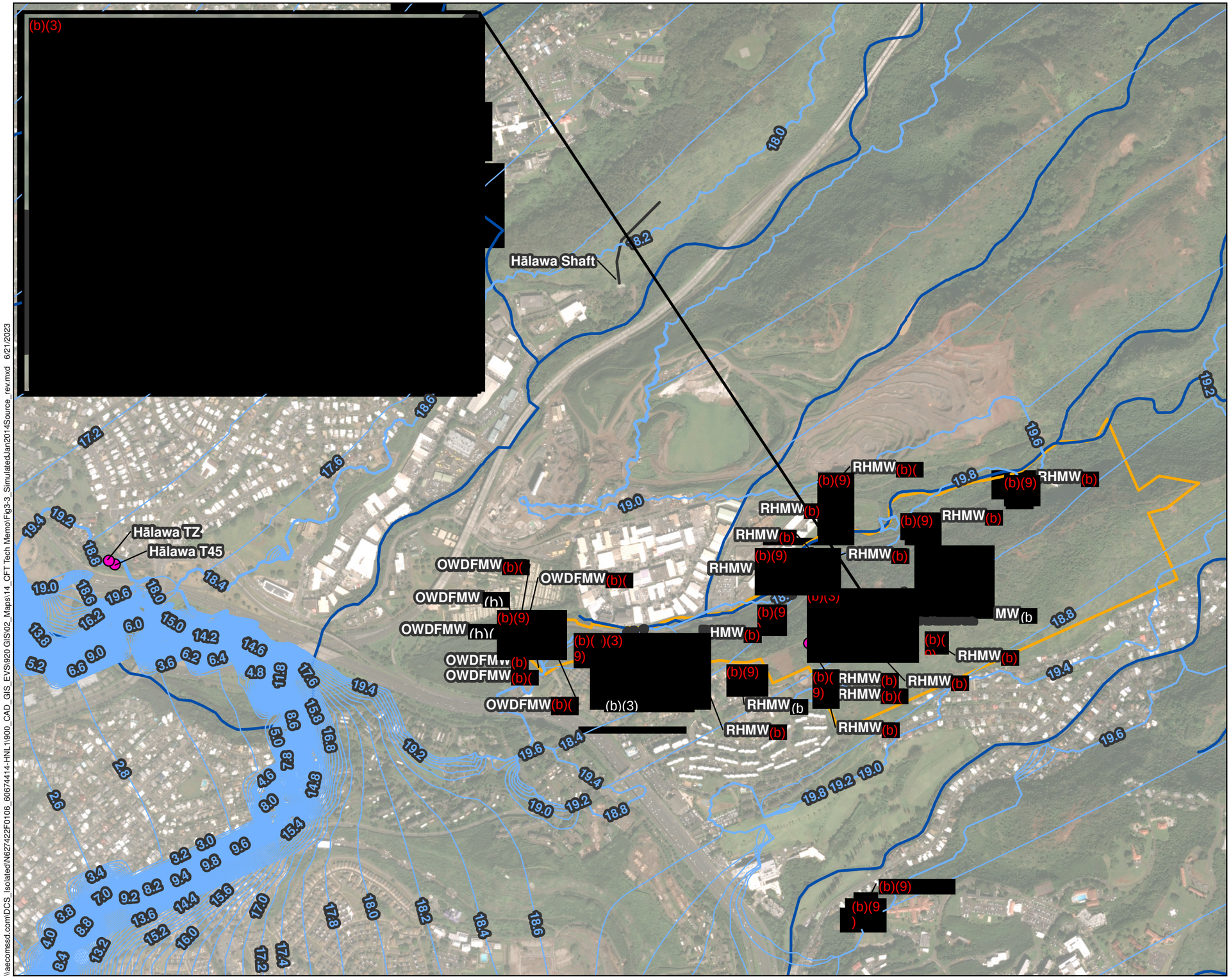
1. Map projection: NAD 1983 Hawaii State Plane Zone 3 feet.
2. Base Map: DigitalGlobe, Inc. (DG) and NRCS. Publication_Date: 2015
3. Spring locations provided by USGS.
4. Water supply well locations provided by DLNR.

N

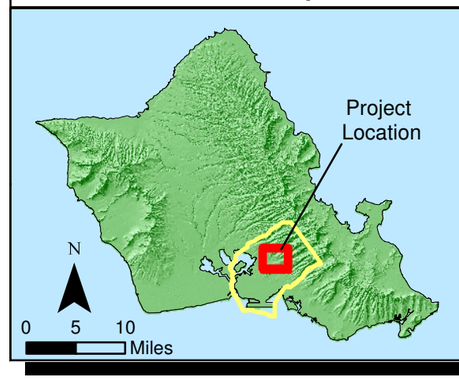
Feet
0 500 1,000 1,500

Figure 3-2
Simulated May 2021
TPH-o Concentrations After 120 days
Red Hill Bulk Fuel Storage Facility
JBPHH, O'ahu, HI

\\aecomnssd.com\DCS_Isolated\N6274422F0106_60674414-HNL1\900_CAD_GIS_EVS\920 GIS\02_Maps\14_CFT Tech Memo\Fig3-2_SimulatedMay2021_rev.mxd 6/21/2023



Location Map



Legend

- Source Zone
- Monitoring Well
- Potentiometric Surface (ft
- Stream
- Red Hill Facility Boundary
- Groundwater Flow Model

Notes

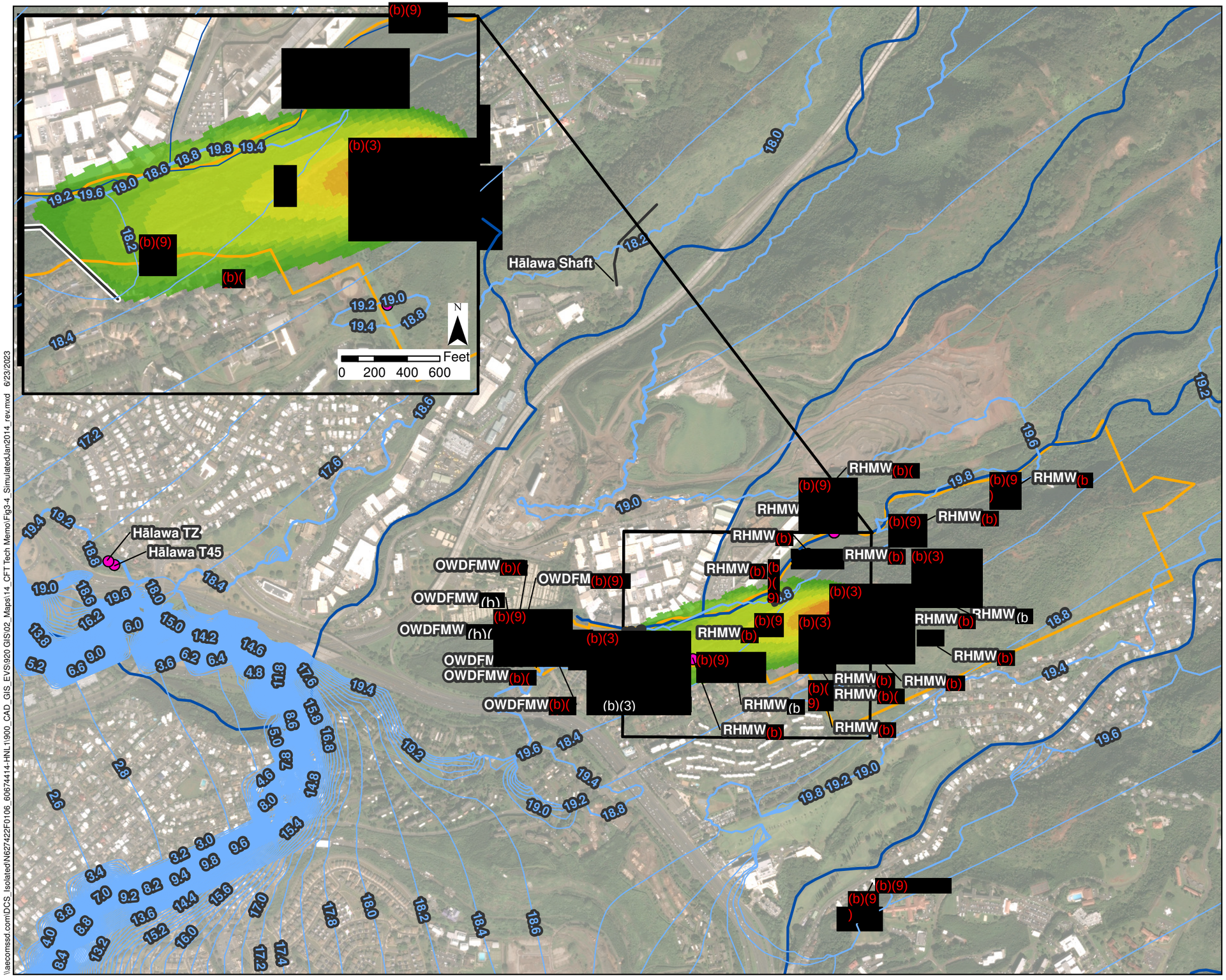
1. Map projection: NAD 1983 Hawaii State Plane Zone 3 feet.
2. Base Map: DigitalGlobe, Inc. (DG) and NRCS. Publication_Date: 2015
3. Spring locations provided by USGS.

N

0 500 1,000 1,500 Feet

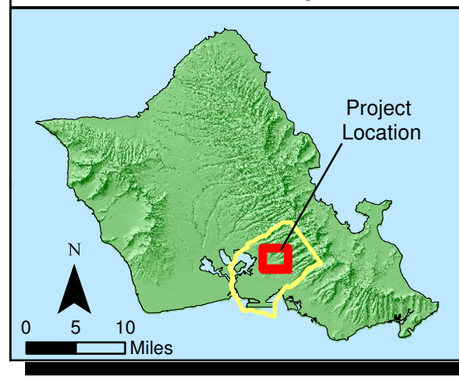
Figure 3-3
Simulated December 2013
Release Source Zone
Red Hill Bulk Fuel Storage Facility
JBPHH, O'ahu, HI

\\aecomnssd.com\DCS_Isolated\N6274422F0106_60674414-HNL1\900_CAD_GIS_EVS\920 GIS\02_Maps\14_CFT Tech Memo\Fig3-3_SimulatedJan2014Source_rev.mxd 6/21/2023



\\aecomssd.com\DCS_Isolated\N6274422F0106_60674414-HNL1\900_CAD_GIS_EVS\920 GIS\02_Maps\14_CFT Tech Memo\Fig3-4_SimulatedJan2014_rev.mxd 6/23/2023

Location Map



Legend

Simulated TPH-d Concentrations (µg/L)

- 200 to < 400
- 400 to < 600
- 600 to < 800
- 800 to < 1,000
- 1,000 to < 2,000
- 2,000 to < 3,000
- 3,000 to < 4,000
- 4,000 to < 5,000
- 5,000 to <10,000
- > 10,000
- Source Zone
- Monitoring Well
- Potentiometric Surface (ft msl)
- (b)(Water Development Tunnel
- Stream
- Red Hill Facility Boundary
- Groundwater Flow Model Domain

