Red Hill Bulk Fuel Storage Facility Final Technical Report

Pearl Harbor, Hawaii

August 2007

Prepared for:

Department of the Navy, Commander
Naval Facilities Engineering Command, Pacific
Pearl Harbor, HI 96860-3134

Indefinite Delivery/ Indefinite Quantity Contract
Contract Number N62742-02-D-1802, CTO 007

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LIST OF ACRONYMS AND ABBREVIATIONS

%R	percent recovery
1,2-DCA	1, 2-Dichloroethane
3-D	three dimensional
µg/L	micrograms per Liter
$\mu g/m^3$	micrograms per cubic meter
µS/hr	microSiemens per hour
AMEC	AMEC Earth and Environmental, Inc.
ARARs	Applicable or Relevant and Appropriate Requirements
ASTM	American Society for Testing and Materials
ATL	Air Toxics Ltd.
ATSDR	Agency for Toxic Substances and Disease Registry
AVGAS	aviation gasoline
bgs	below ground surface
BTEX	benzene, toluene, ethylbenzene and xylenes
C	Centigrade
CADD	Computer Aided Design and Drafting
CDI	calculated average daily intake of constituents of potential concern
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
cfm	cubic feet per minute
CFR	Code of Federal Regulations
cm/yr	Centimeters per Year
CO	Contracting Officer
COC	chain-of-custody
COPC	constituents of potential concern
COPEC	Chemicals of Potential Ecological Concern
CPI	calculated average daily intake of COPC
CSF	Cancer Slope Factor
CSM	conceptual site model
CSEM	conceptual site exposure model
CTO	Contract Task Order
CWRM	Commission of Water Resource Management
Dawson	Dawson Group Inc.
DLNR	Department of Land and Natural Resources
DVR	Data Validation Report
DPP	The City and County of Honolulu, Department of Planning and Permitting
DQOs	Data Quality Objectives
dtw	depth to water
EALs	Environmental Action Levels
EB	equipment blank
EC	electrical conductivity
EDB	ethylene dibromide
EPCs	Exposure Point Concentrations
EPH	extractable-petroleum hydrocarbons

F-76	diesel marine fuel
famsl	feet above mean sea level
fbgs	feet below ground surface
fbtoc	feet below top of casing
fbwt	feet below water table
FD	Field duplicate
FISC	Fleet Industrial Supply Center
FSP	Field Sampling Plan
ft	feet/foot
ft^{-1}	per foot
gal	gallons
GS	soil gas
GIS	Geographic Information System
GWALS	Groundwater Action Levels
H&S	Health and Safety
HAR	Hawaii Administrative Rules
HBWS	Honolulu Board of Water Supply
HDOH	State of Hawaii, Department of Health
HEER	Hazard Evaluation and Emergency Response
HERL	Hawaii Environmental Response Law
HI	hazard index
HPWS	Hawaii Potable Water Systems
HQ	hazard quotient
HRS	Hawaii Revised Statutes
IDs	identifiers
IDW	investigation-derived waste
IRP	Installation Restoration Program
IWWP	installation-wide work plan
JP-5	Jet Propulsion Fuel 5
JP-8	Jet Propulsion Fuel 8
K	hydraulic conductivity
LCS	Laboratory Control Sample
LDC	Laboratory Data Consultants, Inc.
Lpm	Liter Per Minute
LNAPL	light non-aqueous phase liquid
MADEP	Massachusetts Department of Environmental Protection
MCLs	Maximum Contaminant Levels
Mgal	million gallon
mgd	million gallons per day
mg/L	milligram per Liter
MOGAS	motor gasoline
MRL	method reporting limit
msl	mean sea level
MSDS	Material Safety Data Sheets
MS/MSDs	Matrix Spike/Matrix Spike Duplicates

MTBE	methyl tert-butyl ether
MW	Monitoring Well
NAVFAC	Naval Facilities Engineering Command
N	normal sample
NAPs	natural attenuation parameters
ND	Navy Distillate
ND	not detected
NPDW	National Primary Drinking Water
NSFO	Navy Special Fuel Oil
NTU	nephelometric turbidity units
Ogden	Ogden Environmental and Energy Services Co., Inc.
OSHA	Occupational Safety and Health Administration
OWDF	Oily Waste Disposal Facility
OWS	Oil/Water Separator
PACDIV	Pacific Division
PAH	polynuclear aromatic hydrocarbons
PEST	Parameter ESTimation
PID	photo-ionization detector
POE	point of entry
ppbV	parts per billion by Volume
PPE	Personal Protective Equipment
ppm	parts per million
ppt	parts per thousand
PRG	Preliminary Remediation Goals
psi	pounds per square inch
PTC	Pioneer Technologies Corporation
PUC	Primary Urban Center
PVC	polyvinyl chloride
QA	quality assurance
QAPP	Quality Assurance Project Plan
QC	quality control
RBCA	Risk Based Corrective Action
RCRA	Resource Conservation and Recovery Act
RfD	reference doses
RHS	Red Hill Shaft
the Facility	Red Hill Bulk Fuel Storage Facility
RI	Remedial Investigation
RI/FS	Remedial Investigation/Feasibility Study
RLs	reporting limits
RME	Reasonable maximum exposure
RPD	Relative Percent Difference
RT3D	Reactive Transport 3 Dimensional
s	seconds
SCP	State Contingency Plan
SDWA	Safe Drinking Water Act

SDWB	Safe Drinking Water Branch
SI	Site Investigation
SO	soil
SOP	standard operating procedure
SOW	Statement of Work
SSRBL	site-specific risk-based action level
SVM	soil vapor monitoring
SVMPs	soil vapor monitoring points
SVMWs	soil vapor monitoring wells
SVOCs	Semi-Volatile Organic Compounds
SWAP	Source Water Assessment Program
SWB	Solid Waste Branch
T3 RA	Tier 3 Risk Assessment
TAMC	Tripler Army Medical Center
TB	Trip Blank
TBCs	To-Be Considered
TCE	trichloroethylene
TEC	TEC Inc.
TFH	total fuel hydrocarbons
TGM	Technical Guidance Manual
TGM-UST	Technical Guidance Manual for Underground Storage Tanks Closure and Release Response
The Facility	Red Hill Bulk Fuel Storage Facility
TMDLs	Total Maximum Daily Loads
TOC	Top of Casing
TPH	Total Petroleum Hydrocarbons
TPH-DRO	Total Petroleum Hydrocarbons in the Diesel Range Organics
TPH-GRO	Total Petroleum Hydrocarbons in the Gasoline Range Organics
TPH-RRO	Total Petroleum Hydrocarbons in the Residual Range Organics
TRC	Technical Review Committee
UAA	Use Attainability Analysis
UH	University of Hawaii at Manoa
UIC	Underground Injection Control
US	United States
USDA	United States, Department of Agriculture
USEPA	United States, Environmental Protection Agency
USGS	U.S. Geological Survey
USTs	underground storage tanks
V2SDT	Variable Saturated Two Dimensional Flow and Transport
VOCs	Volatile Organic Compounds
VPH	volatile petroleum hydrocarbons
WG	groundwater
WP	Work Plan
WQ	Water Quality

WRRC	Water Resources Research Center
Wilbros	Wilbros Engineers

EXECUTIVE SUMMARY

This Site Investigation (SI) Technical Report presents the results of an environmental investigation and risk assessment at the United States (U.S.) Navy Bulk Fuel Storage Facility at Red Hill, Oahu, Hawaii. The investigation was conducted by TEC Inc. (TEC) for Naval Facilities Engineering Command (NAVFAC) Pacific, and the Fleet and Industrial Supply Center (FISC) at Pearl Harbor, Hawaii. The project site, located on Federal property between South Halawa Valley and Moanalua Valley, stores and transmits petroleum fuels for the U.S. Navy Pacific Fleet. This investigation was conducted under Contract No. N62742-02-D-1802, Amendment 6, dated September 7, 2004.

Site Description

The U.S. Navy Red Hill Bulk Fuel Storage Facility (the Facility) is an operational facility that includes 20, 12.5-million gallon (Mgal) underground storage tanks (USTs) located within the Red Hill Ridge, and a series of tunnels and pipelines which transmit fuel to and from Pearl Harbor Naval Base. Facility was constructed prior to World War II to support naval activities in the Pacific. The USTs were constructed in the field using mining techniques, and are deferred from many Federal and State UST program requirements. According to records, the main fuel types stored at the facility have been diesel oil, Navy Special Fuel Oil (NSFO), Navy Distillate (ND), Jet Propulsion Fuel 5 and 8 (JP-5 and JP-8), and F-76 (diesel marine fuel). In addition, Tank 17 contained Aviation Gasoline (AVGAS) and Motor Gasoline (MOGAS) between 1964 and 1969; and Tank 18 contained AVGAS between 1964 and 1968. A review of the Facility records, which were classified until 1995, indicated that several USTs were repaired and may have released petroleum to the environment. The Facility is approximately 100 feet above the basal groundwater table on the boundary of the Waimalu and Moanalua Aquifer Systems of the Pearl Harbor and Honolulu Aquifer Sector, respectively. Both aquifers are sources of potable water for several public water systems. Most notably, the U.S. Navy Red Hill Pumping Station (well 2254-01), located approximately 2,500 feet hydraulically down-gradient from the Facility, draws water from a submerged infiltration tunnel which extends approximately 1,280 feet across the groundwater table.

Previous Environmental Investigations

Between 1990 and 2000, Ogden Environmental and Energy Services Co., Inc. ([Ogden], 1996) and Earth Tech, Inc. in (Earth Tech, 2000) investigated an oily waste disposal basin adjacent to Adit 3. Petroleum waste infiltrated to a perched water bearing zone beneath the basin, but was not detected in the underlying basal aquifer. Adit 3 is approximately 600 feet west of U.S. Navy well 2254-01.

In 2002, the U.S. Navy initiated an SI, conducted by AMEC Earth and Environmental, Inc. ([AMEC], 2002). Rock core samples were collected from directly beneath the Facility USTs, and groundwater samples were collected from a single well installed within the lower access tunnel, directly down-gradient from the Facility. Results indicated that petroleum had been released from several USTs, as observed in core samples, and in groundwater samples. After evaluating the results of the SI, the State of Hawaii, Department of Health (HDOH), Solid Waste

Branch (SWB) requested that quarterly groundwater monitoring be conducted, a Tier 3 risk assessment be conducted to evaluate the risk to the U.S. Navy pumping well at Red Hill, and a contingency plan be developed to ensure the protection of the U.S. Navy pumping well at Red Hill from future contamination.

The U.S. Navy initiating quarterly groundwater sampling at the existing monitoring well (formerly MW1, currently RHMW01) and at the U.S. Navy well 2254-01. Dawson Group, Inc. (Dawson) conducted the first four sampling events: February 2005; June 2005; September 2005; and December 2005. In addition, the U.S. Navy conducted a detailed SI at the Facility with the following objectives:

1. Assess the current site-specific risk from petroleum releases from the Facility to the subsurface rock and groundwater;
2. Assess future site-specific risk associated with hypothetical future releases from the Facility; and
3. Develop a contingency plan to mitigate current and future risks that are determined to be unacceptable in the Facility-specific risk assessment.

The SI included the development of a three dimensional (3-D) groundwater flow and contaminant transport model to estimate the concentrations of fuel dissolved in the basal groundwater beneath the Facility that would be required to be observed at nearby drinking water wells above risk based concentrations (U.S. Navy well 2254-01; Honolulu Board of Water Supply [HBWS] Halawa Shaft well 2354-01; or HBWS Moanalua wells 2153-10, 2153-12 and 2153-22). The resulting simulated concentrations at RHMW01, RHMW02, and RHMW03 would then be considered the site specific risk based level (SSRBL) at each well.

Current Investigation

In September of 2004, NAVFAC Pacific contracted TEC to conduct the current SI. Prior to conducting field work, a preliminary risk assessment was conducted to evaluate migration pathways. The preliminary risk assessment eliminated the insignificant migration pathways and focused on the migration pathways with the most potential to impact human health and the environment. The release of fuel to the drinking water aquifer and subsequent migration of dissolved compounds to nearby drinking water wells will have the greatest potential impact to human health. The soil vapor pathway to indoor spaces of the Facility and nearby family housing was another potential pathway of concern. The potential impact of soil vapor to the Facility is greater than the impact to the nearby family housing, which is more than 700 feet from the Facility. Ground surface exposure pathways to surface soil, surface water or sediments were considered insignificant.

This SI was conducted in two phases. The Phase I field efforts commenced in June 2005, which included the following tasks.

- Installing two monitoring wells (adjacent to Tanks 6 and 14) within the lower access tunnel (RHMW02 and RHMW03, respectively), and one background monitoring well (RHMW04) at ground-level, up-gradient from the Facility.
- Sampling and analysis of one round of groundwater for petroleum constituents, including data validation for a risk assessment from the four Facility wells and U.S. Navy well 2254-01. In addition, natural attenuation parameters were sampled to provide data for the fate and transport model.
- Installing three nested soil vapor monitoring wells (SVMWs), each with three soil vapor monitoring points (SVMPs) in existing slant borings under Tanks 2, 14 and 16.
- Sampling and analysis of soil vapor for benzene, toluene, ethylbenzene and xylenes [BTEX]; and other petroleum constituents including data validation for a risk assessment.

The Phase II field and reporting efforts commenced in November 2005, which included the following tasks.

- Conducting a regional pumping test to provide groundwater results used to calibrate and verify the groundwater flow model, including surveying the coordinates for important monitoring wells.
- Installing dedicated pumps and collection and analysis of an additional round of groundwater and subsequent validation from the five facility wells and U.S. Navy well 2254-01 for a risk assessment.
- Installing, sampling and analyzing soil vapor from additional nested SVMWs in existing slant borings under Tanks 6, 10, 11 and 12.
- Developing and localizing the 3-D groundwater MODFLOW model from the HDOH Safe Drinking Water Branch (SDWB) Source Water Assessment Program (SWAP) regional model, and simulating contaminate fate and transport to develop site specific action levels for the Facility.
- Summarizing project activities, results, risk assessment and conclusions in a SI Technical Report, and developing potential mitigation steps in a Contingency Plan.

Nature and Extent of Contamination

Rock Core

The three borings associated with the new monitoring wells were drilled in volcanic bedrock where no petroleum-impacted material was expected to be encountered above the water table. Continuous cores were collected and screened with field instruments, and by direct observation from borings in the lower access tunnel. The background well was evaluated by rock cuttings. A single rock sample from each boring was evaluated at a fixed laboratory. The rock samples were analyzed for petroleum constituents and no results were detected above reporting limits or associated action levels.

Groundwater

The first round of groundwater samples was collected in September 2005. Total Petroleum Hydrocarbons in the Diesel Range Organics (TPH-DRO) exceeded the State of Hawaii Environmental Action Levels (EALs) for drinking water at all wells except 2254-01. No evidence of petroleum was observed at 2254-01.

Groundwater from RHMW02, located up-gradient of Tanks 5 and 6, had the highest concentrations of petroleum compounds, and was the only well in which target Volatile Organic Compounds (VOCs) and Semi-Volatile Organic Compounds (SVOC) were observed. Concentrations of TPH-DRO, Total Petroleum Hydrocarbons in the Gasoline Range Organics (TPH-GRO), TCE, naphthalene, 1-methylnaphthalene and 2-methylnaphthalene all exceeded one or more drinking water action levels (EALs or USEPA Region 9 Preliminary Remediation Goals [PRGs]) in this well.

Lead was the only other compound that exceeded drinking water action levels; however, that exceedence was observed in an unfiltered sample from RHMW01 and was not considered appropriate for risk assessment, since filtered results did not exceed action levels. In addition, lead was not a component of fuels from the tanks near RHMW01, located downgradient of Tank 1 and 2. Leaded fuel was limited to Tanks 17 and 18, between 1962 and 1969. Lead was observed in the front of several borings which extended beneath each tank (AMEC 2002), and may be part of the construction material.

The second round of groundwater samples were collected in July 2006. Results were similar, except TCE was not observed.

Soil Vapor

Soil vapor samples were collected in May and June 2006 (Phase I) and November 2006 (Phase II), from SVMWs in slant borings beneath Tanks 2, 14, 16; and Tanks 6, 10, 11 and 12, respectively. Samples were collected to evaluate risk via soil vapor intrusion to the Red Hill Tunnels, and to evaluate the SVMWs as potential leak detection devices. The risk to industrial workers was insignificant. Total target VOCs measured ranged from less than the detection limit to 580.1 micrograms per cubic meter (μ/m^3) at at RHSV06-15-35 located beneath Tank 6. Total target VOCs greater than 100 μ/m^3 were observed in SVMPs beneath Tanks 6, 11, 12 and 14. These tanks should be evaluated for potential leaks. The results of this pilot study indicated that soil vapor provided additional verification of leaks. However, the boreholes are small in diameter and limited to one at each tank, so they may not detect all leaks. Finally, periodic sampling would allow the results to be compared for trends, and increasing trends would indicate leaks.

Fate and Transport Modeling

TEC, the University of Hawaii at Manoa (UH) and the NAVFAC Hawaii collaborated on the development of a localized numerical 3-D groundwater model based a HDOH Source Water Assessment Program (SWAP) model developed by UH. The localized model evaluated the depths of the valley fills within the model area to assess how water moves between the Waimalu, Moanalua, and Kalihi Aquifer systems. The U.S. Navy Pumping Well 2254-01 and the Facility are within the groundwater sub-basin between North Halawa Valley fill and Moanalua Valley fill called the Red Hill sub-basin for the purposes of this report. The HBWS Halawa Shaft is north of the Red Hill sub-basin and the HBWS Moanalua wells are south. Particle tracking simulations using MODPATH indicated that particles from the Facility would not reach the HBWS wells under normal or extreme pumping conditions. In addition, a pumping test conducted as part of SI indicated that stresses from the U.S. Navy well 2254-01 were strongly observed within the Red Hill Sub-basin, less strongly observed south of the Moanalua Valley fill, and poorly observed north of the North Halawa Valley fill. These measurements were also observed in the simulations, although the effects of the North Halawa Valley fill were underestimated by the model. This indicates that the North Halawa Valley fill is more of a barrier to flow then the model simulated. The model also indicated that approximately 13.4 million gallons per day (mgd) of water flows from the Red Hill Sub-basin across the North Halawa Valley boundary during steady state flow simulations; however, this may be over estimated due to the underestimation of the valley fill effect here.

Contaminant transport simulations were conducted using MODPATH to evaluate conservative particle transport, and Reactive Transport 3 Dimensional (RT3D) model (Clement, 1997), a high level transport model that accounts for all major transport processes including advection, diffusion, dispersion, decay and sorption. The simulation objective was to estimate the dissolved concentrations of constituents of potential concern (COPC) at the Facility monitoring wells that would result in exceeding drinking water action levels at the nearby municipal water supply wells. Simulations were run under an average pumping scenario, in which area supply wells were pumped at average pumping rates for the period of 1996 to 2005. Once the critical concentrations within the Facility monitoring wells were estimated, a drought condition was simulated in which the U.S. Navy well 2254-01 was pumped at maximum rates. This drought condition was simulated to determine the worst case scenario, and sensitivity of the system to pumping conditions.

The type of fuel stored in the USTs is an important factor in evaluating the risk of a fuel release at the Facility. AVGAS and MOGAS were stored in two USTs between 1964 and 1969 in two of the tanks. Since then jet propellant (JP-5 and JP-8) have been the on-site fuels with the most potential to impact human health and the environment. Jet propellant is similar to kerosene, with a total solubility of about 4.5 milligrams per Liter (mg/L), very low concentrations of BTEX, and an effective solubility of benzene of approximately 0.75 mg/L. Other fuels stored in the Facility are diesel and less soluble NSFO.

Modeling, using TPH and benzene as the surrogate risk drivers, provide the following understanding.

- Contaminated infiltrating rainwater does not present a risk to the U.S. Navy well 2254-01. Simulations of maximum benzene concentrations in infiltrating rainwater over the entire Facility footprint did not present a measurable risk at adjacent drinking water wells;

- Valley fills in the North Halawa Valley and Moanalua Valley are effective barriers to particle migration of water beneath the Facility. MODPATH simulations showed that contaminated water from beneath the Facility would not migrate to the HBWS Halawa Shaft or HBWS Moanalua wells.
- In order to reach HDOH EALs at the infiltration gallery (U.S. Navy well 2254-01), transport simulations required an extended source of fuel as light non-aqueous phase liquid (LNAPL) on the groundwater table at the down-gradient monitoring well (RHMW01).
- SSRBLs at RHMW01, RHMW02 and RHMW03 coincide with solubility limits of JP-5, where benzene is 0.75 mg/L and TPH is 4.5 mg/L. This would only result from fuel on the water table.
- Groundwater action levels (GALs) at the U.S. Navy well 2254-01 are the HDOH drinking water EALs.

Risk Assessment

A revised conceptual site model (CSM) was developed to illustrate the contaminant pathways of concern. Direct contact to soil, surface water, or sediments were not considered significant exposure pathways because releases from the Facility USTs will not impact these media. Pathways of concern were limited to groundwater to drinking water wells; and soil vapor to indoor air.

The current soil vapor risk was evaluated by comparing SVMP concentrations to HDOH EALs for residential and industrial receptors. Soil vapor samples were collected beneath 7 of the 20 USTs, based on highest concentrations observed in core samples. Although benzene (vapor risk driver) was observed in four of 18 samples collected, the highest concentration was 16 $\mu g/m^3$ compared to the HDOH EALs of 250 $\mu g/m^3$ for residential receptors and 1,100 $\mu g/m^3$ for industrial receptors. Although not all tanks were evaluated, it is not anticipated that concentrations from untested tanks would be significantly greater than 16 $\mu g/m^3$ since the most contaminated core holes were tested. In addition, conditions within the Facility tunnels require continuous and extensive ventilation that should be maintained and evaluated on a regular basis. Residential neighborhoods are at least 700 feet from the USTs and will not be impacted by the current soil vapor conditions; therefore the residential action level is not relevant or appropriate.

Current groundwater risk was evaluated at the U.S. Navy well 2254-01. To date, no petroleum compounds were observed in samples from this well. Concentrations of TPH, naphthalene, 1-methylnaphthalene, 2-methylnaphthalene, and TCE in water samples from the Facility monitoring wells (RHMW01 to RHMW03) exceeded their respective HDOH drinking water EALs. These contaminants are naturally degraded to below detectable levels before the water enters the U.S. Navy well 2254-01, which is the nearest extraction point.

According to the fate and transport modeling simulations, a JP-5 LNAPL plume is required to extend to within 1,099 feet from the U.S. Navy well 2254-01 infiltration gallery for benzene to exceeed the Federal MCL and HDOH EAL. This could result from a release as small as 16,000 gallons from the Facility. It is estimated that a release this size would take between 5 and 6 years to reach the infiltration gallery of the U.S. Navy well 2254-01 above these levels, although larger releases could cause this time to be much shorter.

Evidence of a release of concern at RHMW01 would be:

- Fuel on the groundwater table;
- TPH concentrations at 4.5 mg/L or greater; and/or
- Benzene at 0.75 mg/L or greater.

Currently, there is no method to determine whether the Facility USTs have chronic leaks because they are deferred from leak detection requirements. In addition, the increasing age of the Facility increases the chance that both the metal tank liners and the concrete foundation walls may fail together, making future releases more of a concern. To be protective of human health and the groundwater resources, it is recommended that the associated Red Hill Contingency Plan (TEC 2007) be reviewed and implemented to ensure that future releases from the Facility do not continue to place the groundwater resource at risk.

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SECTION 1
INTRODUCTION AND PURPOSE

This Site Investigation (SI) Report has been prepared by TEC Inc. (TEC) under Contract No. N62742-02-D-1802, Amendment 6. The investigation was conducted by TEC for Naval Facilities Engineering Command (NAVFAC) and the Fleet and Industrial Supply Center (FISC) at Pearl Harbor, Hawaii.

The U. S. Navy Red Hill Bulk Fuel Storage Facility (the Facility) is located in the Red Hill Ridge on the leeward side of the Koolau Mountains between South Halawa Valley and Moanalua Valley, northeast of the U.S. Naval Base at Pearl Harbor (Figure 1-1). It overlies the Pearl Harbor and Honolulu Aquifer Sectors which are drinking water sources for the island of Oahu, and is surrounded by Federal, State and residential property. This SI was conducted to evaluate the nature and extent of fuel releases to the environment from the 20, 12.5-million gallon (Mgal) underground storage tanks (USTs) that make up the Facility, and includes a site-specific risk assessment to estimate the current and future risk of these releases to human health and the environment. These USTs contain fuel reserves to maintain U.S. Naval fleet activities in the Pacific.

The Facility USTs are field constructed, and are therefore deferred from many of the State and Federal UST Program statutes; however, the U.S. Navy must comply with the Hawaii Administrative Rules (HAR) title 11, chapter 281, subchapter 7: Release Response Action. In addition, fuel releases were identified in an earlier remedial investigation (RI) conducted by AMEC Earth and Environmental, Inc. ([AMEC], 2002); therefore, releases from the Facility must meet the requirements of the *State of Hawaii Oil and Hazardous Substance Contingency Plan* (State Contingency Plan [SCP]) (HAR title 11, chapter 451) (State of Hawaii, Department of Health [HDOH], 1997) and the Hawai‘i Environmental Response Law (HERL) (HRS 19-128D). In order to meet these requirements, the U.S. Navy implemented a detailed SI at the Facility with the following objectives:

1. Assessing the current site-specific risk from petroleum releases from the Facility to the subsurface rock and groundwater;
2. Assessing future site-specific risk associated with hypothetical future releases from the Facility; and
3. Developing a contingency plan to mitigate current and future risks that are determined to be unacceptable in the Facility-specific risk assessment.

1.1 Location and Environmental Setting

The Facility is located on the island of Oahu, Hawaii, approximately 2.5 miles east of Pearl Harbor (Figure 1-1). The Facility lies along the western edge of the Koolau Range and is situated on a topographic ridge that divides the Halawa Valley and the Moanalua Valley (Figures 1-2 and 1-3). The Facility occupies approximately 144 acres of land and is bordered to the southwest by the Salt Lake volcanic crater. The majority of the surface topography of the Facility lies at an elevation of approximately 200 to 500 feet above mean sea level (msl), however, much of the work conducted onsite is in the lower access tunnel, which is located between 100 to 120 feet above msl (Figure 1-4). Specific information is provided in the following subsections. Additional details can be found in the Preliminary Risk Assessment (Appendix O).

1.1.1 Surrounding Population

Oahu is the center of economic activity for the Hawaiian Islands. Honolulu, located in the south-central portion of the island, is heavily urbanized and densely populated. The Facility lies at the northern edge of an urbanized area that is zoned F-1, Military and Federal (Figure 1-5). Urbanized areas stretch from the southern coast of Oahu northward, occupying the majority of the coastal plain.

Oahu (Honolulu County) has a population of approximately 876,156 people. Populated areas closest to the Facility are Pearl City and Aiea to the west and Honolulu to the south and east. On the basis of 2000 census data, the populations of Pearl City, Aiea and Honolulu are 30,976, 9,019 and 371,657, respectively (U.S. Census Bureau, 2000). There is a Coast Guard and U.S. Navy housing complex in Aliamanu Crater to the southwest of the Facility. Pearl Harbor also lies to the southwest of the Facility. The population of the Pearl Harbor military base is unlisted (Ogden, 1999). The nearest residential area is located southeast of the Facility in Moanalua Valley, directly adjacent to the Facility perimeter (Figure 1-2).

1.1.2 Land Use and Zoning

The City and County of Honolulu, Department of Planning and Permitting (DPP) zoning information (Figure 1-5), indicates that the Facility is located on federal government land (zoned F-1, Military and Federal) with public land located to the immediate north and northeast (zoned P-1, Restricted Parkland). Halawa Correctional Facility is located in the residential area depicted north of the public land (zoned R-5, Residential). The Facility is bordered by an industrial development to the north and northwest (zoned I-2, Intensive Industrial) and a quarry to the north and northwest beyond the Halawa Correctional Facility (zoned Ag-2, General Agricultural). The John A. Burns Freeway (Interstate H-3) is located to the northwest (Figure 1-5).

Moanalua Village (a residential development), is located immediately adjacent, and south to east of the Facility (zoned R-5, Residential). Moanalua Golf Course (zoned P-2, General Parkland and R-5, Residential), a small section of public land (zoned P-1, Restricted Parkland) and the Tripler Army Medical Center (TAMC) (zoned F-1, Military and Federal) are located further south. A high cliff face with a 100 to 200 ft elevation difference is present between the Facility, and both Moanalua Village and the Moanalua Golf Course. Northeast of the Facility, is public land, which is mostly forested (zoned P-1, Restricted Parkland), and to the east of the Moanalua Village residential development is Moanalua Valley Park (zoned P-2, General Parkland) followed by additional public land (zoned P-1, Restricted Parkland).

Residences, townhouses and apartment buildings are located to the southwest of the Facility (zoned A-2, Apartment), and a public school (Red Hill Elementary School) is also present in this area. The Facility continues to the west, and is adjacent to the Coast Guard Reservation which borders Highway 78. The closest residential property to the Facility is the area zoned for apartment buildings located approximately 305 feet (ft) southwest of Tank 2. Red Hill Elementary School is located approximately 1,080 ft southwest of Tank 2. The Moanalua Village residential development is located approximately 880 ft south of Tank 2. The area zoned for apartment buildings is located approximately 2,113 ft southwest of Tank 20 (the tank farthest to the east), and Red Hill Elementary School is located approximately 2,850 ft from Tank 20. The Moanalua Village residential development is located approximately 875 ft south of Tank 20.

The Primary Urban Center (PUC) Development Plan land use map for the PUC west sector encompasses the Facility location. The DPP helps establish, promote and implement long-range planning programs for Honolulu. The DPP's PUC Development Plan presents a vision and a clear set of planning policies for the area extending from Kahala to Pearl City on Oahu. The PUC Development Plan is designed as a general framework intended to support more detailed planning at the neighborhood level. The PUC Development Plan provides clear, conceptual, long-range policies for topics of concern to all of the region's communities. Based on review of this anticipated future land use map, the Facility is not identified as military land, but is rather identified as industrial property. In addition, the area north of the Facility to the John A. Burns Freeway (Interstate H-3) and slightly beyond is also identified for industrial land use. This includes the area between the Naval Reservation and the South Halawa Stream, north of the prison, which is currently open land, zoned P-1, Restricted Parkland. Moanalua Village remains identified as a lower-density residential neighborhood and the apartment buildings to the southwest of the Facility are identified as medium and higher-density residential/mixed use (TEC and AMEC, 2005).

The USDA identified no agricultural lands of importance to the State of Hawaii in the immediate vicinity of the Facility (USDA, 1977).

1.1.3 Surface Water

Halawa Stream

The southern segment of the Halawa Stream is approximately 665 ft to the north of the Facility (Figure 1-2). Halawa Stream was listed on the impaired water's list, based upon the visual assessment of nutrients and turbidity. HDOH is in the process of developing total maximum daily loads (TMDLs) for Halawa Stream. USEPA's Watershed Assessment Tracking & Environmental Results System, indicates that the Halawa Stream is completely impaired to support aquatic life. Elements considered impaired include nutrients, pathogens, turbidity and exotic species. Potential sources are identified as: urban runoff/storm sewers; other urban runoff; and other natural sources (TEC and AMEC, 2005).

South Halawa Stream is also concrete-lined, channelized and does not support sensitive habitat, according to the *Remedial Investigation Phase II, Red Hill Oily Waste Disposal Facility* (Earth Tech, 1999). The concrete-lined segment runs for at least 4,200 ft into the valley, along the entire perimeter of Red Hill. All of the monitoring stations are situated on the north Halawa Stream or downstream of the convergence of the north and south branches. Since the stream is concrete-lined and impaired for the support of aquatic life, it is not considered a potential ecological receptor for this Site (TEC and AMEC, 2005).

Moanalua Stream

The northern segment of the Moanalua Stream is approximately 1,760 ft to the south (Figure 1-2). Moanalua Stream was listed on the impaired water's list, based upon the visual assessment of nutrients, turbidity and trash. Moanalua Stream is noted to be of medium priority. USEPA's Watershed Assessment Tracking & Environmental Results System, indicates that the Moanalua Stream is also completely impaired to support aquatic life. Sources of impairment are urban runoff/storm sewers; other urban runoff; and other natural sources (TEC and AMEC, 2005).

1.1.4 Soils

Soils in the vicinity of the Facility are mapped as Helemano-Wahiawa association consisting of well-drained, moderately fine textured and fine textured soils. These soils typically range from nearly level to moderately sloping and occur in broad areas dissected by very steep gulches. They formed in material weathered from basalt (U.S., Department of Agriculture [USDA], 1972).

On the basis of a review of previous investigations performed in the vicinity of the Red Hill facility, soils consisting of clays and clayey gravels are common to a depth of 10 ft below ground surface (bgs). Along the slopes and over much of the open area south of the Schofield Saddle, the basaltic bedrock is covered with 10 to 30 ft of Koolau residuum (Wentworth, 1945). These soils were derived from weathering of the underlying basalt bedrock or were deposited as alluvium/colluvium. The younger alluvium/colluvium deposits were derived from fractured basalts and tuff. Beneath the surficial soils, alternating layers of clay and fractured basalts were encountered at depth. The western slope of the Halawa Valley is generally barren of soil and consists of outcropping basalt lava flows to the valley floor.

1.1.5 Geology

Red Hill is located on the southern edge of the Koolau Range, approximately 2.5 miles northeast of Pearl Harbor. The Koolau formation consists almost entirely of basaltic lava flows that erupted from a fissure line approaching 30 miles in length (Wentworth, 1951) and trending in a northwest rift zone. Figure 1-6 presents the regional surface geologic features (modified from U.S. Geological Survey [USGS], 2003).

During a volcanic quiet period approximately 2 million years, valleys approaching 600 meters in depth were cut into the Koolau volcanic range and sediment accumulated in the valley floors. The erosion of the Koolau volcano resulted in the formation of a delta of sediment consisting of silt and sand. The delta increased in thickness as it approached the sea.

Both pahoehoe and a'a lava flows are present in the Koolau formation. Pahoehoe lava is characterized by relatively thin-bedded basaltic flows. It is smooth, fine-grained lava with a rope-like appearance and is characterized by thin-walled vesicles. A'a lava is a jagged, blocky lava flow that contains clinker beds. These clinker beds are the more permeable feature of the a'a lava. According to Mink (Mink, 1999), the a'a lava may act as a very localized confining layer to the basal system with unconfined conditions present just a few ft away. The a'a lava is more abundant in the lower flanks (Wentworth, 1951).

The Facility lies along a topographic ridge between the Halawa and Moanalua Valleys. The ridge is a remnant of the original Koolau shield volcano flank and it is composed of basaltic lava flows. The valleys on either side of the ridge are a result of fluvial erosion and are filled with alluvium/colluvium. A review of soil boring logs of boring V1D at the Facility indicates that it is predominantly underlain by pahoehoe lava.

At a nearby drilling site, approximately 2,000 ft southwest of V1D, it was reported (Earth Tech, 1999) the basalt bedrock appeared completely dry and massive at approximately 20 ft above msl, which was distinct from the highly fractured basalt overlying this unit and significantly different from the log of V1D. At the southwest location, basal groundwater was encountered directly beneath this massive unit at an elevation of approximately 1 to 2 ft below msl. After the monitoring wells were installed, the potentiometric groundwater surface stabilized at an elevation of approximately 16 ft above msl, suggesting that the massive lower basalt acts as a localized low-permeability layer, resulting in the confined groundwater conditions exhibited by the basal aquifer. However, Mink (Mink, 1999) states that although the a'a lava can act as a local confining unit, it tends to be very limited in extent and, therefore, unconfined conditions may be encountered in close proximity.

Information in the Wilbros Engineers (Wilbros) report (Wilbros, 1998) supports Mink's findings and states that the Facility is bounded on each side by deep alluvial fills and sedimentary caprock (marine and terrestrial sediments) in the down-gradient direction. In the area of the lower tunnel and the Red Hill portion of the Harbor Tunnel, the basal aquifer is located in permeable basalt on which the tunnel and tanks are located (Wilbros, 1998). This further supports Mink's theory that confined conditions are generally limited in extent.

1.1.6 Hydrogeology

As part of the HDOH groundwater protection program, the state of Hawaii developed an aquifer classification system that is consistent with the U.S. Environmental Protection Agency (USEPA). For the Island of Oahu, the aquifer classifications are documented in *Aquifer Identification and Classification for Oahu: Groundwater Protection Strategy for Hawaii* (Mink and Lau, 1990). Figure 1-7 presents Oahu's different aquifer sectors along with their sustainable yields (modified from USGS, 2003) in relation to the Facility. Figure 1-8 presents the Facility in relation to aquifers and the classification codes and status codes for the aquifer systems in the vicinity. The aquifer status codes describe the aquifers water quality, utility, and vulnerability to contamination. The Facility appears to be located on the boundary between the Moanalua Aquifer system, which is part of the Honolulu Aquifer sector, and the Waimalu Aquifer system, which is part of the Pearl Harbor Aquifer sector. Both the Moanalua Aquifer and Waimalu Aquifer systems are classified by Mink and Lau as unconfined, basal and flank. Their status is listed as a currently used, fresh (chloride content below 250 milligrams per Liter [mg/L]) drinking water source that is irreplaceable and has a high vulnerability to contamination (Mink and Lau, 1990).

On the basis of water table measurements conducted in wells near the Facility in May of 2006, the basal groundwater potentiometric surface is approximately 21 ft above msl. The groundwater flow in the Red Hill area is expected to be to the southwest toward Aliamanu Crater (Figure 1-9). Hydraulic conductivity is expected to vary from 500 to 1,500 ft per day in this area; however, welded tuffs associated with the Aliamanu Crater may have significantly lower permeabilities and may affect the groundwater flow direction from the Facility.

1.1.7 Groundwater Usage

The Facility is located up-gradient of the Hawaii State Underground Injection Control (UIC) Line, which typically segregates potable from non-potable groundwater. The nearest public drinking water well (Halawa Shaft, well number 2354-01) is located hydraulically cross-gradient of the Facility. This drinking water well is approximately 5,000 ft to the northwest of the Facility and pumps water from the basal aquifer. On average, 11 million gallons per day (mgd) are withdrawn from this location and account for approximately 7% of Honolulu County's water supply (Gooding, 2006).

The NAVFAC Hawaii operates a water pumping station within the lower tunnel system proximal to Adit No. 3 and situated approximately 3,000 ft to the west and hydraulically down-gradient from the Facility. The water pumping station is referred to as the U.S. Navy well 2254-01, and its location is depicted in Figure 1-2**.** U.S. Navy well 2254-01 pumps water from a subterranean infiltration gallery at the water table that extends approximately 610 ft toward the Facility, then turns and continues another 660 ft across the ridge (southeast), to the Pearl Harbor water distribution system. Between 4.2 and 16 mgd are withdrawn from this location. Details regarding the amounts of groundwater used are provided in Section 3.2.2 (Hydrogeology).

1.1.8 Biological Resources

A biological field survey of the Red Hill Naval Reservation was performed during the *Phase I Remedial Investigation of the adjacent Red Hill Oily Waste Disposal Facility* (Ogden, 1996) and the results are summarized here. The Facility is covered by the following vegetation types:

- Haole koa (Leucaena leucocephala) scrub;
- Disturbed habitat, and
- Vegetation communities in developed areas.

Haole koa scrub grows throughout Oahu, primarily in areas that have been disturbed by grazing or human activities. The scrub community on Red Hill is dominated by *Haole koa*, Guinea grass *(Panicum maximum)* and Chinese violet *(Asystasia gangetica).* Disturbed habitat is comprised of weedy plant species that can withstand frequent disturbance. The species in this community are similar to those found in nonnative grasslands. These disturbed habitats have a higher amount of non-grass species and sparsely cover areas (TEC and AMEC, 2005).