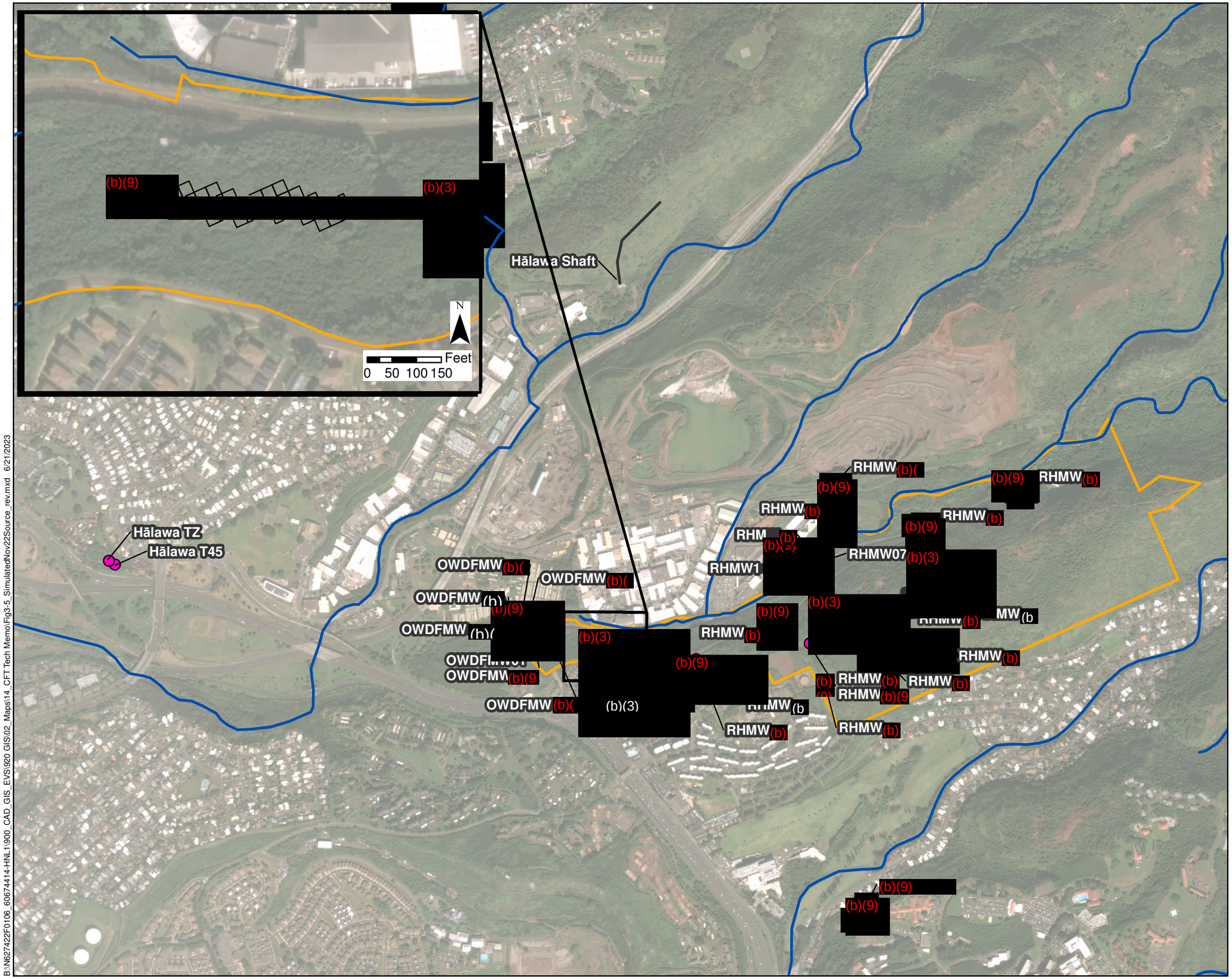
Notes

1. Map projection: NAD 1983 Hawaii State Plane Zone 3 feet.
2. Base Map: DigitalGlobe, Inc. (DG) and NRCS. Publication_Date: 2015
3. Spring locations provided by USGS.
4. Water supply well locations provided by DLNR.

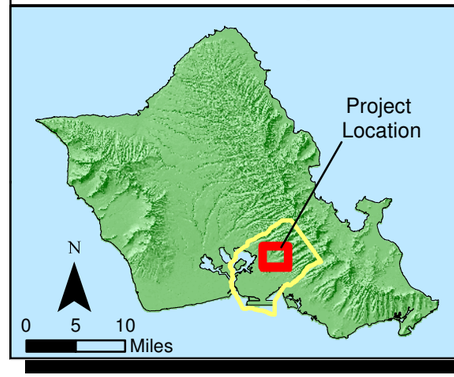
N

0 500 1,000 1,500 Feet

Figure 3-4
Simulated December 2013
TPH-d Concentrations after One Year
Red Hill Bulk Fuel Storage Facility
JBPHH, O'ahu, HI



Location Map



Legend

- Source Zone
- Monitoring Well
- (b)(Water Development Tunnel
- Stream
- Red Hill Facility Boundary
- Groundwater Flow Model Domain

Notes

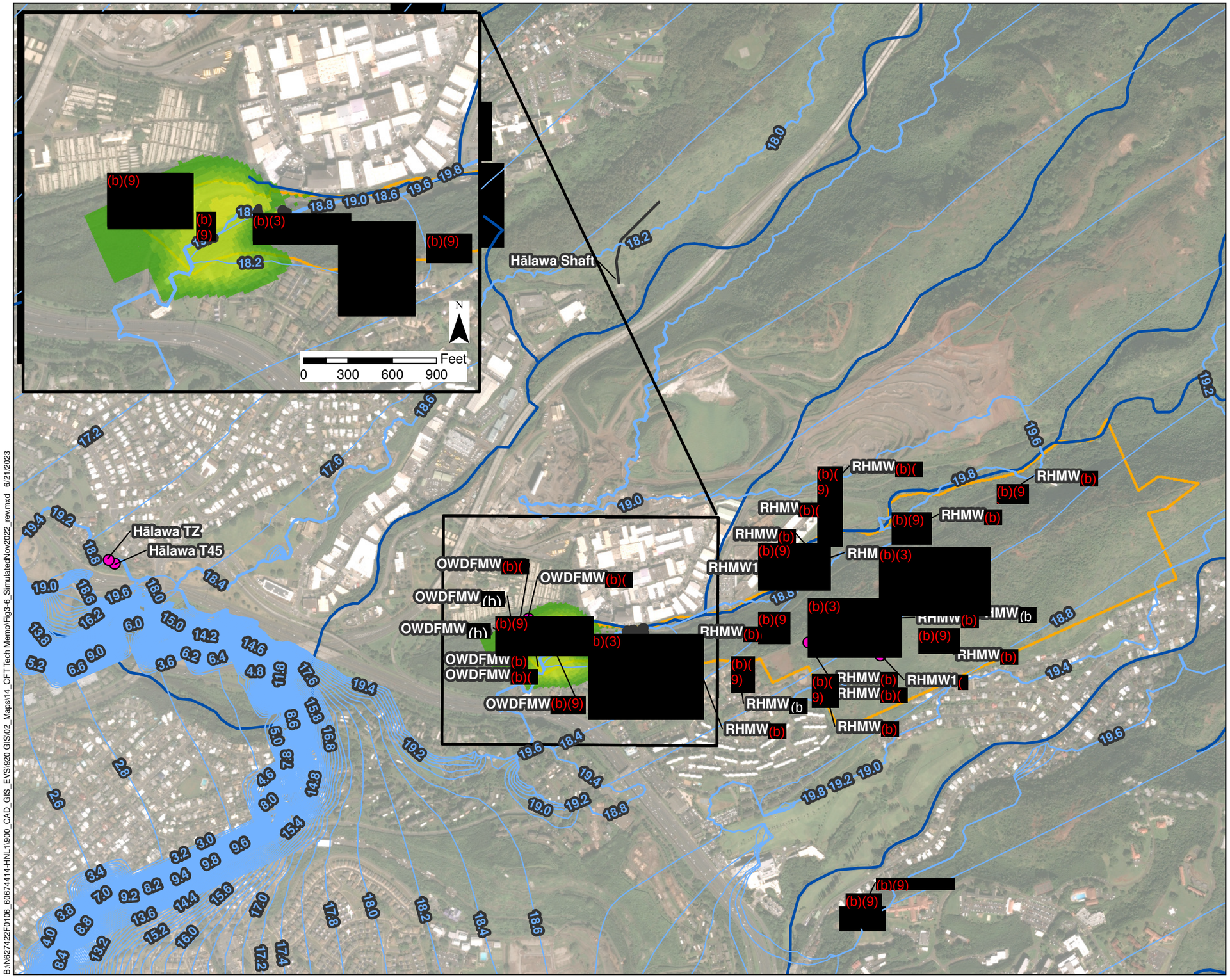
1. Map projection: NAD 1983 Hawaii State Plane Zone 3 feet.
2. Base Map: DigitalGlobe, Inc. (DG) and NRCS. Publication_Date: 2015
3. Spring locations provided by USGS.

N

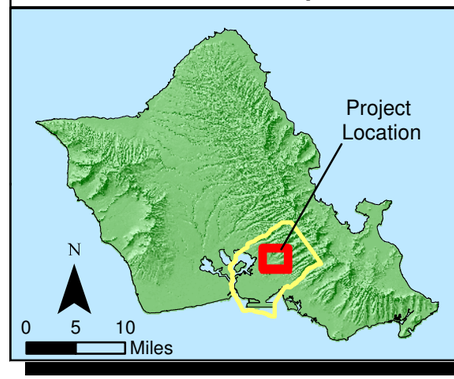
0 500 1,000 1,500 Feet

Figure 3-5
Simulated November 2021
Release Source Zone
Red Hill Bulk Fuel Storage Facility
JBPHH, O'ahu, HI

B:\N627422F0106_60674414-HNL1\900_CAD_GIS_EVS\920 GIS\02_Maps\14_CFT Tech Memo\Fig3-5_SimulatedNov22Source_rev.mxd 6/21/2023



Location Map



Legend

Simulated TPH-d Concentrations (µg/L)

- 200 to < 400
- 400 to < 600
- 600 to < 800
- 800 to < 1,000
- 1,000 to < 2,000
- 2,000 to < 3,000
- 3,000 to < 4,000
- 4,000 to < 5,000
- 5,000 to < 10,000
- > 10,000
- Source Zone
- Monitoring Well
- Potentiometric Surface (ft msl)
- (b)(Water Development Tunnel
- Stream
- Groundwater Flow Model Domain
- Red Hill Facility Boundary