The developed habitats are near buildings, roads, or other structures with small amounts of vegetation (i.e., lawns and ornamental bushes). Native and sensitive species were not observed, as the appropriate habitat is not present (TEC and AMEC, 2005).

1.1.9 Threatened & Endangered Species and Critical Habitat

No native or sensitive species were observed in the 1995 biological survey of the area (TEC and AMEC, 2005). Critical habitat that supports the *Elepaio* (a native bird species) is located over 1.2 miles to the northeast and southeast of the Facility. Critical habitat that supports native plant species is also located over 1.4 miles to the northeast of the Facility. Three segments of the Honolulu Watershed Forest Reserve, a segment of the critical habitat for the Elepaio bird, and a portion of a wildlife management area are located over 1.7 miles to the southeast of the Facility. No natural area reserves, preserves, seabird sanctuaries, state monuments, state parks, state park reserves, state waysides, wildlife refuges, hunting areas, or trails are located within the vicinity of the Facility. Pearl Harbor, Salt Lake and the streams near the Facility are identified as the nearest wetlands (TEC and AMEC, 2005). Coastal resources are at least 3 miles from the Facility, and are not considered to be areas of concern for the Facility (TEC and AMEC, 2005).

1.2 Site History

The Facility was constructed by the U.S. Government in the early 1940s and incorporates 20 USTs, each with a capacity of approximately 12.5 million gallons (Figure 1-3). The tanks are constructed of steel and currently contain Jet Propulsion fuel 5 (JP-5), JP-8 and F-76 (diesel marine fuel). Previously, several of the tanks have also been used to store Navy Special Fuel Oil (NSFO) and Navy Distillate (ND). Between 1964 and 1969, aviation gasoline (AVGAS) and motor gasoline (MOGAS) were stored in Tanks 17 and 18. The fueling system is a self-contained underground unit that was installed into native rock comprised primarily of basalt with some inter-bedded tuffs and breccias. Each tank measures approximately 245 ft in height and 100 ft in diameter. The upper domes of the tanks lie at depths varying between approximately 100 ft and 200 ft bgs. The tanks are currently being inspected and refurbished by Dunkin and Bush, Inc.

The tanks are connected by main upper and lower subsurface service tunnels, which contain light rail systems, water, electric utilities and fuel pipelines. In the lower tunnel, each parallel tank is connected by a short access tunnel, which branches off the main service tunnel and terminates into a face-wall under each tank. Individual tank ancillary piping emerging from each face-wall connects the fuel transmission lines. The fuel pipelines traverse approximately 2.5 miles from the bulk tanks to a pump station at Pearl Harbor. The pump station is used to pump fuel from fuel tankers in Pearl Harbor to the Facility.

It is unknown if the tanks are presently leaking; however, on the basis of previous and current results (AMEC, 2002 and Dawson 2005a, 2005b, 2005c and 2006) and associated analytical data, one or more unreported releases have occurred at the Facility. Additional site history is provided in Section 2.3 and (the Work Plan) Appendix C (*Facility Construction History*) of the *Red Hill Bulk Fuel Storage Facility Work Plan, Pearl Harbor, Hawaii* (TEC, 2005a).

1.3 Previous Investigations and Conditions

This sub-section provides a description of the pertinent environmental investigations conducted at the Facility prior to the current SI, since the Facility was declassified. Each of these investigations is summarized below. Details of the investigations can be found in the individual reports.

1.3.1 Wilbros Engineering Report

In 1998, Wilbros evaluated the conditions of the Facility and estimated the impact to the basal aquifer if a major release were to occur. During the environmental impact evaluation, for estimating purposes, Wilbros used two hypothetical scenarios of petroleum releases from the large capacity USTs in conjunction with geologic/hydrogeologic data. The first scenario involved a massive petroleum release with no improvements to the Facility, and the second scenario included improvements to the Facility designed to prevent large-scale impacts to the environment. Wilbros suggested that due to the potential for irreparable damage to the aquifer in the event of a massive release, preventive measures be taken to avoid a catastrophic disruption of potable water service to the Pearl Harbor community (Wilbros, 1998).

1.3.2 Oily Waste Facility Investigations

Ogden completed several investigations at the Red Hill (former) Oily Waste Disposal Facility (OWDF), which is located approximately 3,200 ft west of the Facility tanks (Figure 1-2). A Remedial Investigation/Feasibility Study (RI/FS) was initiated (Ogden, 1992). Additional field activities occurred in January 1993 (Ogden, 1993). Additional risk assessment and removal action activities were performed in 1994 and 1995 and were summarized (Ogden, 1996). These investigations (Ogden, 1992 - 1996) were completed to determine the nature and extent, and required remedial actions (i.e., removal action) for the shallow petroleum contamination associated with past OWDF operations.

These investigations found that the stilling basin contained liquids and solid debris containing volatile organic compounds (VOCs), total petroleum hydrocarbons (TPH) and total fuel hydrocarbons (TFH), semi-volatile organic compounds (SVOCs), and priority pollutant metals. Soil and the perched water system beneath the stilling basin were found to contain VOCs, TPH, TFH, and polynuclear aromatic hydrocarbons (PAHs). Ogden developed plans for closure of the stilling basin. This plan included removal of the waste liquids, solid debris and of soil containing TPH and PAHs near the base of the stilling basin.

Earth Tech performed a Phase II RI at the OWDF in 1998 (Earth Tech, 1999), with the objective to determine the nature and extent of impact to the soil and basal drinking groundwater beneath the Facility. This report concluded that transport of contaminants to the basal aquifer from the OWDF was insignificant. OWDF related contaminants were not detected in groundwater samples obtained from within the basal aquifer nor from water samples obtained from the U.S. Navy Well 2254-01. Earth Tech recommended that no further action regarding the perched groundwater or the basal aquifer beneath the OWDF be taken.

1.3.3 Ogden/AMEC Red Hill Investigations

In March 1998, Ogden, subsequently known as AMEC, was contracted to identify potential petroleum product releases from the Facility. The resulting site characterization was conducted in two phases: Phase I - Research Activities, and Phase II - Field Investigation Activities (AMEC, 1998). Slant borings were drilled and sampled under each of the 20 USTs. Additionally, 2 vertical borings were drilled and sampled below tank 1. A single groundwater monitoring well was installed into the basal aquifer at this location. From this well, groundwater samples were collected and analyzed.

A preliminary screening-level risk evaluation was conducted and indicated that 7 constituents were detected in core samples at concentrations of potential concern: ethylbenzene, methylene chloride, 2-methylnaphthalene, naphthalene, phenanthrene, TPH extractables (hydrocarbon range C10-C28), and an unknown hydrocarbon compound. Three constituents were detected in groundwater at concentrations of potential concern: bis(2-ethylhelyl)phthalate, lead and TPH extractables (C10-C28). Light non-aqueous phase liquid (LNAPL) was also detected within several slant borings

On the basis of the preliminary risk screening, the report recommended that a comprehensive risk assessment be completed to accurately assess current and potential future risk associated with the Facility.

1.3.4 Dawson Group Quarterly Groundwater Monitoring

In order to comply with HAR 11-281, Subchapter 7, the U.S. Navy began quarterly groundwater sampling at existing wells in February of 2005. Dawson Group Inc. (Dawson) sampled RHMW01 and U.S. Navy well 2254-01 for four quarters in 2005: February, June, September and December. Results from the Dawson sampling event are summarized here. Complete results from the Dawson sampling events are reported in Appendix G.

During each of the quarterly sampling rounds the following samples were collected. Three groundwater samples (two primary and one duplicate) were collected from U.S. Navy well 2254-01 and analyzed for total petroleum hydrocarbons in the diesel range organics (TPH-DRO), total petroleum hydrocarbons in the gasoline range organics (TPH-GRO), 1,2-Dichloroethane (1,2-DCA); benzene, toluene, ethylbenzene and xylenes (BTEX), Methyl tert-butyl ether (MTBE), total lead (in the first two rounds), dissolved lead (in the last two rounds) and ethylene dibromide (EDB). Two groundwater samples (one primary and one duplicate) were collected from RHMW01 (formerly MW-V1D) and analyzed for TPH-DRO, TPH-GRO, 1,2-DCA, BTEX, total lead (in the first two rounds), dissolved lead (in the last two rounds) and EDB.

Total lead for the first two quarters was not filtered. In the last two sampling rounds (September and December) lead was filtered and the samples were analyzed for dissolved lead only.

U.S. Navy well 2254-01

Total lead was detected in the first two rounds at concentrations ranging from 0.05 micrograms per Liter (µg/L) to 5.6 µg/L. Dawson filtered lead in rounds three and four and dissolved lead was detected, ranging from 0.02 µg/L to 0.27 µg/L.

TPH-DRO was detected in round two only, ranging from 0.058 mg/L to 0.067 mg/L. The laboratory report noted that for these detections, the chromatographic fingerprint did not resemble a petroleum product.

The only VOC detected in the four rounds was toluene in round one, ranging from 0.81 µg/L to 1.2 µg/L. During this first round of sampling, toluene was present in the trip blank associated with these samples.

The PAH naphthalene was detected in round three and four ranging from 0.024 µg/L to 0.085 µg/L. In addition 2-methylnaphthalene was detected in round four.

No constituents were detected at concentrations above the HDOH Tier 1 Groundwater Action Levels (GWALs) (HDOH, 1995) or HDOH EALs (HDOH, 2005).

RHMW01

In the first two rounds of quarterly sampling, total lead was detected at concentrations above the HDOH Tier 1 GWAL of 5.6 µg/L for discharge to surface water but below the HDOH drinking water EAL of 15 µg/L. In the subsequent sampling rounds the total lead sample was filtered during collection and prior to analysis. The filtered results in these last two rounds of sampling fell below both the HDOH Tier 1 GWAL and HDOH EALs.

TPH-DRO and numerous PAHs were detected above the laboratory MRLs in all four sampling rounds conducted by Dawson (see Appendix G). In the second sampling round (June, 2005) TPH-GRO was detected above the laboratory method reporting limit (MRL) of 0.050 mg/L.

None of the detected concentrations in the four rounds of sampling exceeded the established HDOH Tier 1 GWALs.

TPH-DRO exceeded the HDOH drinking water EAL of 100 µg/L in all four sampling rounds. The laboratory report noted that for these detections (rounds two and four), the chromatographic fingerprint did not resemble a petroleum product. In rounds one and three, the laboratory reported that the chromatographic fingerprint resembled a petroleum product eluting in approximately the correct carbon range, but the elution pattern did not match the calibration standard. Total petroleum hydrocarbons in the residual range organics (TPH-RRO) exceeded the HDOH EALs in rounds one and three. In these rounds, the laboratory reported the chromatographic fingerprint resembled an oil, but did not match the calibration standard. Only sample RH-W-002 in round one was reported as matching the chromatographic fingerprint of TPH-DRO and TPH-RRO over the HDOH EALs. The PAHs benzo(a)anthracene and benzo(a)pyrene exceeded HDOH EALs in rounds two and four. The results during all four quarters for constituents of potential concern (COPC) were below the 2002 investigation results

(AMEC, 2002). The groundwater in the well showed evidence of COPC contamination in the basal aquifer.

Based on the findings of the investigations, Dawson recommended the following:

- Installation of a dedicated pump within RHMW01 to avoid cross-contamination, facilitate low-flow sampling methodology, more efficiently sample the monitoring well, and contribute to the repeatability of sampling methods;
- Filter total lead samples during collection and prior to analysis; and
- Continue sampling at U.S. Navy well 2254-01 and RHMW01 on a quarterly basis.

1.4 Report Format

This report will follow applicable guidelines in the *Technical Guidance Manual for Underground Storage Tanks Closure and Release Response* (TGM-UST) (HDOH, 2000) and will also include a risk assessment. The report contains elements from several reporting categories of the TGM-UST including Appendix 5-C (*Format for Initial Release Response Report*), Appendix 5-F (*Format for Corrective Action Plan*) as well as a risk assessment (HDOH, 2000). The report is divided into the following sections.

- Executive Summary - concise summary of the report.
- Section 1 - Introduction, site description, surrounding populations land use, and a summary of previous investigations and conditions.
- Section 2 - Summary of existing site characterization activities.
- Section 3 - Comprehensive nature and extent of contamination.
- Section 4 - Conceptual site model and contaminate fate and transport results.
- Section 5 - Applicable or Relevant and Appropriate Requirements (ARARs) and To Be Considered (TBC).
- Section 6 - Comprehensive Tier 3 Risk Assessment.
- Section 7 - Recommendations and conclusions.
- Section 8 - List of references.

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Figure 1-1

Regional Location Map

Red Hill Fuel Storage Facility

Oahu, Hawaii

TEC inc

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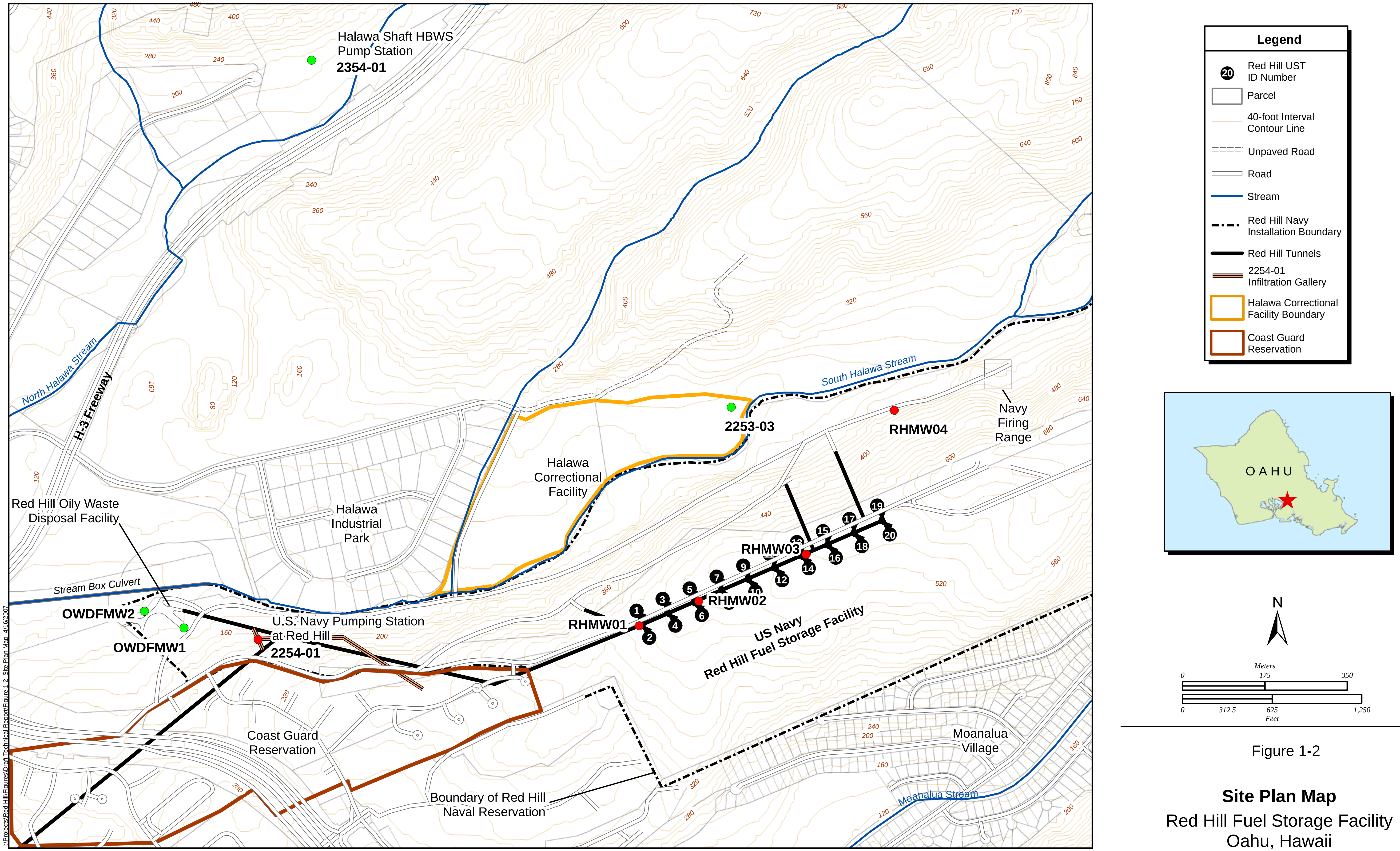


I:\Projects\Red Hill\Figures\Draft Technical Report\Figure 1-2 Site Plan Map 4/16/2007

Figure 1-2

Site Plan Map

Red Hill Fuel Storage Facility
Oahu, Hawaii

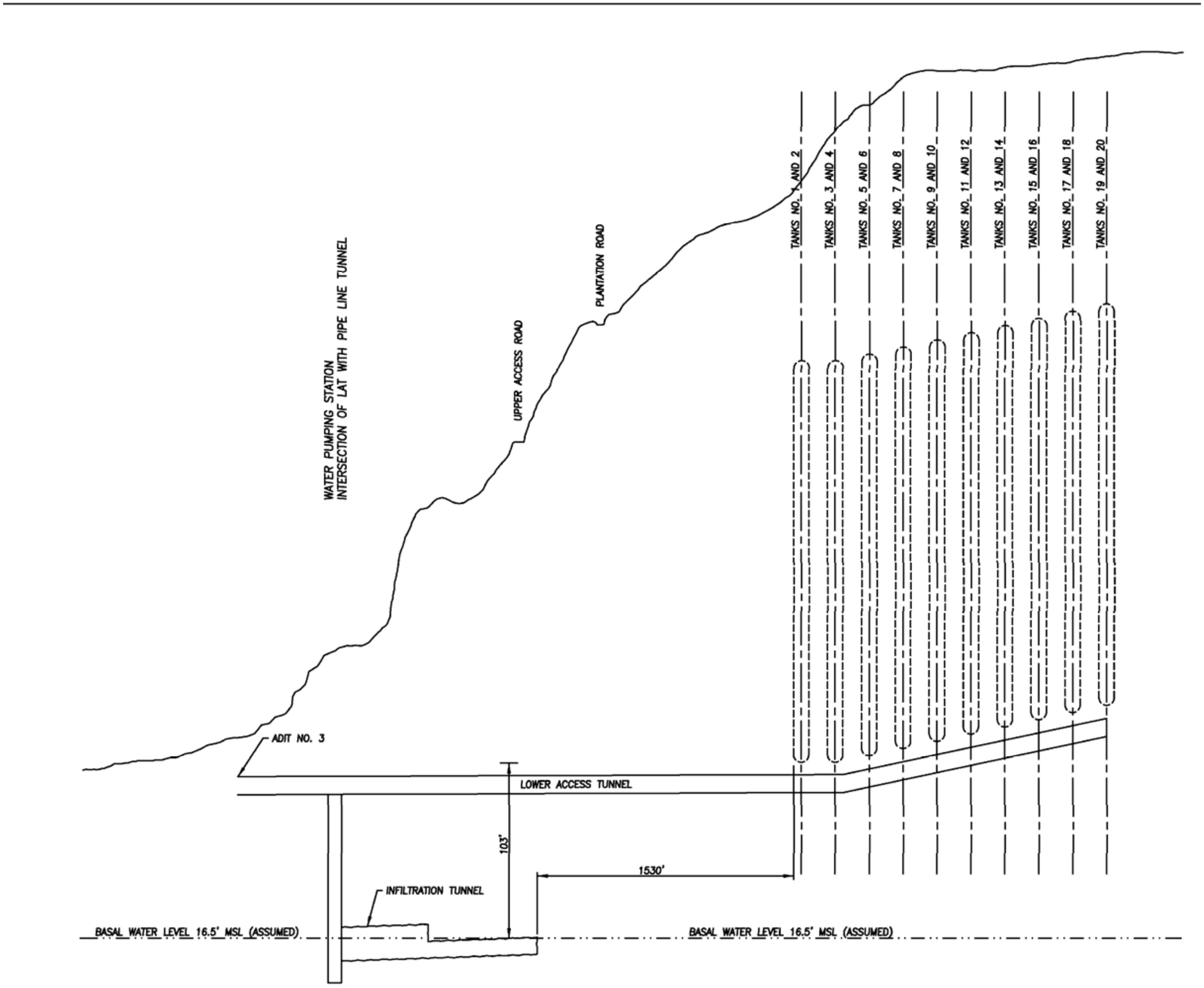
Printing Date: Apr. 16, 2007, I:\Projects\Red Hill\Figures\Draft Technical Report, Fig 1-3 Red Hill Scene.mxd

Figure 1-3
Red Hill Tanks and Surrounding Infrastructure

Red Hill Fuel Storage Facility
Oahu, Hawaii

N

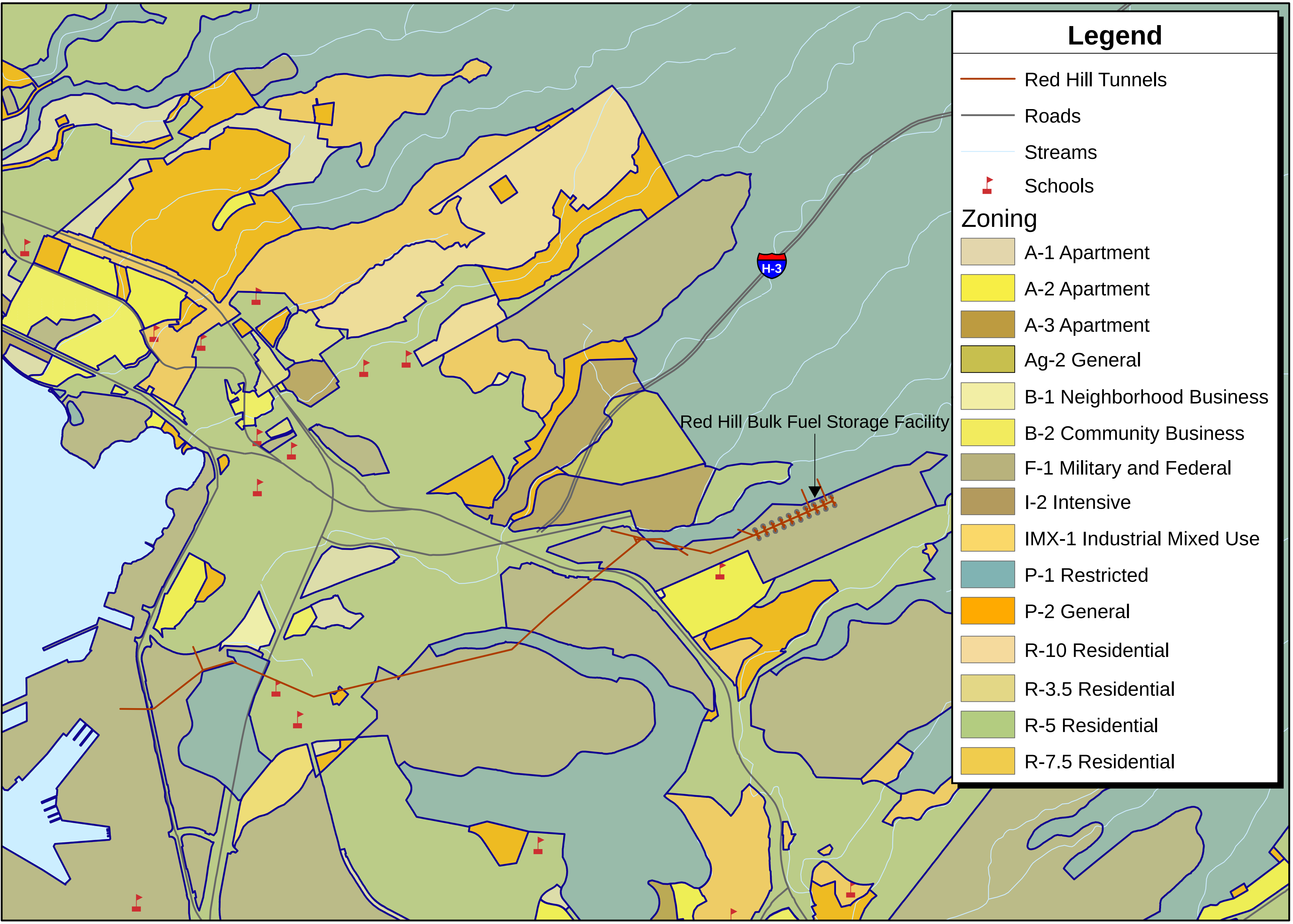
1 inch = ~ 300 feet



Printing Date: Apr. 16, 2007, I:\Projects\Red Hill\Figures\Draft Technical Report\Figure 1-4_Fuel Storage Tanks and Water Tunnel Cross Section.mxd

Figure 1-4
Fuel Storage Tanks and Water Tunnel Cross Section
Red Hill Fuel Storage Facility
Oahu, Hawaii

SCALE: HORIZ. 1" = 500'
VERT. 1" = 60'



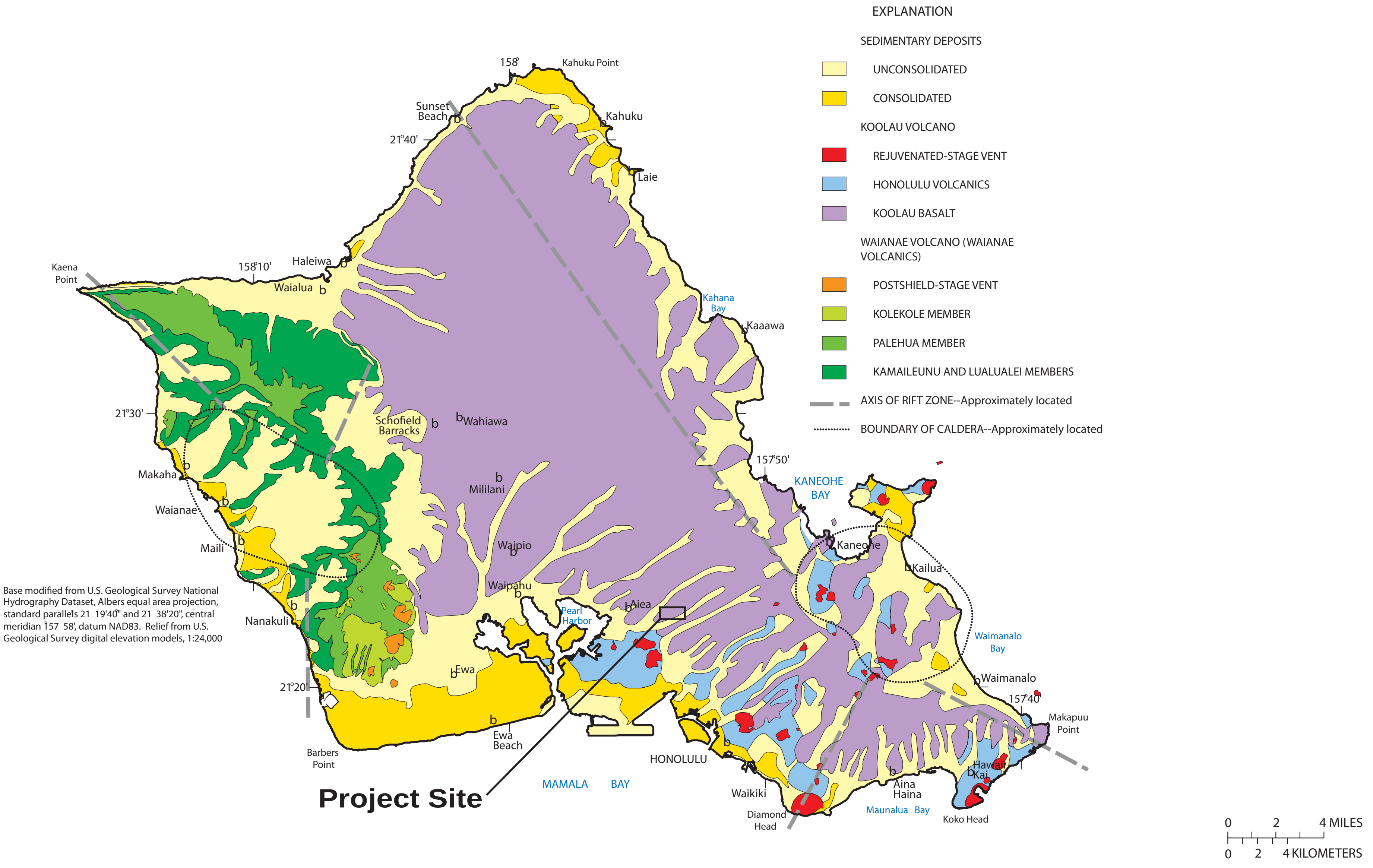
I:\Projects\Red Hill\Figures\Draft Technical Report\Figure 1-5_Zoning Map. 4/16/2007

Figure 1-5
Zoning Map
Red Hill Fuel Storage Facility
Oahu, Hawaii

Meters
0 750 1,500
0 1,550 3,100 6,200
Feet

Source Data:
City & County of Honolulu,
GIS Base Layers

N



Base modified from U.S. Geological Survey National Hydrography Dataset, Albers equal area projection, standard parallels 21° 19'40" and 21° 38'20", central meridian 157° 58', datum NAD83. Relief from U.S. Geological Survey digital elevation models, 1:24,000

(Modified from USGS 2003) Generalized surficial geology, island of Oahu, Hawaii (modified from Stearns, 1939: Langenheim and Clague, 1987; and Presley and others, 1997).

Figure 1-6
Regional Geologic Features

Red Hill Fuel Storage Facility
Oahu, Hawaii

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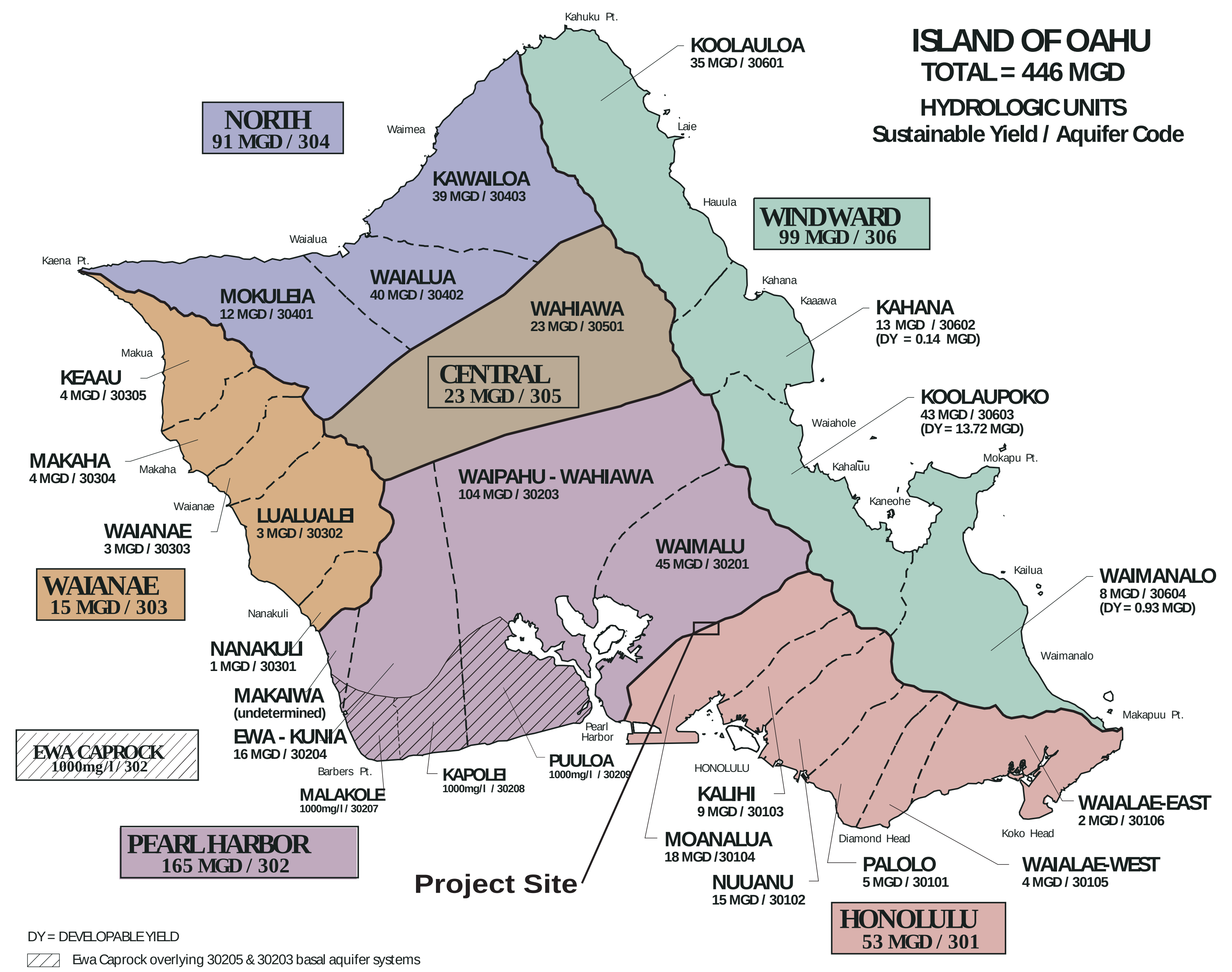
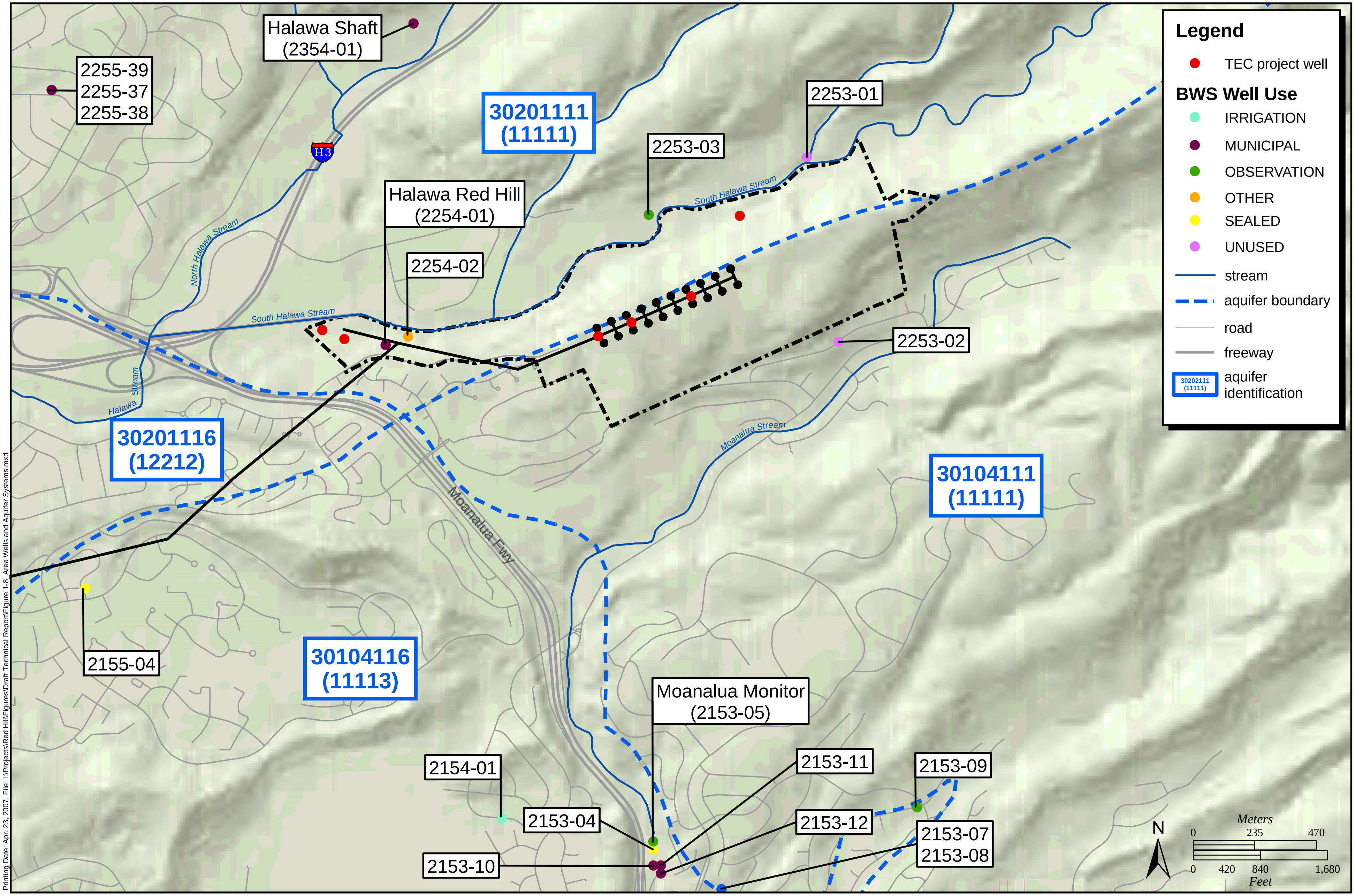


03/31/2000 (Modified from USGS 2003)

Figure 1-7
Regional Hydrologic Units and Sustainable Yields
Red Hill Fuel Storage Facility
Oahu, Hawaii

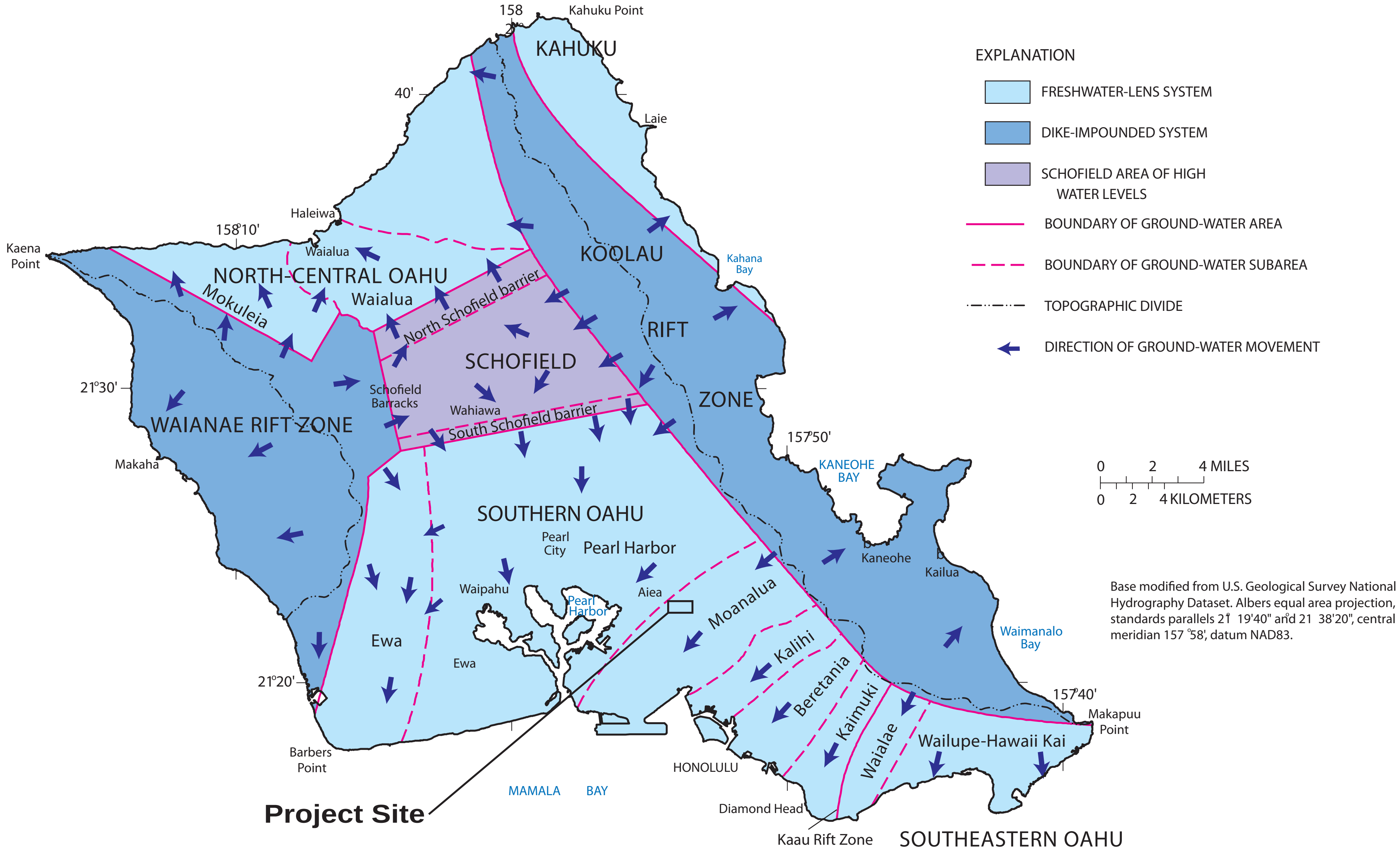


Printing Date: Apr. 23, 2007, File: I:\Projects\Red Hill\Figures\Draft Technical Report\Figure 1-8 Area Wells and Aquifer Systems.mxd

TEC inc

Figure 1-8
Area Wells and Aquifer Systems
Red Hill Fuel Storage Facility
Oahu, Hawaii

Source Data:
City & County of Honolulu,
GIS base layers
DLNR Board of Water Supply,
2005 water supply well IDs



Base modified from U.S. Geological Survey National Hydrography Dataset. Albers equal area projection, standards parallels 21° 19'40" and 21° 38'20", central meridian 157°58', datum NAD83.