Notes

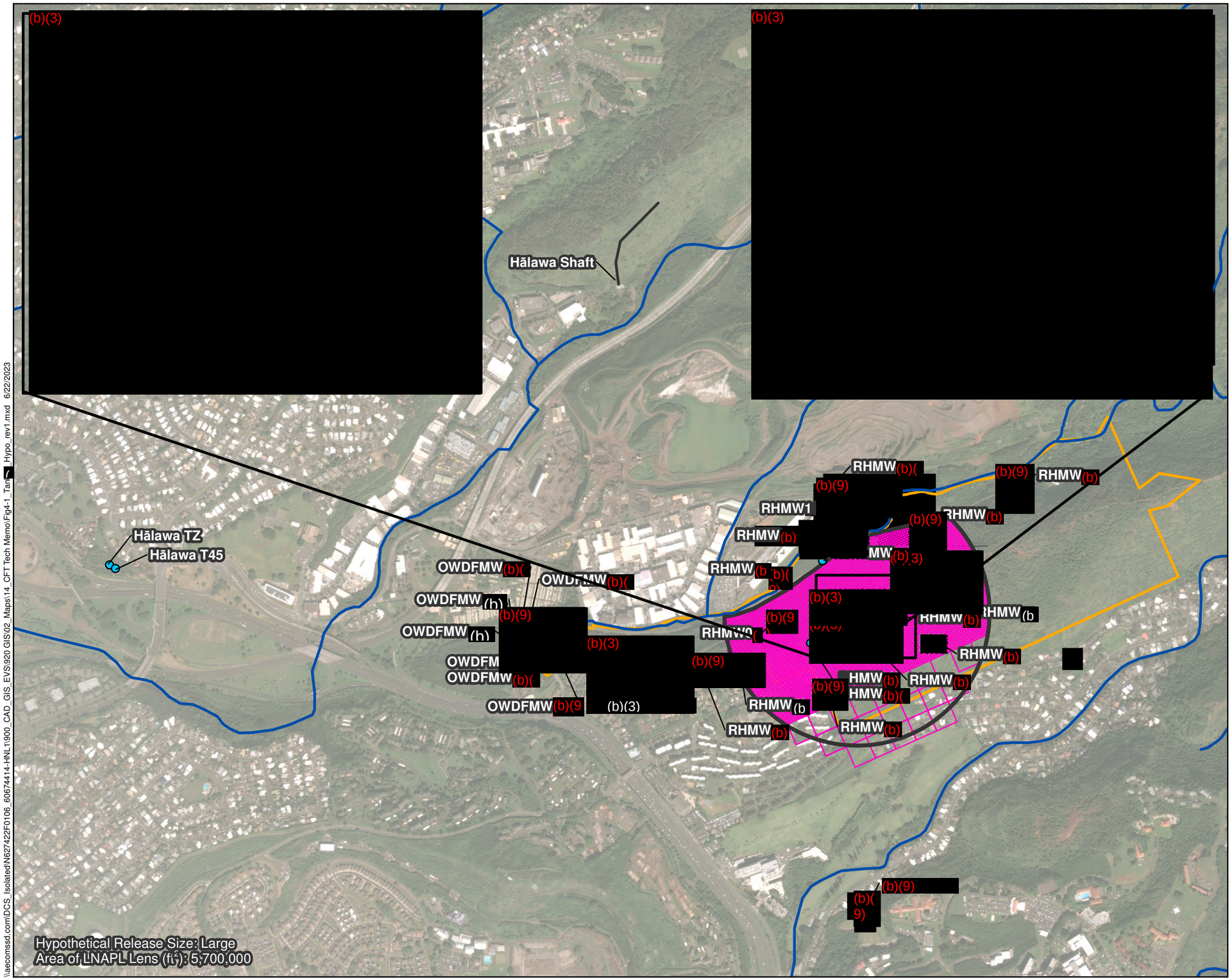
1. Map projection: NAD 1983 Hawaii State Plane Zone 3 feet.
2. Base Map: DigitalGlobe, Inc. (DG) and NRCS. Publication_Date: 2015
3. Spring locations provided by USGS.
4. Water supply well locations provided by DLNR.

N

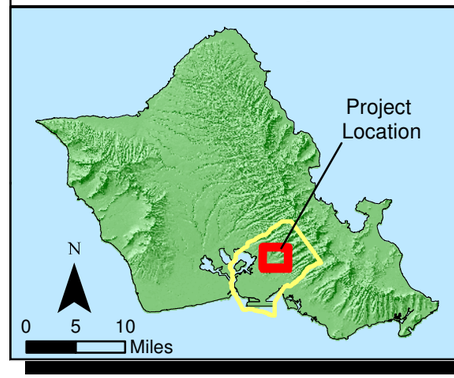
Feet
0 500 1,000 1,500

Figure 3-6
Simulated November 2021
TPH-d Concentrations After One Year
Red Hill Bulk Fuel Storage Facility
JBPHH, O'ahu, HI

B:\N627422F0106_60674414-HNL1\900_CAD_GIS_EVS\920 GIS\02_Maps\14_CFT Tech Memo\Fig3-6_SimulatedNov2022_rev.mxd 6/21/2023



Location Map



Legend

- LNAPL Lens Grid Cell
- Monitoring Well
- (b)(Water Development Tunnel
- Stream
- Red Hill Facility Boundary
- Groundwater Flow Model Domain

Notes

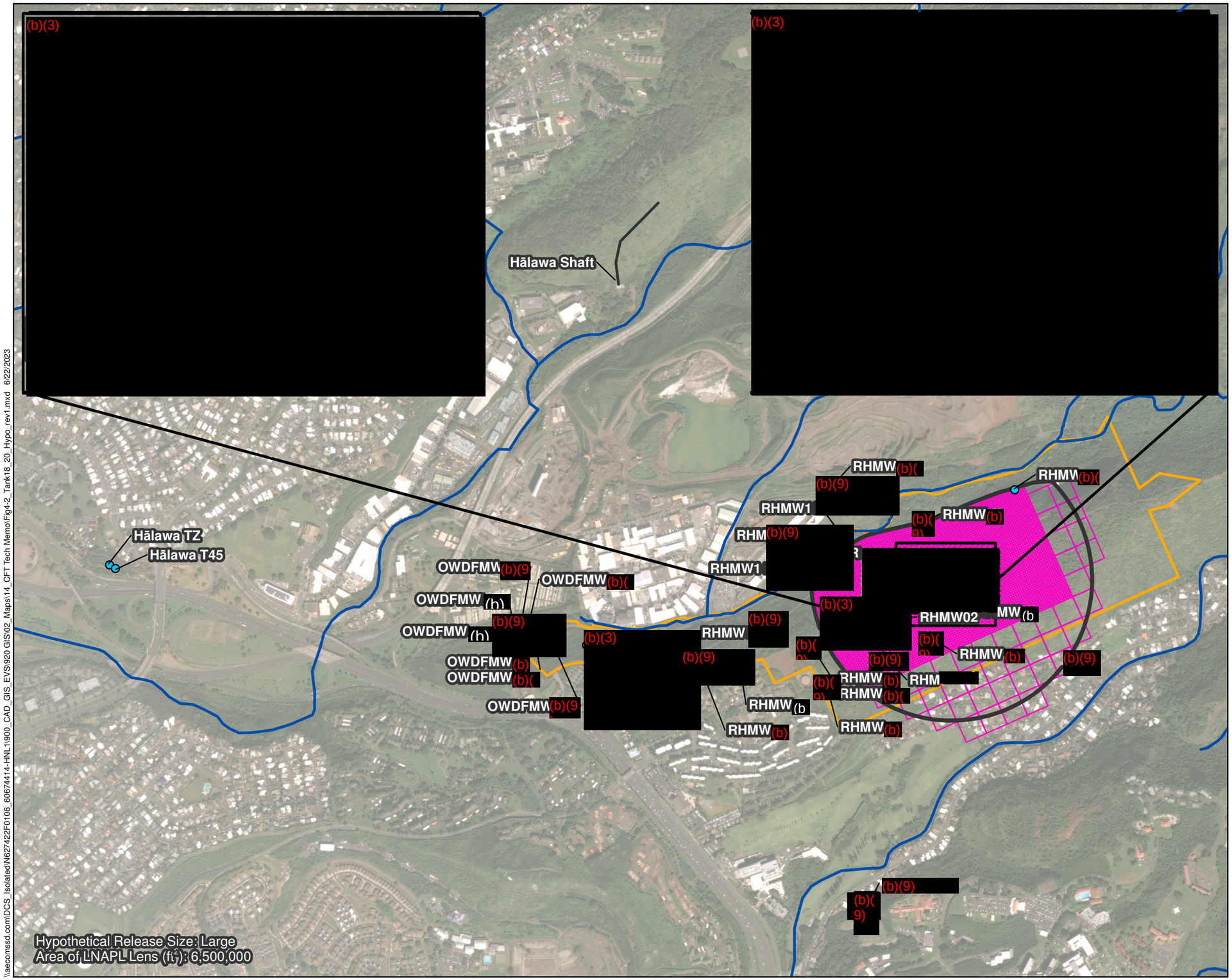
1. Map projection: NAD 1983 Hawaii State Plane Zone 3 feet.
2. Base Map: DigitalGlobe, Inc. (DG) and NRCS. Publication_Date: 2015

N

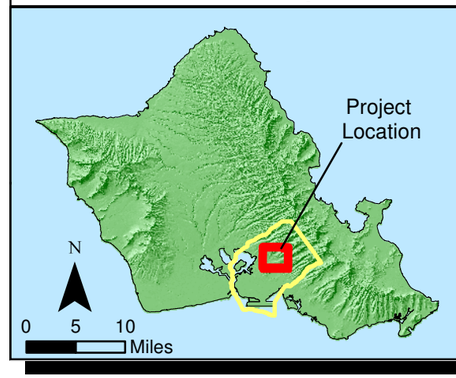
0 500 1,000 1,500 Feet

Figure 4-1
Tank (b Hypothetical Release Source Zones
CF&T Technical Memorandum
Red Hill Bulk Fuel Storage Facility
JBPHH, O'ahu, HI

\\aecomssd.com\DCS_Isolated\N627422F0106_60674414-HNL1\900_CAD_GIS_EVS\920 GIS\02_Maps\14_CFT Tech Memo\Fig4-1_Tank_Hypo_rev1.mxd 6/22/2023



Location Map



Legend

- LNAPL Lens Grid Cell
- Monitoring Well
- (b)(Water Development Tunnel
- Stream
- Red Hill Facility Boundary
- Groundwater Flow Model Domain

Notes

1. Map projection: NAD 1983 Hawaii State Plane Zone 3 feet.
2. Base Map: DigitalGlobe, Inc. (DG) and NRCS. Publication_Date: 2015

N

0 500 1,000 1,500 Feet

Figure 4-2
Tanks 18 & 20
Hypothetical Release Source Zones
CF&T Technical Memorandum
Red Hill Bulk Fuel Storage Facility
JBPHH, O'ahu, HI

\\aecomssd.com\DCS_Isolated\N627422F0106_60674414-HNL1\900_CAD_GIS_EVS\920 GIS\02_Maps\14_CFT Tech Memo\Fig4-2_Tank18_20_Hypo_rev1.mxd 6/22/2023

Hypothetical Release Size: Small
Area of LNAPL Lens (ft²): 21,000
Radius (ft): 81.6

Hypothetical Release Size: Medium
Area of LNAPL Lens (ft²): 110,000
Radius (ft): 187

Hypothetical Release Size: Large
Area of LNAPL Lens (ft²): 5,300,000

Hālawa Shaft
Hālawa TZ
Hālawa T45
RHMW1
RHMW14
RHMW
HMW
OWDFMW

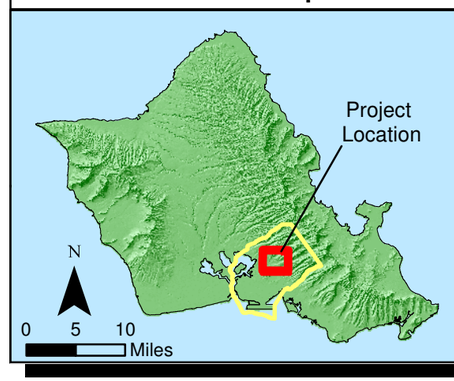
N

0 80 160 240 Feet

0 50 100 150 Feet

0 500 1,000 1,500 Feet

Location Map



Legend

- LNAPL Lens Grid Cell
- Monitoring Well
- Water Development Tunnel
- Stream
- Red Hill Facility Boundary
- Groundwater Flow Model Domain

Notes

1. Map projection: NAD 1983 Hawaii State Plane Zone 3 feet.
2. Base Map: DigitalGlobe, Inc. (DG) and NRCS. Publication_Date: 2015

Figure 4-3
RHMW
Hypothetical Release Source Zones
CF&T Technical Memorandum
Red Hill Bulk Fuel Storage Facility
JBPHH, O'ahu, HI