(Modified from USGS 2003)

Groundwater areas and generalized directions of groundwater movement, island of Oahu, Hawaii (modified from Hunt, 1996).

Figure 1-9
Regional Groundwater Flow by Aquifer
Red Hill Fuel Storage Facility
Oahu, Hawaii

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SECTION 2
SITE CHARACTERIZATION INVESTIGATION ACTIVITIES

The SI activities for the Facility were divided into two phases. A summary of the project activities are presented below.

2.1 Phase I

In June 2005, borings were cored and excavated using air rotary techniques through bedrock in three locations. A single rock sample from each boring was analyzed at a certified environmental laboratory (Accutest, Florida). Rock cores and cuttings were examined in the field for evidence of contaminant migration; however borings were installed in locations away from primary sources in order to minimize the potential for creating a conduit from the release area to the basal groundwater table. No petroleum was observed in rock cores; therefore isolation casing was not required. Groundwater monitoring wells were installed in the air rotary borings. Groundwater samples were analyzed for petroleum constituents and natural attenuation parameters. Finally, a pilot study soil vapor monitoring system was installed in three slant borings under three USTs and soil vapor samples were collected from nine nested soil vapor monitoring points (SVMPs) associated with these slant borings.

2.1.1 Borings

The data quality objectives associated with advancing rock core borings for this SI are presented below.

- Install borings in locations optimized for groundwater monitoring wells. Locations were chosen to divide the Facility into three areas: Tanks 15 through Tanks 20; Tanks 7 through 14; and Tanks 1 through 6.
- Install borings in locations away from potentially contaminated unsaturated rock. If petroleum was observed in the coreholes during drilling, isolation casing would have been required to ensure drilling did not contaminate the basal groundwater and influence the study. Locations were chosen within the main lower access tunnel, between adjacent tanks to maximize the distance from potential releases. Rock cores were collected and evaluated in the field to ensure that evidence of petroleum was documented for this reason. No evidence of petroleum was documented above the water table.
- Rock cores were evaluated for stratigraphy, fractures, bedding planes, clinker zones and other structural features that would affect migration of liquids, including light non-aqueous phase liquid (LNAPL) or infiltrating groundwater that may contain dissolved phase petroleum. These features were mapped into bore logs and used to evaluate the potential for fuels to reach the basal water table.
- Install a background boring up-gradient from the Facility in a location that a background groundwater monitoring well will sample water quality prior to being impacted by petroleum releases from the Facility. Results for dissolved oxygen, nitrate, sulfate, ferrous iron and methane are compared to wells within the Facility to estimate natural

attenuation and assimilative capacity. Results are used in the numerical contaminant transport model to evaluate biodegradation effects.

To meet these objectives, three air rotary borings were advanced and monitoring wells were installed between June and September 2005. The air rotary borings associated with RHMW02 and RHMW03 are located northeast and hydraulically up-gradient of the access areas to Tanks 6 and 14, respectively (Figure 2-1). These were advanced with a skid-mounted Hagby ONRAM 100/3 coring drill rig, with an electrical motor for enclosed space work, and designed to drill in tight areas with low overhead clearance using continuous coring techniques operated by Valley Well Drilling, of Kapolei, Hawaii. A three-phase 430 volt, 100 amp line was installed from the Facility transformer to each of the two drilling locations to operate the electric drill. The coring system utilized wireline retrieval and N-series core barrels and core bits. N-series equipment generated a minimum 2.97-inch diameter borehole, which were then reamed to a minimum 4.8 inch diameter borehole using a P-series reaming bit, required to install 2-inch inside diameter polyvinyl chloride (PVC) wells. Cores were collected continuously in 5-ft runs, and stored in 5-ft core boxes onsite. Environmentally sensitive drilling mud (EZ-Mud, Baroid Industrial Drilling Products) was required to drill through several clinker zones. Recovered drilling fluids and cuttings were captured in a 55-gallon (gal) drums and stored onsite until project completion. Boreholes were drilled to approximately 15 to 20 ft below the water table to account for a small amount of slough, prior to setting the wells. The boring locations were adjusted in the field to take into account the locations of obstructions to equipment, such as pipelines, overhead clearance, etc.

The background boring associated with groundwater monitoring well RHMW04 was located approximately 800 ft northeast of the Adit No. 5 entrance, near the U.S. Navy firing range (Figure 2-1). This location is hydraulically up-gradient of the USTs and was chosen to provide geochemistry for water moving through the basal aquifer beneath the Facility. The location was adjusted in the field to account for surface conditions. The boring was advanced using a Mobile B-90 air rotary drill and an 8-inch percussion hammer bit to allow for a 4-inch inside diameter PVC well. Cuttings were logged and scanned for VOCs using field instruments. No evidence of VOCs were observed. A perched groundwater layer was observed at approximately 90 ft bgs, at an elevation consistent with the south Halawa Stream, which runs directly north of the drilling location. The perched layer was estimated to be between 10 and 40 ft thick. Cuttings from the borehole were captured in an investigation-derived waste (IDW) evaporation cell and allowed to dry. The cuttings were disposed of onsite subsequent to the completion of the boring and receipt of the laboratory analyses of the sampling results from a single rock sample and evaluation of field instrument readings.

All cores were collected in polyurethane core boxes, and each was screened with a photo-ionization detector (PID) and logged by a geologist following FISC approved standard operating procedure (SOP) and PACDIV Installation Restoration Program (IRP) Procedure I-E, *Soil and Rock Classification* (PACDIV, 1998). Cores were then labeled and stored in core boxes at the respective tanks. Soil boring and MW Construction Logs are presented in Appendix A.

Sections of the core were selected for chemical analysis based upon field observations, PID results and depth. Soil sample information is listed in Table 2-1. The sections of core were placed in 8-ounce glass jars with Teflon lined lids. Effort was made to include as much core sample as possible to reduce the amount of headspace. Samples were sent to the laboratory under strict chain-of-custody (COC) procedures (Section 2.5.3). The samples were crushed by the laboratory prior to analysis to aid in extraction.

Table 2-1. Soil Analytical Testing Summary

Matrix	Category	Sample Location	Sample Beginning Depth	Sample Date	Sample Type	Alkyl Lead Compounds D3341	Total Solids E160_3	Metals and Cations SW6010B	TPH SW8015B	VOCs SW8260B	SVOCs SW8270C
SO	Soil-=>10	RHMW02S01	86.5	7/5/2005	N	X	X	X	X	X	X
SO	Soil-=>10	RHMW03S01	102.5	8/15/2005	FD		X	X	X	X	X
SO	Soil-=>10	RHMW03S01	102.5	8/15/2005	N		X	X	X	X	X
SO	Soil-0-10	RHMW04S02	1.5	7/12/2005	N	X	X	X	X	X	X

SO	Soil
N	Normal sample
FD	Field duplicate

No utilities were present at any of the boring locations. Information about the monitoring wells is provided in Table 2-2.

Table 2-2. Monitoring Well Data

Well Identifier	Location	Elevation (TOC, ft msl)	Water Elevation (May 2006)	Borehole Diameter (inches)	Borehole Depth (ft msl)	Casing Type	Solid Casing Interval (ft msl)	Screened Casing Interval (ft msl)	Filter Pack Interval (ft msl)	Bentonite Seal Interval (ft msl)	Grout Interval (ft msl)
RHMW02	Lower Access Tunnel, North of Tank 6	106.57	21.26	5	3.1	2-inch, Sched 80 PVC	106.57 - 22.6	22.57 - 7.6	27.8 - 7.6	69.57 - 27.8	105.9 - 69.6
RHMW03	Lower Access Tunnel, North of Tank 14	122.11	21.51	5	4.1	2-inch, Sched 80 PVC	122.11 - 19.8	19.81 - 4.8	25.1 - 5.1	64.61 - 25.1	121.5 - 64.6
RHMW04	Western Access Road, South of Navy Firing Range	313.03	21.36	8	-7.5	4-inch, Sched 80 PVC	313.03 - 23	23.03 - 8	30.5 - 8	132 - 30.5	312.4 - 132

TOC = Top of Casing
ft = feet
msl = mean sea level
PVC = polyvinyl chloride

2.1.2 Monitoring Well Installation

Wells were installed in the air rotary borings. The monitoring wells were constructed in accordance with PACDIV IRP Procedure 1-C-1, *Monitoring Well Installation* (PACDIV, 1998). Monitoring wells RHMW02 and RHMW03 were constructed with 2-inch diameter, Schedule 80 PVC casing. RHMW04 was constructed with 4-inch diameter, Schedule 80 PVC casing. The screened intervals in RHMW02 and RHMW03 were constructed of 15 ft of 2-inch outer diameter, 0.02-inch slotted, flush threaded Schedule 80 PVC screen. RHMW04 screened interval was constructed of 15 ft of 4-inch outer diameter, 0.02-inch slotted, flush threaded Schedule 80 PVC screen. The screen was set so that at least 2-5 ft of screen was present above the interpreted water table. This distance was selected to take into account fluctuations in the water table and to allow entry of separate-phase product, if present. A clean sand filter pack, (Monterey No. 3), was placed in the annular space from the bottom of the borehole to approximately 5-7.5 ft above the screened interval.

2.1.3 Monitoring Well Development

New well installations were allowed to set for 24 hours and then were developed. Wells RHMW01 and U.S. Navy well 2254-01 were not developed, as these pre-existing wells were previously developed at installation. The wells were developed in accordance with PACDIV IRP Procedure 1-C-2, *Monitoring Well Development* (PACDIV, 1998). Well development was initiated by surging with a surge block. The wells were then bailed to reduce sediments until clear water was produced. Measurements and observations were taken and included pH, conductivity, temperature, dissolved oxygen and turbidity. Development was considered complete when 3 successive measurements of parameters had stabilized to within 10% of each other. Development water was placed in the Facility Oil/Water Separator (OWS) system. A water quality control (QC) sample analytical testing summary is presented in Table 2-3 below. Well development logs are presented in Appendix B.

Table 2-3. Water Quality Control Analytical Testing Summary

Matrix	Category	Sample Location	Sample Date	Sample Type	Metals and Cations SW6010B	TPH SW8015B	Volatile Organics SW8260B	Semivolatile Organics SW8270C
WQ	QC	Equipment Blank	8/15/2005	EB	X	X	X	X
WQ	QC	Trip Blank	9/20/2005	TB			X	
WQ	QC	Trip Blank	7/10/2006	TB			X	

EB	Equipment Blank
TB	Trip Blank
QC	Quality Control
WQ	Water Quality

2.1.4 Groundwater Sampling

The first SI groundwater sampling event was conducted in September 2005. Sample information is listed in Table 2-4. Each well was carefully purged with a disposable bailer, and water parameters were measured. The parameters of pH, conductivity, temperature, dissolved oxygen and turbidity were measured until they stabilized to within 10%. After stabilization, the wells were sampled. Samples were placed directly into laboratory-supplied containers and shipped to the laboratory under strict COC procedures (Section 2.5.3). Other water quality parameters that were measured in the field included dissolved oxygen, iron, and carbon dioxide. The subcontract laboratory was Accutest Laboratories of Orlando, Florida; and Oceanic Laboratories (now Test America), located in Aiea, Hawaii. Accutest Laboratories analyzed samples for definitive results used in the risk assessment. Test America provided screening results for geochemistry. The final water quality parameters from purging are presented with groundwater results in Section 3, the sampling logs are presented in Appendix C.

Table 2-4. Ground Water Analytical Testing Summary –September 2005

Sample Location	Sample Date	Sample Type	Alkalinity E310_1	Methane, ethane, ethene RSK-175	Metals and Cations SW6010B	TPH SW8015B	Volatile Organics SW8260B	Semivolatile Organics SW8270C	Anions SW9056
RHMW01-GW01	9/20/2005	N	X	X	X	X	X		X
RHMW02-GW01	9/20/2005	FD	X	X	X	X	X	X	X
RHMW02-GW01	9/20/2005	N	X	X	X	X	X	X	X
RHMW03-GW01	9/20/2005	N	X	X	X	X	X	X	X
RHMW04-GW01	9/19/2005	N	X		X	X		X	X
RHMW04-GW01	9/20/2005	N		X		X	X		
RHMW2254-GW01	9/19/2005	N			X	X			
RHMW2254-GW01	9/20/2005	N		X		X	X		

N	Normal sample
FD	Field duplicate
WG	Groundwater

During this sampling event wells RHMW01 and U.S. Navy well 2254-01 had a reduced analytical program since similar data was being collected by Dawson during this same time period. Samples were also analyzed for natural attenuation/water quality parameters of nitrate, nitrite (USEPA Method E353.2), orthophosphate (USEPA Method E365.2) and dissolved silica (USEPA Method E370.1). These analyses were performed by Test America. Groundwater sampling logs are presented in Appendix C. Third party data validation of samples was performed by Laboratory Data Consultants, Inc. (LDC), located in Carlsbad, California.

2.1.5 Soil Vapor Monitoring Pilot Study

The data quality objectives associated with the installation of soil vapor monitoring points for this SI are presented below. Table 2-5 provides a soil gas analytical testing summary.

- Install nested SVMPs (two to three per boring) in existing cased angle borings in which petroleum compounds were detected during drilling. SVMP installation required first removing the existing PVC casing, installing the probes to the sampling point, then isolate nested SVMPs from each other corresponding to sections of each Tank (front, middle and back).

- Collect samples from these borings for VOCs to evaluate potential indoor air migration pathway. Initial sample results will undergo data validation so that the results can be used for risk assessment decision-making.
- Evaluate the results to determine whether these SVMPs may be used as a leak detection method.

Table 2-5. Soil Gas Analytical Testing Summary

Matrix	Category	Sample Location	Sample Date	Sample Type	Volatiles in Air TO-15
GS	Soil Gas	RHSV02-15-40	5/16/2006	N	X
GS	Soil Gas	RHSV02-46-73	5/16/2006	N	X
GS	Soil Gas	RHSV02-79-110	5/16/2006	N	X
GS	Soil Gas	RHSV14-15-40	5/16/2006	N	X
GS	Soil Gas	RHSV14-46-73	5/16/2006	N	X
GS	Soil Gas	RHSV14-79-110	5/16/2006	N	X
GS	Soil Gas	RHSV16-15-40	5/16/2006	N	X
GS	Soil Gas	RHSV16-46-73	5/16/2006	FD	X
GS	Soil Gas	RHSV16-46-73	5/16/2006	N	X
GS	Soil Gas	RHSV16-79-110	6/23/2006	N	X

GS	Soil gas
N	Normal sample
FD	Field duplicate

Between December 12, 2005 and April 19, 2006, nested SVMPs were installed in angle borings beneath Tanks 2, 14 and 16. These tanks were chosen based on evidence of petroleum during the initial drilling, and because the diameter of the casings was 2-inch, (others were 1.5- and 1-inch diameter) and more easily converted based on size. Attempts were made to remove the casings from angle borings beneath Tank 1 and 5, but they appeared to be grouted in place. The SVMPs were installed inside each of the angled borings in the outer third, middle third and inner third of the vadose zone below the bottom of the corresponding USTs.

Prior to installing the SVMPs, the cased angle borings were evaluated for contamination that may have entered through the screen and pooled at the bottom. No evidence of separate-phase petroleum product was found in casings at Tanks 2, 14 and 16 (Appendix H). In general, the angle boring screens were 15 ft long and located at the outer third of the borings. The screen was cut, and the casing was used as a conduit to install the SVMPs and bentonite plugs in the open hole. In order to isolate each third of the boring, a bentonite seal was placed at approximately 100-ft, 66-ft, 33-ft and at the surface. SVMPs were installed in sections of open hole approximately 30-ft long, separated by bentonite plugs.

The SVMPs are constructed of ¼-inch ID copper tubing (93-ft, 60-ft and 25-ft sections) with each probe's copper tube labeled with a metal tag indicating depth. The bottom 10-ft section of each SVMP tube contains 3/16-inch holes to allow vapor to enter, and check valves (one per probe tube) were installed at the surface. The SVMPs are separated by a minimum of a 7-ft thick grout plug. A grout plug was also placed at the point of entry (POE) of each boring, and from POE to approximately 8 ft below POE. A steel well cover is in place at grade. Figure 2-2 describes the general design of each of the nested SVMPs.

On May 16 and June 23, 2006, nine samples and a duplicate were collected from the nine nested SVMPs (Table 2-5); however, RHSV14-79-110 (Tank 14, from 79 to 110 ft from POE) drew a vacuum, and though analyzed, did not provide reliable data. Samples were collected by first purging the associated void and tubing for one minute at 3 cubic ft per minute (cfm) with a series 2688CE44 WOB-L Piston vacuum pump. Samples were collected following purging. First, the canisters were checked to ensure that they were at a vacuum of greater than or equal to 25 inches of mercury. Then, the canister inlet was connected to the probe outlet via TygonR tubing and all the lines were opened at the same time. This procedure allowed the soil vapor to be withdrawn into the canister, replacing the vacuum. When the canister vacuum reached ambient pressure (after approximately 20 seconds), the canister valve and the monitoring probe check valve were closed. The dedicated Tygon® tubing was then removed from the canister and coiled for storage in the traffic box. QC information (such as final canister vacuum), was recorded on the sample label, logbook and field forms. Once the QC information was recorded, the summa canister was then capped. Canisters were shipped to Air Toxics Ltd. (ATL) under COC procedures via direct air courier. All samples were analyzed by EPA Method TO-15 for VOCs. Sample results were validated by Laboratory Data Consultants, Inc. (LDC) for use in the risk assessment. Data for soil vapor sampling is presented in Appendix E.

2.2 Phase II

In November of 2005, the U.S. Navy modified TEC's contract to include:

- Installation of dedicated sampling pumps at RHMW01, RHMW02, RHMW03, RHMW04 and U.S. Navy well 2254-01;
- Collection, analysis and data validation of a second round of groundwater samples from the aforementioned wells;
- Conduct a pump test to provide transient data to evaluate the 3-D localized groundwater flow model, and include a closed loop survey of 8 important monitoring points to ensure absolute water levels are well-calibrated to each other at these locations;
- Installation and sampling of additional nested SVMPs (under Tanks 6, 10, 11 and 12)

- Develop a 3-D groundwater flow model and utilize it for Tier 3 site specific fate and transport modeling of chemicals of concern that may become dissolved in the groundwater;
- Complete the environmental SI report and contingency plan, including a risk assessment of both current and potential future conditions at the Facility, and develop steps to mitigate unacceptable risk. These activities are further described below.

2.2.1 Installation of Dedicated Pumps

Installation of dedicated sampling pumps was completed in wells RHMW01, RHMW02, RHMW03, RHMW04 and U.S. Navy well 2254-01 (Figure 2-1). Each pump had a pre-fabricated tubing length to ensure that the pump intake is below the water table throughout the expected range of water elevations in these wells. The installation consisted of the following tasks:

- Unpacking the pump assemblies;
- Opening the monitoring wells;
- Decontamination of pump assemblies;
- Installation of the pump assemblies in the wells; and
- Testing of the pumps.

Well design specifications and the pump models installed in each well are listed in Table 2-6. Pumps are pneumatically driven and require a controller box along with a supply of compressed gas to operate. Inert nitrogen was used to operate the pumps.

Table 2-6. Wells and Pump Models

Well	RHMW01	RHMW02	RHMW03	RHMW04	U.S. Navy Well 2254-01
Sampling Method	Dedicated pump	Dedicated pump	Dedicated pump	Dedicated pump	Dedicated pump
Pump Model	GEO850.SS24	GEO1.66SS36			
Location	Lower Tunnel, South of Tank 1	Lower Tunnel, North of Tank 6	Lower Tunnel, North of Tank 14	Access Rd, South of Navy Firing Range	Lower Tunnel, Near Adit 3
dtw (ft)	82	84	101	293	81
Controller Pressure (psi)	50	70	80	190	55
Charge Time (s)	11	12	10	25	13
Exhaust Time (s)	5	10	15	22	12
Discharge Volume per Cycle (gal)	0.012	0.09	0.11	0.09	0.09
Purge Requirements	Stable Parameters or 2.2 gal	Stable Parameters or 6.6 gal	Stable Parameters or 8 gal	Stable Parameters or 25 gal	Stable Parameters or 2.9 gal

Well	RHMW01	RHMW02	RHMW03	RHMW04	U.S. Navy Well 2254-01

dtw = depth to water
ft = feet
psi = pounds per square inch
s = seconds
gal = gallons

2.2.2 Groundwater Sampling

The second SI groundwater sampling event was completed in July 2006 using the dedicated pumps. Sample information is listed in Table 2-7. Sampling of wells RHMW01, RHMW02, RHMW03, RHMW04 and RHMW2254 began with groundwater level measurements; no separate-phase product was encountered. Well RHMW2254-01 was installed in the man-way of the U.S. Navy well 2254-01 infiltration gallery, therefore water was being withdrawn constantly; for this reason, well RHMW2254-01 did not require purging.

Table 2-7. Ground Water Analytical Testing Summary - July 2006

Sample Location	Sample Date	Sample Type	Methane, ethane, ethene RSK-175	Metals and Cations SW6010B	TPH SW8015B	Volatile Organics SW8260B	Semivolatile Organics SW8270C
RHMW01-GW02	7/10/2006	N	X	X	X	X	
RHMW02-GW02	7/10/2006	FD	X	X	X	X	X
RHMW02-GW02	7/10/2006	N	X	X	X	X	X
RHMW03-GW02	7/10/2006	N	X	X	X	X	X
RHMW04-GW02	7/10/2006	N	X	X	X	X	X
RHMW2254-GW02	7/10/2006	N	X	X	X	X	X

N	Normal sample
FD	Field duplicate
WG	Groundwater

The parameters of pH, conductivity, temperature, dissolved oxygen and turbidity were measured until they stabilized to within 10%. After stabilization, the wells were sampled. Samples were placed directly into laboratory-supplied containers and shipped to the laboratory under strict COC procedures (Section 2.5.3). Other water quality parameters that can be measured in the field, including dissolved oxygen, iron and carbon dioxide, were also collected at this time. The contracting laboratory was Accutest Laboratories of Orlando, Florida; and Oceanic Laboratories (now Test America), located in Aiea, Hawaii. Accutest Laboratories analyzed samples for definitive results used in the risk assessment. Test America provided screening results for geochemistry. The final water quality parameters from purging are presented with groundwater results in Section 3, the sampling logs are presented in Appendix C.

2.2.3 Soil Vapor Sampling

In September 2006, 9 more SVMPs were installed beneath Tanks 6, 10, 11 and 12; Tank 12 receiving three SVMPs and Tanks 11, 10 and 6 receiving two SVMPs each. SVMPs were purged and sampled for VOCs using USEPA Method TO-15. Field readings were obtained by means of collecting the last Liter of purged air in a Ziploc® bag and then sampling the bagged air with a PID-4 gas meter for oxygen, carbon dioxide and VOC concentrations.

ATL, of Folsom California, provided 6-liter summa canisters for 10 sampling events (9 SVMPs plus 1 duplicate). Purging and sampling was completed as discussed in Section 2.1.5. SVMP construction information for Phase I and II activities is presented below in Table 2-8.

Table 2-8. SVMP Construction Information

Boring Location	Total Depth	SVMP Name	SVMP Material	Begin Interval (fbgs)	End Interval (fbgs)	Filter Pack	Front Bentonite Seal interval (fbgs)	Rear Bentonite Seal interval (fbgs)	Surface Completion
Tank 2	126.3	SVMP2-12-35	Type L, 0.25-inch Soft Copper	12	35	Open Hole	42-35	12-5	Flush-mount 12-inchTraffic Box
Tank 2	126.3	SVMP2-42-70	Type L, 0.25-inch Soft Copper	70	42	Open Hole	78-70	42-35	Flush-mount 12-inchTraffic Box
Tank 2	126.3	SVMP2-78-126	Type L, 0.25-inch Soft Copper	126	78	Open Hole	NA	78-70	Flush-mount 12-inchTraffic Box
Tank 6	126.6	SVMP6-15-35	Type L, 0.25-inch Soft Copper	35	15	Open Hole	40-35	15-8	Flush-mount 12-inchTraffic Box
Tank 6	126.6	SVMP6-40-56	Type L, 0.25-inch Soft Copper	56	40	Open Hole	NA	40-35	Flush-mount 12-inchTraffic Box
Tank 10	130.7	SVMP10-13-30	Type L, 0.25-inch Soft Copper	30	13	Open Hole	40-33	13-6	Flush-mount 12-inchTraffic Box
Tank 10	130.7	SVMP10-40-130	Type L, 0.25-inch Soft Copper	130	40	Open Hole	NA	40-33	Flush-mount 12-inchTraffic Box
Tank 11	131	SVMP11-13-30	Type L, 0.25-inch Soft Copper	30	13	Open Hole	40-30	13-6	Flush-mount 12-inchTraffic Box
Tank 11	131	SVMP11-40-131	Type L, 0.25-inch Soft Copper	131	40	Open Hole	NA	40-30	Flush-mount 12-inchTraffic Box
Tank 12	133.6	SVMP12-15-40	Type L, 0.25-inch Soft Copper	40	15	Open Hole	46-40	15-10	Flush-mount 12-inchTraffic Box
Tank 12	133.6	SVMP12-46-68	Type L, 0.25-inch Soft Copper	68	40	Open Hole	76-68	46-40	Flush-mount 12-inchTraffic Box
Tank 12	133.6	SVMP12-76-133	Type L, 0.25-inch Soft Copper	133	76	Open Hole	NA	76-68	Flush-mount 12-inchTraffic Box
Tank 14	136	SVMP14-12-35	Type L, 0.25-inch Soft Copper	35	12	Open Hole	42-35	12-5	Flush-mount 12-inchTraffic Box
Tank 14	136	SVMP14-42-69	Type L, 0.25-inch Soft Copper	69	42	Open Hole	76-69	42-35	Flush-mount 12-inchTraffic Box
Tank 14	136	SVMP14-76-136	Type L, 0.25-inch Soft Copper	136	76	Open Hole	NA	76-69	Flush-mount 12-inchTraffic Box
Tank 16	104.8	SVMP16-12-33	Type L, 0.25-inch Soft Copper	33	12	Open Hole	42-33	12-5	Flush-mount 12-inchTraffic Box
Tank 16	104.8	SVMP16-42-69	Type L, 0.25-inch Soft Copper	69	42	Open Hole	78-69	42-33	Flush-mount 12-inchTraffic Box
Tank 16	104.8	SVMP16-78-104	Type L, 0.25-inch Soft Copper	104.8	78	Open Hole	NA	78-69	Flush-mount 12-inchTraffic Box

Fbgs feet below ground surface

2.3 Aquifer Tests

A regional aquifer test was designed to incorporate pump results from several municipal pumping wells, as well as specific groundwater monitoring wells in which data loggers were installed, all within the local model boundaries. Due to the complexity of the hydrogeology, the scale of the study area, and the number of pumping wells involved, results of the test were not evaluated using analytical techniques. Instead, they were used to calibrate the localized groundwater flow model. Measured water levels from the data loggers were compared to simulated water levels from the same wells. The objectives of the assessment were to:

- Evaluate the geologic interpretations of the model, such as interpreted depths of valley fills;
- Evaluate the values given for hydraulic parameters particular stratigraphic units, such as basalt, valley fill and caprock;
- Evaluate the given boundary conditions and locations to ensure they do not negatively impact the area of concern in the vicinity of the Facility; and
- Evaluate if other assumptions and simplifications included in the model will provide acceptable results compared to measured data.

For this test, the primary pumping well was U.S. Navy well 2254-01. In addition, following consultation with the Honolulu Board of Water Supply (HBWS), pumpage from the Halawa shaft (well No. 2354-01) and Moanalua wells (2153-10, -12 and -22) was also included in the simulations. These HBWS wells were included to help better define the effectiveness of the valley fills separating the Moanalua and Waimalu aquifer sectors. Monitoring points were also evaluated during the tests, including (see Figure 2-1 for locations):

- RHMW02, RHMW03, RHMW04 and U.S. Navy well 2254-01;
- One well located adjacent to Adit No. 3 in the Former Oily Waste Disposal Facility (OWDFMW08);
- The Halawa Deep Monitoring Well (2253-03) and the Halawa Shaft (2354-01); and
- A monitoring well observed adjacent to TAMC MW-2.

These wells were monitored for changes in water elevation via pressure transducer data loggers (Table 2-9). In addition, chloride concentrations were collected from one deep basal monitoring well, the Halawa Deep Monitoring Well (2253-03), which is also currently being monitored for chloride content by the State of Hawaii, Commission of Water Resource Management (CWRM), of the Department of Land and Natural Resources (DLNR).

Table 2-9. Water Quality Control Analytical Testing Summary

Well	Location	Date Data Retrieved	Time	Depth to Water (fbtoc)	TOC Elevation (ft)	Data Logger Depth (fbwt)	Water Level (famsl)
TAMC MW02	Tripler Army Medical Center	05/10/06	14:10	158.59	178.51	8.93	19.92
		05/19/06	7:30	158.65	178.51	9.03	19.86
		05/19/06	7:30	158.65	178.51	9.05	19.86
		05/30/06	9:20	158.68	178.51	8.99	19.82
HBWS Halawa (2354-01)	Corner of Ulune/ Kahuapaani St.	05/17/06	8:45	41.50	58.00	1.93	16.50
		05/19/06	8:30	41.50	58.00	1.96	16.50
		05/19/06	8:30	41.50	58.00	1.92	16.50
		05/30/06	9:07	41.46	58.00	2.03	16.54
Halawa Deep (2253-03)	Behind Halawa Prison	04/28/06	8:30	206.42	226.68	10.80	20.26
		05/10/06	11:00	206.31	226.68	10.91	20.37
		05/10/06	11:00	206.31	226.68	7.27	20.37
		05/30/06	8:10	206.15	226.68	7.56	20.53
OWDFMW08	Red Hill (Oily Waste Disposal Facility)	04/28/06	8:30	118.82	138.94	10.43	20.12
		05/10/06	11:00	118.70	138.94	10.11	20.24
		05/12/06	9:51	119.20	138.94	10.53	19.74
		05/30/06	11:43	118.45	138.94	10.71	20.49
RHMW02	Red Hill FSF (Tank 6)	05/03/06	10:10	85.02	105.01	12.86	19.99
		05/10/06	15:40	85.85	105.01	13.06	20.20
		05/30/06	11:00	84.69	105.01	13.20	20.33
RHMW03	Red Hill FSF (Tank 14)	05/17/06	10:13	100.75	121.31	14.42	20.56
		05/30/06	11:20	100.90	121.31	13.88	20.56
RHMW04	Access Road (Adjacent to Firing Range)	05/12/06	7:35	292.08	313.03	12.50	20.95
		05/19/06	9:25	291.75	313.03	12.81	21.27
		05/30/06	10:10	291.84	313.03	12.71	21.17
RHMW2254 (2254-01)	U.S. Navy Red Hill Shaft	05/10/06	14:10	85.70	105.76	11.12	20.06
		05/24/06	7:30	92.56	105.76	4.26	13.20

ft = feet
fbtoc = feet below top of casing
fbwt = feet below water table
famsl = feet above mean sea level

2.3.1 Survey

In March of 2006, a closed-loop survey was conducted by Control Point Surveying, Inc., of Honolulu, Hawaii, a Hawaii-registered land surveyor, to determine precise locations (horizontal and vertical coordinates) of 7 monitoring wells, including 4 located within the lower access tunnel of the Facility (Table 2-10). The same benchmarks were used consistently to minimize possible discrepancies. The closed loop survey was performed to U.S. Coast and Geodetic Survey and/or USGS markers. The survey determined the horizontal coordinates to a minimum accuracy of 0.1 ft and an elevation to a minimum of 0.01 ft. The horizontal coordinates were reported in the Universal Transverse Mercator, State Plane, Zone 3, NAD83 (ft) coordinate system and the vertical coordinates were reported as NAVD 29 (ft). The surveys are third order

(Urquhart, 1962). The locations were identified in an XYZ-coordinate system using northings, eastings and elevations. The survey was required to determine absolute groundwater table elevations in these wells, for use in the site-specific groundwater flow model calibration, and to evaluate groundwater gradients in the area adjacent to the Facility to assess contaminant migration in groundwater via advection.

Table 2-10. Monitoring Well Survey

Well	Northing (ft)	Easting (ft)	Description	Elevation (ft, msl)
RHMW01	74041.08	1675059.16	Ground Level	102.51
			Top of Casing	102.41
RHMW02	74282.05	1675639.24	Ground Level	105.67
			Top of Casing	105.01
RHMW03	74610.90	1676391.37	Ground Level	122.11
			Top of Casing	121.31
RHMW04	75742.64	1677345.57	Ground Level	313.03
			Top of Casing	312.57
RHMW2254-01	74006.92	1672560.73	Ground Level	105.79
			Top of Casing	105.76
OWDFMW08	74112.75	1671997.36	Ground Level	138.94
			Top of Casing	138.57
OWDFMW09	74202.61	1671757.38	Ground Level	119.35
			Top of Casing	118.91

ft = feet
msl = mean sea level

2.3.2 Groundwater Elevation Measurements

The groundwater elevation measurements were calculated based on the depth to groundwater as measured from the north notch in the TOC. This notch serves as a permanent reference point for groundwater measurements from the well. All groundwater level measurements were read where the tape intersected the notch at the TOC to when the meter indicated reaching water. Data relative to sea level was calculated using the measured elevation corresponding to the well.

2.3.3 Regional Pump Test Activities

Prior to initiating the aquifer test, TEC coordinated activities with the HBWS, CWRM, DLNR and the US Army Corps of Engineers. Data loggers were serviced, checked and installed in the wells during the week of May 13, 2006. The observation period covered approximately one month from May 10, 2006 to June 1, 2006, although some data loggers recorded water levels earlier. The main test was initiated by completely shutting off U.S. Navy well 2254-01 between May 12 and May 19. This allowed for the water levels near U.S. Navy well 2254-01 to recover from pumping stresses. However, the HBWS Halawa Shaft and the HBWS Moanalua wells maintained their regular pumping patterns. After the recovery period, U.S. Navy well 2254-01 was subject to a period of above-average pumping between May 19 and May 26. As compared to the ten-year averaged pumping rate at the U.S. Navy well 2254-01 of around 4.3 mgd, the pump rates alternated between 10 and 18 mgd during this period. This caused notable drawdown in all observation wells, except in Halawa Shaft and Halawa observation well. After the period of increased pumping, a three-day recovery period was evaluated in which no pumping occurred at the U.S. Navy well 2254-01 between May 26 and May 29. The entirety of the main observation period for the transient model calibration took 17 days. The data loggers recorded the return to static conditions, the response to the aquifer test, and the return to normal conditions after the test. The data was down-loaded from the data loggers in June of 2006, for evaluation (Appendix K). Figure 2-1 illustrates the locations of the wells included in the regional pump test. Figure 2-3 is a chart of the water levels at each of these wells during this period.

2.3.4 Groundwater Flow Model

In order to conduct a site-specific risk assessment and provide a site contingency plan for the Facility, the U.S. Navy tasked TEC to develop a 3-D numerical groundwater flow model to be used to simulate contaminant migration to offsite drinking water sources. The U.S. Navy, TEC, the UH Water Resources Research Center (WRRC), and HDOH Safe Drinking Water Branch (SDWB) collaborated on the development of a localized groundwater flow model based on MODFLOW 2000 and the HDOH SDWB Source Water Assessment Program (SWAP) Oahu regional model (Whittier, et al., 2004). A detailed description of the local model development is provided in Appendix L. Figure 2-4 depicts the boundaries of the local model with respect to the Facility and Oahu. Figure 2-5 illustrates the stratigraphy and morphology of the conceptual grid model used in the numerical analysis. Figure 2-6 shows cross sections A-A’, trending from the shoreline to the Koolau boundary, and B-B’, trending from Waimalu to Kalihi through the pertinent valleys.

2.3.4.1 Steady State Conditions Calibration

The local groundwater flow model was calibrated for both steady state and dynamic or “transient” conditions. The steady state calibration was conducted by estimating the hydraulic parameters of the major stratigraphic units from literature values, then simulating water table elevations using average recharge and pumping conditions for the period between 1996 and 2005, then, the model was iteratively run using a Parameter Estimation (PEST) algorithm (Doherty, 2000), until the differences between the measured and simulated groundwater elevations were minimized. Thirty pumping wells located in the local model area were used to develop the steady state water table conditions. Figure 2-7 is the calibrated groundwater contours generated by the model for the 1996 through 2005 average pumping and recharge scenario for the steady state model calibration. Figure 2-8 is the results of the steady state calibration of the local model for 11 observation wells within the model boundaries. The optimized hydraulic parameters derived in this manner are given in Table 2-11. A thorough description of this process and the wells chosen for the calibration are provided in Appendix L, Section 4.3 of this document.

Table 2-11. Water Quality Control Analytical Testing Summary

Hydro-geologic Unit	Horizontal, Transversal Hydraulic Conductivity [ft/day]	Horizontal, Longitudinal Hydraulic Conductivity [ft/day]	Vertical Hydraulic Conductivity [ft/day]	Effective Porosity
Caprock	115	115	115	0.10
Valley Fill	0.066	0.066	0.066	0.15
Basalt	1476	4428	7.4	0.05

Longitudinal represents the general lava-flow direction, transversal is orthogonal to it.
ft/day feet per day

2.3.4.2 Transient Conditions Calibration

An important objective of the local model use was to be able to evaluate the effects of drought conditions and heavy groundwater pumping on groundwater movement and dissolved particles, such as petroleum compounds released to the basal aquifer from the Facility. In order to ensure that the model could adequately predict groundwater movement under these short term stresses, the pumping test described in Section 2.3.1.3 was simulated by the local model. Aquifer characteristics of Specific Storage and Specific Yield were estimated for basalt, caprock and valley fill material. Since the comparison of the relative change in water level was more important than the absolute elevations, initial simulated water levels were shifted to observed elevations, and the PEST algorithm was used to minimize differences. Figure 2-9 provides the results of the final simulated pump test results compared to measured results at three locations: within Facility; to the west of the Halawa Valley Fills at the HBWS Halawa Shaft; and to the east of the Moanalua Valley Fill at the Tripler Army Medical Center monitoring well. Table 2-12 provides the results of the parameter estimation for Specific Yield and Specific Storage for basalt, caprock, and valley fill.