\\aecomssd.com\DCS_Isolated\N627422F0106_60674414-HNL1\900_CAD_GIS_EVS\920 GIS\02_Maps\14_CFT Tech Memo\Fig4-3_RHMW_Hypo_rev1.mxd 6/22/2023

Hypothetical Release Size: Small
Area of LNAPL Lens (ft²): 20,000
Radius (ft): 80

Hypothetical Release Size: Medium
Area of LNAPL Lens (ft²): 110,000
Radius (ft): 187

Hypothetical Release Size: Large
Area of LNAPL Lens (ft²): 5,300,000

Hālawa Shaft
Hālawa TZ
Hālawa T45

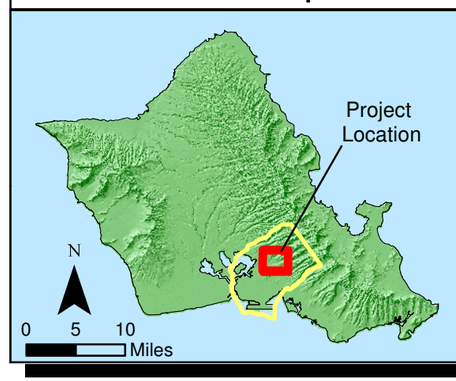
Feet
0 80 160 240

Feet
0 50 100 150

Feet
0 500 1,000 1,500

N

Location Map



Legend

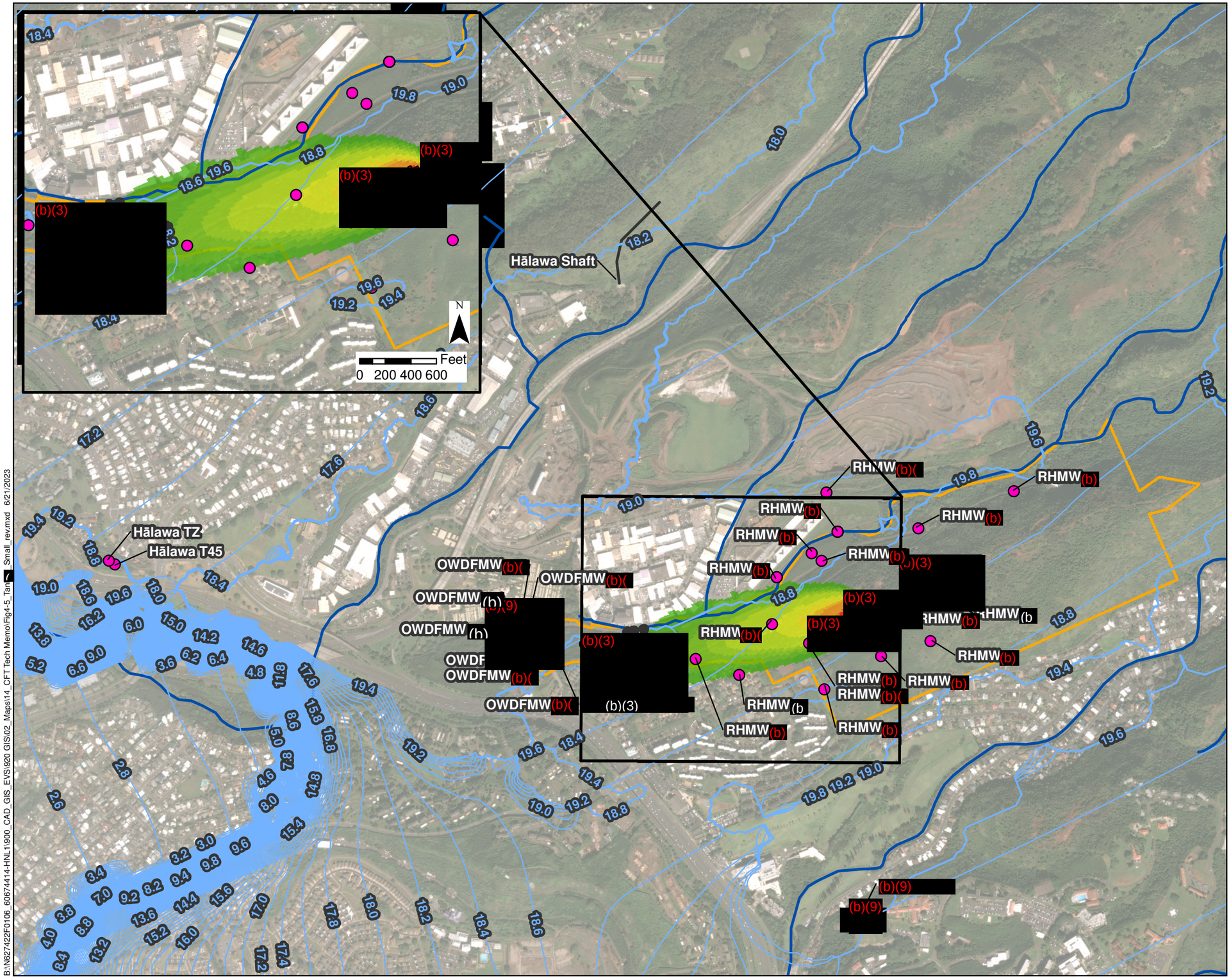
- LNAPL Lens Grid Cell
- Monitoring Well
- (b)(Water Development Tunnel
- Stream
- Red Hill Facility Boundary
- Groundwater Flow Model Domain

Notes

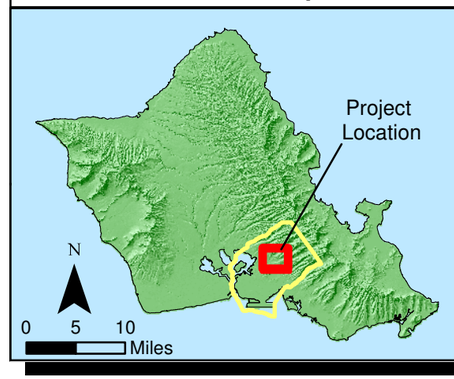
1. Map projection: NAD 1983 Hawaii State Plane Zone 3 feet.
2. Base Map: DigitalGlobe, Inc. (DG) and NRCS. Publication_Date: 2015

Figure 4-4
(b)(Adit 3
Hypothetical Release Source Zones
CF&T Technical Memorandum
Red Hill Bulk Fuel Storage Facility
JBPHH, O'ahu, HI

\\aecomssd.com\DCS_Isolated\N627422F0106_60674414-HNL1\900_CAD_GIS_EVS\920 GIS\02_Maps\14_CFT Tech Memo\Fig4-4_Adit3_Hypo_rev1.mxd 6/22/2023



Location Map



Legend

Simulated TPH-d Concentrations (µg/L)

- 200 to < 400
- 400 to < 600
- 600 to < 800
- 800 to < 1,000
- 1,000 to < 2,000
- 2,000 to < 3,000
- 3,000 to < 4,000
- 4,000 to < 5,000
- 5,000 to < 10,000
- > 10,000

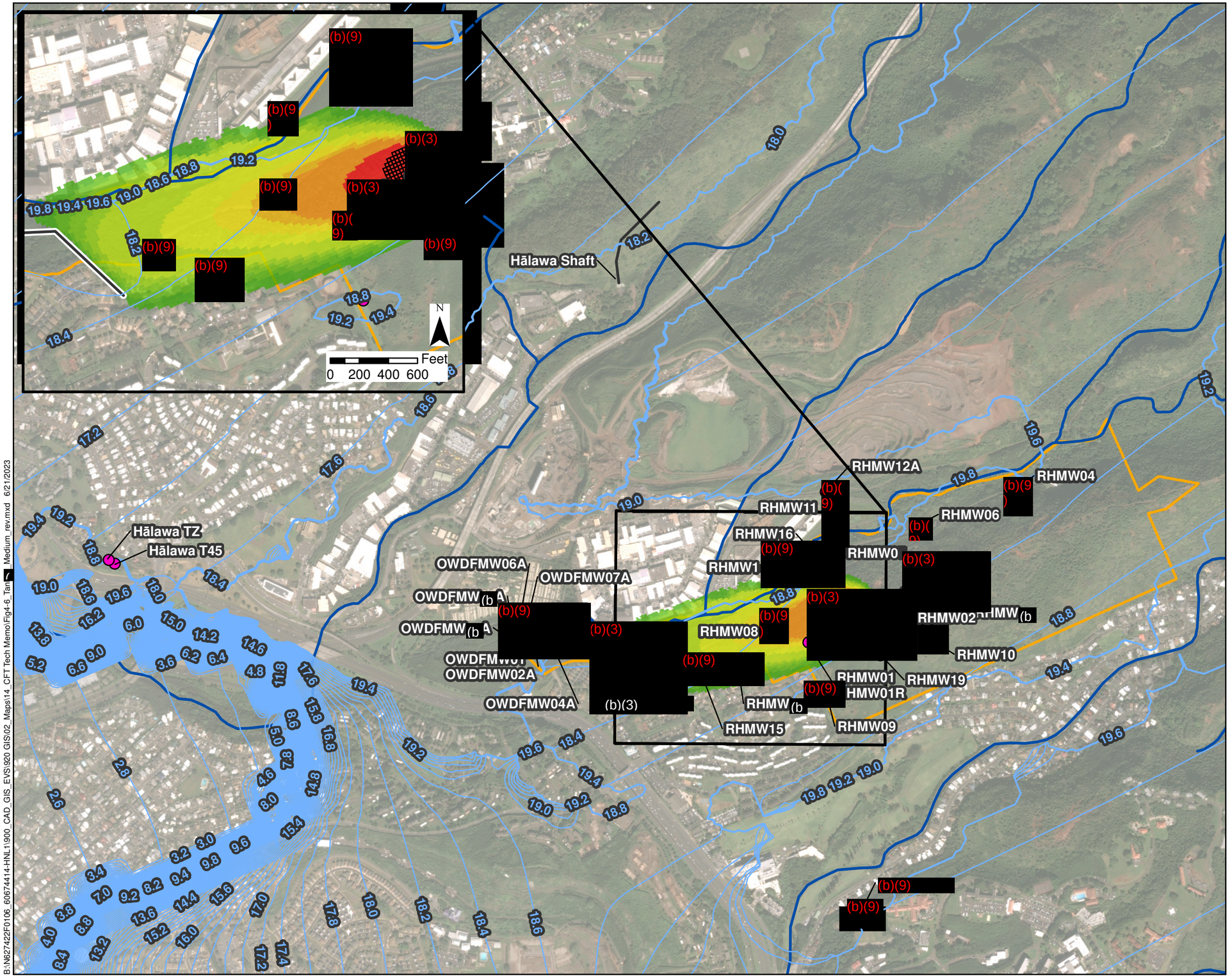
- Source Zone
- Monitoring Well
- Potentiometric Surface (ft msl)
- (b)(Water Development Tunnel
- Stream
- Red Hill Facility Boundary
- Groundwater Flow Model Domain

Notes

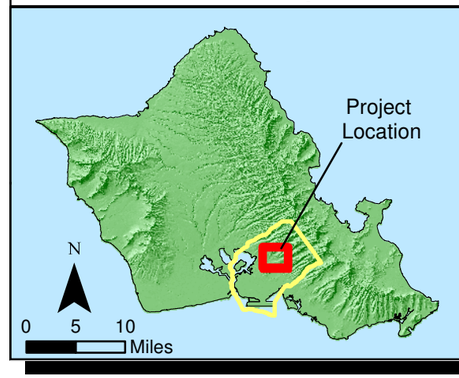
1. Map projection: NAD 1983 Hawaii State Plane Zone 3 feet.
2. Base Map: DigitalGlobe, Inc. (DG) and NRCS. Publication_Date: 2015
3. Spring locations provided by USGS.
4. Water supply well locations provided by DLNR.