Table 2-12. Aquifer Parameters for the Local Transient Model

Hydrogeologic Unit	Specific Storage [ft^{-1}]	Specific Yield
Caprock	3.05×10^{-5}	0.10
Valley Fill	1.52×10^{-5}	0.12
Basalt	1.07×10^{-5}	0.031

ft^{-1} per foot

2.3.5 Seawater Transition Zone Assessment

In October 2005, the State of Hawaii Department of Land Natural Resources (DLNR) Commission on Water Resource Management (CWRM) collected conductivity data (micro-siemens per centimeter) from the water table to the total depth at the South Halawa Deep Monitoring Well (well 2253-03), located just north of the Facility. The data were converted to mg/L of chloride ions (Cl^-) using an approximating transfer function by ETIC of Oakland California, to represent the seawater transition zone in the Red Hill sub-basin. The data are presented in Figure 2-10. In this profile, the freshwater lens (Cl^- less than 250 mg/L) extended to approximately 90 feet below msl. At 90 feet below msl, a sharp boundary was observed in which the salinity concentration transitioned sharply from fresh (less than 250 mg/L of chloride [Cl^-]) to about 1,600 mg/L Cl^-. Between 100 and 700 feet below msl, salinity remained constant between 1,600 and 1,650 mg/L Cl^-. Between 700 and 1,020 feet below msl, the transition zone was encountered in which salinity increased at approximately 660 mg/L Cl^- per 100 feet of depth, then stabilized at seawater concentrations (about 20,000 mg/L Cl^-).

Previous estimates of the Upper Transition Zone (Todd Engineering, 2005) in South Halawa Valley showed the upper boundary at about 300 feet below msl in the vicinity of well 2253-03. These estimates have been revised based on these new data, and are presented in Figure 2-11.

2.4 Risk Assessment

A site-specific Tier 3 risk assessment was conducted by TEC. The risk assessment used the general guidance in the TGM-UST (HDOH, 2000) and additional specific guidance from HDOH (2005). Both of these approaches are generally based on the risk assessment methods described by the USEPA for the Superfund Program (USEPA, 1989). A tiered approach for the risk assessment was used as recommended by HDOH (2005) and using the action levels as specified in that same document.

A Tier 3 risk assessment was used for the evaluation of potential future groundwater exposures and risks. A Tier 3 risk assessment is a detailed, site specific evaluation when Tier 2 risks exceed acceptable levels and it is not cost effective or feasible to remediate the Facility to Tier 2 site specific target levels. Compared to a Tier 2 risk assessment, a Tier 3 risk assessment may use modified toxicity factors, as well as site specific exposure factors and alternative models. The risk assessment is detailed in Section 6 of this report.

2.5 Standard Procedures

Phase I and II activities implemented QC standards, sample identifier standards; and strict COC, Decontamination and IDW procedures. These areas are further discussed below.

2.5.1 Field QC Samples

During soil, groundwater and soil vapor sampling efforts, field QC samples were collected to help monitor sampling procedures and to identify potential outside sources of contamination. Field QC samples consisted of trip blanks, duplicates and equipment rinsate blanks. The field QC samples were collected in accordance with NAVFAC-approved PACDIV IRP *Procedure III-B, Field QC Samples (Water, Soil)* (PACDIV, 1998). These samples are presented with the data, in Appendix F.

The duplicate samples collected are shown in Tables 2-1, 2-4 and 2-6. Duplicate sample results show reasonable correlation. Two samples had one chemical each that exceeded a relative percent difference (RPD) of 100: in soil gas sample RHSV06-15-35 ethylbenzene had and RPD of 123 and in groundwater sample RHMW02-GW02 methane had an RPD of 123. For 6 results in soil gas samples one sample contained a detected chemical above the reporting limit and the duplicate sample did not. For 3 results in groundwater samples one sample contained a detected chemical above the reporting limit and the duplicate sample did not. For all duplicate samples, when one sample has a detect for an analyte and the analyte is undetected in the duplicate sample, the result for the detected sample is used in subsequent analyses. Results of all comparisons of duplicate samples where at least one sample of the pair had a detect are shown in Appendix I. No data qualifications were made. These results were determined not to affect the usability of the data.

The equipment blanks and trip blanks collected and analyzed are shown in Table 2-3. Acetone, a common laboratory contaminant, was detected in 1 equipment blank at a concentration of 9.5 ug/L, less than the laboratory reporting limit. There were no other substances detected in blanks.

2.5.2 Sample Identification

Sample identifiers (IDs) were assigned to each sample to facilitate correct identification, data tracking and storage. Sample IDs are as follows:

RHMW01W01

Where:

RH = Red Hill

MW = Monitoring Well

01 = Sequential number assigned to a monitoring well

W = Water sample

01 = Sequential sample collected

D = Duplicate

Also:

EB = Equipment Rinsate Blank

S = Soil (rock)

RHSV02-25 = Soil Vapor at Tank 2, 25 feet from POE.

2.5.3 Chain -of-Custody Procedures

As samples were collected, each one was labeled with the respective ID, date, time, analyses required and sampler’s initials. The labels were then secured with clear tape, and the containers were wrapped in cushioning material (i.e., bubble wrap). Samples were placed in coolers containing ice for shipment. A completed COC was also included, as well as any required shipping bills (i.e., the foreign soil permit). Samples were then shipped by Federal Express overnight air to mainland laboratories, or directly taken to the on-island laboratory.

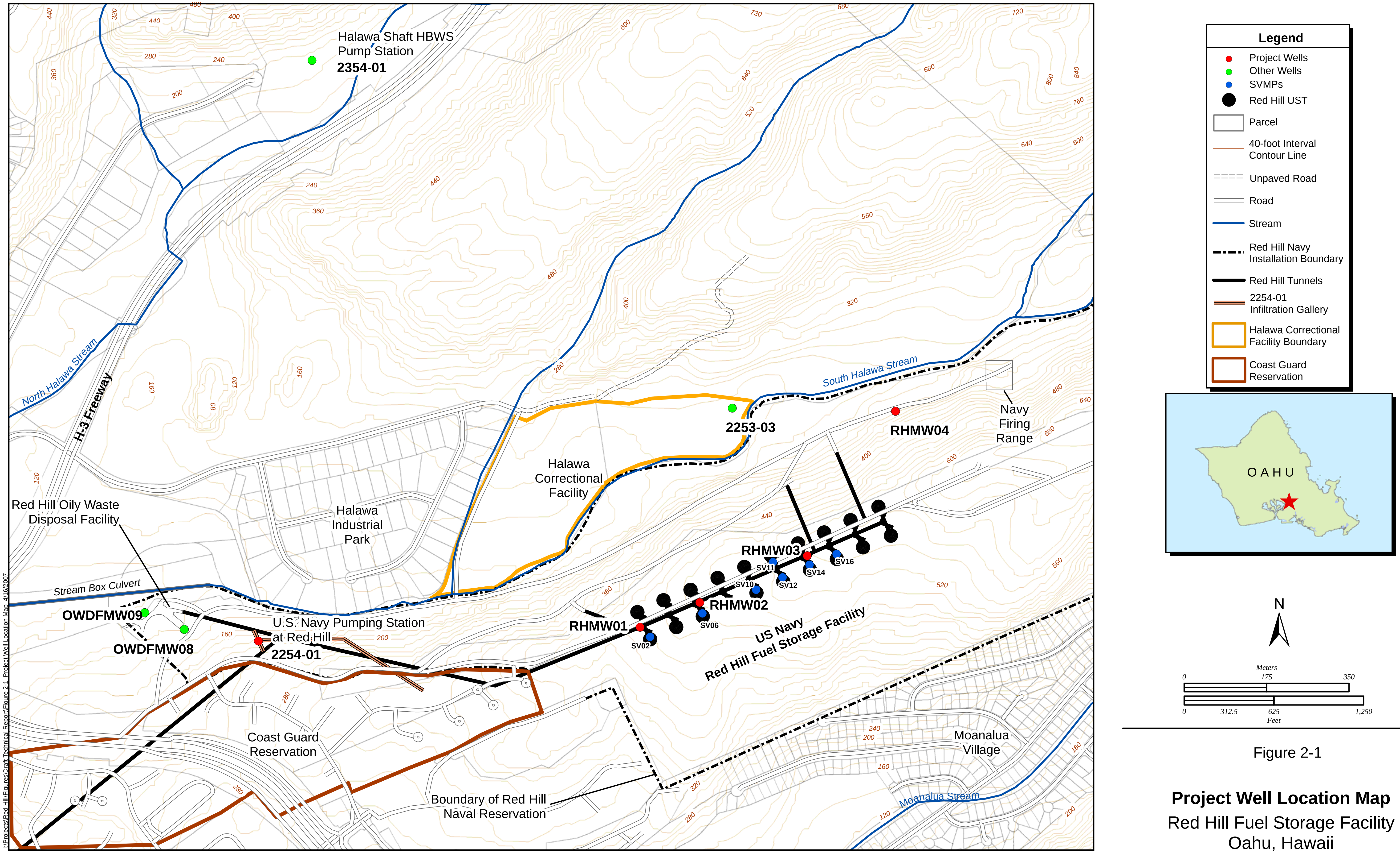
2.5.4 Decontamination Procedures

All reusable equipment used in sampling was decontaminated in accordance with PACDIV IRP Procedure I-F, *Equipment Decontamination* (PACDIV, 1998). Single use equipment was disposed as described in Section 2.5.5. Equipment requiring decontamination included drilling equipment, groundwater sampling and monitoring equipment (i.e., probes, etc.). Single use equipment (i.e., disposable bailers and tubing) was used whenever possible. The drilling equipment was cleaned with a high-pressure, hot steam wash before use.

Other re-usable sampling equipment (such as the core samplers) were decontaminated with non-phosphate soap wash/potable water solution, potable water rinse, isopropyl alcohol rinse and de-ionized water rinse. Pumps were cleaned in the same manner, after having the decontamination fluids run through them completely. Monitoring equipment such as pH and conductivity meters were rinsed with de-ionized water and their specific calibration fluids. This additional rinse of the monitoring equipment with their specific calibration fluids was done in order to not damage the equipment sensors. Decontamination was performed in plastic buckets set on plastic sheeting to avoid loss of fluid. The soap-containing decontamination fluids were containerized in 55-gal drums, properly labeled and stored as IDW awaiting disposal.

2.5.5 Investigation-Derived Waste

IDW generated during field activities included removed groundwater, rock chips and clean single-use sampling equipment and personal protective equipment (PPE). The generated water that was free from surfactants was placed into the drains of the Red Hill OWS. Water that contained soap from decontamination procedures was containerized in 55-gal drums, properly labeled and to be disposed of at a later date. Rock chips generated from the drilling of the background well were sampled, analyzed and found to be clean.



I:\Projects\Red Hill\Figures\Draft Technical Report\Figure 2-1 Project Well Location Map 4/16/2007

Figure 2-1

Project Well Location Map

Red Hill Fuel Storage Facility
Oahu, Hawaii

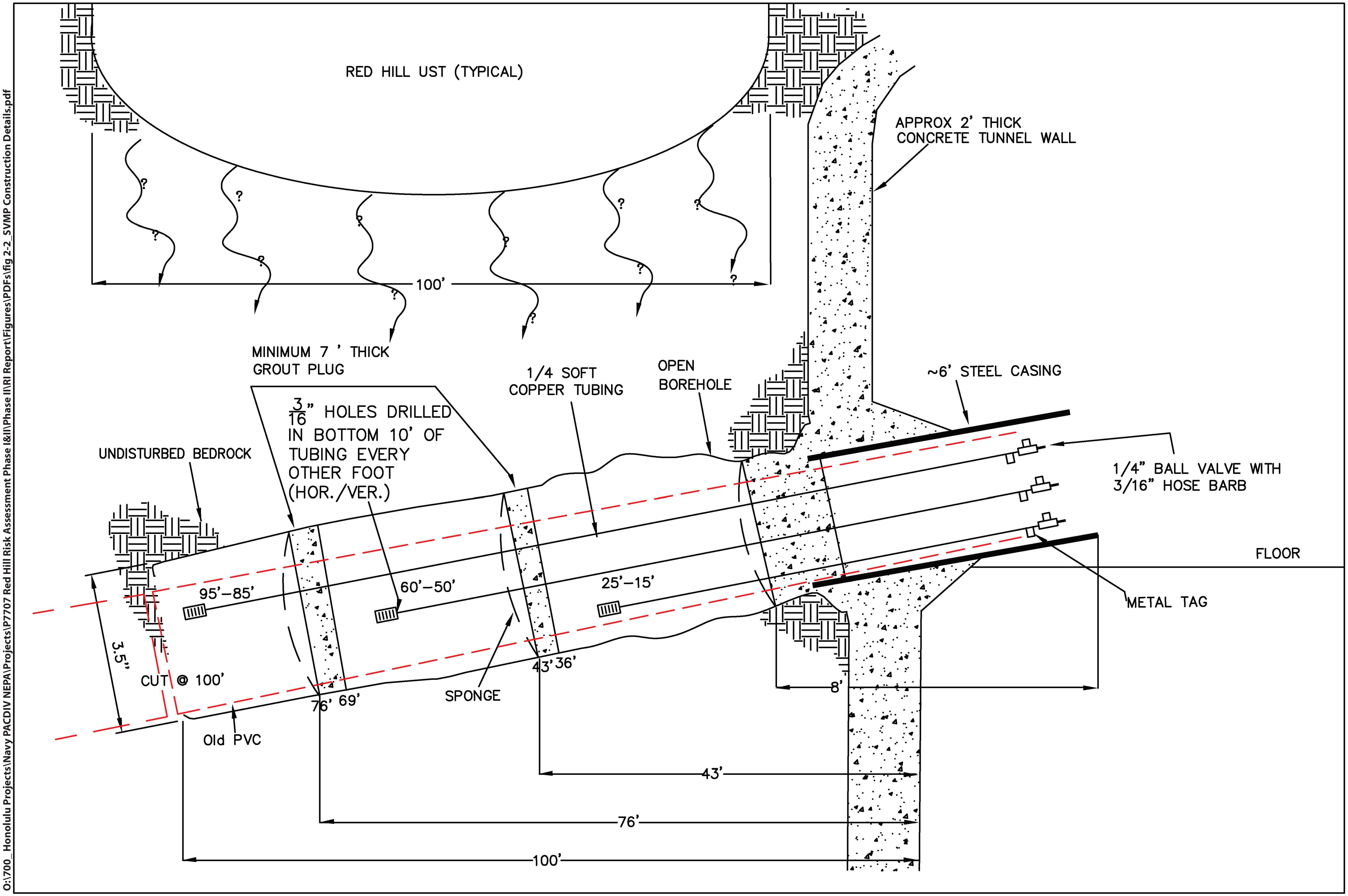


Figure 2-2

Soil Vapor Monitoring Point Construction Details

Red Hill Fuel Storage Facility

Oahu, Hawaii

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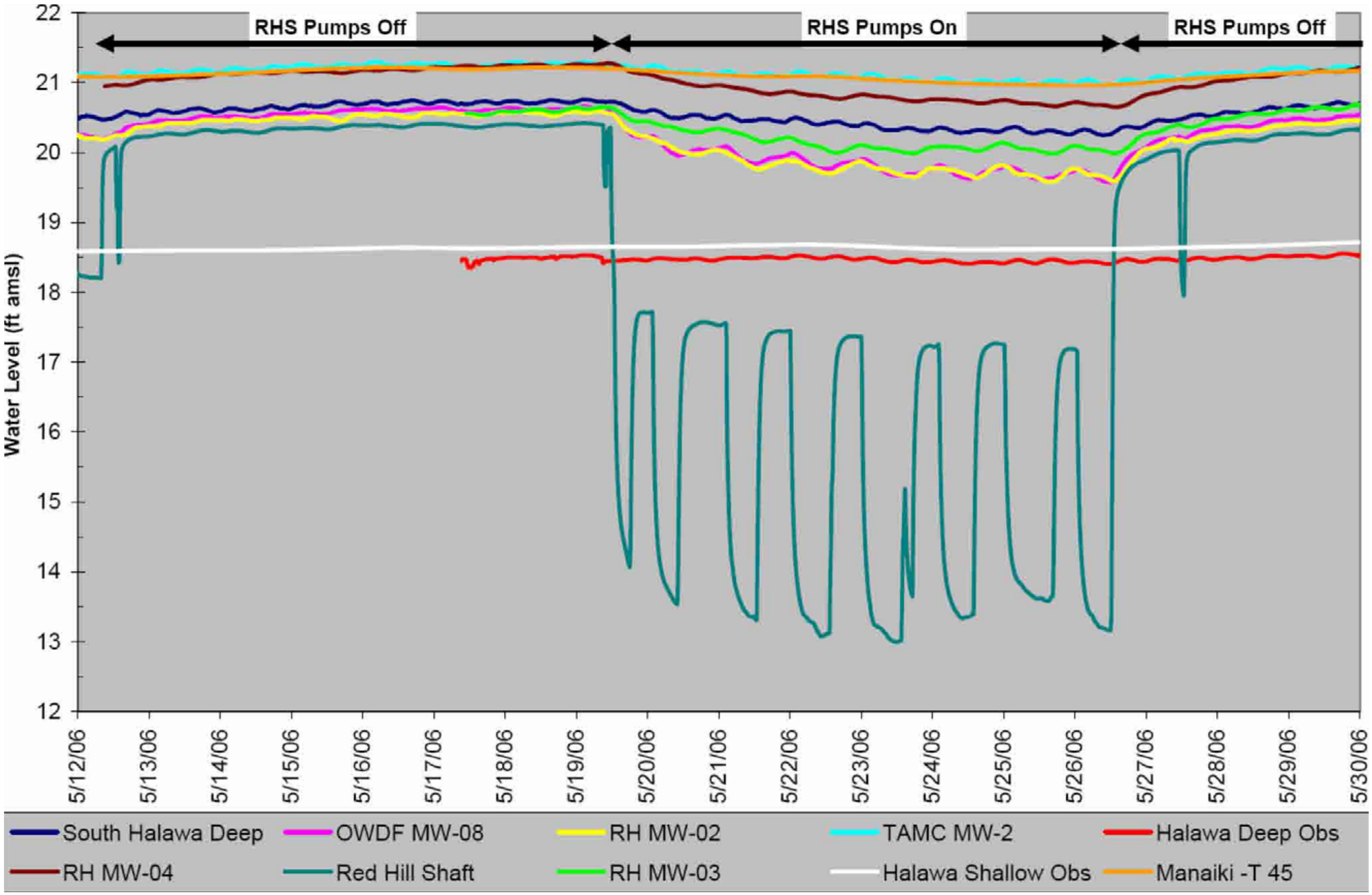


Figure 2-3
Regional Pump Test Water Level Signatures
Red Hill Fuel Storage Facility
Oahu, Hawaii

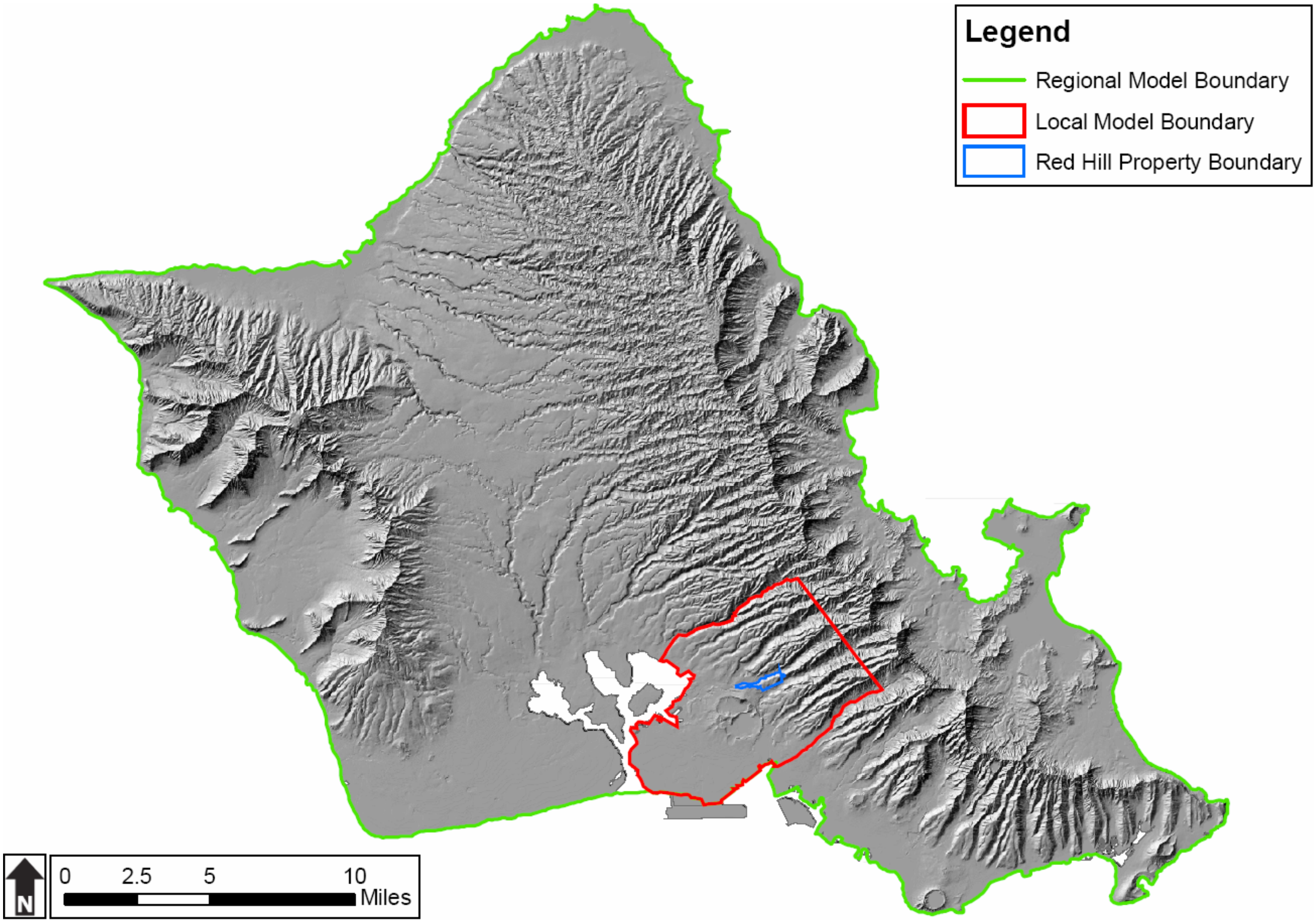
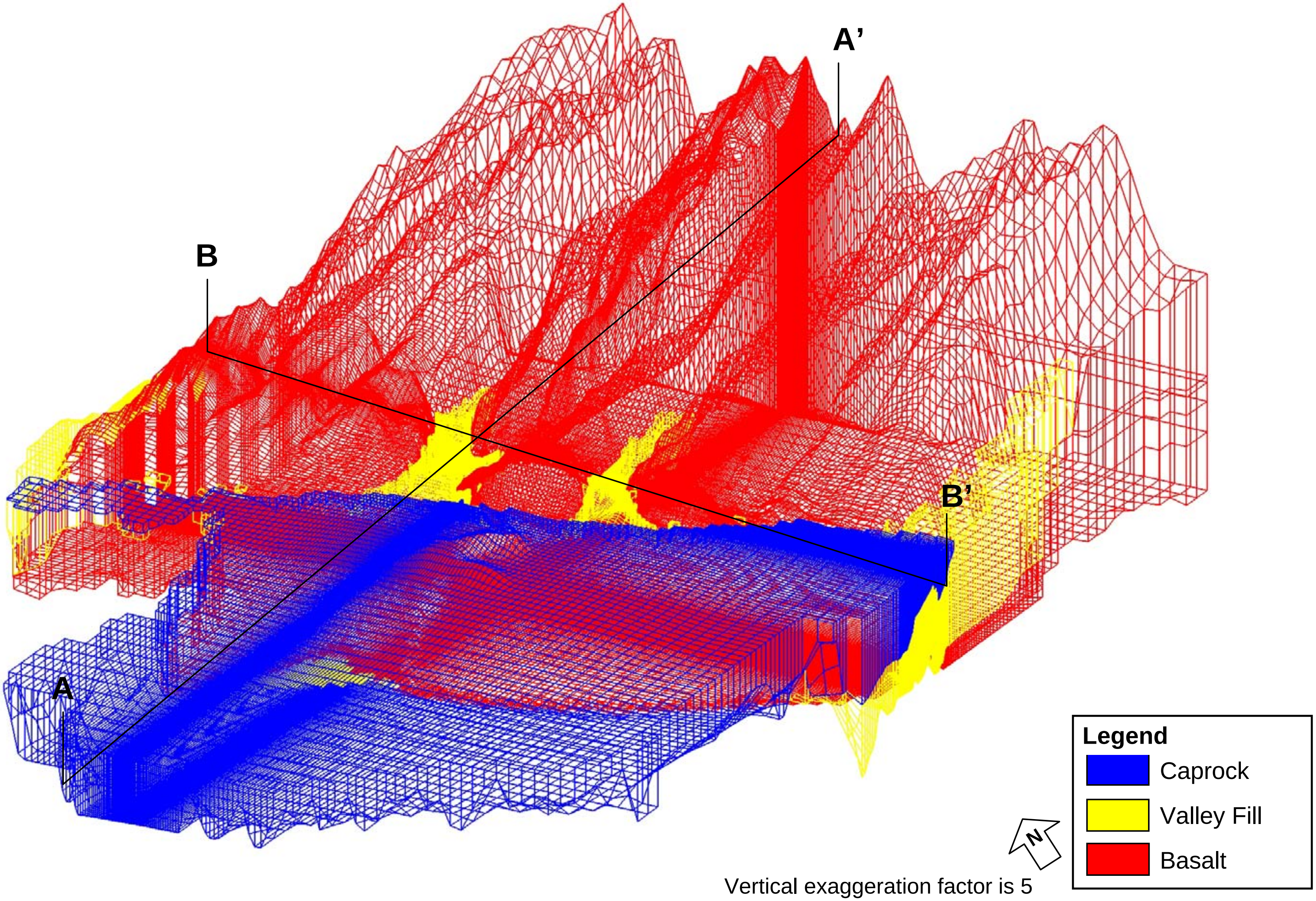


Figure 2-4
Presentation of Local Model Boundaries
Red Hill Fuel Storage Facility
Oahu, Hawaii



Vertical exaggeration factor is 5

Figure 2-5
Stratigraphy and Morphology of Conceptual Grid Model
Red Hill Fuel Storage Facility
Oahu, Hawaii

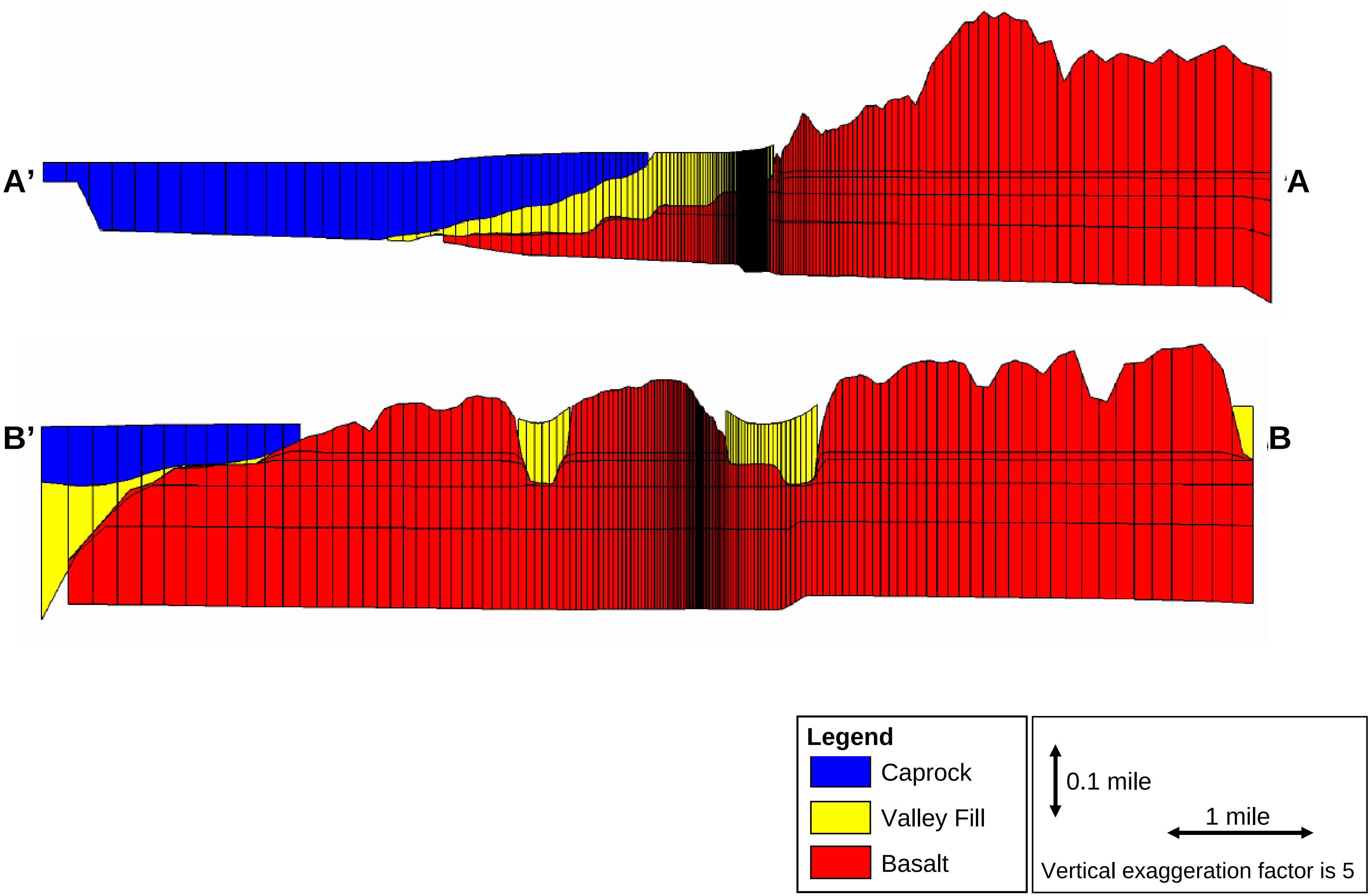


Figure 2-6
Cross Sections of Models A-A’ and B-B’ Through the Model Grid
Red Hill Fuel Storage Facility
Oahu, Hawaii

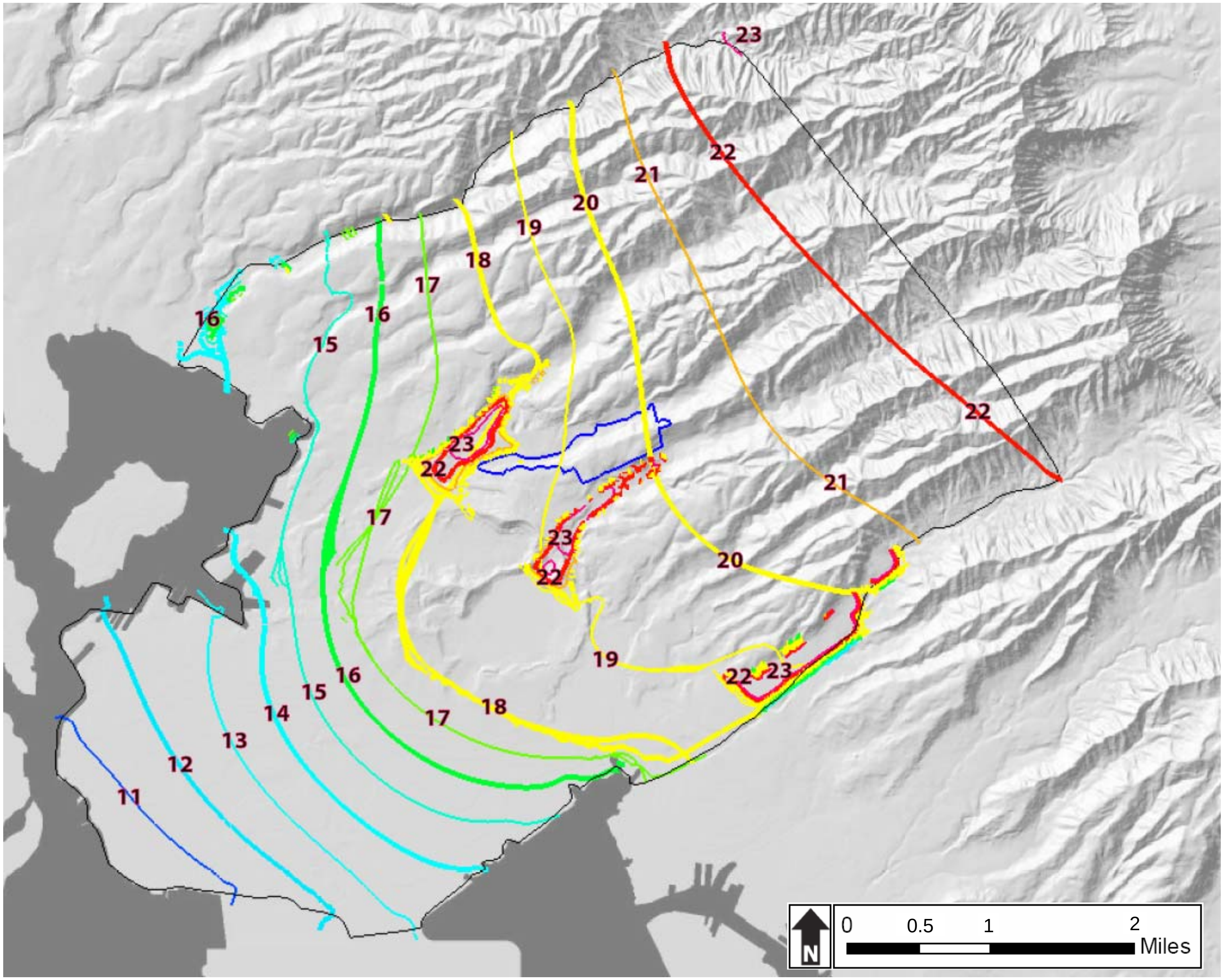


Figure 2- 7

Simulated Groundwater Contours of the Local Model (ft above mean sea level)

Red Hill Fuel Storage Facility

Oahu, Hawaii

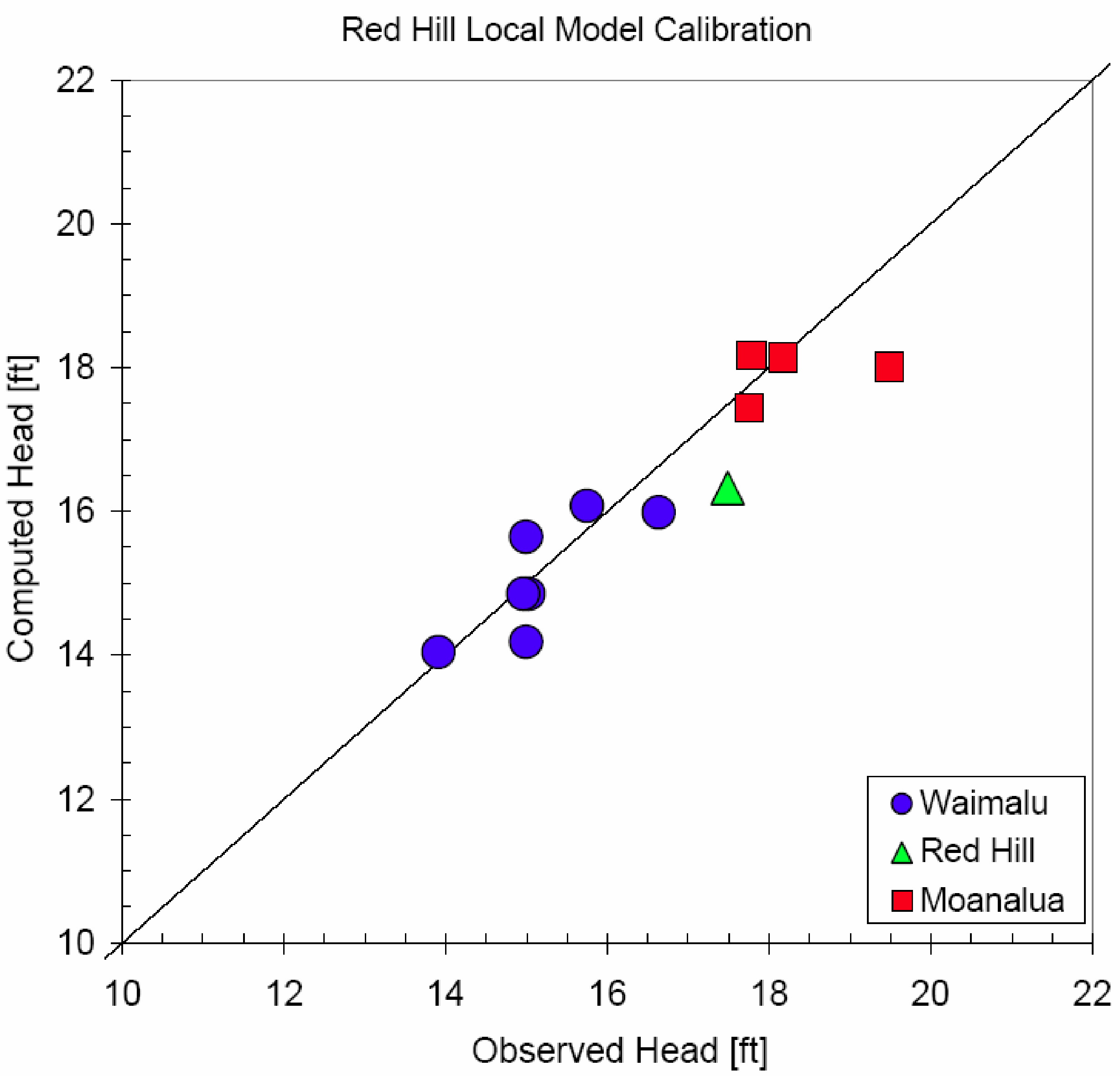


Figure 2-8

Comparison of Observed and Simulated Steady-state Water Levels from the Local Model

Red Hill Fuel Storage Facility

Oahu, Hawaii

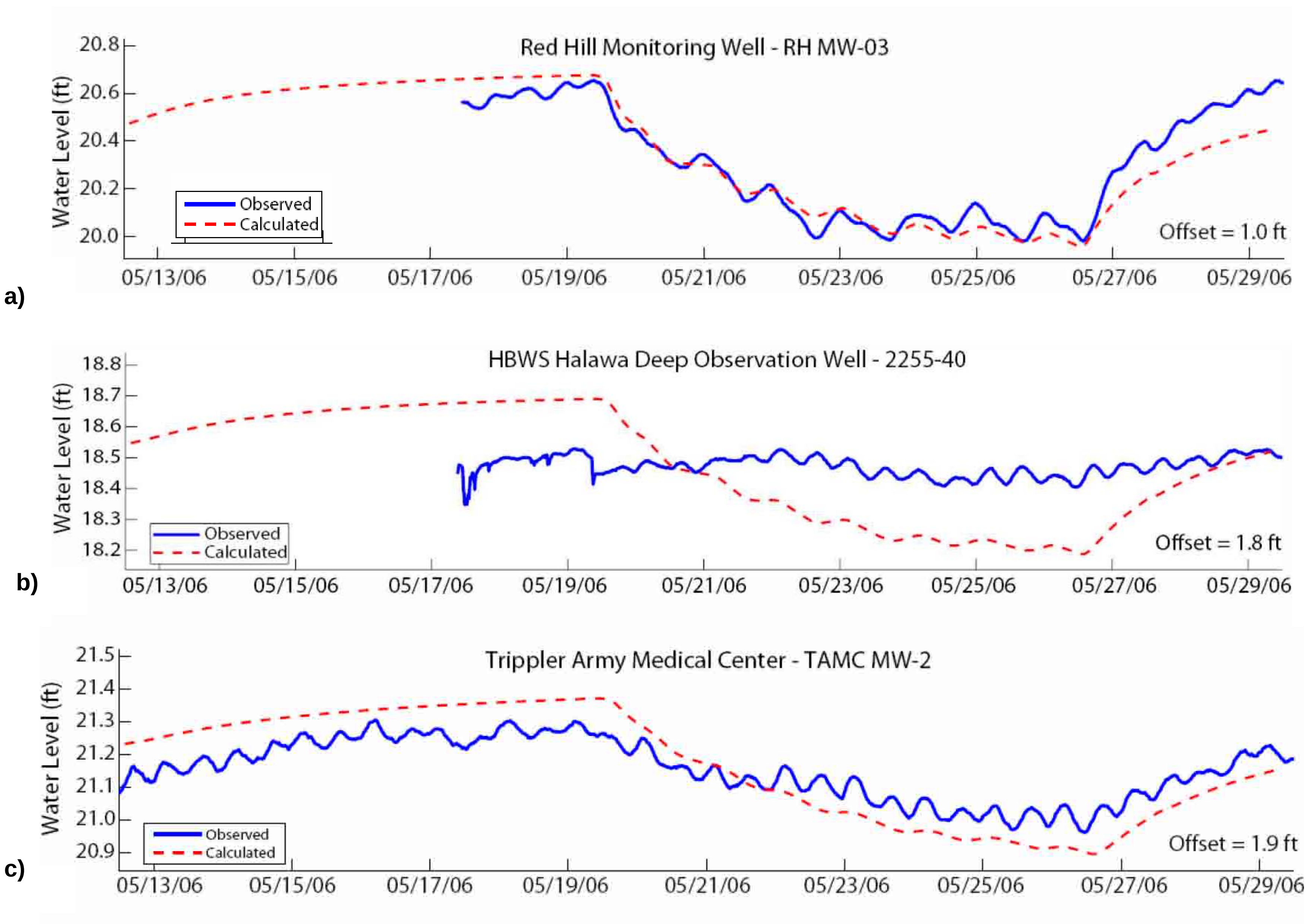
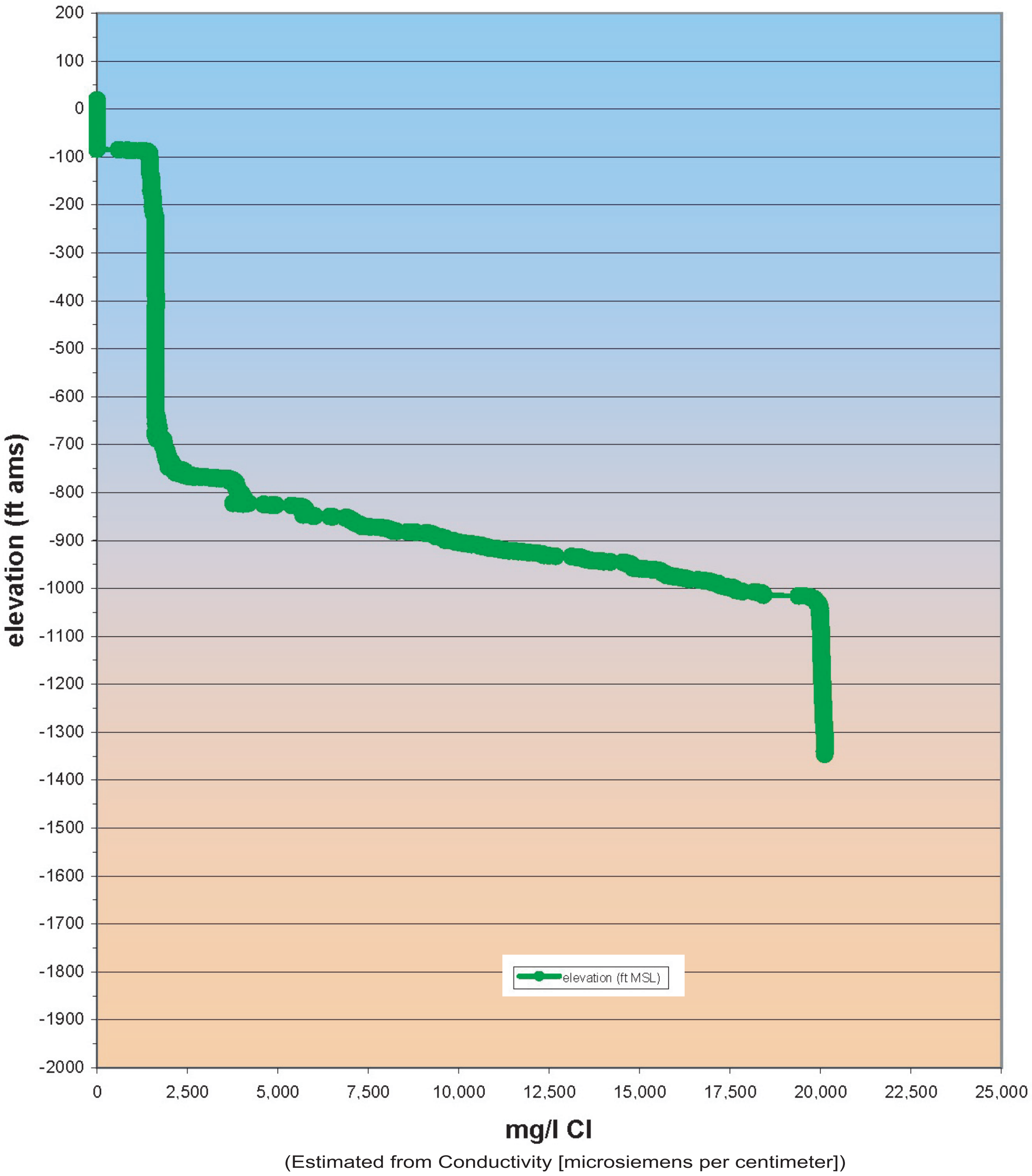


Figure 2-9
Simulated and Observed Water Levels for a) the Facility, b) HBWS Deep Observation well, and c) Tripler Army Medical Center
Red Hill Fuel Storage Facility, Oahu, Hawaii



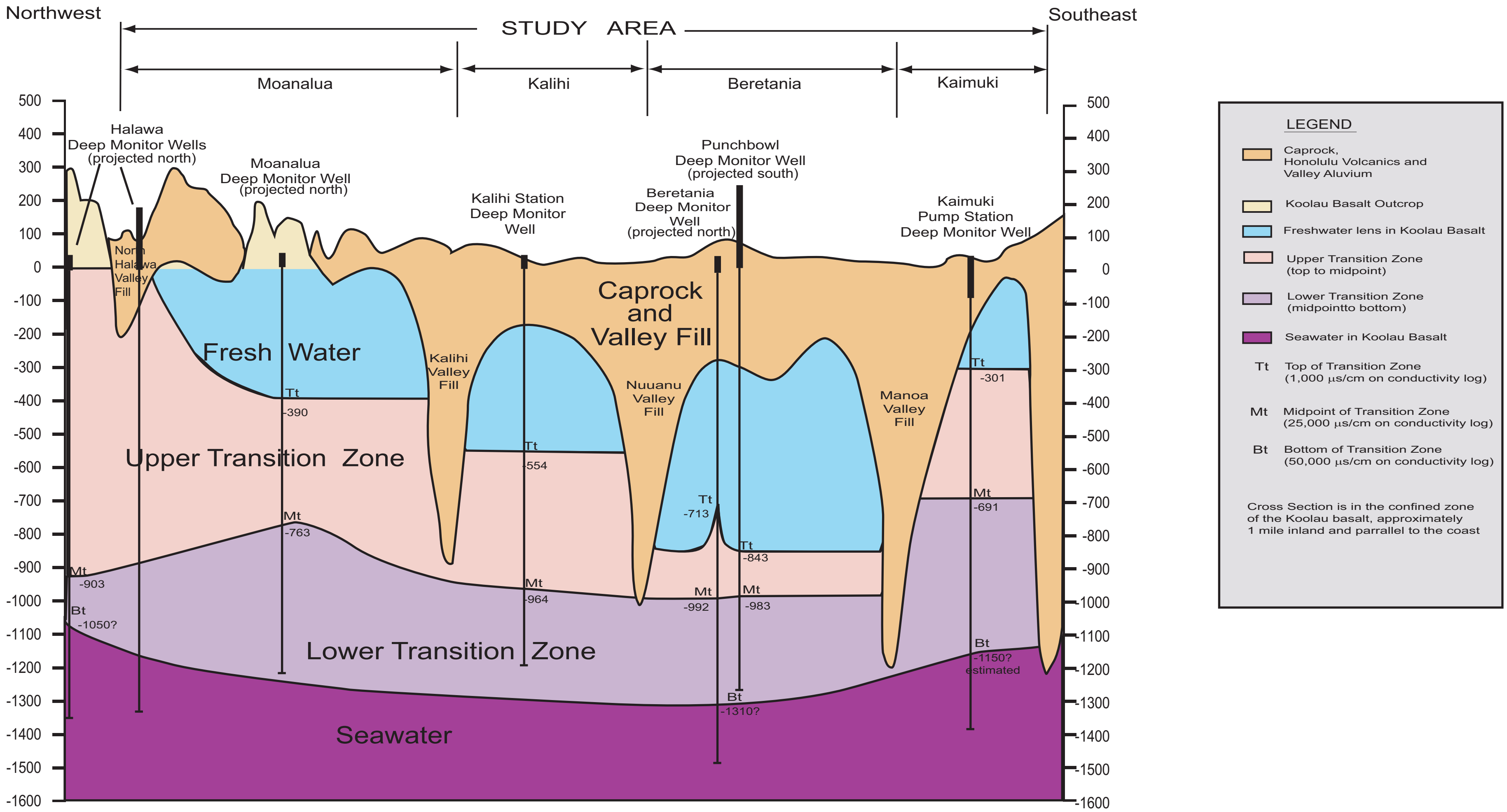
(Modified from ETIC, 2006)

Figure 2-10

Chloride Ion Profile at Halawa Deep Monitoring Well (Well 2253-03)

Red Hill Fuel Storage Faciity

Oahu, Hawaii



(Modified from Todd Engineers, 2005)

Figure 2-11

Transition Zone Characteristics

Red Hill Fuel Storage Faciity

Oahu, Hawaii

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SECTION 3
SITE CHARACTERIZATION RESULTS

This section presents the results of the SI tasks described in Section 2. These include contaminant nature and extent; as well as results from the hydrogeological investigations. In order to further characterize the subsurface in the Facility and surrounding areas, subsurface rock core, groundwater and soil vapor samples were collected, aquifer tests were performed, and a 3-D numerical groundwater flow model was developed to evaluate chemical migration. The subsections below describe the results of these analyses.

3.1 Chemical Analyses

During the development and planning stages of this project, full consideration was given to the review of COPCs. At that time, there was concern about under-reporting risk associated with TPH, since it had not historically been given an action level, and was not typically evaluated as a risk driver. As a result, the Massachusetts Department of Environmental Protection (MADEP) analytical and risk assessment procedures were chosen. The MADEP process involves separating the TPH into fractions, three each for volatile petroleum hydrocarbons (VPH) and extractable petroleum hydrocarbons (EPH), and evaluating risk based on these (MADEP, 2002).

In 2005, Hawaii promulgated new Environmental Action Levels (EALs) which utilize the more common USEPA SW846 8015 Modified (SW8015M) analytical methods for TPH-DRO and TPH-GRO (HDOH, 2005). Samples collected during drilling and during the first groundwater sampling event conducted in September of 2005 were analyzed by SW8015M and MADEP methods and results are reported here. Following this event, the U.S. Navy consulted with HDOH (Mr. Richard Takaba and Mr. Roger Brewer) and it was agreed that SW8015M analyses for TPH-DRO and TPH-GRO were sufficient to use in risk assessments for HDOH. In the second groundwater sampling event, only the SW8015M methods were analyzed. It is anticipated that the USEPA SW846 8015M analytical methods will continue to be used to evaluate risk and for quarterly monitoring at the Facility.

A statistical evaluation of chemical concentrations for these substances for which there was at least one detection (by media) is shown in Table 3-1. Individual sample results of detected substances are provided in Tables 3-2 to 3-4. All results are provided in Appendix F. A narrative summary for each media follows.

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Table 3-1. Final Results of Statistical Evaluation of Chemical Concentrations
Red Hill Fuel Storage Facility,
Oahu, Hawaii

Matrix	Category	Analytical Method	Compound	Min_D_Value	Max_D_Value	Units	Max_Location ID	Max_Logdate	Depth	No_ Analysis	No_ Detects	Frequency of Detects
GS	Red Hill-Soil Gas	TO-15	1,1,2,2-TETRACHLOROETHANE	29	29	µg/m^3	RHSV06-15-35	11/3/2006		18	1	0.06
GS	Red Hill-Soil Gas	TO-15	1,2,4-TRIMETHYLBENZENE	3.4	105.5	µg/m^3	RHSV06-15-35	11/3/2006		18	8	0.44
GS	Red Hill-Soil Gas	TO-15	1,3,5-TRIMETHYLBENZENE	11	87	µg/m^3	RHSV06-15-35	11/3/2006		18	4	0.22
GS	Red Hill-Soil Gas	TO-15	1,4-DICHLOROBENZENE	4	14	µg/m^3	RHSV11-40-131	11/3/2006		18	5	0.28
GS	Red Hill-Soil Gas	TO-15	4-ETHYLTOLUENE	3.8	69	µg/m^3	RHSV06-15-35	11/3/2006		18	6	0.33
GS	Red Hill-Soil Gas	TO-15	ACETONE	13	110	µg/m^3	RHSV16-15-40	5/16/2006		18	12	0.67
GS	Red Hill-Soil Gas	TO-15	BENZENE	2.1	16	µg/m^3	RHSV14-46-73	5/16/2006		18	5	0.28
GS	Red Hill-Soil Gas	TO-15	BENZYL CHLORIDE	12	12	µg/m^3	RHSV06-15-35	11/3/2006		18	1	0.06
GS	Red Hill-Soil Gas	TO-15	CARBON DISULFIDE	3.7	130	µg/m^3	RHSV16-15-40	5/16/2006		18	10	0.56
GS	Red Hill-Soil Gas	TO-15	CYCLOHEXANE	4.4	7.6	µg/m^3	RHSV06-15-35	11/3/2006		18	3	0.17
GS	Red Hill-Soil Gas	TO-15	DICHLORODIFLUOROMETHANE	3.3	20	µg/m^3	RHSV11-13-30	11/3/2006		18	2	0.11
GS	Red Hill-Soil Gas	TO-15	ETHANOL	8	91	µg/m^3	RHSV16-15-40	5/16/2006		18	6	0.33
GS	Red Hill-Soil Gas	TO-15	ETHYLBENZENE	3.3	18	µg/m^3	RHSV14-46-73	5/16/2006		18	5	0.28
GS	Red Hill-Soil Gas	TO-15	ISOPROPANOL	18	18	µg/m^3	RHSV16-15-40	5/16/2006		18	1	0.06
GS	Red Hill-Soil Gas	TO-15	ISOPROPYLBENZENE (CUMENE)	6.15	42	µg/m^3	RHSV14-46-73	5/16/2006		18	2	0.11
GS	Red Hill-Soil Gas	TO-15	M,P-XYLENE (SUM OF ISOMERS)	3.4	66.5	µg/m^3	RHSV06-15-35	11/3/2006		18	13	0.72
GS	Red Hill-Soil Gas	TO-15	METHYL ETHYL KETONE (2-BUTANONE)	3.2	75	µg/m^3	RHSV16-15-40	5/16/2006		18	8	0.44
GS	Red Hill-Soil Gas	TO-15	n-HEPTANE	4.4	17	µg/m^3	RHSV06-15-35	11/3/2006		18	4	0.22
GS	Red Hill-Soil Gas	TO-15	n-HEXANE	2.6	9.6	µg/m^3	RHSV14-46-73	5/16/2006		18	5	0.28
GS	Red Hill-Soil Gas	TO-15	n-PROPYLBENZENE	9	18	µg/m^3	RHSV14-46-73	5/16/2006		18	4	0.22
GS	Red Hill-Soil Gas	TO-15	O-XYLENE (1,2-DIMETHYLBENZENE)	3	40.5	µg/m^3	RHSV06-15-35	11/3/2006		18	6	0.33
GS	Red Hill-Soil Gas	TO-15	TETRACHLOROETHYLENE(PCE)	6.6	7.6	µg/m^3	RHSV02-46-73	5/16/2006		18	2	0.11
GS	Red Hill-Soil Gas	TO-15	TETRAHYDROFURAN	3.9	9.1	µg/m^3	RHSV16-79-110	6/23/2006		18	4	0.22
GS	Red Hill-Soil Gas	TO-15	TOLUENE	2.7	32	µg/m^3	RHSV11-40-131	11/3/2006		18	14	0.78
SO	Red Hill-Soil-=>10	E160.3	SOLIDS, PERCENT	84.65	86.9	PERCENT	RHMW02S01	7/5/2005	86.5	2	2	1.00
SO	Red Hill-Soil-0-10	E160.3	SOLIDS, PERCENT	86.2	86.2	PERCENT	RHMW04S02	7/12/2005	1.5	1	1	1.00
WG	Red Hill-GWdeep-R01	E310.1	ALKALINITY, TOTAL (AS CaCO3)	89500	328000	µg/L	RHMW03-GW01	9/20/2005		4	4	1.00
WG	Red Hill-GWdeep-R01	RSK-175	METHANE	0.49	1270	µg/L	RHMW02-GW01	9/20/2005		5	5	1.00
WG	Red Hill-GWdeep-R01	SW6010B	CALCIUM	28600	810000	µg/L	RHMW01-GW01	9/20/2005		4	4	1.00
WG	Red Hill-GWdeep-R01	SW6010B	LEAD	8.5	19.6	µg/L	RHMW01-GW01	9/20/2005		5	2	0.40
WG	Red Hill-GWdeep-R01	SW6010B	MAGNESIUM	21500	37600	µg/L	RHMW02-GW01	9/20/2005		5	5	1.00
WG	Red Hill-GWdeep-R01	SW6010B	POTASSIUM	6120	6120	µg/L	RHMW03-GW01	9/20/2005		5	1	0.20
WG	Red Hill-GWdeep-R01	SW6010B	SODIUM	37300	98300	µg/L	RHMW03-GW01	9/20/2005		4	4	1.00
WG	Red Hill-GWdeep-R01	SW6010B	STRONTIUM	140	3450	µg/L	RHMW01-GW01	9/20/2005		5	5	1.00
WG	Red Hill-GWdeep-R01	SW8015B	EXTRACTABLE PETROLEUM HYDROCARBONS C11-C22 AROMAT	216	741	µg/L	RHMW02-GW01	9/20/2005		5	2	0.40
WG	Red Hill-GWdeep-R01	SW8015B	EXTRACTABLE PETROLEUM HYDROCARBONS C19-C36 ALIPHAT	262	274	µg/L	RHMW02-GW01	9/20/2005		5	2	0.40
WG	Red Hill-GWdeep-R01	SW8015B	EXTRACTABLE PETROLEUM HYDROCARBONS C9-C18 ALIPHAT	199	802.5	µg/L	RHMW02-GW01	9/20/2005		5	2	0.40
WG	Red Hill-GWdeep-R01	SW8015B	PETROLEUM HYDROCARBONS ABOVE C-10	2500	2500	µg/L	RHMW02-GW01	9/20/2005		1	1	1.00
WG	Red Hill-GWdeep-R01	SW8015B	TPH as DIESEL RANGE ORGANICS	162	2660	µg/L	RHMW02-GW01	9/20/2005		3	3	1.00
WG	Red Hill-GWdeep-R01	SW8015B	VOLATILE PETROLEUM HYDROCARBONS C8-C12 ALIPHATIC	549.5	549.5	µg/L	RHMW02-GW01	9/20/2005		5	1	0.20
WG	Red Hill-GWdeep-R01	SW8015B	VOLATILE PETROLEUM HYDROCARBONS C9-C10 AROMATIC	12.4	396	µg/L	RHMW02-GW01	9/20/2005		5	2	0.40
WG	Red Hill-GWdeep-R01	SW8260B	ACETONE	92.6	92.6	µg/L	RHMW04-GW01	9/20/2005		5	1	0.20

Table 3-1. Final Results of Statistical Evaluation of Chemical Concentrations
Red Hill Fuel Storage Facility,
Oahu, Hawaii

Matrix	Category	Analytical Method	Compound	Min_D _Value	Max_D_ Value	Units	Max_Location ID	Max_Logdate	Depth	No_ Analysis	No_ Detects	Frequency of Detects
WG	Red Hill-GWdeep-R01	SW8260B	ISOPROPYLBENZENE (CUMENE)	3.25	3.25	µg/L	RHMW02-GW01	9/20/2005		5	1	0.20
WG	Red Hill-GWdeep-R01	SW8260B	NAPHTHALENE	301	301	µg/L	RHMW02-GW01	9/20/2005		5	1	0.20
WG	Red Hill-GWdeep-R01	SW8260B	n-BUTYLBENZENE	4.35	4.35	µg/L	RHMW02-GW01	9/20/2005		5	1	0.20
WG	Red Hill-GWdeep-R01	SW8260B	n-PROPYLBENZENE	5.4	5.4	µg/L	RHMW02-GW01	9/20/2005		5	1	0.20
WG	Red Hill-GWdeep-R01	SW8260B	SEC-BUTYLBENZENE	3.75	3.75	µg/L	RHMW02-GW01	9/20/2005		5	1	0.20
WG	Red Hill-GWdeep-R01	SW8260B	TRICHLOROETHYLENE (TCE)	8.2	8.2	µg/L	RHMW02-GW01	9/20/2005		5	1	0.20
WG	Red Hill-GWdeep-R01	SW8270C	1-METHYLNAPHTHALENE	103	103	µg/L	RHMW02-GW01	9/20/2005		3	1	0.33
WG	Red Hill-GWdeep-R01	SW8270C	2-METHYLNAPHTHALENE	87.85	87.85	µg/L	RHMW02-GW01	9/20/2005		3	1	0.33
WG	Red Hill-GWdeep-R01	SW8270C	BENZO(a)ANTHRACENE	0.071	0.071	µg/L	RHMW02-GW01	9/20/2005		3	1	0.33
WG	Red Hill-GWdeep-R01	SW8270C	BENZO(b)FLUORANTHENE	0.069	0.069	µg/L	RHMW02-GW01	9/20/2005		3	1	0.33
WG	Red Hill-GWdeep-R01	SW8270C	NAPHTHALENE	121.5	121.5	µg/L	RHMW02-GW01	9/20/2005		3	1	0.33
WG	Red Hill-GWdeep-R01	SW9056	CHLORIDE (AS CL)	35900	86800	µg/L	RHMW04-GW01	9/19/2005		4	4	1.00
WG	Red Hill-GWdeep-R01	SW9056	FLUORIDE	240	580	µg/L	RHMW02-GW01	9/20/2005		4	3	0.75
WG	Red Hill-GWdeep-R01	SW9056	SULFATE (AS SO4)	4700	27700	µg/L	RHMW03-GW01	9/20/2005		4	4	1.00
WG	Red Hill-GWdeep-R02	RSK-175	METHANE	262	5530	µg/L	RHMW01-GW02	7/10/2006		5	3	0.60
WG	Red Hill-GWdeep-R02	SW8015	TPH as GASOLINE RANGE ORGANICS	121.5	121.5	µg/L	RHMW02-GW02	7/10/2006		5	1	0.20
WG	Red Hill-GWdeep-R02	SW8015B	TPH as DIESEL RANGE ORGANICS	142	2795	µg/L	RHMW02-GW02	7/10/2006		5	3	0.60
WG	Red Hill-GWdeep-R02	SW8260B	ACETONE	6.2	6.2	µg/L	RHMW02-GW02	7/10/2006		5	1	0.20
WG	Red Hill-GWdeep-R02	SW8260B	ETHYLBENZENE	1.3	1.3	µg/L	RHMW02-GW02	7/10/2006		5	1	0.20
WG	Red Hill-GWdeep-R02	SW8260B	ISOPROPYLBENZENE (CUMENE)	4.95	4.95	µg/L	RHMW02-GW02	7/10/2006		5	1	0.20
WG	Red Hill-GWdeep-R02	SW8260B	METHYLENE CHLORIDE	24.9	24.9	µg/L	RHMW02-GW02	7/10/2006		5	1	0.20
WG	Red Hill-GWdeep-R02	SW8260B	NAPHTHALENE	339	339	µg/L	RHMW02-GW02	7/10/2006		5	1	0.20
WG	Red Hill-GWdeep-R02	SW8260B	n-BUTYLBENZENE	5.9	5.9	µg/L	RHMW02-GW02	7/10/2006		5	1	0.20
WG	Red Hill-GWdeep-R02	SW8260B	n-PROPYLBENZENE	8.45	8.45	µg/L	RHMW02-GW02	7/10/2006		5	1	0.20
WG	Red Hill-GWdeep-R02	SW8260B	SEC-BUTYLBENZENE	5.5	5.5	µg/L	RHMW02-GW02	7/10/2006		5	1	0.20
WG	Red Hill-GWdeep-R02	SW8260B	t-BUTYLBENZENE	1	1	µg/L	RHMW02-GW02	7/10/2006		5	1	0.20
WG	Red Hill-GWdeep-R02	SW8270C	1-METHYLNAPHTHALENE	137.5	137.5	µg/L	RHMW02-GW02	7/10/2006		4	1	0.25
WG	Red Hill-GWdeep-R02	SW8270C	2-METHYLNAPHTHALENE	66.45	66.45	µg/L	RHMW02-GW02	7/10/2006		4	1	0.25
WG	Red Hill-GWdeep-R02	SW8270C	ACENAPHTHENE	0.605	0.605	µg/L	RHMW02-GW02	7/10/2006		4	1	0.25
WG	Red Hill-GWdeep-R02	SW8270C	FLUORENE	0.325	0.325	µg/L	RHMW02-GW02	7/10/2006		4	1	0.25
WG	Red Hill-GWdeep-R02	SW8270C	NAPHTHALENE	175.5	175.5	µg/L	RHMW02-GW02	7/10/2006		4	1	0.25

GS Soil Gas
SO Soil
WG Groundwater
µg/m^3 micrograms per cubic meter
µg/L micrograms per Liter

EPA/625/R-96/010b Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air, Second Edition Compendium Method TO-15 , published by USEPA for TO-15 (VOCs in air).

EPA 600/4-79-020 Methods for Chemical Analysis of Water and Wastes published by USEPA for E160.3 (Total Solids), E310.1 (Total Alkalinity)

RSK-175 published by R. S. Kerr Environmental Research Lab USEPA (Methane).

Table 3-2. Groundwater Round 1 Sample Results for Substances Detected
Red Hill Fuel Storage Facility
Oahu, Hawaii

Chemical		RHMW01-GW01				RHMW02-GW01				RHMW02-GW01D-1			
										(Duplicate of RHMW02-GW01)			
		UG/L				UG/L				UG/L			
		Result	Q	MDL	RL	Result	Q	MDL	RL	Result	Q	MDL	RL
SW8015B													
	TPH as DIESEL RANGE ORGANICS	-	-	-	-	2660	-	480	1200	-	-	-	-
	TPH as GASOLINE RANGE ORGANICS	-	-	-	-	ND	UJ	50	100	-	-	-	-
SW8015	**TPH as GASOLINE RANGE ORGANICS**	-	-	-	-	-	-	-	-	ND	UJ	50	100
SW8015B													
	PETROLEUM HYDROCARBONS ABOVE C-10	-	-	-	-	-	-	-	-	2500	-	490	1200
	EXTRACTABLE PETROLEUM HYDROCARBONS C11-C22 AROMAT	216	-	140	190	746	-	160	210	736	-	160	210
	EXTRACTABLE PETROLEUM HYDROCARBONS C19-C36 ALIPHAT	262	-	190	190	ND	UJ	210	210	274	-	210	210
	EXTRACTABLE PETROLEUM HYDROCARBONS C9-C18 ALIPHAT	199	-	190	190	435	-	210	210	1170	-	210	210
	VOLATILE PETROLEUM HYDROCARBONS C8-C12 ALIPHATIC	ND	-	30	55	515	-	150	280	584	-	30	55
	VOLATILE PETROLEUM HYDROCARBONS C9-C10 AROMATIC	12.4	-	10	20	392	-	50	100	400	-	20	40
SW8260B													
	ACETONE	ND	-	5	25	ND	UJ	25	130	ND	UJ	25	130
	ISOPROPYLBENZENE (CUMENE)	ND	-	0.5	1	3.3	-	2.5	5	3.2	J	2.5	5
	NAPHTHALENE(SW8260B)	ND	-	1	2	283	J	5	10	319	-	5	10
	n-BUTYLBENZENE	ND	-	0.5	1	4.1	J	2.5	5	4.6	-	2.5	5
	n-PROPYLBENZENE	ND	-	0.5	1	5.1	-	2.5	5	5.7	-	2.5	5
	SEC-BUTYLBENZENE	ND	-	0.5	1	3.4	J	2.5	5	4.1	J	2.5	5
	TRICHLOROETHYLENE (TCE)	ND	-	0.5	1	8.2	-	2.5	5	ND	UJ	2.5	5
SW8270C													
	1-METHYLNAPHTHALENE	-	-	-	-	104	-	1	4.2	102	-	1	4.2
	2-METHYLNAPHTHALENE	-	-	-	-	88.5	-	1	4.2	87.2	-	1	4.2
	ACENAPHTHENE	-	-	-	-	ND	-	0.52	1	ND	-	0.52	1
	ACENAPHTHYLENE	-	-	-	-	ND	-	0.52	1	ND	-	0.52	1
	ANTHRACENE	-	-	-	-	ND	-	0.52	1	ND	-	0.52	1
	BENZO(a)ANTHRACENE	-	-	-	-	ND	-	0.052	0.21	0.071	-	0.052	0.21
	BENZO(a)PYRENE	-	-	-	-	ND	-	0.1	0.21	ND	-	0.1	0.21
	BENZO(b)FLUORANTHENE	-	-	-	-	ND	-	0.052	0.21	0.069	-	0.052	0.21

µg/L - micrograms per Liter
Q - data qualifier
U - Indicates that the compound was analyzed for but not detected at or above the stated limit
J - Indicates an estimated value
UJ - Indicates the compound or analyte was analyzed for but not detected; the sample detection limit is an estimated value
MDL - method detection limit
RL - reporting limit
TPH - Total Petroleum hydrocarbons
ND - non detect
\- not analyzed

Table 3-2. Groundwater Round 1 Sample Results for Substances Detected
Red Hill Fuel Storage Facility
Oahu, Hawaii

Chemical		RHMW01-GW01				RHMW02-GW01				RHMW02-GW01D-1			
										(Duplicate of RHMW02-GW01)			
		UG/L				UG/L				UG/L			
		Result	Q	MDL	RL	Result	Q	MDL	RL	Result	Q	MDL	RL
	BENZO(g,h,i)PERYLENE	-	-	-	-	ND	-	0.1	0.21	ND	-	0.1	0.21
	BENZO(k)FLUORANTHENE	-	-	-	-	ND	-	0.1	0.21	ND	-	0.1	0.21
	CHRYSENE	-	-	-	-	ND	-	0.1	0.21	ND	-	0.1	0.21
	DIBENZ(a,h)ANTHRACENE	-	-	-	-	ND	-	0.052	0.21	ND	-	0.052	0.21
	FLUORANTHENE	-	-	-	-	ND	-	0.26	1	ND	-	0.26	1
	FLUORENE	-	-	-	-	ND	-	0.26	1	ND	-	0.26	1
	INDENO(1,2,3-c,d)PYRENE	-	-	-	-	ND	-	0.052	0.21	ND	-	0.052	0.21
	NAPHTHALENE(SW8270C)	-	-	-	-	120	-	1	4.2	123	-	1	4.2
	PHENANTHRENE	-	-	-	-	ND	-	0.52	1	ND	-	0.52	1
	PYRENE	-	-	-	-	ND	-	0.26	1	ND	-	0.26	1
SW6010B	LEAD	19.6	-	5	5	ND	-	5	5	ND	-	5	5
RSK-175													
	ETHANE	ND	-	0.6	1	ND	-	0.6	1	ND	-	1.2	2
	ETHENE	ND	-	0.8	1	ND	-	0.8	1	ND	-	1.6	2
	METHANE	811	-	0.3	0.5	1140	J	0.3	0.5	1400	-	0.6	1
SW9056													
	CHLORIDE (AS CL)	35900	-	2000	2000	64200	-	2000	2000	64400	-	2000	2000
	FLUORIDE	240	-	200	200	580	-	200	200	580	-	200	200
	SULFATE (AS SO4)	4700	-	2000	2000	12400	-	2000	2000	12400	-	2000	2000
E310.1	ALKALINITY, TOTAL (AS CaCO3)	142000	-	5000	5000	145000	-	5000	5000	300000	-	5000	5000
SW6010B													
	CALCIUM	810000	-	10000	10000	28600	-	1000	1000	28600	-	1000	1000
	COPPER	-	-	-	-	-	-	-	-	-	-	-	-
	MAGNESIUM	22700	-	5000	5000	-	-	-	-	37600	-	5000	5000
	POTASSIUM	ND	-	5000	5000	ND	-	5000	5000	ND	-	5000	5000
	SODIUM	46600	-	5000	5000	80100	-	5000	5000	79300	-	5000	5000
	STRONTIUM	3450	-	10	10	212	-	10	10	203	-	10	10

µg/L - micrograms per Liter
Q - data qualifier
U - Indicates that the compound was analyzed for but not detected at or above the stated limit
J - Indicates an estimated value
UJ - Indicates the compound or analyte was analyzed for but not detected; the sample detection limit is an estimated value
MDL - method detection limit
RL - reporting limit
TPH - Total Petroleum hydrocarbons
ND - non detect
\- not analyzed

Table 3-2. Groundwater Round 1 Sample Results for Substances Detected
Red Hill Fuel Storage Facility
Oahu, Hawaii

Chemical		RHMW03EB1				RHMW03-GW01				RHMW04-GW01				RHMW2254W01			
		(Equipment Blank)															
		UG/L				UG/L				UG/L				UG/L			
		Result	Q	MDL	RL	Result	Q	MDL	RL	Result	Q	MDL	RL	Result	Q	MDL	RL
SW8015B																	
	TPH as DIESEL RANGE ORGANICS	ND	-	95	240	162	J	97	240	338	-	98	250	-	-	-	-
	TPH as GASOLINE RANGE ORGANICS	ND	-	50	100	ND	-	50	100	ND	UJ	50	100	-	-	-	-
SW8015	**TPH as GASOLINE RANGE ORGANICS**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SW8015B																	
	PETROLEUM HYDROCARBONS ABOVE C-10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	EXTRACTABLE PETROLEUM HYDROCARBONS C11-C22 AROMAT	-	-	-	-	ND	-	140	190	ND	UJ	170	230	ND	-	170	220
	EXTRACTABLE PETROLEUM HYDROCARBONS C19-C36 ALIPHAT	-	-	-	-	ND	-	190	190	ND	UJ	230	230	ND	-	220	220
	EXTRACTABLE PETROLEUM HYDROCARBONS C9-C18 ALIPHAT	-	-	-	-	ND	-	190	190	ND	UJ	230	230	ND	-	220	220
	VOLATILE PETROLEUM HYDROCARBONS C8-C12 ALIPHATIC	ND	UJ	30	55	ND	-	30	55	ND	-	30	55	ND	-	30	55
	VOLATILE PETROLEUM HYDROCARBONS C9-C10 AROMATIC	ND	UJ	10	20	ND	-	10	20	ND	-	10	20	ND	-	10	20
SW8260B																	
	ACETONE	9.5	J	5	25	ND	-	5	25	92.6	-	5	25	ND	UJ	5	25
	ISOPROPYLBENZENE (CUMENE)	ND	-	0.5	1	ND	-	0.5	1	ND	UJ	0.5	1	ND	UJ	0.5	1
	NAPHTHALENE(SW8260B)	ND	-	1	2	ND	-	1	2	ND	UJ	1	2	ND	UJ	1	2
	n-BUTYLBENZENE	ND	-	0.5	1	ND	-	0.5	1	ND	UJ	0.5	1	ND	UJ	0.5	1
	n-PROPYLBENZENE	ND	-	0.5	1	ND	-	0.5	1	ND	UJ	0.5	1	ND	UJ	0.5	1
	SEC-BUTYLBENZENE	ND	-	0.5	1	ND	-	0.5	1	ND	UJ	0.5	1	ND	UJ	0.5	1
	TRICHLOROETHYLENE (TCE)	ND	-	0.5	1	ND	-	0.5	1	ND	UJ	0.5	1	ND	UJ	0.5	1
SW8270C																	
	1-METHYLNAPHTHALENE	ND	-	0.24	0.96	ND	-	0.24	0.96	ND	UJ	0.28	1.1	-	-	-	-
	2-METHYLNAPHTHALENE	ND	-	0.24	0.96	ND	-	0.24	0.96	ND	UJ	0.28	1.1	-	-	-	-
	ACENAPHTHENE	ND	-	0.48	0.96	ND	-	0.48	0.96	ND	UJ	0.57	1.1	-	-	-	-
	ACENAPHTHYLENE	ND	-	0.48	0.96	ND	-	0.48	0.96	ND	UJ	0.57	1.1	-	-	-	-
	ANTHRACENE	ND	-	0.48	0.96	ND	-	0.48	0.96	ND	-	0.57	1.1	-	-	-	-
	BENZO(a)ANTHRACENE	ND	-	0.048	0.19	ND	-	0.048	0.19	ND	-	0.057	0.23	-	-	-	-
	BENZO(a)PYRENE	ND	-	0.096	0.19	ND	-	0.096	0.19	ND	-	0.11	0.23	-	-	-	-
	BENZO(b)FLUORANTHENE	ND	-	0.048	0.19	ND	-	0.048	0.19	ND	-	0.057	0.23	-	-	-	-

µg/L -	micrograms per Liter
Q -	data qualifier
U -	Indicates that the compound was analyzed for but not detected at or above the stated limit
J -	Indicates an estimated value
UJ -	Indicates the compound or analyte was analyzed for but not detected; the sample detection lir
MDL -	method detection limit
RL -	reporting limit
TPH -	Total Petroleum hydrocarbons
ND -	non detect
-	not analyzed

Table 3-2. Groundwater Round 1 Sample Results for Substances Detected
Red Hill Fuel Storage Facility
Oahu, Hawaii