Figure 4-5
Tank (b - Small Release ((b)(3) gal)
Simulated TPH-d Concentrations
Red Hill Bulk Fuel Storage Facility
JBPHH, O'ahu, HI

B:\N627422F0106_60674414-HNL\1\900_CAD_GIS_EVS\920 GIS\02_Maps\14_CFT Tech Memo\Fig4-5_Tank (b)_Small_rev.mxd 6/21/2023



Location Map



Legend

Simulated TPH-d Concentrations (µg/L)

- 200 to < 400
- 400 to < 600
- 600 to < 800
- 800 to < 1,000
- 1,000 to < 2,000
- 2,000 to < 3,000
- 3,000 to < 4,000
- 4,000 to < 5,000
- 5,000 to < 10,000
- > 10,000

- Source Zone
- Monitoring Well
- Potentiometric Surface (ft msl)
- (b)(Water Development Tunnel
- Stream
- Red Hill Facility Boundary
- Groundwater Flow Model Domain

Notes

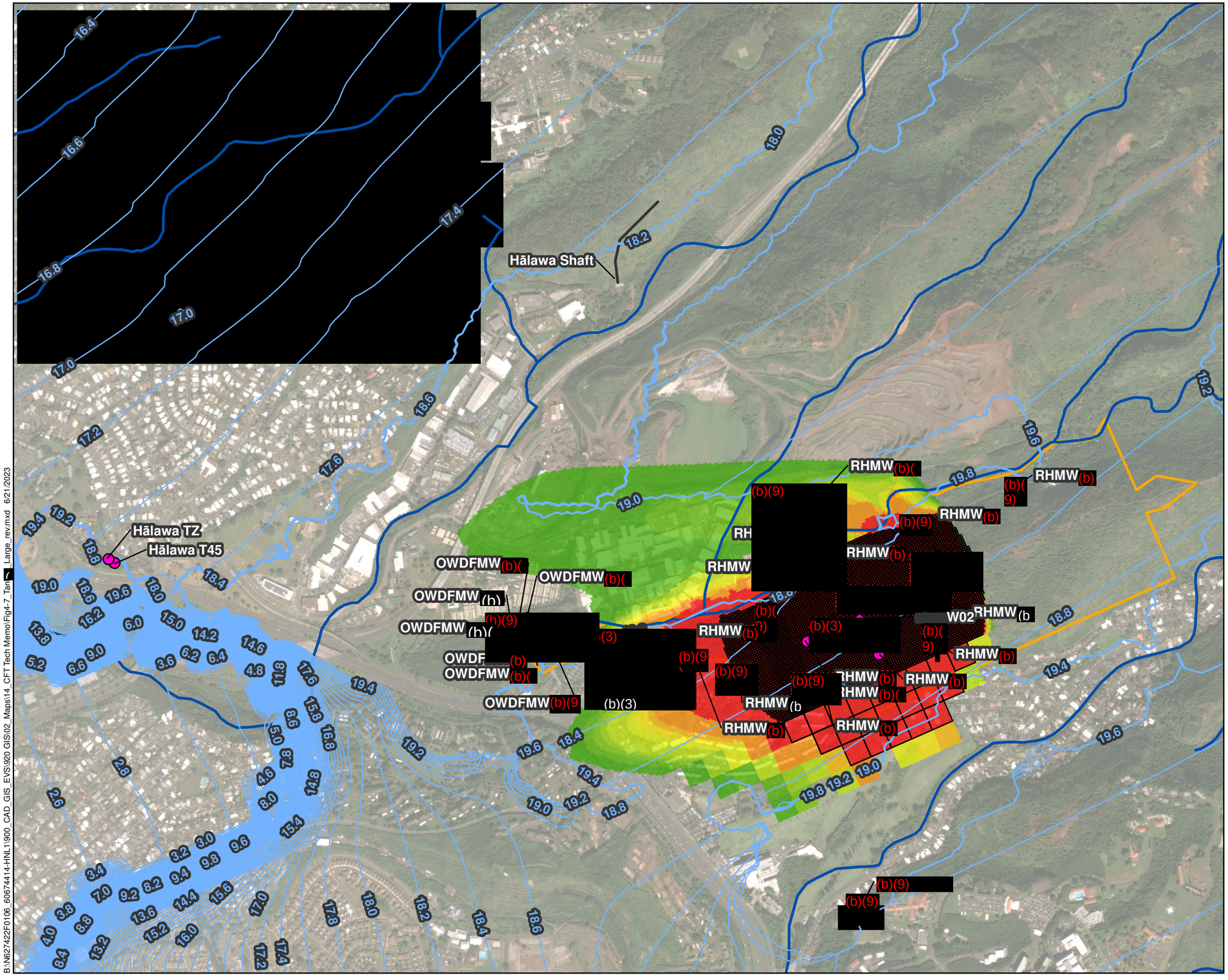
1. Map projection: NAD 1983 Hawaii State Plane Zone 3 feet.
2. Base Map: DigitalGlobe, Inc. (DG) and NRCS. Publication_Date: 2015
3. Spring locations provided by USGS.
4. Water supply well locations provided by DLNR.

N

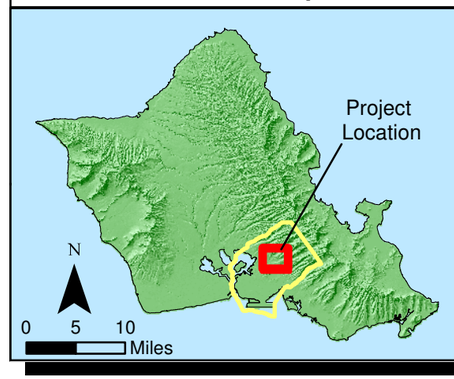
Feet
0 500 1,000 1,500

Figure 4-6
Tank (b - Medium Release ((b)(3) gal)
Simulated TPH-d Concentrations
Red Hill Bulk Fuel Storage Facility
JBPHH, O'ahu, HI

B:\N627422F0106_60674414-HNL1\900_CAD_GIS_EVS\920 GIS\02_Maps\14_CFT Tech Memo\Fig4-6_Tank Medium_rev.mxd 6/21/2023



Location Map



Legend

Simulated TPH-d Concentrations (µg/L)

- 200 to < 400
- 400 to < 600
- 600 to < 800
- 800 to < 1,000
- 1,000 to < 2,000
- 2,000 to < 3,000
- 3,000 to < 4,000
- < 4,000 to 5,000
- < 5,000 to 10,000
- > 10,000

- Source Zone
- Monitoring Well (not in the basal aquifer)
- Potentiometric Surface (ft msl)
- (b)(Water Development Tunnel
- Stream
- Red Hill Facility Boundary
- Groundwater Flow Model Domain

Notes

1. Map projection: NAD 1983 Hawaii State Plane Zone 3 feet.
2. Base Map: DigitalGlobe, Inc. (DG) and NRCS. Publication_Date: 2015
3. Spring locations provided by USGS.
4. Water supply well locations provided by DLNR.

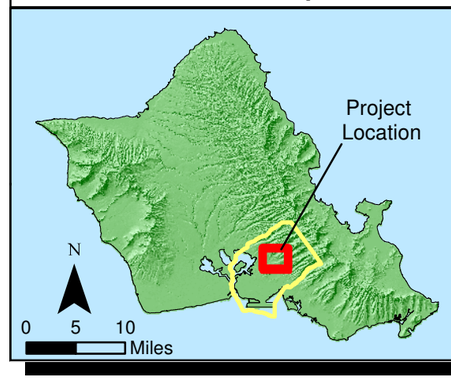
N

0 500 1,000 1,500 Feet

Figure 4-7
Tank (b - Large Release ((b)(3) gal)
Simulated TPH-d Concentrations
Red Hill Bulk Fuel Storage Facility
JBPHH, O'ahu, HI

B:\N627422F0106_60674414-HNL\900_CAD_GIS_EVS\920 GIS\02_Maps\14_CFT Tech Memo\Fig4-7_Tank (b - Large_rev.mxd 6/21/2023

Location Map



Legend

Simulated TPH-d Concentrations (µg/L)

- 200 to < 400
- 400 to < 600
- 600 to < 800
- 800 to < 1,000
- 1,000 to < 2,000
- 2,000 to < 3,000
- 3,000 to < 4,000
- 4,000 to < 5,000
- 5,000 to < 10,000
- < 10,000

Source Zone

Monitoring Well

Potentiometric Surface (ft msl)

(b)(Water Development Tunnel

Stream

Red Hill Facility Boundary

Groundwater Flow Model Domain

Notes

1. Map projection: NAD 1983 Hawaii State Plane Zone 3 feet.
2. Base Map: DigitalGlobe, Inc. (DG) and NRCS. Publication_Date: 2015
3. Spring locations provided by USGS.
4. Water supply well locations provided by DLNR.

N

0 500 1,000 1,500 Feet

Figure 4-8
Tanks 18 & 20 - Small Release ((b)(3) gal)
Simulated TPH-d Concentrations
Red Hill Bulk Fuel Storage Facility
JBPHH, O'ahu, HI

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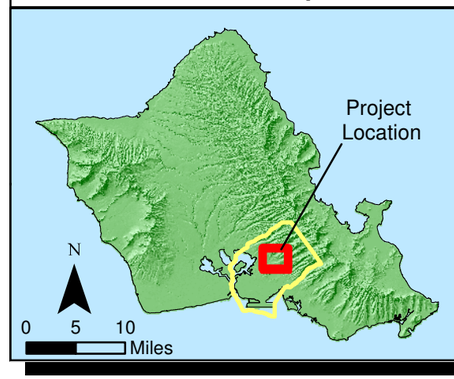
Location Map



Legend

Simulated TPH-d Concentrations (µg/L)

- 200 to < 400
- 400 to < 600
- 600 to < 800
- 800 to < 1,000
- 1,000 to < 2,000
- 2,000 to < 3,000
- 3,000 to < 4,000
- 4,000 to < 5,000
- 5,000 to < 10,000
- > 10,000

- Source Zone
- Monitoring Well
- Potentiometric Surface (ft msl)
- (b)(Water Development Tunnel
- Stream
- Red Hill Facility Boundary
- Groundwater Flow Model Domain

Notes

1. Map projection: NAD 1983 Hawaii State Plane Zone 3 feet.
2. Base Map: DigitalGlobe, Inc. (DG) and NRCS. Publication_Date: 2015
3. Spring locations provided by USGS.
4. Water supply well locations provided by DLNR.