Chemical		RHMW03EB1				RHMW03-GW01				RHMW04-GW01				RHMW2254W01			
		(Equipment Blank)															
		UG/L				UG/L				UG/L				UG/L			
		Result	**Q**	**MDL**	**RL**	**Result**	**Q**	**MDL**	**RL**	**Result**	**Q**	**MDL**	**RL**	**Result**	**Q**	**MDL**	**RL**
	BENZO(g,h,i)PERYLENE	ND	-	0.096	0.19	ND	-	0.096	0.19	ND	-	0.11	0.23	-	-	-	-
	BENZO(k)FLUORANTHENE	ND	-	0.096	0.19	ND	-	0.096	0.19	ND	UJ	0.11	0.23	-	-	-	-
	CHRYSENE	ND	-	0.096	0.19	ND	-	0.096	0.19	ND	-	0.11	0.23	-	-	-	-
	DIBENZ(a,h)ANTHRACENE	ND	-	0.048	0.19	ND	-	0.048	0.19	ND	-	0.057	0.23	-	-	-	-
	FLUORANTHENE	ND	-	0.24	0.96	ND	-	0.24	0.96	ND	-	0.28	1.1	-	-	-	-
	FLUORENE	ND	-	0.24	0.96	ND	-	0.24	0.96	ND	UJ	0.28	1.1	-	-	-	-
	INDENO(1,2,3-c,d)PYRENE	ND	-	0.048	0.19	ND	-	0.048	0.19	ND	-	0.057	0.23	-	-	-	-
	NAPHTHALENE(SW8270C)	ND	-	0.24	0.96	ND	-	0.24	0.96	ND	-	0.28	1.1	-	-	-	-
	PHENANTHRENE	ND	-	0.48	0.96	ND	-	0.48	0.96	ND	-	0.57	1.1	-	-	-	-
	PYRENE	ND	-	0.24	0.96	ND	-	0.24	0.96	ND	-	0.28	1.1	-	-	-	-
SW6010B	**LEAD**	ND	-	5	5	ND	-	5	5	ND	-	5	5	ND	-	5	5
RSK-175																	
	ETHANE	-	-	-	-	ND	-	0.6	1	-	-	-	-	ND	-	1.2	2
	ETHENE	-	-	-	-	ND	-	0.8	1	-	-	-	-	ND	-	1.6	2
	METHANE	-	-	-	-	0.57	-	0.3	0.5	0.49	-	0.3	0.5	1100	-	0.6	1
SW9056																	
	CHLORIDE (AS CL)	-	-	-	-	74900	-	2000	2000	86800	-	2000	2000	-	-	-	-
	FLUORIDE	-	-	-	-	360	-	200	200	ND	-	200	200	-	-	-	-
	SULFATE (AS SO4)	-	-	-	-	27700	-	2000	2000	9800	-	2000	2000	-	-	-	-
E310.1	**ALKALINITY, TOTAL (AS CaCO3)**	-	-	-	-	328000	-	5000	5000	89500	-	5000	5000	-	-	-	-
SW6010B																	
	CALCIUM	-	-	-	-	35000	-	1000	1000	29500	-	1000	1000	-	-	-	-
	COPPER	-	-	-	-	-	-	-	-	-	-	-	-	ND	-	25	25
	MAGNESIUM	-	-	-	-	33500	-	5000	5000	25300	-	5000	5000	21500	-	5000	5000
	POTASSIUM	-	-	-	-	6120	-	5000	5000	ND	-	5000	5000	ND	-	5000	5000
	SODIUM	-	-	-	-	98300	-	5000	5000	37300	-	5000	5000	-	-	-	-
	STRONTIUM	-	-	-	-	185	-	10	10	140	-	10	10	166	-	10	10

µg/L - micrograms per Liter
Q - data qualifier
U - Indicates that the compound was analyzed for but not detected at or above the stated limit
J - Indicates an estimated value
UJ - Indicates the compound or analyte was analyzed for but not detected; the sample detection lir
MDL - method detection limit
RL - reporting limit
TPH - Total Petroleum hydrocarbons
ND - non detect
\- not analyzed

Table 3-3. Groundwater Round 2 Sample Results for Substances Detected
Red Hill Fuel Storage Facility
Oahu, Hawaii

Chemical		RHMW01-GW02				RHMW02-GW02				RHMW03-GW02			
		µg/l				µg/l				µg/l			
		Result	Q	MDL	RL	Result	Q	MDL	RL	Result	Q	MDL	RL
SW8015B	**TPH as DIESEL RANGE ORGANICS**	509	0	100	250	2800	0	110	280	142	0	100	250
SW8015	**TPH as GASOLINE RANGE ORGANICS**	ND	U	50	100	124	J	50	100	ND	U	50	100
SW8260													
	2,2-DICHLOROPROPANE	ND	U	0.5	1	ND	U	0.5	1	ND	U	0.5	1
	4-CHLOROTOLUENE	ND	U	0.5	1	ND	U	0.5	1	ND	U	0.5	1
	ACRYLONITRILE	ND	U	5	10	ND	U	5	10	ND	U	5	10
	BENZENE	ND	U	0.5	1	ND	U	0.5	1	ND	U	0.5	1
	BROMOBENZENE	ND	U	0.5	1	ND	U	0.5	1	ND	U	0.5	1
	BROMOFORM	ND	U	0.5	1	ND	U	0.5	1	ND	U	0.5	1
	BROMOMETHANE	ND	U	1	2	ND	U	1	2	ND	U	1	2
	CARBON TETRACHLORIDE	ND	U	0.5	1	ND	U	0.5	1	ND	U	0.5	1
	CHLOROBENZENE	ND	U	0.5	1	ND	U	0.5	1	ND	U	0.5	1
	CHLOROETHANE	ND	U	1	2	ND	U	1	2	ND	U	1	2
	CHLOROFORM	ND	U	0.5	1	ND	U	0.5	1	ND	U	0.5	1
	M,P-XYLENE (SUM OF ISOMERS)	ND	U	0.5	2	ND	U	0.5	2	ND	U	0.5	2
	NAPHTHALENE(SW8260)	ND	U	1	2	343	0	5	10	ND	U	1	2
	P-CYMENE (p-ISOPROPYLTOLUENE)	ND	U	0.5	1	ND	U	0.5	1	ND	U	0.5	1
	SEC-BUTYLBENZENE	ND	U	0.5	1	6.4	0	0.5	1	ND	U	0.5	1
	STYRENE	ND	U	0.5	1	ND	U	0.5	1	ND	U	0.5	1
	tert-BUTYL METHYL ETHER	ND	U	0.5	1	ND	U	0.5	1	ND	U	0.5	1
	TETRACHLOROETHYLENE(PCE)	ND	U	0.5	1	ND	U	0.5	1	ND	U	0.5	1
	TRICHLOROFLUOROMETHANE	ND	U	0.5	2	ND	U	0.5	2	ND	U	0.5	2
	VINYL ACETATE	ND	U	5	10	ND	U	5	10	ND	U	5	10
	VINYL CHLORIDE	ND	U	0.5	1	ND	U	0.5	1	ND	U	0.5	1
	1-METHYLNAPHTHALENE	ND	U	0.25	1	142	0	1.4	5.4	ND	U	0.25	1
	ACENAPHTHYLENE	ND	U	0.5	1	ND	U	0.54	1.1	ND	U	0.5	1
	ANTHRACENE	ND	U	0.5	1	ND	U	0.54	1.1	ND	U	0.5	1
	BENZ[A]ANTHRACENE,1-ME	ND	U	0.05	0.2	ND	U	0.054	0.22	ND	U	0.05	0.2
	BENZO(b)FLUORANTHENE	ND	U	0.05	0.2	ND	U	0.054	0.22	ND	U	0.05	0.2
SW8270C													
	PYRENE	ND	U	0.25	1	ND	U	0.27	1.1	ND	U	0.25	1
	LEAD	ND	U	1.7	10	ND	U	1.7	10	ND	U	1.7	10
	METHANE	5530	0	1.5	2.5	3160	J	1.5	2.5	262	0	0.3	0.5

µg/L - micrograms per Liter
Q - data qualifier
U - Indicates that the compound was analyzed for but not detected at or above the stated limit
J - Indicates an estimated value
UJ - Indicates the compound or analyte was analyzed for but not detected; the sample detection limit is an estimated value

MDL - method detection limit
RL - reporting limit
TPH - Total Petroleum hydrocarbons
ND - non detect
\- not analyzed

Table 3-3. Groundwater Round 2 Sample Results for Substances Detected
Red Hill Fuel Storage Facility
Oahu, Hawaii

	Chemical	RHMW04-GW02				RHMW05-GW02D-1				RHMW2254-GW02			
						(Duplicate of RHMW02-GW02)							
		µg/l				µg/l				µg/l			
		Result	Q	MDL	RL	Result	Q	MDL	RL	Result	Q	MDL	RL
SW8015B	TPH as DIESEL RANGE ORGANICS	ND	U	100	260	2790	0	110	270	ND	U	110	260
SW8015	TPH as GASOLINE RANGE ORGANICS	ND	U	50	100	119	J	50	100	ND	U	50	100
SW8260													
	2,2-DICHLOROPROPANE	ND	U	0.5	1	ND	U	2.5	5	ND	U	0.5	1
	4-CHLOROTOLUENE	ND	U	0.5	1	ND	U	2.5	5	ND	U	0.5	1
	ACRYLONITRILE	ND	U	5	10	ND	U	25	50	ND	U	5	10
	BENZENE	ND	U	0.5	1	ND	U	2.5	5	ND	U	0.5	1
	BROMOBENZENE	ND	U	0.5	1	ND	U	2.5	5	ND	U	0.5	1
	BROMOFORM	ND	U	0.5	1	ND	U	2.5	5	ND	U	0.5	1
	BROMOMETHANE	ND	U	1	2	ND	U	5	10	ND	U	1	2
	CARBON TETRACHLORIDE	ND	U	0.5	1	ND	U	2.5	5	ND	U	0.5	1
	CHLOROBENZENE	ND	U	0.5	1	ND	U	2.5	5	ND	U	0.5	1
	CHLOROETHANE	ND	U	1	2	ND	U	5	10	ND	U	1	2
	CHLOROFORM	ND	U	0.5	1	ND	U	2.5	5	ND	U	0.5	1
	M,P-XYLENE (SUM OF ISOMERS)	ND	U	0.5	2	ND	U	2.5	10	ND	U	0.5	2
	NAPHTHALENE(SW8260)	ND	U	1	2	335	0	5	10	ND	U	1	2
	P-CYMENE (p-ISOPROPYLTOLUENE)	ND	U	0.5	1	ND	U	2.5	5	ND	U	0.5	1
	SEC-BUTYLBENZENE	ND	U	0.5	1	4.6	0	2.5	5	ND	U	0.5	1
	STYRENE	ND	U	0.5	1	ND	U	2.5	5	ND	U	0.5	1
	tert-BUTYL METHYL ETHER	ND	U	0.5	1	ND	U	2.5	5	ND	U	0.5	1
	TETRACHLOROETHYLENE(PCE)	ND	U	0.5	1	ND	U	2.5	5	ND	U	0.5	1
	TRICHLOROFLUOROMETHANE	ND	U	0.5	2	ND	U	2.5	10	ND	U	0.5	2
	VINYL ACETATE	ND	U	5	10	ND	U	25	50	ND	U	5	10
	VINYL CHLORIDE	ND	U	0.5	1	ND	U	2.5	5	ND	U	0.5	1
	1-METHYLNAPHTHALENE	ND	U	0.26	1	133	0	1.3	5	ND	U	0.26	1
	ACENAPHTHYLENE	ND	U	0.51	1	ND	U	0.5	1	ND	U	0.51	1
	ANTHRACENE	ND	U	0.51	1	ND	U	0.5	1	ND	U	0.51	1
	BENZ[A]ANTHRACENE,1-ME	ND	U	0.051	0.2	ND	U	0.05	0.2	ND	U	0.051	0.2
	BENZO(b)FLUORANTHENE	ND	U	0.051	0.2	ND	U	0.05	0.2	ND	U	0.051	0.2
SW8270C													
	PYRENE	ND	U	0.26	1	ND	U	0.25	1	ND	U	0.26	1
	LEAD	ND	U	3.4	10	ND	U	1.7	10	ND	U	1.7	10
	METHANE	ND	U	0.3	0.5	754	J	1.5	2.5	ND	U	0.3	0.5

µg/L - micrograms per Liter
Q - data qualifier
U - Indicates that the compound was analyzed for but not detected at or above the stated limit
J - Indicates an estimated value
UJ - Indicates the compound or analyte was analyzed for but not detected; the sample detection limit is an estimated value

MDL - method detection limit
RL - reporting limit
TPH - Total Petroleum hydrocarbons
ND - non detect
\- not analyzed

Table 3-4. Soil Gas Sample Results for Substances Detected
Red Hill Fuel Storage Facility
Oahu, Hawaii

Chemical	**RHSV02-15-40 (-)**			**RHSV02-46-73 (-)**			**RHSV02-79-110 (-)**			**RHSV06-15-35 (-)**		
	UG/M3			**UG/M3**			**UG/M3**			**UG/M3**		
	Result	**Q**	**RL**	**Result**	**Q**	**RL**	**Result**	**Q**	**RL**	**Result**	**Q**	**RL**
TO-15												
1,2,4-TRIMETHYLBENZENE	ND	U	3.3	ND	U	3.3	ND	U	3.3	81		3.8
1,3,5-TRIMETHYLBENZENE	ND	U	3.3	ND	U	3.3	ND	U	3.3	91		3.8
1,4-DICHLOROBENZENE	ND	U	4	ND	U	4	ND	U	4	ND	U	4.6
4-ETHYLTOLUENE	ND	U	3.3	ND	U	3.3	ND	U	3.3	52		3.8
BENZENE	ND	U	2.1	ND	U	2.1	ND	U	2.1	ND	U	2.5
ETHYLBENZENE	ND	U	2.9	ND	U	2.9	ND	U	2.9	6.1		3.4
ISOPROPYLBENZENE (CUMENE)	ND	U	3.3	ND	U	3.3	ND	U	3.3	4.1		3.8
M,P-XYLENE (SUM OF ISOMERS)	ND	U	2.9	3.5		2.9	ND	U	2.9	33		3.4
n-HEPTANE	ND	U	2.7	ND	U	2.7	ND	U	2.7	6		3.2
n-PROPYLBENZENE	ND	U	3.3	ND	U	3.3	ND	U	3.3	7.8		3.8
O-XYLENE (1,2-DIMETHYLBENZENE)	ND	U	2.9	ND	U	2.9	ND	U	2.9	29		3.4
TOLUENE	ND	U	2.5	ND	U	2.5	ND	U	2.5	16		2.9

μg/M^3 - micrograms per cubic meter
Q - data qualifier
Indicates that the compound was analyzed for but not
U - detected at or above the stated limit
J - Indicates an estimated value
Indicates the compound or analyte was analyzed for but
not detected; the sample detection limit is an estimated
UJ - value
RL - reporting limit
ND - non detect

Table 3-4. Soil Gas Sample Results for Substances Detected
Red Hill Fuel Storage Facility
Oahu, Hawaii

Chemical	RHSV06-15-35 (-)-D			RHSV06-40-56 (-)			RHSV10-13-30 (-)			RHSV10-40-130 (-)		
	UG/M3			UG/M3			UG/M3			UG/M3		
	Result	Q	RL	Result	Q	RL	Result	Q	RL	Result	Q	RL
TO-15												
1,2,4-TRIMETHYLBENZENE	130		3.7	6.5		3.8	ND	U	4.6	ND	U	3.8
1,3,5-TRIMETHYLBENZENE	83		3.7	ND	U	3.8	ND	U	4.6	ND	U	3.8
1,4-DICHLOROBENZENE	5.5		4.6	ND	U	4.6	ND	U	5.6	ND	U	4.6
4-ETHYLTOLUENE	86		3.7	3.8		3.8	ND	U	4.6	ND	U	3.8
BENZENE	3.4		2.4	ND	UJ	2.5	ND	U	3	ND	U	2.5
ETHYLBENZENE	25		3.3	ND	U	3.4	ND	U	4	ND	U	3.4
ISOPROPYLBENZENE (CUMENE)	8.2		3.7	ND	U	3.8	ND	U	4.6	ND	U	3.8
M,P-XYLENE (SUM OF ISOMERS)	100		3.3	6.7		3.4	4.5		4.1	3.4		3.4
n-HEPTANE	28		3.1	ND	UJ	3.2	ND	U	3.8	ND	U	3.2
n-PROPYLBENZENE	18		3.7	ND	U	3.8	ND	U	4.6	ND	U	3.8
O-XYLENE (1,2-DIMETHYLBENZENE)	52		3.3	ND	U	3.4	ND	U	4.1	ND	U	3.4
TOLUENE	41		2.9	6	J	2.9	17		3.5	6		2.9

$\mu g/M^3$ - micrograms per cubic meter
Q - data qualifier
Indicates that the compound was analyzed for but not
U - detected at or above the stated limit
J - Indicates an estimated value
Indicates the compound or analyte was analyzed for but
not detected; the sample detection limit is an estimated
UJ - value
RL - reporting limit
ND - non detect

Table 3-4. Soil Gas Sample Results for Substances Detected
Red Hill Fuel Storage Facility
Oahu, Hawaii

Chemical	**RHSV11-13-30 (-)**			**RHSV11-40-131 (-)**			**RHSV12-15-40 (-)**			**RHSV12-46-68 (-)**		
	UG/M3			**UG/M3**			**UG/M3**			**UG/M3**		
	Result	**Q**	**RL**	**Result**	**Q**	**RL**	**Result**	**Q**	**RL**	**Result**	**Q**	**RL**
TO-15												
1,2,4-TRIMETHYLBENZENE	12		3.7	49		4.5	40		3.7	ND	U	3.6
1,3,5-TRIMETHYLBENZENE	ND	U	3.7	14		4.5	11		3.7	ND	U	3.6
1,4-DICHLOROBENZENE	5.6		4.6	14		5.5	ND	U	4.5	ND	U	4.4
4-ETHYLTOLUENE	7.1		3.7	31		4.5	28		3.7	ND	U	3.6
BENZENE	ND	U	2.4	ND	U	2.9	2.6		2.4	ND	U	2.3
ETHYLBENZENE	ND	U	3.3	9.6		4	10		3.2	ND	U	3.2
ISOPROPYLBENZENE (CUMENE)	ND	U	3.7	ND	U	4.5	ND	U	3.7	ND	U	3.6
M,P-XYLENE (SUM OF ISOMERS)	8.6		3.3	38		4	35		3.2	3.8		3.2
n-HEPTANE	ND	U	3.1	4.4		3.7	8.4		3	ND	U	3
n-PROPYLBENZENE	ND	U	3.7	9		4.5	9.6		3.7	ND	U	3.6
O-XYLENE (1,2-DIMETHYLBENZENE)	3.7		3.3	16		4	16		3.2	ND	U	3.2
TOLUENE	8.8		2.9	32		3.4	18		2.8	5.2		2.8

$\mu g/M^3$ - micrograms per cubic meter
Q - data qualifier
Indicates that the compound was analyzed for but not
U - detected at or above the stated limit
J - Indicates an estimated value
Indicates the compound or analyte was analyzed for but
not detected; the sample detection limit is an estimated
UJ - value
RL - reporting limit
ND - non detect

Table 3-4. Soil Gas Sample Results for Substances Detected
Red Hill Fuel Storage Facility
Oahu, Hawaii

Chemical	RHSV12-76-133 (-)			RHSV14-15-40 (-)			RHSV14-46-73 (-)			RHSV14-79-110 (-)		
	UG/M3			UG/M3			UG/M3			UG/M3		
	Result	Q	RL	Result	Q	RL	Result	Q	RL	Result	Q	RL
TO-15												
1,2,4-TRIMETHYLBENZENE	ND	U	3.5	ND	U	3.3	9		3.3	5.4		5.1
1,3,5-TRIMETHYLBENZENE	ND	U	3.5	ND	U	3.3	42		3.3	ND	U	5.1
1,4-DICHLOROBENZENE	ND	U	4.3	ND	U	4	ND	U	4	7.6		6.2
4-ETHYLTOLUENE	ND	U	3.5	ND	U	3.3	45		3.3	ND	U	5.1
BENZENE	ND	U	2.3	ND	U	2.1	16		2.1	ND	U	3.3
ETHYLBENZENE	ND	U	3.1	ND	U	2.9	18		2.9	ND	U	4.5
ISOPROPYLBENZENE (CUMENE)	ND	U	3.5	ND	U	3.3	42		3.3	ND	U	5.1
M,P-XYLENE (SUM OF ISOMERS)	ND	U	3.1	ND	U	2.9	32		2.9	7.4		4.5
n-HEPTANE	ND	U	3	ND	U	2.7	8.6		2.7	ND	U	4.2
n-PROPYLBENZENE	ND	U	3.5	ND	U	3.3	18		3.3	ND	U	5.1
O-XYLENE (1,2-DIMETHYLBENZENE)	ND	U	3.1	ND	U	2.9	26		2.9	ND	U	4.5
TOLUENE	5.4		2.7	ND	U	2.5	23		2.5	5.4		3.9

μg/M^3 - micrograms per cubic meter
Q - data qualifier
Indicates that the compound was analyzed for but not
U - detected at or above the stated limit
J - Indicates an estimated value
Indicates the compound or analyte was analyzed for but
not detected; the sample detection limit is an estimated
UJ - value
RL - reporting limit
ND - non detect

Table 3-4. Soil Gas Sample Results for Substances Detected
Red Hill Fuel Storage Facility
Oahu, Hawaii

Chemical	RHSV16-15-40 (-)			RHSV16-46-73 (-)			RHSV16-46-73 (-)-D			RHSV16-79-110 (-)		
	UG/M3			UG/M3			UG/M3			UG/M3		
	Result	Q	RL	Result	Q	RL	Result	Q	RL	Result	Q	RL
TO-15												
1,2,4-TRIMETHYLBENZENE	3.4		3.3	ND	U	3.3	ND	U	3.3	ND	U	3.3
1,3,5-TRIMETHYLBENZENE	ND	U	3.3	ND	U	3.3	ND	U	3.3	ND	U	3.3
1,4-DICHLOROBENZENE	4		4	ND	U	4.1	ND	U	4	ND	U	4
4-ETHYLTOLUENE	ND	U	3.3	ND	U	3.3	ND	U	3.3	ND	U	3.3
BENZENE	2.1		2.1	3.6		2.2	ND	U	2.1	ND	U	2.1
ETHYLBENZENE	ND	U	2.9	ND	U	3	ND	U	2.9	3.3		2.9
ISOPROPYLBENZENE (CUMENE)	ND	U	3.3				ND	U	3.3	ND	U	3.3
M,P-XYLENE (SUM OF ISOMERS)	6.9		2.9	ND	U	3	ND	U	2.9	9.3		2.9
n-HEPTANE	ND	U	2.7	ND	U	2.8	ND	U	2.7	ND	U	2.7
n-PROPYLBENZENE	ND	U	3.3	ND	U	3.3	ND	U	3.3	ND	U	3.3
O-XYLENE (1,2-DIMETHYLBENZENE)	ND	U	2.9	ND	U	3	ND	U	2.9	3		2.9
TOLUENE	7.7		2.5	2.7		2.6	ND	U	2.5	4.4		2.5

$\mu g/M^3$ - micrograms per cubic meter
Q - data qualifier
Indicates that the compound was analyzed for but not
U - detected at or above the stated limit
J - Indicates an estimated value
Indicates the compound or analyte was analyzed for but
not detected; the sample detection limit is an estimated
UJ - value
RL - reporting limit
ND - non detect

3.1.1 Rock Cores

In July and August 2005, soil and rock cores were collected from two borings in the lower access tunnel of the Facility (RHMW02 and RHMW03), and rock cuttings were collected from the background boring on the northern access road adjacent to the U.S. Navy Firing Range (RHMW04). Cores and cuttings were screened with a PID field instrument and a single rock sample from each boring was analyzed at Accutest Laboratories, Florida (Table 3-5). Since there was no evidence of petroleum contamination via field observations, samples from within the lower access tunnel were collected just above the water table to provide information regarding conditions at the capillary fringe interface. At the background boring, a soil sample was collected near the surface to provide information about the surface condition at this up-gradient location. No rock core samples were collected, since this boring was advanced with an air hammer. No elevated PID readings or field observations of petroleum hydrocarbon product impacts were noted in the samples or other remaining cores collected.

Table 3-5. Soil and Rock Samples

ID	Depth	Date Sampled	PID Reading
RHMW02S01	86.5	7/5/05	0.0
RHMW03S01	102.5	8/15/05	0.0
RHMW03S01*	102.5	8/15/05	0.0
RHMW04S02	1.5	7/12/05	0.0

*Duplicate QC sample

Chemical analytical results indicated that no compounds were detected above the reporting limits (RLs), therefore no summary table is provided here. Complete subsoil and surface soil analytical reports are provided in Appendix F.

3.1.2 Groundwater

Groundwater samples were collected during both project phases. On September 19, 20 and 21 2005, 5 samples and a duplicate (RHMW01-GW01, RHMW02-GW01, RHMW02-GW01D (duplicate), RHMW03-GW01, RHMW04-GW01 and RHMW2254-GW01) were collected from 5 wells at the Facility. On July 10, 2006, Phase II monitoring (Round 2) was performed with 6 samples collected (RHMW01-GW02, RHMW02-GW02, RHMW02-GW02D (duplicate), RHMW03-GW02, RHMW04-GW02, and RHMW2254-GW02).

Field recorded measurements of water quality parameters are presented in Table 3-6 (logs are presented in Appendix C). The recorded water quality parameters are consistent with potable drinking water parameters. During Phase I sampling, no elevated PID readings were observed at the well heads; however, groundwater from RHMW02 exhibited a slight petroleum odor. Groundwater from the other wells did not exhibit evidence of petroleum hydrocarbon impacts.

Table 3-6. Final Well Development Water Quality Parameters

Phase I								
Well	**Date**	**Final Water Level***	**Volume Removed (gal)**	**pH**	**Temp (C)**	**Color**	**EC (µS/m)**	**Turbidity (NTU)**
RHMW01	9/20/05	88.2	2.74	7.88	23.67	Grey, milky	0.385	--
RHMW02	9/20/05	87.1	15.00	6.93	24.34	Grey, clear	0.720	--
RHMW03	9/21/05	103.7	20.25	7.11	26.50	Dark grey	0.734	--
RHMW04	9/23/05	293.00	36.00	7.88	22.30	Grey, clear	0.460	0.23
RHMW2254-01	9/19/05	ND	ND	8.05	24.90	Clear	0.560	0.28

ND	Not developed, previously developed at time of installation
*	Final water level is from top of casing
EC	Electronic Conductivity
µS/m	micro Siemens per meter
gal	gallons
C	Centigrade
NTU	nephelometric turbidity units
--	No observations

3.1.2.1 Groundwater Results, September 2005

Analytical results for detected compounds in groundwater are presented in Table 3-2 for Phase I. Complete groundwater analytical reports are provided in Appendix F. The lateral distribution of chemicals in groundwater at the Facility is presented in Figures 3-1 through 3-4. Table 3-2 provides the analytical results for all compounds that were detected during this sampling event. The analytical results discussed in the following subsections have been validated as being of acceptable quality.

Total Petroleum Hydrocarbons

TPH-DRO was detected in 3 of 7 groundwater samples collected (RHMW02-GW01, RHMW03-GW01 and RHMW04-GW01). The highest concentration was detected in sample RHMW02-GW01, at 2,660 µg/L. TPH-DRO was detected at concentrations of 338 µg/L and 162 µg/L in samples RHMW04-GW01 and RHMW03-GW01, respectively. TPH-GRO was not detected in any samples during this sampling event. Figure 3-1 presents the lateral distribution of TPH in groundwater wells throughout the Facility.

Volatile Organic Compounds

Six target VOCs were detected one sample (RHMW02-GW01) during this event. Naphthalene was the VOC detected at the highest concentration in sample RHMW02-GW01, at 301 µg/L.

Other petroleum-related VOCs detected in sample RHMW02-GW01 included isopropylbenzene, n-butylbenzene, n-propylbenzene, sec-butylbenzene.

Trichloroethylene (TCE) was detected at 8.2 µg/L, but TCE is not a petroleum–related compound. Acetone was the VOC detected at the highest concentration in a sample collected at RHMW04-GW01 (92.6 µg/L); however, acetone is not a petroleum constituent and is a known laboratory contaminant. Figure 3-2 presents the lateral distribution of target VOCs in groundwater wells throughout the Facility.

Semi-Volatile Organic Compounds

SVOCs were only detected in RHMW02-GW01. Naphthalene, 1-methylnaphthalene and 2-methylnaphthalene were detected at 121.5 µg/L, 103 µg/L, and 87.85 µg/L, respectively. Benzo(a)anthracene and benzo(b)fluoranthane were also detected in this sample. Figure 3-3 presents the lateral distribution of SVOCs in groundwater wells throughout the Facility.

Lead

Lead was detected in only one sample, RHMW01-GW01 at 19.6 µg/L. Figure 3-4 presents the location of lead detected in groundwater at the Facility.

Natural Attenuation Parameters

These are screening level results and are not used for risk assessment. Natural attenuation factors were evaluated in water samples from the five basal aquifer wells. These results are described and evaluated in the Section 4.3.5.1 of this report.

3.1.2.2 Groundwater Results, July 2006

Analytical results for detected compounds in groundwater are summarized in Table 3-3 for the second SI groundwater sampling event. Complete groundwater analytical reports are provided in Appendix F. The lateral distribution of chemicals in groundwater at the Facility is presented in Figures 3-1 and 3-4. The analytical results discussed in the following subsections have been validated for decision-making.

Total Petroleum Hydrocarbons

TPH-DRO was detected in four of six groundwater samples collected (RHMW01-GW02, RHMW02-GW02, RHMW03-GW02 and RHMW02-GW02D). The highest concentration was detected in sample RHMW02-GW02, at 2,795 µg/L. TPH-DRO was detected at concentrations of 509 µg/L and 142 µg/L in samples RHMW01-GW02 and RHMW03-GW02, respectively. TPH-GRO was detected in RHMW02-GW02 only, at a concentration of 122 µg/L. Figure 3-1 presents the lateral distribution of TPH detected in groundwater wells throughout the Facility.

Volatile Organic Compounds

VOCs were detected only in sample RHMW02-GW02 and the duplicate RHMW02-GW02D. Naphthalene was detected at the highest concentration in sample RHMW02-GW02 at 39 µg/L. Other target VOCs detected included ethylbenzene, isopropylbenzene, n-butylbenzene, n-propylbenzene, sec-butylbenzene and t-butylbenzene. Acetone and methylene chloride, which are not target VOCs, were also detected. Figure 3-2 presents the location of target VOCs detected in groundwater wells at the Facility.

Semi-Volatile Organic Compounds

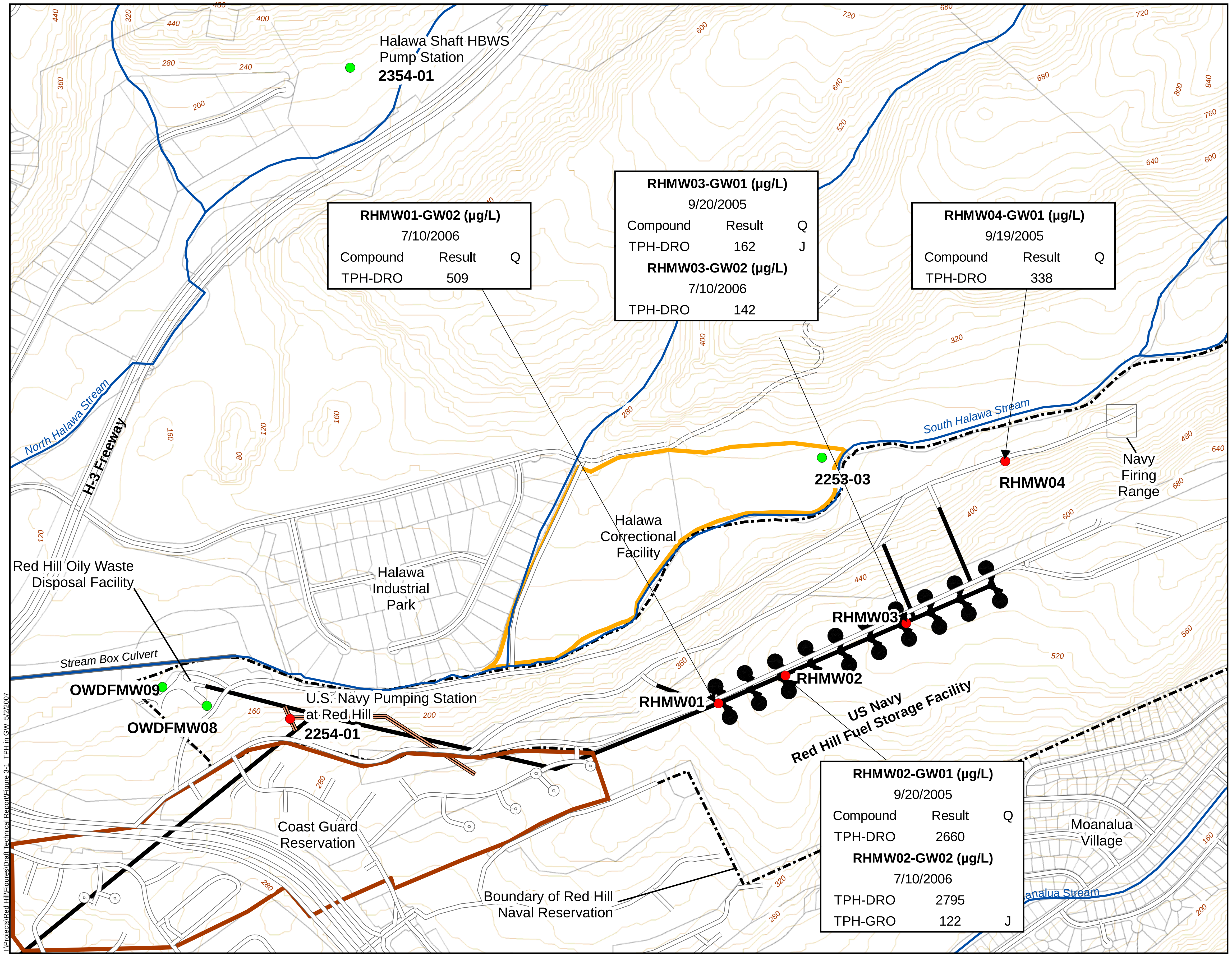
SVOCs were detected only in sample RHMW02-GW02 and the duplicate RHMW02-GW02D. Naphthalene, 1-methylnaphthalene and 2-methylnaphthalene were detected at 175.5 µg/L, 137.5µg/L and 66.45 µg/L, respectively. Acenaphthene and fluorene were also detected in these samples. Figure 3-3 presents the location of target SVOCs detected in groundwater wells at the Facility.

Lead

Lead was not detected in any of the samples analyzed during this second event. Figure 3-4 presents the lateral distribution of lead in groundwater wells throughout the Facility.

Natural Attenuation Parameters

Dissolved oxygen, nitrate, sulfate iron and methane were measured at each sample location to evaluate natural biodegradation of petroleum in the aquifer. Data is considered screening level. Natural attenuation factors were evaluated in water samples from the five onsite basal aquifer wells. These results are described and evaluated in the Contaminant Fate and Transport Section (Section 4.3.5.1).