N

0 500 1,000 1,500 Feet

Figure 4-9
Tanls 18 & 20 - Medium Release ((b)(3) gal)
Simulated TPH-d Concentrations
Red Hill Bulk Fuel Storage Facility
JBPHH, O'ahu, HI

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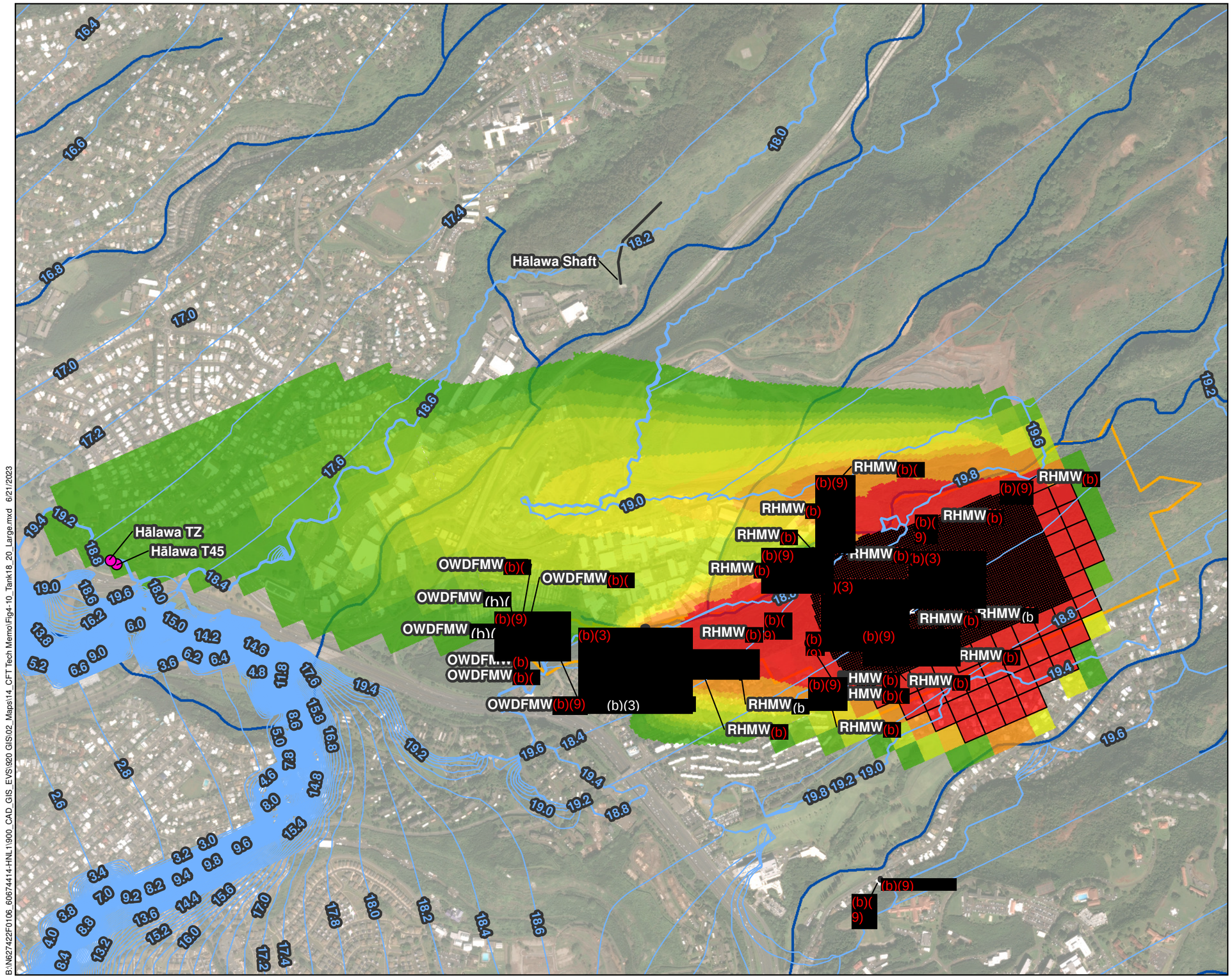
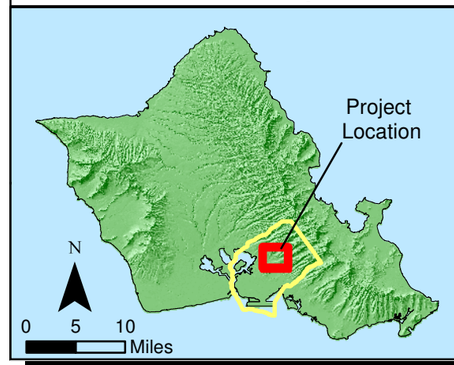


Location Map



Legend

Simulated TPH-d Concentrations (µg/L)

- 200 to < 400
- 400 to < 600
- 600 to < 800
- 800 to < 1,000
- 1,000 to < 2,000
- 2,000 to < 3,000
- 3,000 to < 4,000
- 4,000 to < 5,000
- 5,000 to < 10,000
- > 10,000
- Source Zone
- Monitoring Well
- Potentiometric Surface (ft msl)
- (b)(Water Development Tunnel
- Stream
- Red Hill Facility Boundary
- Groundwater Flow Model Domain

Notes

1. Map projection: NAD 1983 Hawaii State Plane Zone 3 feet.
2. Base Map: DigitalGlobe, Inc. (DG) and NRCS. Publication_Date: 2015
3. Spring locations provided by USGS.
4. Water supply well locations provided by DLNR.

N

0 500 1,000 1,500 Feet

Figure 4-10
Tank 18 & 20 - Large Release ((b)(3) gal)
Simulated TPH-d Concentrations
Red Hill Bulk Fuel Storage Facility
JBPHH, O'ahu, HI

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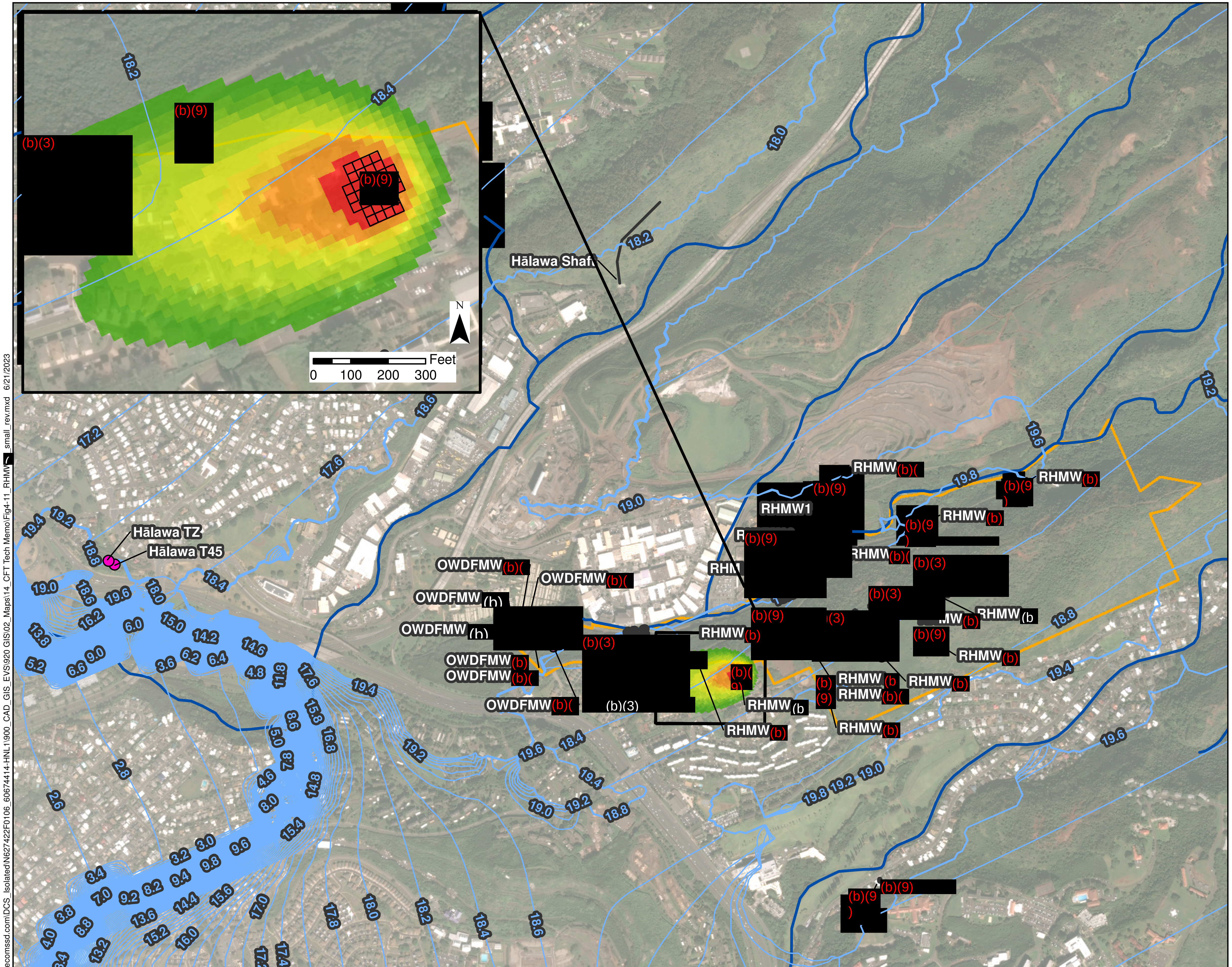

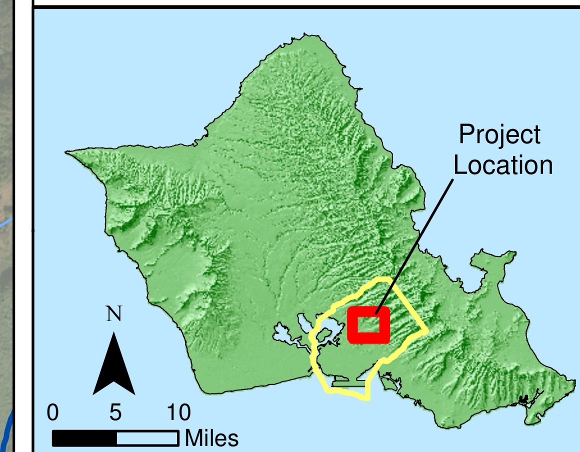

Legend

Simulated TPH-d Concentrations (µg/L)

- 200 to < 400
- 400 to < 600
- 600 to < 800
- 800 to < 1,000
- 1,000 to < 2,000
- 2,000 to < 3,000
- 3,000 to < 4,000
- 4,000 to < 5,000
- 5,000 to < 10,000
- > 10,000
- Source Zone
- Monitoring Well (not in the basal aquifer)
- Potentiometric Surface (ft msl)
- (b)([redacted] Water Development Tunnel
- Stream
- Red Hill Facility Boundary
- Groundwater Flow Model Domain

Notes

1. Map projection: NAD 1983 Hawaii State Plane Zone 3 feet.
2. Base Map: DigitalGlobe, Inc. (DG) and NRCS. Publication_Date: 2015
3. Spring locations provided by USGS.
4. Water supply well locations provided by DLNR.