RHMW01-GW02 (µg/L)
7/10/2006

Compound	Result	Q
TPH-DRO	509	

RHMW03-GW01 (µg/L)
9/20/2005

Compound	Result	Q
TPH-DRO	162	J

RHMW03-GW02 (µg/L)
7/10/2006

Compound	Result	Q
TPH-DRO	142	

RHMW04-GW01 (µg/L)
9/19/2005

Compound	Result	Q
TPH-DRO	338	

RHMW02-GW01 (µg/L)
9/20/2005

Compound	Result	Q
TPH-DRO	2660	

RHMW02-GW02 (µg/L)
7/10/2006

Compound	Result	Q
TPH-DRO	2795	
TPH-GRO	122	J

Legend

●	Project Wells
●	Other Wells
●	Red Hill UST
☐	Parcel
—	40-foot Interval Contour Line
- - -	Unpaved Road
═	Road
—	Stream
-·-	Red Hill Navy Installation Boundary
—	Red Hill Tunnels
═	2254-01 Infiltration Gallery
☐	Halawa Correctional Facility Boundary
☐	Coast Guard Reservation

Acronyms

µg/L - Micrograms per liter
TPH-DRO - Total Petroleum Hydrocarbons Diesel Range Organics
TPH-GRO - Total Petroleum Hydrocarbons Gasoline Range Organics

Data Qualifiers (Q)

J - Indicates an estimated value

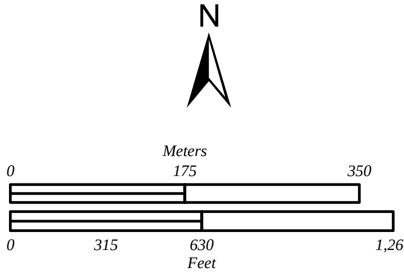
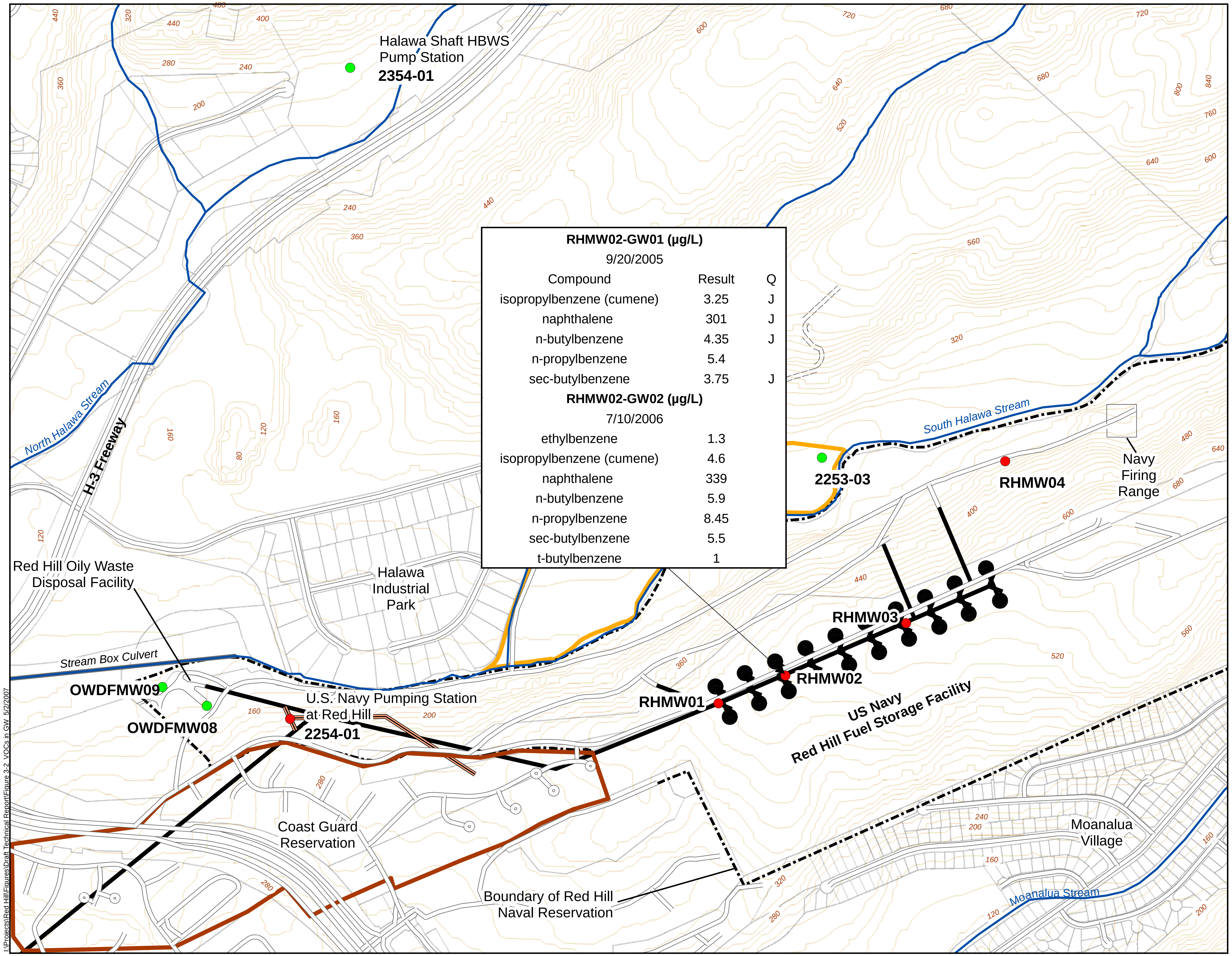


Figure 3-1

TPH in Groundwater

Red Hill Fuel Storage Facility
Oahu, Hawaii

I:\Projects\Red Hill\Figures\Draft Technical Report\Figure 3-1 TPH in GW 5/2/2007



RHMW02-GW01 (µg/L)		
9/20/2005		
Compound	Result	Q
isopropylbenzene (cumene)	3.25	J
naphthalene	301	J
n-butylbenzene	4.35	J
n-propylbenzene	5.4	
sec-butylbenzene	3.75	J
RHMW02-GW02 (µg/L)		
7/10/2006		
ethylbenzene	1.3	
isopropylbenzene (cumene)	4.6	
naphthalene	339	
n-butylbenzene	5.9	
n-propylbenzene	8.45	
sec-butylbenzene	5.5	
t-butylbenzene	1	

Legend

- ● Project Wells
- ● Other Wells
- ● Red Hill UST
- ☐ Parcel
- 40-foot Interval Contour Line
- Unpaved Road
- Road
- Stream
- Red Hill Navy Installation Boundary
- Red Hill Tunnels
- 2254-01 Infiltration Gallery
- ☐ Halawa Correctional Facility Boundary
- ☐ Coast Guard Reservation

Acronyms

µg/L - Micrograms per liter
VOCs - Volatile Organic Compounds

Data Qualifiers (Q)

J - Indicates an estimated value

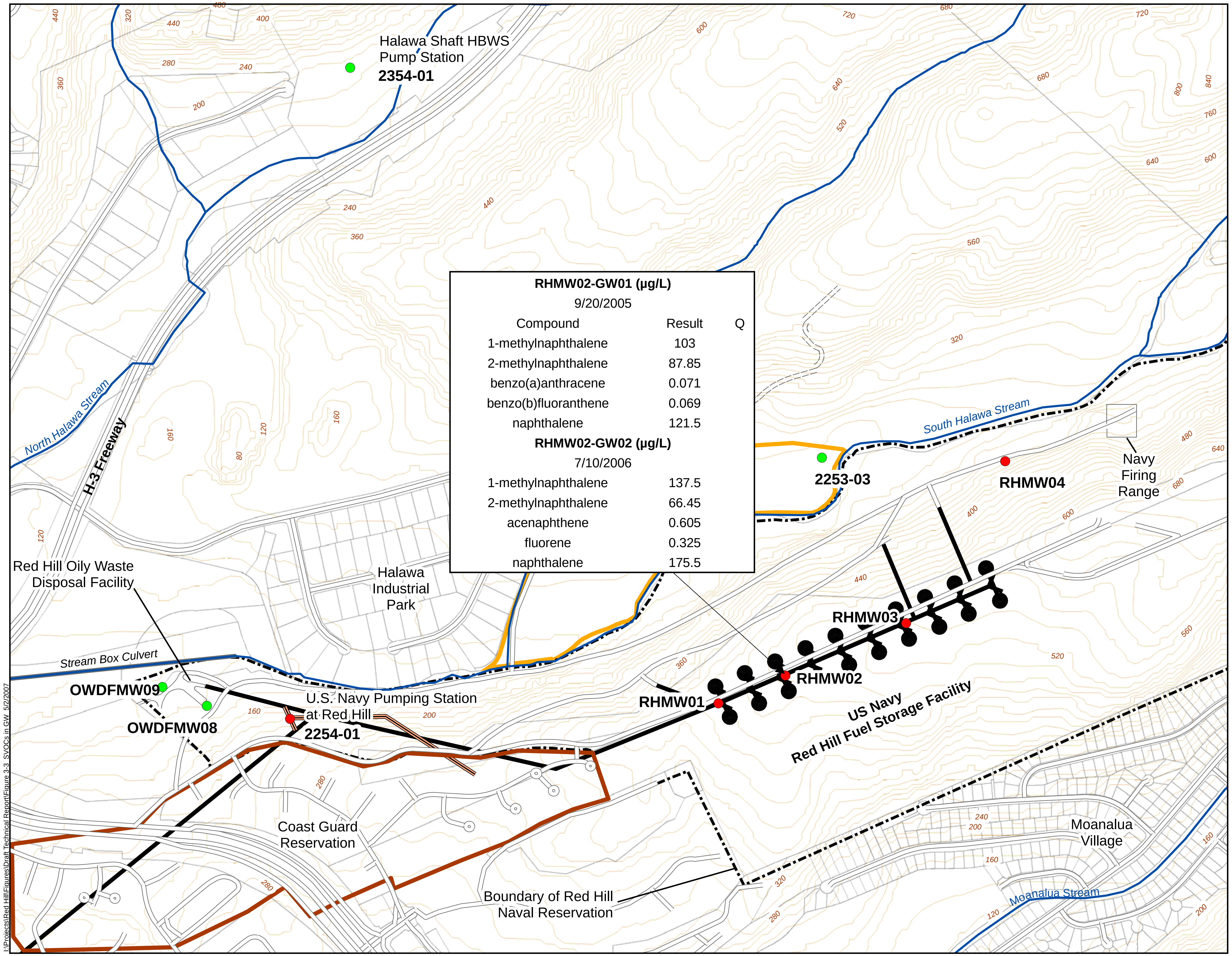
N

Meters
0 175 350
0 315 630 1,260
Feet

Figure 3-2

VOCs in Groundwater
Red Hill Fuel Storage Facility
Oahu, Hawaii

I:\Projects\Red Hill\Figures\Draft Technical Report\Figure 3-2 VOCs in GW 5/2/2007



RHMW02-GW01 (µg/L)

9/20/2005

Compound	Result	Q
1-methylnaphthalene	103	
2-methylnaphthalene	87.85	
benzo(a)anthracene	0.071	
benzo(b)fluoranthene	0.069	
naphthalene	121.5	

RHMW02-GW02 (µg/L)

7/10/2006

Compound	Result	Q
1-methylnaphthalene	137.5	
2-methylnaphthalene	66.45	
acenaphthene	0.605	
fluorene	0.325	
naphthalene	175.5	

I:\Projects\Red Hill\Figures\Draft Technical Report\Figure 3-3_SVOCs in GW_5/2/2007

Legend

●	Project Wells
●	Other Wells
●	Red Hill UST
☐	Parcel
—	40-foot Interval Contour Line
====	Unpaved Road
=	Road
—	Stream
-·-·	Red Hill Navy Installation Boundary
—	Red Hill Tunnels
≡	2254-01 Infiltration Gallery
☐	Halawa Correctional Facility Boundary
☐	Coast Guard Reservation

Acronyms

µg/L - Micrograms per liter

SVOCs - Semi-Volatile Organic Compounds

Data Qualifiers (Q)

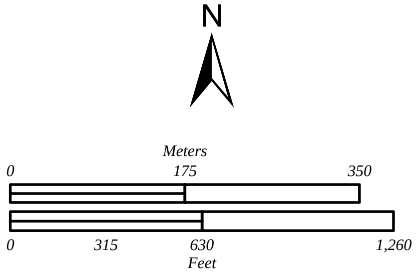
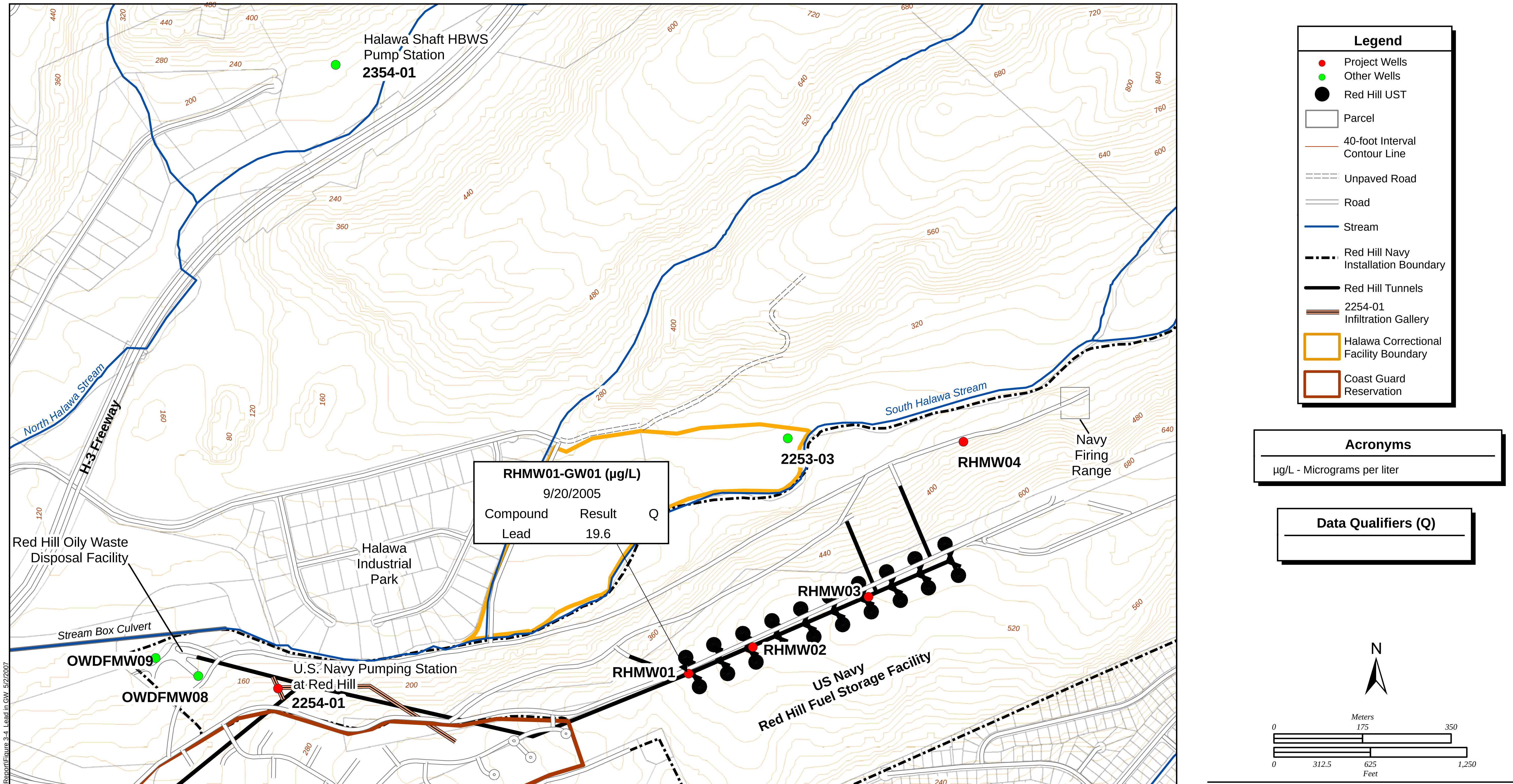


Figure 3-3

SVOCs in Groundwater

Red Hill Fuel Storage Facility
Oahu, Hawaii



RHMW01-GW01 (µg/L)
9/20/2005

Compound	Result	Q
Lead	19.6	

Figure 3-4

Lead in Groundwater

Red Hill Fuel Storage Facility
Oahu, Hawaii

I:\Projects\Red Hill\Figures\Draft Technical Report\Figure 3-4 Lead in GW 5/2/2007

3.1.3 Soil Vapor Pilot Study

Soil vapor samples were collected from 18 SVMPs located beneath 7 of the USTs as part of a pilot study to 1) evaluate potential risk of soil vapor intrusion into the lower access tunnel; and 2) evaluate each SVMP as a potential device for leak detection.

3.1.3.1 Phase I Pilot Study

In May and June of 2006, soil vapor samples were collected from SVMPs installed beneath Tanks 2, 14 and 16 (Table 2-8). A QC sample (duplicate) was collected at Tank 16 (RHSV01-0). A soil vapor sampling log is presented in Appendix H.

Analytical results for detected compounds in SVMPs are presented in Table 3-4 for this first event. Complete SVMP analytical reports are provided in Appendix F. The lateral distribution of chemicals in soil vapor at the Facility during Round 1 sampling is presented in Figure 3-5. The detected concentrations of BTEX is presented in Figure 3-7 for Round 1 soil vapor monitoring. The analytical results have been validated for decision-making.

During sampling, PID readings ranged between 0.0 to 3.5 parts per million (ppm). Oxygen concentrations ranged from 10.1 to 20.6%.

Tank 2 (RHSV02)

Three SVMPs were installed beneath Tank 2, screened at the front (15 to 40 ft from POE), middle (46 to 73 ft from POE) and outer edge (79 to 110 ft from POE). Results are summarized below.

- Front - Only n-hexane was observed at 2.6 micrograms per cubic meter (µg/m^3).
- Middle - m,p-xylene (3.5 µg/m^3) was the only petroleum-related compound observed. Carbon disulfide (83 µg/m^3) and tetrachloroethylene (7.6 µg/m^3) were observed but are not petroleum related.
- Outer Edge - Ethanol (36 µg/m^3) and dichlorodifluoromethane (3.3 µg/m^3) were detected, though neither are anticipated components of the fuels stored here.
- Acetone was also detected at the front and middle SVMPs; however, acetone is not a petroleum constituent and is a known laboratory contaminant.

Tank 14 (RHSV14)

Three SVMPs were installed beneath Tank 2, screened at the front (15 to 40 ft from POE), middle (46 to 73 ft from POE) and outer edge (79 to 110 ft from POE). Results are summarized below.

- Front - no petroleum-related compounds were detected.
- Middle - 16 compounds were detected, including benzene (16 µg/m^3), toluene (23 µg/m^3), ethylbenzene (18 µg/m^3) and xylenes (58 µg/m^3). Other petroleum indicators

observed were 1,3,5-trimethylbenzene and 1,2,4-trimethylbenzene. The concentration of total VOCs in this sample was 438 µg/m^3.

- Outer Edge - 7 compounds were detected, including xylenes, toluene and 1,2,4-trimethylbenzene. The concentration of total VOCs in this sample was 52 µg/m^3.
- Acetone, methyl ethyl ketone, carbon disulfide and tetrahydrofuran were in two or more of these samples, but are not considered petroleum related.

Tank 16 (RHSV16)

Three SVMPs were installed beneath Tank 16, screened at the front (15 to 40 ft from POE), middle (46 to 73 ft from POE) and outer edge (79 to 110 ft from POE). Results are summarized below.

- Front - 9 compounds were detected, including benzene (2.1 µg/m^3), toluene (7.7 µg/m^3), xylenes (6.9 µg/m^3) and 1,2,4-trimethylbenzene (3.4 µg/m^3). The concentration of total VOCs in this sample was 175 µg/m^3.
- Middle - 3 compounds were detected, including benzene (2.1 µg/m^3) and toluene (7.7 µg/m^3).
- Outer Edge - 7 compounds were detected, including ethylbenzene (3.3 µg/m^3), toluene (4.4 µg/m^3) and xylenes (12.3 µg/m^3). The concentration of total VOCs in this sample was 23 µg/m^3.
- Acetone, methyl ethyl ketone, carbon disulfide and tetrahydrofuran were in one or more of these samples, but are not considered petroleum related.

3.1.3.2 Phase II Pilot Study

On November 3, 2006, soil vapor samples were collected from SVMPs installed beneath Tanks 6, 10, 11 and 12 (Table 2-8). A QC sample (duplicate) was collected at Tank 6 (RHSV6-35-15-D). A soil vapor sampling log is presented in Appendix H.

Analytical results for detected compounds in SVMPs are presented in Table 3-4. Complete SVMP analytical reports are provided in Appendix F. The lateral distribution of chemicals in soil vapor at the Facility during the second sampling event is presented in Figure 3-6. The detected concentrations of BTEX in samples from SVMPs are presented in Figure 3-8. The analytical results have been validated for decision-making.

During sampling, PID readings ranged between 0.0 to 3.5 ppm. Oxygen concentrations ranged from 10.1 to 20.6%.

Tank 6 (RHSV06)

Two SVMPs were installed beneath Tank 6, screened at the front (15 to 35 ft from POE) and middle (40 to 56 ft form POE), limited by the size of the initial borehole. Results are summarized below.

- Front - 17 compounds were detected, including benzene (3.4 µg/m^3), toluene (28.5 µg/m^3), ethylbenzene (15.55 µg/m^3), xylenes (107 µg/m^3), 1,3,5-trimethylbenzene (87 µg/m^3) and 1,2,4-trimethylbenzene (105.5 µg/m^3). The concentration of total VOCs in this sample was 557 µg/m^3.
- Middle - 5 compounds were detected, including toluene (6 µg/m^3), m,p-xylene (6.7 µg/m^3), and 1,2,4-trimethylbenzene (6.5 µg/m^3). The concentration of total VOCs in this sample was 29 µg/m^3.
- Acetone, methyl ethyl ketone and carbon disulfide were detected in one or more of these samples, but are not considered petroleum related.

Tank 10 (RHSV10)

Two SVMPs were installed beneath Tank 10, screened at the front (13 to 30 ft from point POE) and middle to end (40 to 130 ft from POE), limited by the size of the initial borehole. Results are summarized below.

- Front - 2 compounds were detected, including toluene (17 µg/m^3), m,p-xylene (4.5 µg/m^3). The concentration of total VOCs in this sample was 21.5 µg/m^3.
- Middle to End - 3 compounds were detected, including toluene (6 µg/m^3), m,p-xylene (3.4 µg/m^3). The concentration of total VOCs in this sample was 22 µg/m^3.
- Acetone was detected in 1 of these samples, but is not considered petroleum-related.

Tank 11 (RHSV11)

Two SVMPs were installed beneath Tank 11, screened at the front (13 to 30 ft from POE) and middle to end (40 to 131 ft from POE), limited by the size of the initial borehole. Results are summarized below.

- Front - 7 compounds were detected, including toluene (8.8 µg/m^3), xylenes (12.3 µg/m^3) and 1,2,4-trimethylbenezene (12 µg/m^3). The concentration of total VOCs in this sample was 66 µg/m^3.
- Middle to End - 13 compounds were detected, including toluene (32 µg/m^3), ethylbenzene (9.6 µg/m^3), xylenes (54 µg/m^3), 1,3,5-trimethylbenzene (14 µg/m^3) and 1,2,4-trimethylbenezene (49 µg/m^3). The concentration of total VOCs in this sample was 257 µg/m^3.

- Acetone, carbon disulfide and dichlorofluoromethane were detected in one or both of these samples, but are not considered petroleum-related.

Tank 12 (RHSV12)

Three SVMPs were installed beneath Tank 12, screened at the front (15 to 40 ft from POE), middle (46 to 68 ft from POE) and outer edge (76 to 110 ft from POE). Results are summarized below.

- Front - 12 compounds were detected, including benzene (2.6 µg/m^3), toluene (18 µg/m^3), xylenes (51 µg/m^3), 1,3,5-trimethylbenzene (11 µg/m^3), and 1,2,4-trimethylbenzene (40 µg/m^3). The concentration of total VOCs in this sample was 206 µg/m^3.
- Middle - 2 compounds were detected, including toluene (5.2 µg/m^3) and m,p-xylene (3.8 µg/m^3). The concentration of total VOCs in this sample was 9 µg/m^3.
- Outer Edge - 3 compounds were detected, including toluene (5.4 µg/m^3). The concentration of total VOCs in this sample was 27 µg/m^3.
- Acetone, methyl ethyl ketone were detected the outer edge sample, but are not considered petroleum-related.

3.1.3.3 Soil Vapor Pilot Study Summary

The soil vapor monitoring pilot study data was successfully used for risk assessment. There was a substantial variability in the results, indicating that sampling these SVMPs may provide evidence of leaks at the associated tanks. Table 3-7 ranks the SVMPs in terms of most likely candidates to indicate that a leak may have occurred at the associated UST. Based on these results, the SVMPs with the highest soil vapor readings are beneath tanks 16, 6, 14, 11, and 12.

Table 3-7. Total Soil Vapor

Sample	Soil Vapor Total (ppbV)	Ranking based on ppbV	Soil Vapor Total (µg/m^3)	Ranking based on µg/m^3
RHSV02-15-40	17	11	42	11
RHSV02-46-73	43	7	129	7
RHSV02-79-110	20	10	39	12
RHSV06-15-35	**127**	**2**	**557**	**1**
RHSV06-40-56	7	15	29	13
RHSV10-13-30	6	16	22	15
RHSV10-40-130	8	14	22	16
RHSV11-13-30	14	12	66	10
RHSV11-40-131	**63**	**4**	**257**	**4**
RHSV12-15-40	**50**	**6**	**206**	**5**
RHSV12-46-68	2	17	9	17
RHSV12-76-133	10	13	27	14

Sample	Soil Vapor Total (ppbV)	Ranking based on ppbV	Soil Vapor Total (µg/m^3)	Ranking based on µg/m^3
RHSV14-15-40	2	18	5	18
RHSV14-46-73	**117**	**3**	**438**	**3**
RHSV14-79-110	52	5	152	6
RHSV16-15-40	**175**	**1**	**452**	**2**
RHSV16-46-73	26	8	69	9
RHSV16-79-110	23	9	72	8

Bolded values indicate highest soil vapor readings

ppbV	parts per billion by Volume
µg/m^3	micrograms per cubic meter

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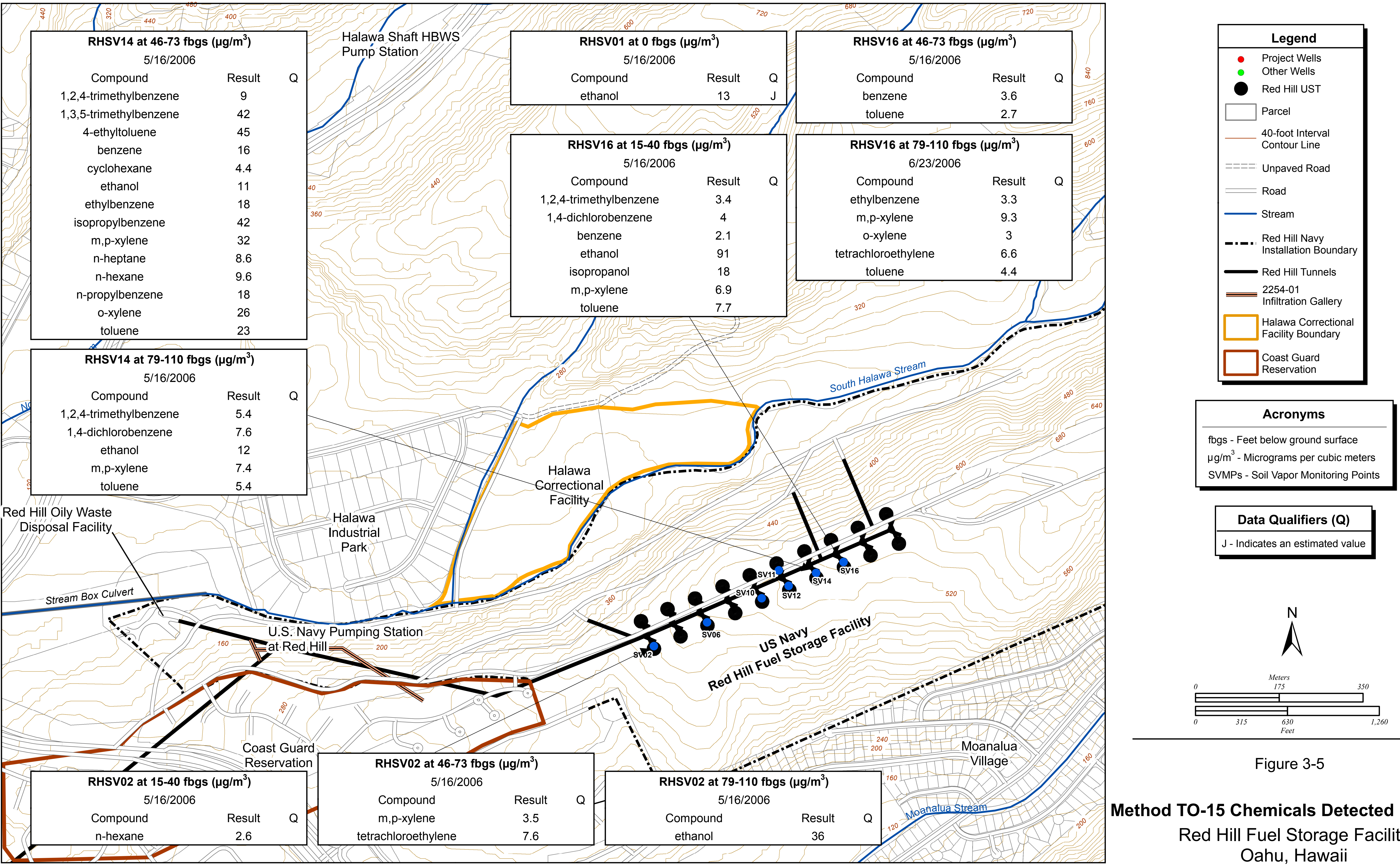


RHSV14 at 46-73 fbgs (µg/m^3)

5/16/2006

Compound	Result	Q
1,2,4-trimethylbenzene	9	
1,3,5-trimethylbenzene	42	
4-ethyltoluene	45	
benzene	16	
cyclohexane	4.4	
ethanol	11	
ethylbenzene	18	
isopropylbenzene	42	
m,p-xylene	32	
n-heptane	8.6	
n-hexane	9.6	
n-propylbenzene	18	
o-xylene	26	
toluene	23	

RHSV14 at 79-110 fbgs (µg/m^3)

5/16/2006

Compound	Result	Q
1,2,4-trimethylbenzene	5.4	
1,4-dichlorobenzene	7.6	
ethanol	12	
m,p-xylene	7.4	
toluene	5.4	

RHSV01 at 0 fbgs (µg/m^3)

5/16/2006

Compound	Result	Q
ethanol	13	J

RHSV16 at 15-40 fbgs (µg/m^3)

5/16/2006

Compound	Result	Q
1,2,4-trimethylbenzene	3.4	
1,4-dichlorobenzene	4	
benzene	2.1	
ethanol	91	
isopropanol	18	
m,p-xylene	6.9	
toluene	7.7	

RHSV16 at 46-73 fbgs (µg/m^3)

5/16/2006

Compound	Result	Q
benzene	3.6	
toluene	2.7	

RHSV16 at 79-110 fbgs (µg/m^3)

6/23/2006

Compound	Result	Q
ethylbenzene	3.3	
m,p-xylene	9.3	
o-xylene	3	
tetrachloroethylene	6.6	
toluene	4.4	

RHSV02 at 15-40 fbgs (µg/m^3)

5/16/2006

Compound	Result	Q
n-hexane	2.6	

RHSV02 at 46-73 fbgs (µg/m^3)

5/16/2006

Compound	Result	Q
m,p-xylene	3.5	
tetrachloroethylene	7.6	

RHSV02 at 79-110 fbgs (µg/m^3)

5/16/2006

Compound	Result	Q
ethanol	36	

Legend

●	Project Wells
●	Other Wells
●	Red Hill UST
▭	Parcel
—	40-foot Interval Contour Line
----	Unpaved Road
—	Road
—	Stream
-·-·	Red Hill Navy Installation Boundary
—	Red Hill Tunnels
▬	2254-01 Infiltration Gallery
▭	Halawa Correctional Facility Boundary
▭	Coast Guard Reservation

Acronyms

fbgs - Feet below ground surface

µg/m^3 - Micrograms per cubic meters

SVMPs - Soil Vapor Monitoring Points

Data Qualifiers (Q)

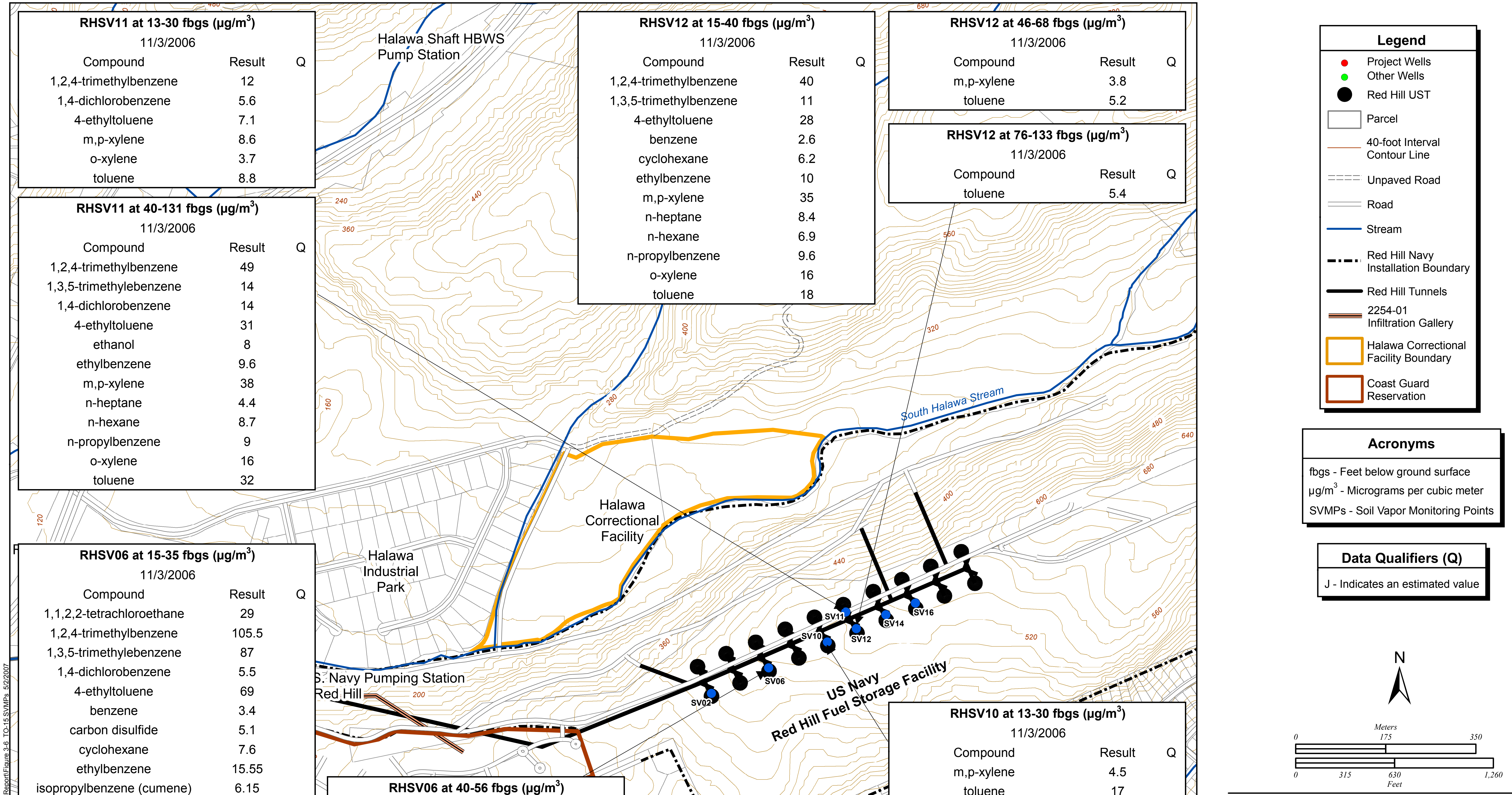
J - Indicates an estimated value

Figure 3-5

Method TO-15 Chemicals Detected in SVMPs

Red Hill Fuel Storage Facility
Oahu, Hawaii

I:\Projects\Red Hill\Figures\Draft Technical Report\Figure 3-5_TO-15 SVMPs_5/2/2007



RHSV11 at 13-30 fbgs (µg/m^3)
11/3/2006

Compound	Result	Q
1,2,4-trimethylbenzene	12	
1,4-dichlorobenzene	5.6	
4-ethyltoluene	7.1	
m,p-xylene	8.6	
o-xylene	3.7	
toluene	8.8	

RHSV11 at 40-131 fbgs (µg/m^3)
11/3/2006

Compound	Result	Q
1,2,4-trimethylbenzene	49	
1,3,5-trimethylbenzene	14	
1,4-dichlorobenzene	14	
4-ethyltoluene	31	
ethanol	8	
ethylbenzene	9.6	
m,p-xylene	38	
n-heptane	4.4	
n-hexane	8.7	
n-propylbenzene	9	
o-xylene	16	
toluene	32	

RHSV12 at 15-40 fbgs (µg/m^3)
11/3/2006

Compound	Result	Q
1,2,4-trimethylbenzene	40	
1,3,5-trimethylbenzene	11	
4-ethyltoluene	28	
benzene	2.6	
cyclohexane	6.2	
ethylbenzene	10	
m,p-xylene	35	
n-heptane	8.4	
n-hexane	6.9	
n-propylbenzene	9.6	
o-xylene	16	
toluene	18	

RHSV12 at 46-68 fbgs (µg/m^3)
11/3/2006

Compound	Result	Q
m,p-xylene	3.8	
toluene	5.2	

RHSV12 at 76-133 fbgs (µg/m^3)
11/3/2006

Compound	Result	Q
toluene	5.4	

RHSV06 at 15-35 fbgs (µg/m^3)
11/3/2006

Compound	Result	Q
1,1,2,2-tetrachloroethane	29	
1,2,4-trimethylbenzene	105.5	
1,3,5-trimethylbenzene	87	
1,4-dichlorobenzene	5.5	
4-ethyltoluene	69	
benzene	3.4	
carbon disulfide	5.1	
cyclohexane	7.6	
ethylbenzene	15.55	
isopropylbenzene (cumene)	6.15	
m,p-xylene	66.5	
n-heptane	17	
n-hexane	4.45	
n-propylbenzene	12.9	
o-xylene	40.5	
toluene	28.5	

RHSV06 at 40-56 fbgs (µg/m^3)
11/3/2006

Compound	Result	Q
1,2,4-trimethylbenzene	6.5	
4-ethyltoluene	3.8	
m,p-xylene	6.7	
toluene	6	J

RHSV10 at 13-30 fbgs (µg/m^3)
11/3/2006

Compound	Result	Q
m,p-xylene	4.5	
toluene	17	

RHSV10 at 40-130 fbgs (µg/m^3)
11/3/2006

Compound	Result	Q
m,p-xylene	3.4	
toluene	6	

Acronyms

fbgs - Feet below ground surface
µg/m^3 - Micrograms per cubic meter
SVMPs - Soil Vapor Monitoring Points

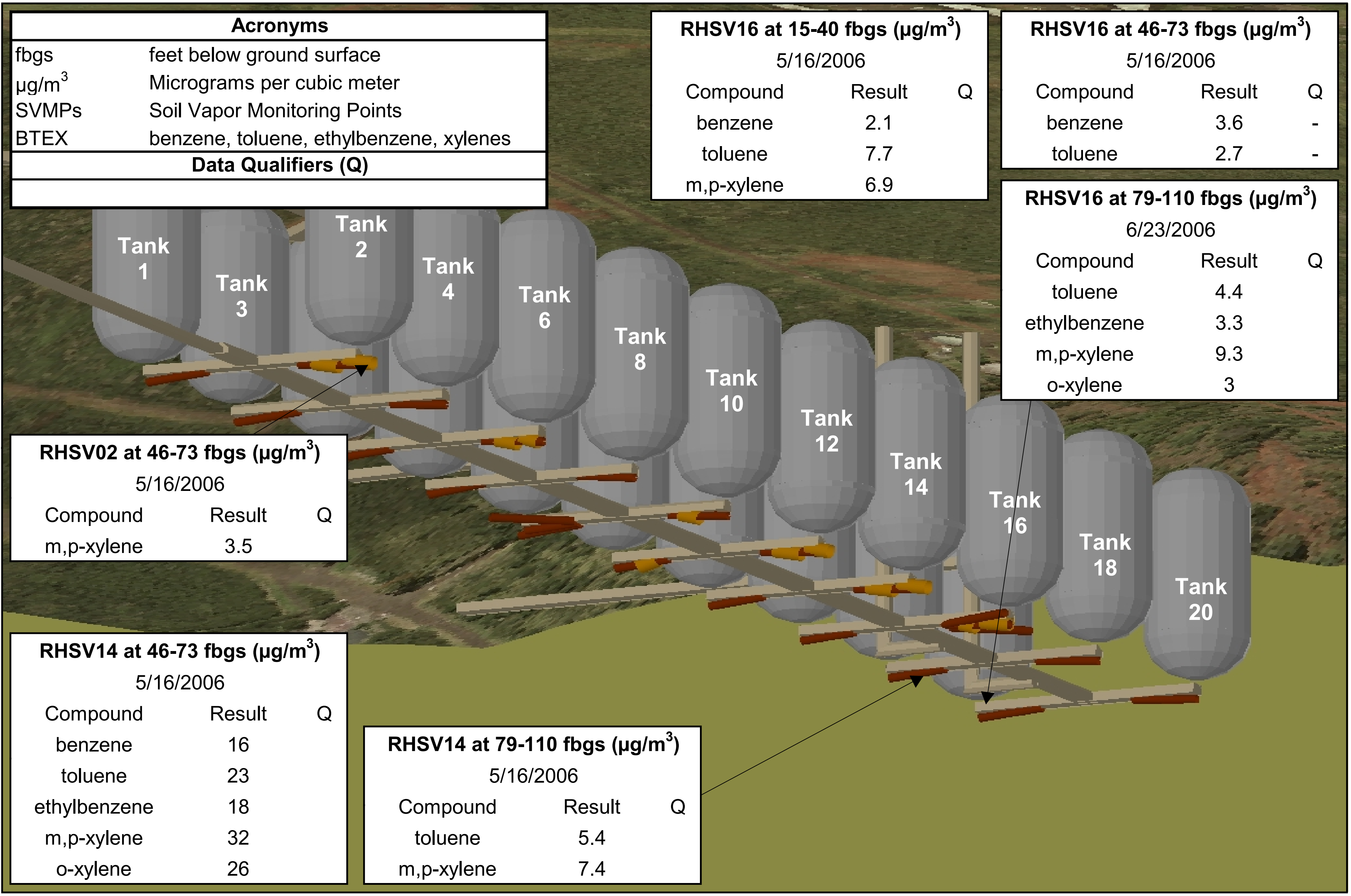
Data Qualifiers (Q)

J - Indicates an estimated value

Figure 3-6

Method TO-15 Chemicals Detected in SVMPs
Red Hill Fuel Storage Facility
Oahu, Hawaii

I:\Projects\Red Hill\Figures\Draft Technical Report\Figure 3-6 TO-15 SVMPs 5/2/2007



Acronyms	
fbgs	feet below ground surface
$\mu g/m^3$	Micrograms per cubic meter
SVMPs	Soil Vapor Monitoring Points
BTEX	benzene, toluene, ethylbenzene, xylenes

Data Qualifiers (Q)

RHSV16 at 15-40 fbgs ($\mu g/m^3$)
5/16/2006

Compound	Result	Q
benzene	2.1	
toluene	7.7	
m,p-xylene	6.9	

RHSV16 at 46-73 fbgs ($\mu g/m^3$)
5/16/2006

Compound	Result	Q
benzene	3.6	-
toluene	2.7	-

RHSV16 at 79-110 fbgs ($\mu g/m^3$)
6/23/2006

Compound	Result	Q
toluene	4.4	
ethylbenzene	3.3	
m,p-xylene	9.3	
o-xylene	3	

RHSV02 at 46-73 fbgs ($\mu g/m^3$)
5/16/2006

Compound	Result	Q
m,p-xylene	3.5	

RHSV14 at 46-73 fbgs ($\mu g/m^3$)
5/16/2006

Compound	Result	Q
benzene	16	
toluene	23	
ethylbenzene	18	
m,p-xylene	32	
o-xylene	26	

RHSV14 at 79-110 fbgs ($\mu g/m^3$)
5/16/2006

Compound	Result	Q
toluene	5.4	
m,p-xylene	7.4	

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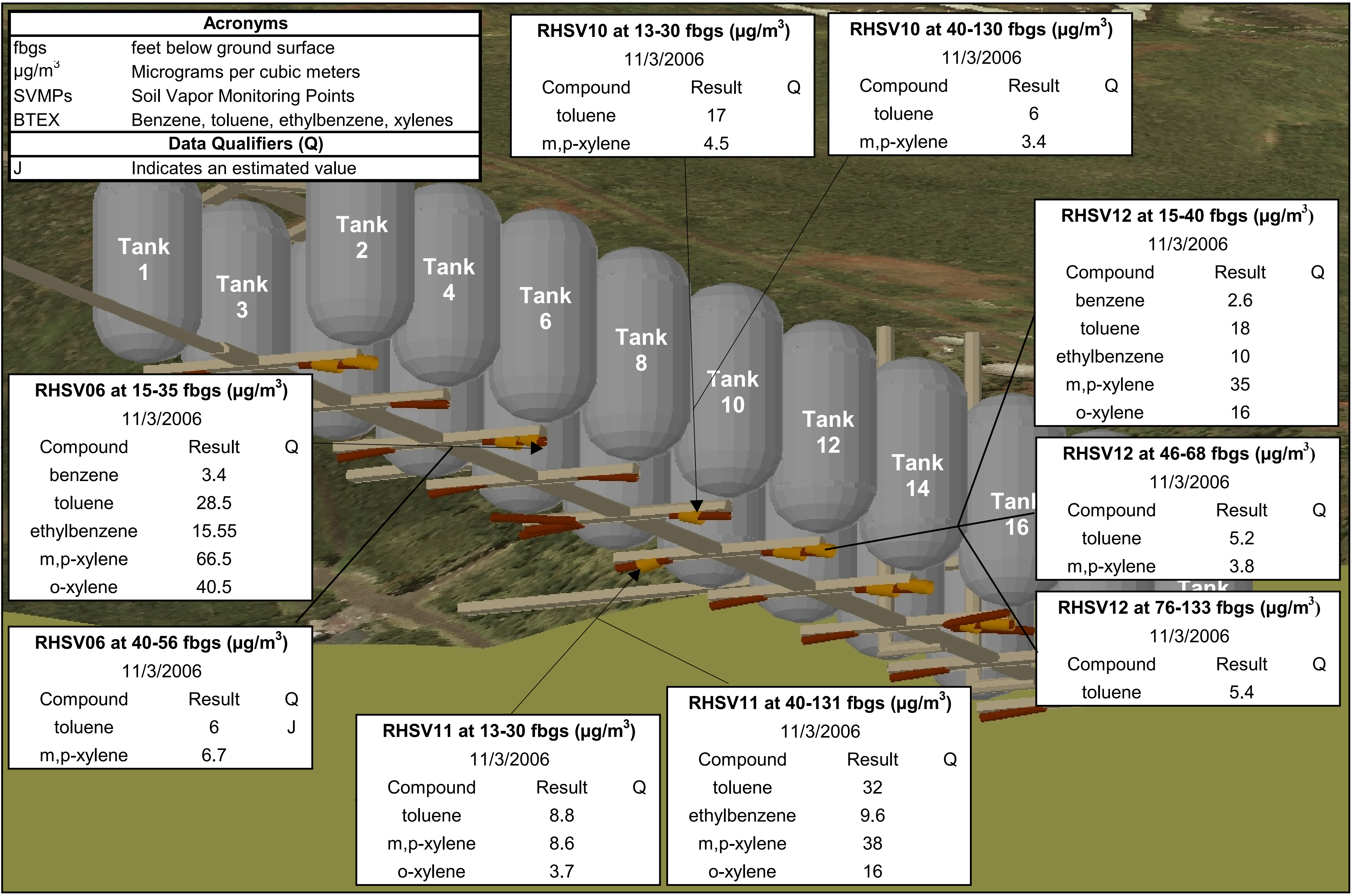
Figure 3-7
BTEX Detected in Round 1
Red Hill Fuel Storage Facility
Oahu, Hawaii

TEC inc



Acronyms	
fbgs	feet below ground surface
µg/m^3	Micrograms per cubic meters
SVMPs	Soil Vapor Monitoring Points
BTEX	Benzene, toluene, ethylbenzene, xylenes
Data Qualifiers (Q)	
J	Indicates an estimated value

RHSV10 at 13-30 fbgs (µg/m^3)
11/3/2006

Compound	Result	Q
toluene	17	
m,p-xylene	4.5	

RHSV10 at 40-130 fbgs (µg/m^3)
11/3/2006

Compound	Result	Q
toluene	6	
m,p-xylene	3.4	

RHSV12 at 15-40 fbgs (µg/m^3)
11/3/2006

Compound	Result	Q
benzene	2.6	
toluene	18	
ethylbenzene	10	
m,p-xylene	35	
o-xylene	16	

RHSV06 at 15-35 fbgs (µg/m^3)
11/3/2006

Compound	Result	Q
benzene	3.4	
toluene	28.5	
ethylbenzene	15.55	
m,p-xylene	66.5	
o-xylene	40.5	

RHSV12 at 46-68 fbgs (µg/m^3)
11/3/2006

Compound	Result	Q
toluene	5.2	
m,p-xylene	3.8	

RHSV12 at 76-133 fbgs (µg/m^3)
11/3/2006

Compound	Result	Q
toluene	5.4	

RHSV06 at 40-56 fbgs (µg/m^3)
11/3/2006

Compound	Result	Q
toluene	6	J
m,p-xylene	6.7	

RHSV11 at 13-30 fbgs (µg/m^3)
11/3/2006

Compound	Result	Q
toluene	8.8	
m,p-xylene	8.6	
o-xylene	3.7	

RHSV11 at 40-131 fbgs (µg/m^3)
11/3/2006

Compound	Result	Q
toluene	32	
ethylbenzene	9.6	
m,p-xylene	38	
o-xylene	16	

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Figure 3-8
BTEX Detected in Round 2
Red Hill Fuel Storage Facility
Oahu, Hawaii

TEC inc

3.2 Geology

The Facility is present along the topographic ridge between Halawa and Moanalua Valleys. The ridge is a remnant of the original Koolau shield volcano flank and is composed of basaltic flows. The valleys on either side of the ridge are a result of fluvial erosion and are filled with alluvium/colluvium.