N

Feet
0 500 1,000 1,500

Figure 4-11
RHMW(b) [redacted] - Small Release ((b)(3) [redacted] gal)
Simulated TPH-d Concentrations
Red Hill Bulk Fuel Storage Facility
JBPHH, O'ahu, HI

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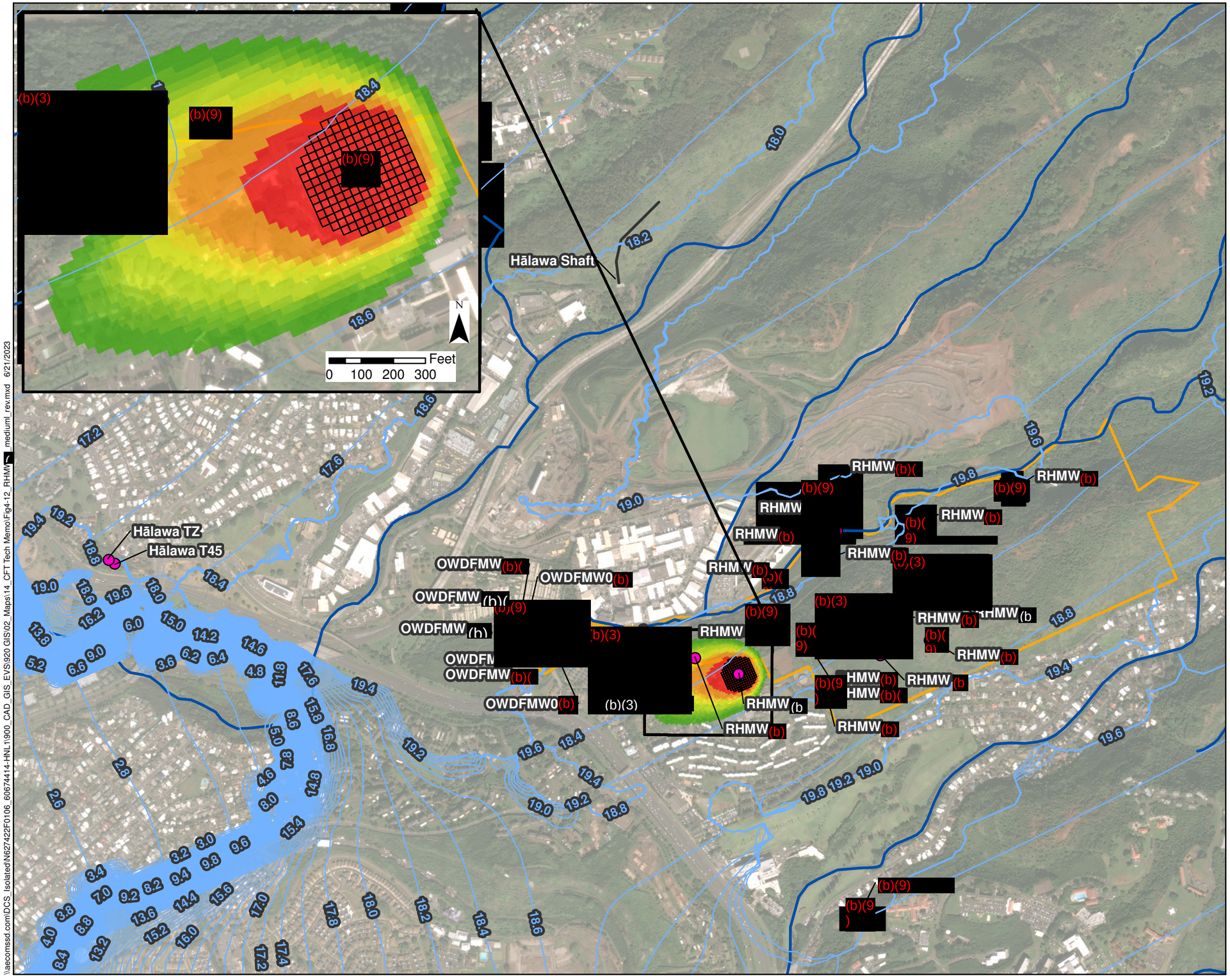
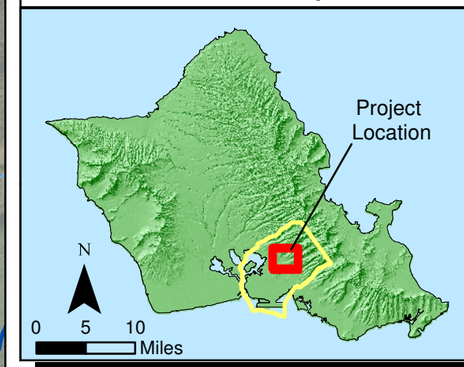


\\aecomssd.com\DCS_Isolated\N6274422F0106_60674414-HNL1\900_CAD_GIS_EVS\920 GIS\02_Maps\14_CFT Tech Memo\Fig4-12_RHMW_mediumL_rev.mxd 6/21/2023

Location Map



Legend

Simulated TPH-d Concentrations (µg/L)

- 200 to < 400
- 400 to < 600
- 600 to < 800
- 800 to < 1,000
- 1,000 to < 2,000
- 2,000 to < 3,000
- 3,000 to < 4,000
- 4,000 to < 5,000
- 5,000 to < 10,000
- > 10,000
- Source Zone
- Monitoring Well
- Potentiometric Surface (ft msl)
- (b)(Water Development Tunnel
- Stream
- Red Hill Facility Boundary
- Groundwater Flow Model Domain

Notes

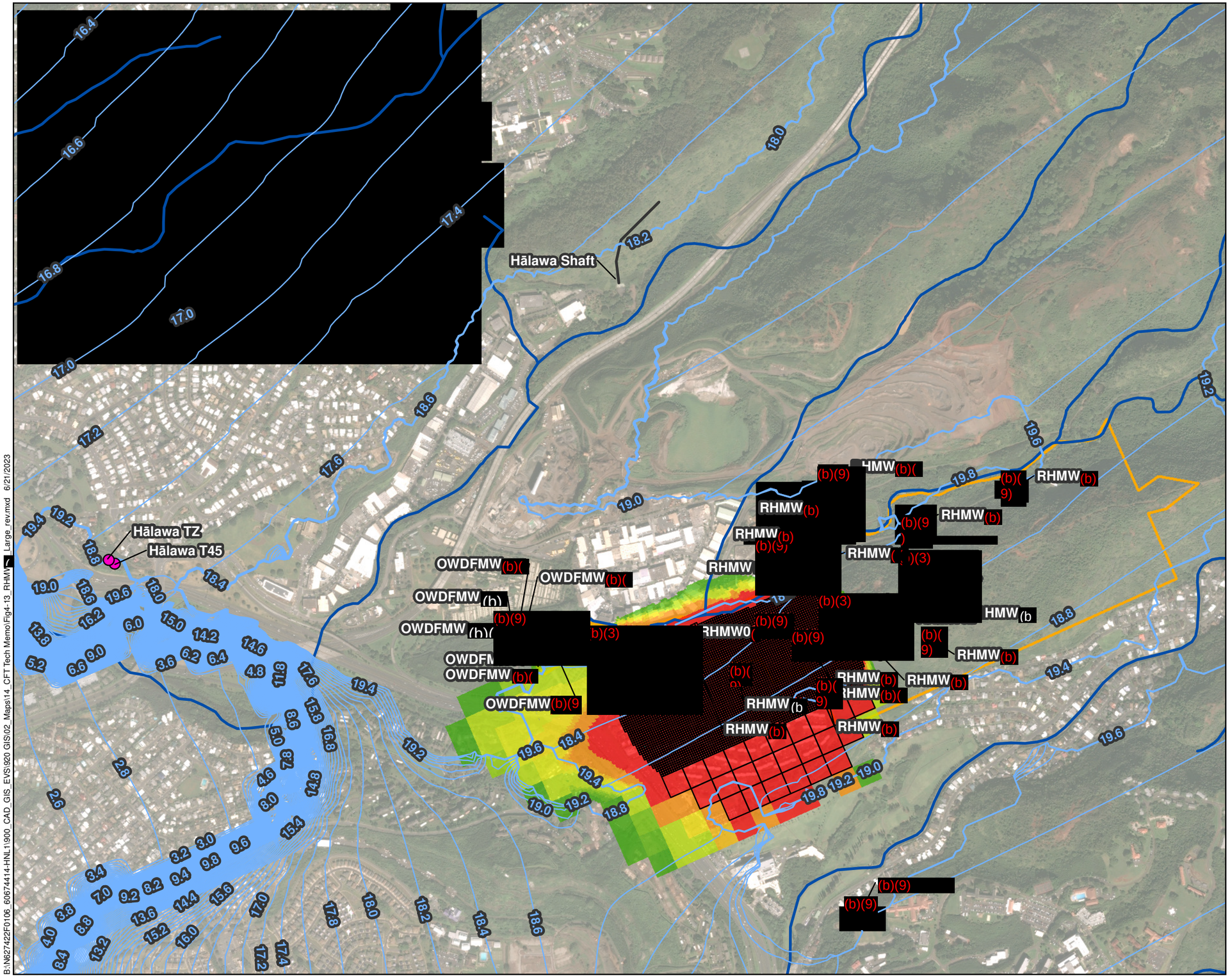
1. Map projection: NAD 1983 Hawaii State Plane Zone 3 feet.
2. Base Map: DigitalGlobe, Inc. (DG) and NRCS. Publication_Date: 2015
3. Spring locations provided by USGS.
4. Water supply well locations provided by DLNR.

N

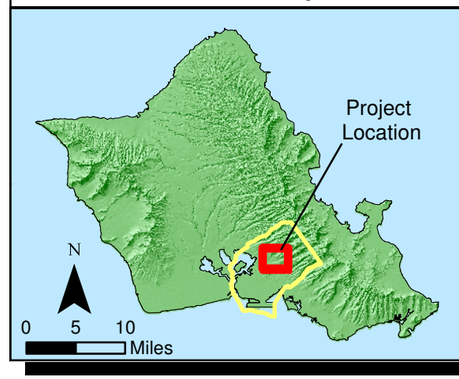
Feet

0 500 1,000 1,500

Figure 4-12
RHMW(b - Medium Release ((b)(3) gal)
Simulated TPH-d Concentrations
Red Hill Bulk Fuel Storage Facility
JBPHH, O'ahu, HI



Location Map



Legend

Simulated TPH-d Concentrations (µg/L)

- 200 to < 400
- 400 to < 600
- 600 to < 800
- 800 to < 1,000
- 1,000 to < 2,000
- 2,000 to < 3,000
- 3,000 to < 4,000
- 4,000 to < 5,000
- 5,000 to < 10,000
- > 10,000

- Source Zone
- Monitoring Well (not in the basal aquifer)
- Potentiometric Surface (ft msl)
- (b)(Water Development Tunnel
- Stream
- Red Hill Facility Boundary
- Groundwater Flow Model Domain

Notes

1. Map projection: NAD 1983 Hawaii State Plane Zone 3 feet.
2. Base Map: DigitalGlobe, Inc. (DG) and NRCS. Publication_Date: 2015
3. Spring locations provided by USGS.
4. Water supply well locations provided by DLNR.

N

0 500 1,000 1,500 Feet

Figure 4-13
RHMW(b - Large Release ((b)(3) gal)
Simulated TPH-d Concentrations
Red Hill Bulk Fuel Storage Facility
JBPHH, O'ahu, HI

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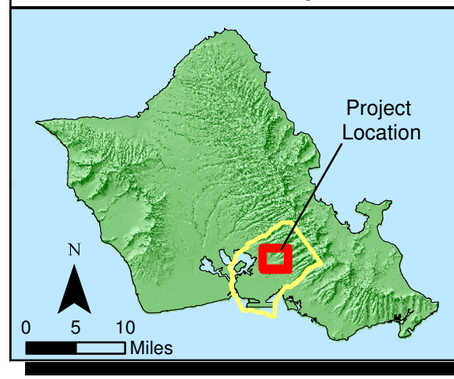
Location Map



Legend

Simulated TPH-d Concentrations (µg/L)

- 200 to < 400
- 400 to < 600
- 600 to < 800
- 800 to < 1,000
- 1,000 to < 2,0000
- 2,000 to < 3,0000
- 3,000 to < 4,000
- 4,000 to < 5,000
- 5,000 to < 10,000
- > 10,000
- Source Zone
- Monitoring Well
- Potentiometric Surface (ft msl)
- (b)(Water Development Tunnel
- Stream
- Red Hill Facility Boundary
- Groundwater Flow Model Domain

Notes

1. Map projection: NAD 1983 Hawaii State Plane Zone 3 feet.
2. Base Map: DigitalGlobe, Inc. (DG) and NRCS. Publication_Date: 2015
3. Spring locations provided by USGS.
4. Water supply well locations provided by DLNR.

N

0 500 1,000 1,500 Feet

Figure 4-14
(b)(Adit 3 - Small Release ((b)(3) gal)
Simulated TPH-d Concentrations
Red Hill Bulk Fuel Storage Facility
JBPHH, O'ahu, HI

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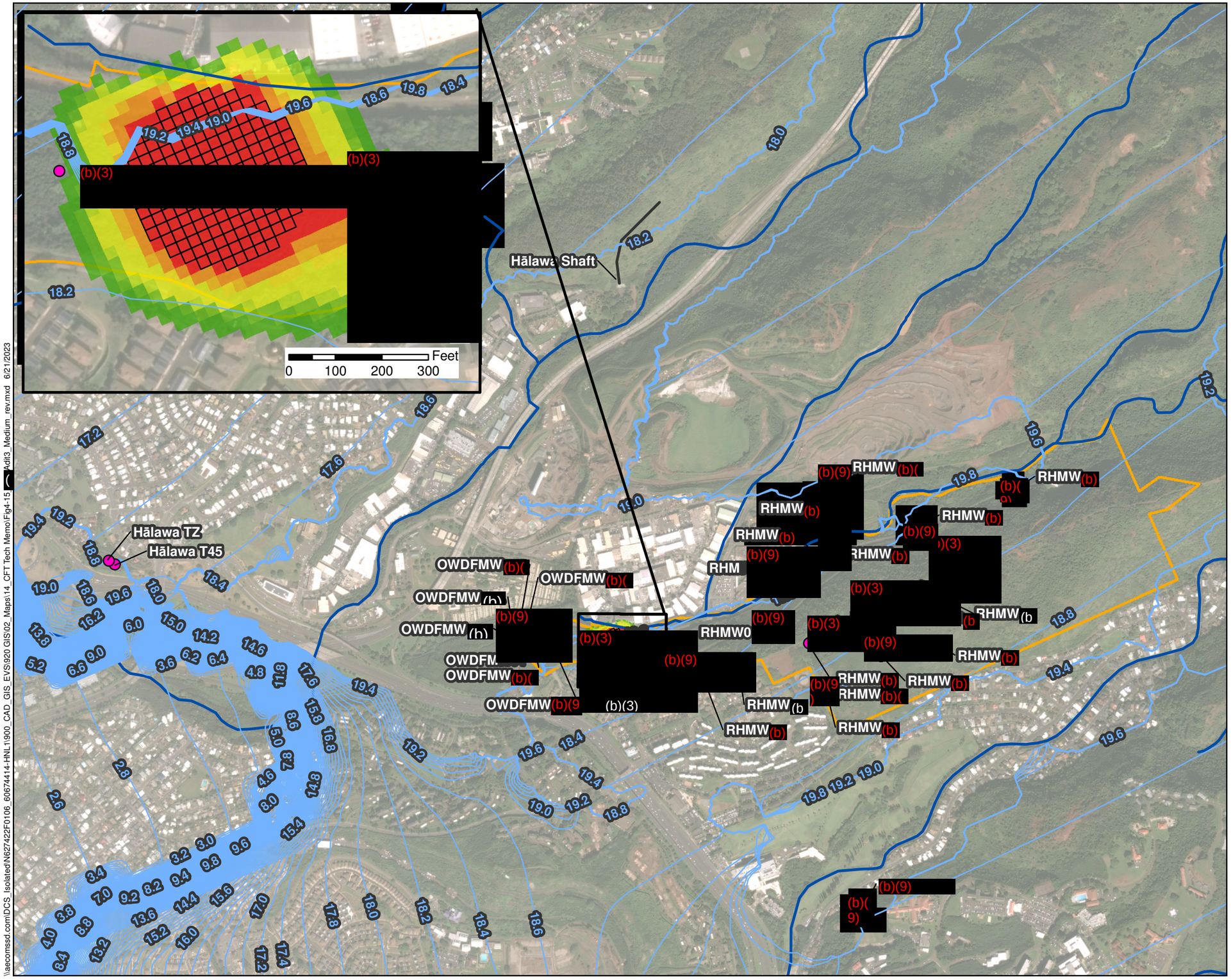
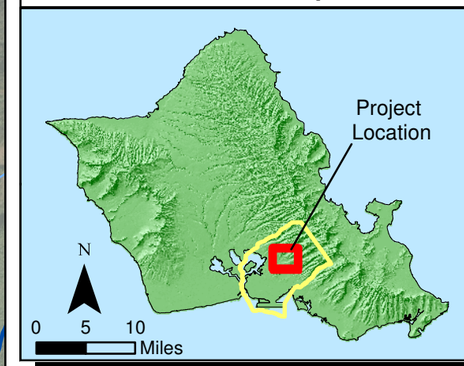


Location Map



Legend

Simulated TPH-d Concentrations (µg/L)

- 200 to < 400
- 400 to < 600
- 600 to < 800
- 800 to < 1,000
- 1,000 to < 2,000
- 2,000 to < 3,000
- 3,000 to < 4,000
- 4,000 to < 5,000
- 5,000 to < 10,000
- > 10,000
- Source Zone
- Monitoring Well
- Potentiometric Surface (ft msl)
- (b)(Water Development Tunnel
- Stream
- Red Hill Facility Boundary
- Groundwater Flow Model Domain

Notes

1. Map projection: NAD 1983 Hawaii State Plane Zone 3 feet.
2. Base Map: DigitalGlobe, Inc. (DG) and NRCS. Publication_Date: 2015
3. Spring locations provided by USGS.
4. Water supply well locations provided by DLNR.

N

Feet
0 500 1,000 1,500

Figure 4-15
(b)(Adit 3 - Medium Release ((b)(3) gal)
Simulated TPH-d Concentrations
Red Hill Bulk Fuel Storage Facility
JBPHH, O'ahu, HI

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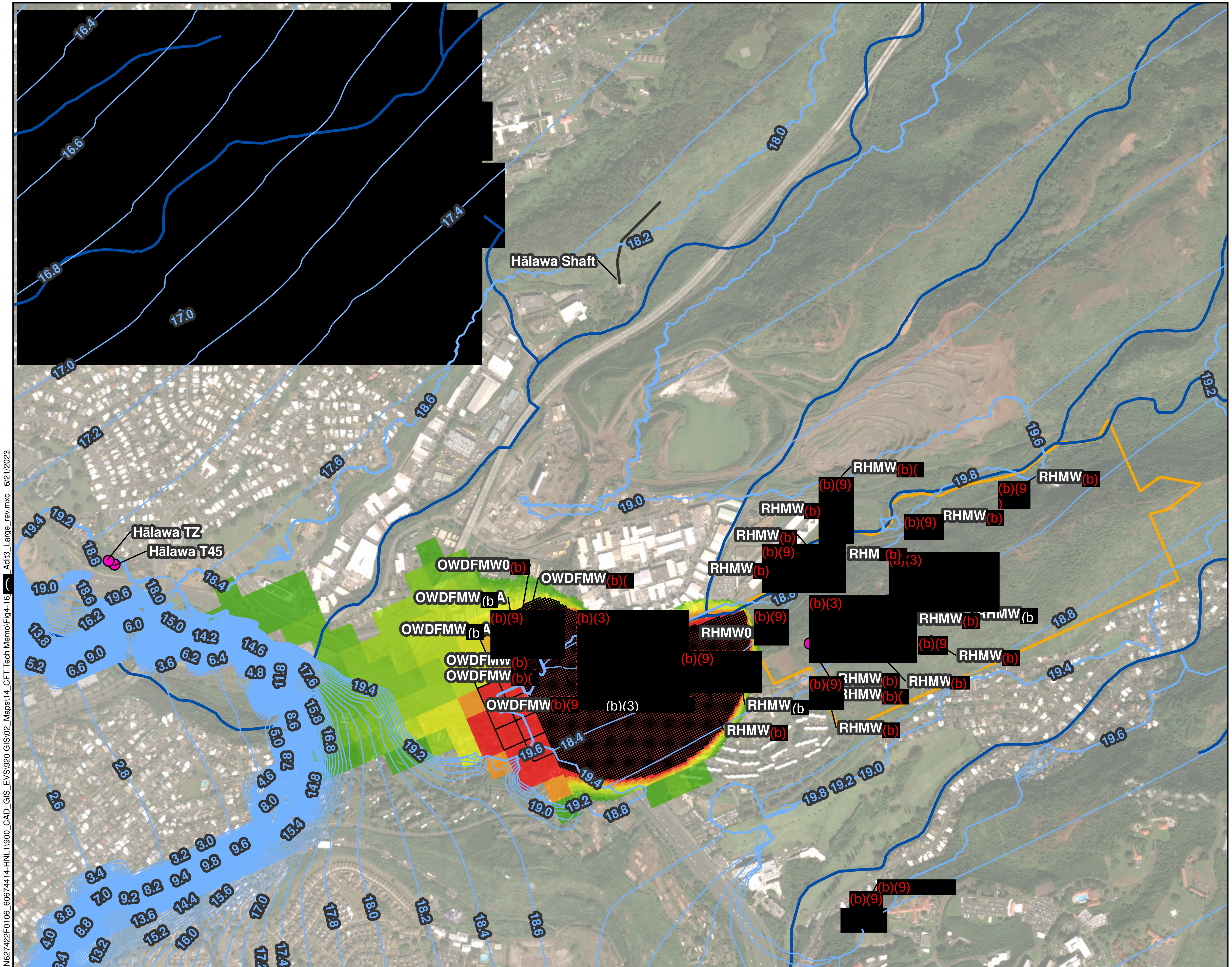

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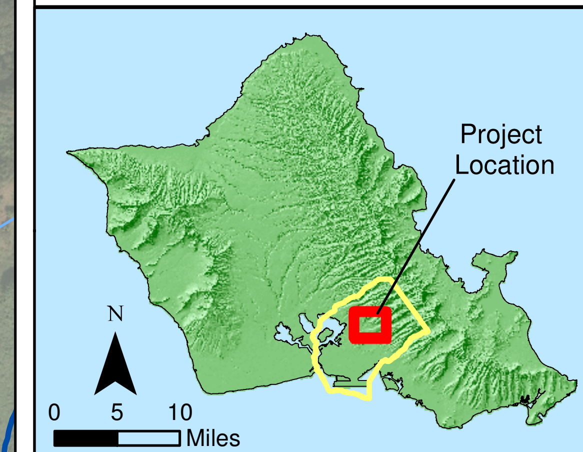
Location Map



Legend

Simulated TPH-d Concentrations (µg/L)

- 200 to < 400
- 400 to < 600
- 600 to < 800
- 800 to < 1,000
- 1,000 to < 2,000
- 2,000 to < 3,000
- 3,000 to < 4,000
- 4,000 to < 5,000
- 5,000 to < 10,000
- > 10,000

Source Zone

Monitoring Well (not in the basal aquifer)

Potentiometric Surface (ft msl)

(b)([redacted] Water Development Tunnel

Stream

Red Hill Facility Boundary

Groundwater Flow Model Domain

Notes

1. Map projection: NAD 1983 Hawaii State Plane Zone 3 feet.
2. Base Map: DigitalGlobe, Inc. (DG) and NRCS. Publication_Date: 2015
3. Spring locations provided by USGS.
4. Water supply well locations provided by DLNR.

N

0 500 1,000 1,500 Feet

Figure 4-16
(b)([redacted] / Adit 3 - Large Release ((b)(3) [redacted] gal)
Simulated TPH-d Concentrations
Red Hill Bulk Fuel Storage Facility
JBPHH, Oʻahu, HI