Soil in the vicinity of the Facility consists of the Helemano-Wahiawa association. These soils are composed of well-drained, moderately fine to fine textured soils. These soils typically range from nearly level to moderately sloping and can occur in broad areas dissected by steep gulches. The soils formed from weathering of basalt (USDA, 1972). Reviews of previous studies (Wentworth, 1945) in the area indicate that the Red Hill ridge has soil consisting of clays and clayey gravels to depths ranging up to 10 ft bgs. These soils are derived from weathering of the underlying basalt bedrock and/or were deposited as alluvium/colluvium. In general, the alluvium/colluvium has been deposited at the bottom of the steeply dipping valleys, as valley fill material. Underlying the surface soils, are alternating vesicular (Pahoehoe) and massive, blocky (a’a) lava flows. The western slope of Halawa Valley is mostly composed of outcropping basaltic lava flows, with little soil cover. Wilbros indicated that the Facility is bounded on each side by deep alluvial fills and sedimentary caprock (marine and terrestrial sediments) in the down-gradient direction (Wilbros, 1998). In the area of the Facility lower tunnel and entry to the Harbor Tunnel, the basal aquifer (and also the tunnels and tanks) are located in permeable basalt.

During the initial excavation of the Facility, barrel logs were documented from the outer walls of the cavities in which each tank was installed. During the current investigation, these logs were interpolated between each tank to provide an interpretation of the geology in the vadose zone of the Red Hill ridge. These are depicted in Figure 3-9. The barrel logs identified “rock”, “clinker”, “loose rock”, “lava dome” and “grout”. Clinker is generally observed on the outer edges of a’a massive basalt flows, therefore the lower portion of the Facility appears to be more massive basalt with clinker interfaces. The upper portion of the Facility appears to be more vesicular, with less vesicular interbedding

Borings in the vicinity of Adit 3 were advanced to install basal monitoring wells in 2000 (EarthTech, 2000). These borings indicated that different conditions occurred there. Dry, massive basalt was present at approximately 20 ft above msl. Under this material, basal groundwater was encountered at approximately 1 to 2 ft below msl. The potentiometric groundwater surface stabilized within groundwater wells at approximately 16 ft above msl. This suggests that the massive lower basalt acts as a confining layer. However, the presence of a’a lava can act as a local confining layer, although the a’a lava is probably limited in its extent.

During the current investigation, the following was encountered:

At background boring RHMW04, surface conditions down to 1.5 ft bgs consisted of dark reddish-brown well-graded gravel. The gravel was underlain by alternating thick layers of vesicular (pahoehoe) basalt and thinner layers of massive (a’a) basalt. The basalt was present to the terminus of the boring at 315 ft bgs. Groundwater was encountered during drilling at approximately 311 ft bgs.

In the lower access tunnel, at wells RHMW02 and RHMW03, 8-inches of concrete was present at the surface, underlain by approximately ½ to ¾ of a ft of sand. Under the sand layer, was approximately 1 and ½ feet of basalt boulders. The boulders were underlain by alternating thick layers of vesicular (pahoehoe) basalt and thinner layers of massive (a'a) basalt. In RHMW02, cinder layers were present at 53 to 63 ft bgs, at 78 ft bgs, 83 ft bgs and 98.5 ft bgs. Groundwater was encountered at 86.9 ft bgs, and basalt was present to the terminus of the boring at 103.5 ft bgs. At RHMW03, cinder layers were present at 52.5 to 56 ft bgs, 57.5 to 58 ft bgs and 62 ft bgs. A possible void was noted between 97.5 and 102.5 ft bgs. Groundwater was first encountered at 90.1 ft bgs. The basalt was present to the terminus of the boring at 115.5 ft bgs

As a reference, the elevations at the Facility aboveground are 200 to 500 ft above msl. The elevation of the lower access tunnel are approximately 102 ft above msl at Tanks 1 and 6, then slopes upward to 122 ft above msl at Tank 14 and an estimated elevation at Tank 20 of about 140 ft above msl. Refer to Appendix A for boring logs.

3.2.1 Hydrology

Groundwater is sequestered to the upper elevations in the Koolau dike zone, which lies inland from the Facility. Due to the high precipitation rates along the Koolau crest, and the truncation of the Koolau Mountain on the eastern side, eastern streams may intercept dike perched groundwater, to feed their flow. On the western side of the Koolau Mountain, only Manoa Stream and Palolo Stream are fed by perched groundwater. In the area of Halawa Valley, streams flow above the basal groundwater table over deeply weathered rock and exchange water with perched water associated with their alluvial material, known as valley fill. Groundwater that flows beneath the Facility does not intercept surface water. The numerical groundwater model developed for this project was calibrated for hydraulic parameters, and presents a detailed discussion of regional and local recharge as well as hydraulic parameters.

3.2.2 Hydrogeology

3.2.2.1 Groundwater Category and Usage

The Facility lies on the Red Hill Ridge, which is classified by HDOH as the boundary between the Honolulu and the Pearl Harbor Aquifers in *Aquifer Identification and Classification for Oahu: Groundwater Protection Strategy for Hawaii*, (Mink and Lau, 1990). Mink and Lau, (1990) indicates that the western part of the Facility overlies the Waimalu Aquifer system, which is part of the Pearl Harbor Aquifer sector, and the eastern portion overlies the Moanalua Aquifer system, which is part of the Honolulu Aquifer sector. Mink and Lau (1990) classifies both the Moanalua and Waimalu Aquifer systems as unconfined, basal and flank, and lists their status as "currently used, fresh (chloride content below 250 mg/L), drinking water source that is irreplaceable and has a high vulnerability to contamination. It should be noted that the Red Hill Ridge is not a hydrogeologic boundary, and there are no geochemical or physical attributes that separate the two aquifers at this location. The likely physical boundary between the Moanalua and Waimalu Aquifer systems is the North Halawa Valley fill, which extends below the water table in the vicinity of the Facility and consists of low permeable sediments.

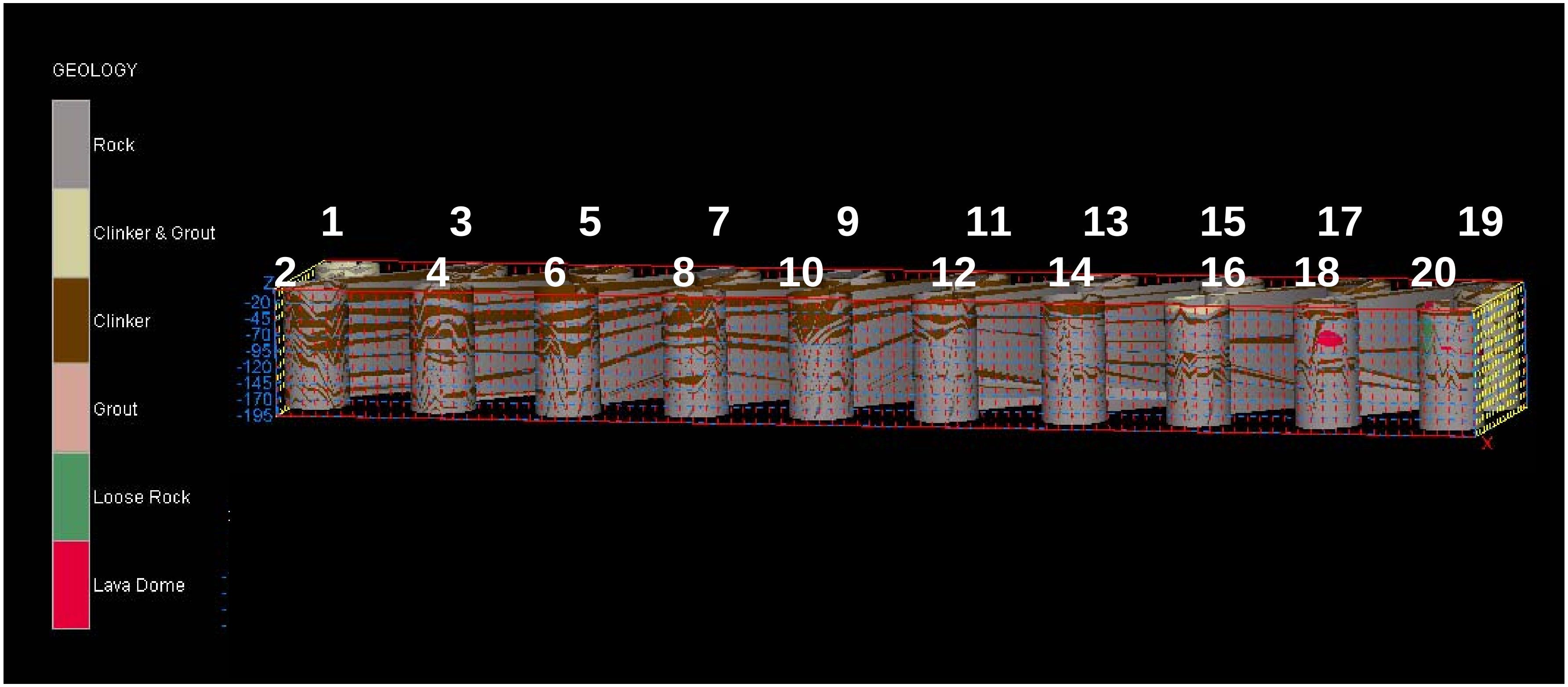

Figure 3-9
Site Stratigraphic Interpretation Based on Tank Construction Barrel Logs
Red Hill Fuel Storage Facility
Oahu, Hawaii

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The Facility is located up-gradient of the Hawaii State UIC Line, which typically segregates potable from non-potable groundwater. The nearest public drinking water well (Halawa Shaft, well 2354-01) is located hydraulically cross-gradient of the Facility. This drinking water well is approximately 5,000 feet to the northwest of the Facility and pumps water from the basal aquifer. On average, 11.8 mgd are withdrawn from this location. This well is part of a water system that serves 607,542 people on Oahu and this particular well supplies approximately 12% of the water in that system.

The U.S. Navy well 2254-01 is located near the Facility. This well consists of a pumping station, located in the lower access tunnel adjacent to Adit 3, approximately 3,000 ft west of the Facility; and an infiltration gallery that extends from the pump station approximately 1,280 feet along the water table, toward the Facility. The infiltration gallery is located hydraulically down-gradient from the Facility and intercepts most of the water that would be affected by releases from the Facility. This well extracts between 4 and 18 mgd of groundwater from this location and supplies approximately 24 percent of the water required for the Pearl Harbor Water System (PHWS), which serves approximately 52,200 military consumers on Oahu.

3.2.2.2 Groundwater Gradient

Groundwater flow in the vicinity of the Facility is expected to regionally be to the southwest, towards Aliamanu crater. Hydraulic conductivity rates have been reported to vary between 500 to 1500 ft per day in the vicinity of the Facility. However, welded tuffs associated with Aliamanu Crater may have significantly lower permeability and may affect localized groundwater flow directions (TEC, 2005a). The steady state local groundwater model was calibrated from a single well in the area, U.S. Navy well 2254-01.

Figure 2-7 provides the simulated steady state groundwater contours for an average pumpage and recharge scenario between 1996 and 2005 in the study area, including a constant 4.5 mgd from U.S. Navy well 2254-01. A graphical estimation of the groundwater gradient from the steady state simulation contours showed a gradient magnitude between 0.00021 and 0.00024 ft/ft, and the direction between 265 and 273 degrees from north. This simulation was conducted with average pumping from all wells in the vicinity and U.S. Navy well 2254-01 pumping at 4.5 mgd. Siimulation results with no pumping from well 2254-01 showed a slight change in gradient direction to about 255 degrees. These simulation results agreed with the current accepted understanding of groundwater flow in this area. Flow is expected to travel approximately parallel to the ridge, with the valley fills in North Halawa Valley (northwest) and Moanalua Valley (south east) channeling the flow in the westerly direction.

In March of 2006, a closed loop survey was performed including seven wells in the study area to get precise relative horizontal and elevation coordinates at “top of casing” measuring points for future groundwater measurements. These survey data were used to reduce the continuous water table measurements collected during the May 2006 pump test. Following the test, data were downloaded from the data loggers and water table gradients were calculated using data collected from RHMW02, RHMW03 and RHMW04. Gradients were calculated once a day between 1030 and 1200 from May 17 to May 31, 2006.

From May 13 through 19, the U.S. Navy well 2254-01 pump was off and the water levels were allowed to stabilize. Between May 20 and May 26, 2006, well 2254-01 pump cycled between off and 10 mgd, and then was shut off again from May 26 to May 31, 2006. Table 3-8 shows the direction and magnitude of the gradient measurements during this period. During the period in which well 2254-01 was off, the calculated gradient ranged between 178 and 185 degrees from north and 0.00048 and 0.00055 ft/ft. During the period when the pump was cycling, the gradient ranged from 204 to 245 degrees from north and 0.00046 and 0.00054 ft/ft.

Appendix K presents the calculations from the USEPA Gradient calculator (http://www.EPA.gov/athens/learn2model/part-two/onsite/gradient4plus-ns.htm). The measured groundwater gradients differ significantly from expected results, as well as the simulated results in that they imply groundwater flow is more directly south under normal conditions. Similar results are observed with the OWD monitor well (OWDMW08) adjacent to Adit 3. Although these results do not have a significant affect on the risk assessment, due to the low solubility of JP-5 and strong natural attenuation mechanisms at work in the basal aquifer, they may have an impact on water resources in the Red Hill basin and should be reviewed by the Public Works Center (NAVFAC Hawaii) for their assessment.

Table 3-8. Groundwater Flow and Gradient Summary

Date	Flow Direction	Gradient Magnitude
5/17/2006	178.2	0.0005359
5/18/2006	179.7	0.0005061
5/19/2006	181.9	0.0004963
5/20/2006	300.8	0.001632
5/21/2006	306.3	0.002623
5/22/2006	306.2	0.002682
5/23/2006	306.5	0.002714
5/24/2006	306.4	0.002577
5/25/2006	305.8	0.002431
5/26/2006	306.8	0.002644
5/27/2006	181.1	0.0004967
5/28/2006	181.6	0.0004959
5/29/2006	182.1	0.0004855
5/30/2006	184.3	0.0005063
5/31/2006	181.0	0.0005528

Notes:

1 Summaries calculated using a single daily measurement from wells: RHMW04, RHMW03, RHMW02, and well 2254-01
2 Flow direction is degrees from north (positive y axis)

3.2.3 Hydraulic Analysis of Materials

In order to address the concerns of potential migration of petroleum impacted groundwater to nearby drinking water wells, the U.S. Navy developed a local 3-D numerical groundwater flow model based on the HDOH regional SWAP model and MODFLOW 2000. This local model was calibrated for steady-state conditions to develop hydraulic parameters of hydraulic conductivity and porosity for three main materials: basalt, valley fill and caprock. The model was then calibrated to dynamic flow conditions using the results of a regional pump test to estimate values for Specific Storativity and Specific Yield (similar to porosity) for the same materials. The model development and results are detailed in Appendix L (Rotzoll and El-Kady, 2006). The flow model was then used to simulate the fate and transport of dissolved petroleum compounds, using MODPATH (Pollock, 1994) and RT3D (Clement, 1997). In order to evaluate particle movement within the fractured basalt aquifer, dispersivity was estimated based on a stochastic assessment of Hawaiian basalt cores as well as literature values. The longitudinal, transverse and vertical dispersivity was estimated at 112 ft., 11.2 ft and 1.12 ft, respectively. The fate and transport development and model simulations are provided in detail in Appendix M. Table 3-9 presents the results of the hydraulic parameter calibration for the numerical model.

Table 3-9. Hydraulic Parameters Developed from Model Calibration

Hydro-geologic Unit	Horizontal, Transversal K [ft/day]	Horizontal, Longitudinal K [ft/day]	Vertical K [ft/day]	Effective Porosity	Specific Storage [ft^{-1}]	Specific Yield
Caprock	0.15	0.15	0.15	0.10	3.05 x 10-5	0.10
Valley Fill	0.066	0.066	0.066	0.15	1.52 x 10-5	0.12
Basalt	1476	4428	7.4	0.05	1.07 x 10-5	0.031

K	hydraulic conductivity
ft/day	feet per day
ft^{-1}	per foot

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SECTION 4
CONCEPTUAL SITE MODEL AND CONTAMINANT FATE AND TRANSPORT

A conceptual site model (CSM) for the Facility was developed in accordance with the USEPA's *Risk Assessment Guidance for Superfund* (USEPA, 1989). A graphic representation of the updated CSM is shown in Figure 4-1. The CSM provides a framework for evaluating each potential exposure pathway. A detailed exposure pathway analysis is provided in the risk assessment (Section 6). This section presents updates to the CSM presented in Section 3 of the installation-wide work plan (IWWP) (TEC, 2005a, 2006a).

4.1 Exposure Pathways and Receptors

Potential receptors include site workers, trespassers, potential future site workers and persons utilizing the basal groundwater pumped out of well 2254-01. The Facility is fenced, posted and well monitored. Trespassers have not been noted on the access road during the most recent RI field activities (2005-2006). Current on-site maintenance activities at grade are minimal, primarily mowing. Within the Facility, maintenance activities are varied including tank refurbishment, electrical work and track repair. Populated areas exist around the Facility, as described in the subsections below.

Migration from the primary sources (Section 4.2) may result in petroleum-impacted subsurface soil at depths, petroleum-impacted basal groundwater. Contaminated subsurface soil is not likely to be directly encountered by receptors since it is located beneath the USTs at depths greater than 300 feet bgs. One possible pathway of exposure is via vapor migration of petroleum contaminants in subsurface soil to receptors in buildings and outdoor areas. Finally, the basal drinking water lens underlies the Facility. Some petroleum constituents have been detected in groundwater from wells under the Facility USTs.

4.1.1 Land Use

The Facility is located on federal government land and there are no occupied buildings above ground. Public land is located to the immediate north and northeast. Immediately north of the public land is forest and Halawa Correctional Facility. An industrial development is located to the north and northwest. Residential land consisting of single-family homes is located immediately adjacent, and south and southeast of the Facility. A high cliff face with a 100 to 200 ft elevation difference exists between the Facility and this residential area. Residences, townhouses and apartment buildings are located to the southwest of the Facility and a public school is also present in this area. The closest residential property to the Facility is the area zoned for apartment buildings located approximately 305 ft southwest of Tank 2. Red Hill Elementary School is located approximately 1,080 ft southwest of Tank 2. The Moanalua Village residential development is located approximately 880 ft south of Tank 2 (Figures 1-2 and 1-5).

4.1.2 Surface Water

Surface water bodies in the vicinity of the Facility; include the southern segment of the Halawa Stream (approximately 665 ft to the north) and the northern segment of the Moanalua Stream (approximately 1,760 ft to the south). The CSM for this site (Figure 4-1) shows that no discharges of water originating from the Facility are likely to these streams.

4.2 Contaminant Fate and Transport

Fate and transport of chemicals in the environment are influenced by the physical and chemical nature of the chemicals, and the media through which they travel. Migration of chemicals may take place through the air, soil sediment, surface water or groundwater. Characteristics that can affect the chemical fate and transport include site-specific topography, geology, hydrogeology, hydrology and meteorology. During transport, chemical concentrations may be attenuated by chemical processes such as biodegradation, photodegradation, hydrolysis, oxidation-reduction re-actions, or by physical processes like dilution. Rate of migration may be affected by partitioning between the different media, as measured by volatility, solubility, adsorption and retardation.

4.2.1 Migration Pathways

As illustrated in the CSM, the migration pathways of potential concern are provided below.

- Migration of soil vapor from LNAPL in unsaturated zone and basal groundwater through fractured bedrock to indoor air;
- Migration of basal groundwater to a stream or ground surface via seeps;
- Migration of leachate through contaminated unsaturated bedrock to the basal aquifer;
- Migration of LNAPL through unsaturated zone to basal aquifer, dissolution into basal groundwater from LNAPL plume on water table; and
- Migration of petroleum dissolved in groundwater to nearby potable water wells.

These pathways of potential concern are discussed below.

4.2.1.1 Migration of Vapor from Bedrock or Groundwater to Indoor Air

Volatilization of petroleum compounds, particularly benzene, is a human health concern. Volatilization into buildings and into open air is evaluated in the risk assessment in Section 6 of this report, based on measurements from SVMPs under 7 Tanks within the Facility. This is expected to be a worst case scenario for soil vapor as it is from directly beneath tanks that have been suspects for petroleum releases.

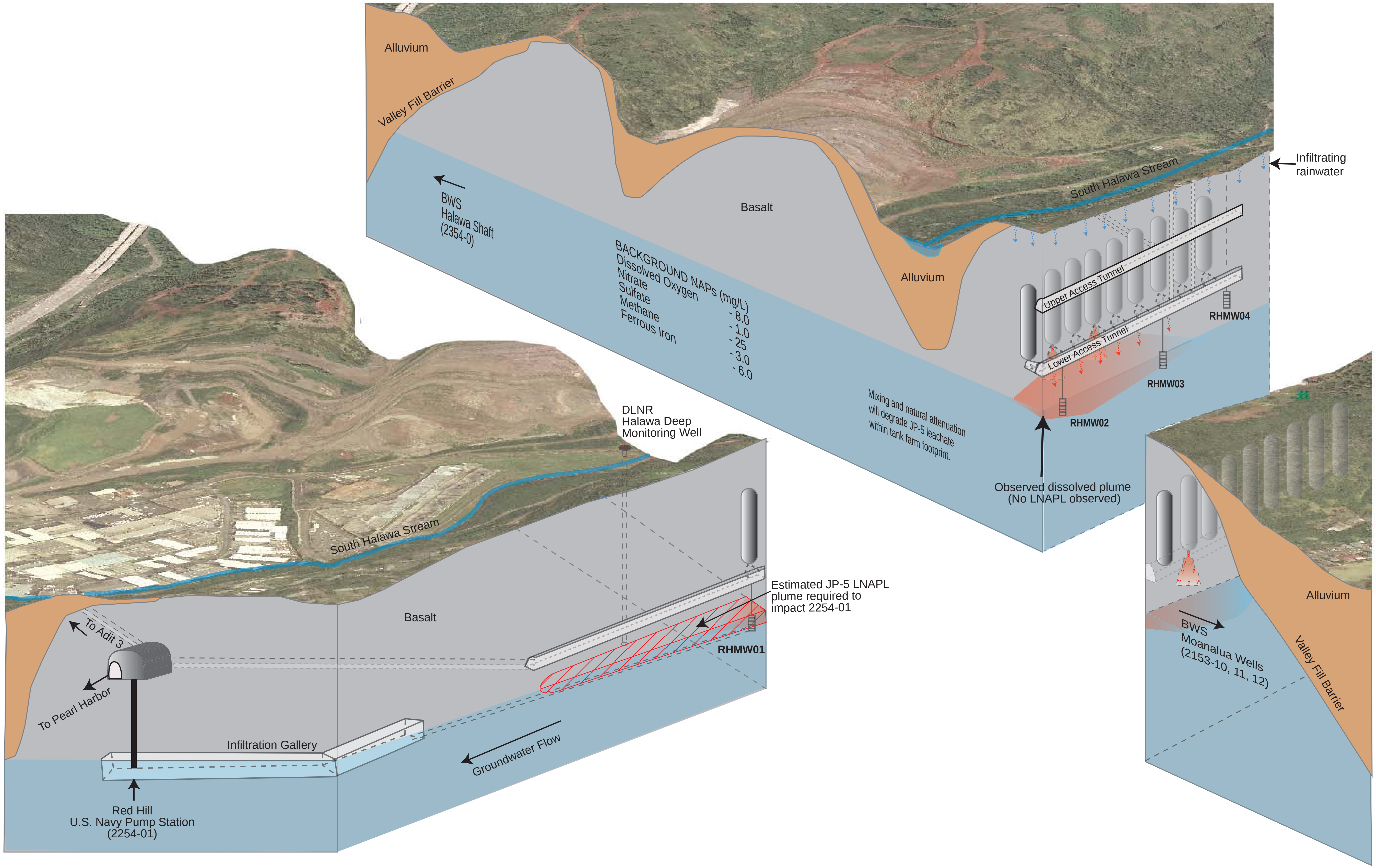

Figure 4-1
Conceptual Site Model

Red Hill Fuel Storage Facility
Oahu, Hawaii

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4.2.1.2 Migration of Groundwater to Nearby Streams and Land Surface via Seeps

The groundwater and stream interaction was evaluated through detailed gradient and channel morphology measurements in the stream area, and on the results of a 3-D MODFLOW groundwater model. Groundwater beneath the Facility is approximately 100 ft below the stream beds in the area. For that reason, groundwater from beneath the Facility will not migrate to the land surface via seeps adjacent to the Facility.

4.2.1.3 Migration of Infiltrating Leachate to the Basal Aquifer

Infiltration is a major mechanism affecting the vertical and horizontal migration of chemicals. In the current CSM, infiltrating rain water can carry dissolved petroleum constituents downward through fractured bedrock and into the underlying basal groundwater. This migration was evaluated by assuming maximum concentration in the infiltrating leachate based on the solubility limits of JP-5, then evaluating mixing and degradation with the local groundwater model and RT3D within the basal groundwater.

4.2.1.4 Migration of LNAPL to the Basal Aquifer

A major concern for the risk assessment and contingency plan is that fuel from one or more of the USTs will be inadvertently released at high enough volume to allow it to migrate through the unsaturated bedrock to the basal water table. LNAPL released to the groundwater table must be removed to the extent practicable, in accordance with HAR, Title 11, Chapter 281, subchapter 7, *Release Response Action*. In addition, LNAPL on the water table has the potential to severely impact the water quality of the drinking water aquifer, and jeopardize the quality of the water consumed from nearby drinking water wells.

It was estimated that as little as 16,000 gallons of JP-5 released from Tanks 1 or 2 could result in exceedences of EALS at the U.S. Navy well 2254-01 (see Appendix M, Section 1.1 for details). No analytical attempt was made to estimate the time of migration, due to the complexity of the system and the size of the release. Estimates for the migration time would be strongly influenced by the rate of the release. For a release of 1 gallon per hour, the minimum time would be 16,000 hours, or 1.8 years. At 10 gallons per hour, the minimum time would be 0.18 years or 66 days. At 100 gallons per hour, the minimum time would be 6.6 days.

4.2.1.5 Migration of Dissolved Petroleum in Basal Aquifer to Drinking Water Wells

Once dissolved in the basal aquifer, hydrocarbons will migrate along groundwater flow lines. Fate and transport mechanisms include advection with moving groundwater, hydrodynamic dispersion causing mixing with the basal aquifer, retardation as equilibrium partitioning between solid and liquid phases, and degradation due to natural processes, known as natural attenuation. These complex mechanisms were evaluated through the development of a 3-D groundwater flow model based on MODFLOW 2000 (Appendix L), and a 3-D reactive transport utility to assess natural attenuation (Appendix M).

4.2.1.6 Natural Attenuation of Petroleum in the Basal Aquifer Beneath the Facility

Natural attenuation was evaluated based on measurements of natural attenuation parameters (NAPs) in the groundwater collected from the project wells. The study showed that both aerobic and anaerobic degradation are strong components of the geochemical groundwater system in the basal aquifer beneath the Facility. Natural attenuation was quantitatively evaluated to determine site-specific risk based levels for chemicals using a numerical transport model described in Section 4.3.5.1 and in Appendix M of this document. Natural attenuation is described analytically for a qualitative understanding of its importance in the paragraphs below.

Dissolved oxygen (DO) is the key aerobic NAP and aerobic degradation of fuel hydrocarbons is a major mechanism in natural attenuation of petroleum because:

- Aerobic degradation occurs very quickly compared to groundwater particle velocities;
- DO must be depleted in the groundwater before the anaerobic microbes become active and anaerobic degradation occur; and
- Approximately 1 mg/L of BTEX can be degraded per 3 mg/L of dissolved oxygen in the inflowing groundwater.

There is strong evidence that aerobic degradation of fuel hydrocarbons is occurring in the basal groundwater beneath the Facility as shown in Table 4.1. DO in the background well (RHMW04) was 8 mg/L, indicating an aerobic assimilative capacity to degrade about 2.6 mg/L of BTEX. In general, the Facility wells were depleted of DO, with the smallest amount associated with the central plume at RHMW02 while a slight rebound was observed in the down plume well (RHMW01). This is evidence of aerobic degradation in which the metabolic activity uses the available oxygen to degrade the petroleum until oxygen is no longer available. At this point aerobic degradation stops and anaerobic activity begins.

Two categories of anaerobic NAPS were evaluated. Nitrate and sulfate are metabolized during anaerobic degradation of fuel hydrocarbons, whereas ferrous iron and methane are produced (byproducts) during certain types of anaerobic degradation. Ferrous iron is the byproduct of the breakdown of ferric iron in anaerobic degradation and thus is limited by the amount of ferric iron available, and methane is produced in a perpetuating process known as methanogenesis.

Concentrations of anaerobic NAPs in the background well are interesting in that they do not represent the ideal ambient groundwater conditions. Ambient concentrations of nitrate, sulfate, ferrous iron and methane are expected to be about 1 mg/L, 25 mg/L, 0 mg/L and 0 mg/L respectively. The background well was somewhat depleted in nitrate (0.5 mg/L) and sulfate (9.6 mg/L); contained a small amount of ferrous iron (0.03 mg/L); and as expected, methane was not detected. In addition, RHMW04 contained a small concentration of petroleum (338 μg/L) in the first sampling event in September of 2005. Otherwise, concentrations of anaerobic NAPs in Facility wells were as expected for an anaerobically degrading petroleum plume. Nitrate and sulfate were mostly utilized and the ferrous iron concentration was greatest in the downgradient well (RHMW01). The methane concentrations were greatest in RHMW02, indicating the most strongly reducing environment where methanogenesis was expected to occur.

As with DO, anaerobic NAPs are expected to degrade petroleum at specific ratios, based on the stoichiometry of the chemical formula for degradation.

- The nitrate to BTEX degradation ratio is about 4.9 mg/L nitrate to degrade 1 mg/L of BTEX. Maximum nitrate available to be utilized was 1.1 mg/L at RHMW03, which would result in a nitrate assimilative capacity of about 0.22 mg/L of BTEX.
- The sulfate to BTEX degradation ratio is about 4.7 mg/L nitrate to degrade 1 mg/L of BTEX. Maximum sulfate available to be utilized was 27.8 mg/L at RHMW03, which would result in a sulfate assimilative capacity of about 5.9 mg/L of BTEX.
- The ferrous iron to BTEX degradation ratio is about 21.8 mg/L ferrous iron produced in the degradation of 1 mg/L of BTEX. Maximum ferrous iron produced was 3.1 mg/L at RHMW01, which would result in a ferrous iron assimilative capacity of about 0.14 mg/L of BTEX.
- The methane to BTEX degradation ratio is about 0.78 mg/L methane produced in the degradation of 1 mg/L of BTEX. Maximum methane produced was 1.4 mg/L at RHMW01, which would result in a methane assimilative capacity of about 1.8 mg/L of BTEX.; however, methanogenesis is theoretically not limited.
- Assuming the NAPs are all available for biodegradation of fuel, the total assimilative capacity of the aquifer beneath the Red Hill Facility is the summation of the individual assimilative capacities, or 10.6 mg/L of BTEX. For a plume of mid-range fuel such as JP-5, an estimate of the relative assimilative capacity is about 70 percent of that of BTEX; therefore, the assimilative capacity would be about 7.1 mg/L in the groundwater beneath the Facility.

Table 4-1. Measured NAP Concentrations from the Natural Attenuation Study

Parameter	RHMW04 (Background) (mg/L)	RHMW03 Up Plume (mg/L)	RHMW02 Central Plume (mg/L)	RHMW01 Down Plume (mg/L)	Well 2254-01 Down Gradient (mg/L)
Dissolved Oxygen	8.0	1.8	1.2	1.9	8.3
Nitrate	0.5	1.1	0.2	0.0	0.6
Ferrous Iron	.03	0.9	2.5	3.1	0.1
Sulfate	9.6	27.8	12.5	0.5	NT
Methane	0.0	0.0	1.4	.08	NT

NT – not taken

mg/L – milligrams per liter

4.3 Conceptual Site Model

The main sources of petroleum from the Facility include the 20 tanks and associated piping which hold petroleum products. The Facility began operating in 1943 and has the capacity to hold approximately 250mgal of fuel. The tank storage system is comprised of two parallel rows of vertical tanks sloping south southeast towards Pearl Harbor. The tanks are installed into native basalt, each measuring 245 ft in height and 100 ft in diameter. The tanks are located approximately 100 to 120 ft above msl, with ground surface elevation ranging from approximately 440 ft msl above Tank 1 to 560 ft msl above Tank 20. The tanks are accessed by interconnected tunnels. The pipelines extend 2.5 miles from the tanks to Pearl Harbor.

The CSM presented in the IWWP has been updated based on the recent investigative work. This includes the following.

- Eighteen SVMPs were installed beneath 7 USTs in previously drilled slant boreholes. Results indicate several SVMPs have elevated vapor concentrations, which may indicate releases.
- Two wells in the lower access tunnel of the Facility and a background well up-gradient in South Halawa Valley were installed.
- Seven wells in the network have been surveyed, including RHMW2254-01, for absolute coordinates to provide water table measurements relative to msl throughout the well network.
- A quarterly groundwater sampling program was initiated for petroleum-based chemicals, with 2 rounds of geochemistry for a natural attenuation pilot study. In addition, these 2 rounds were validated for risk assessment and decision-making. Results indicate that petroleum has migrated to the basal groundwater, but there is no evidence of LNAPL. Also there is no evidence of petroleum in the U.S. Navy well 2254-01 .
- A localized groundwater model was developed based on a detailed stratigraphic assessment of the nearby valley fills to assess the impact of these on groundwater flow in the Red Hill basin.
- A detailed assessment of the fate and transport characteristics of JP-5, the most mobile fuel that is currently being stored at the Facility was conducted to estimate the affect of these kerosene-like fuels on the groundwater resource.
- Fate and transport simulations were conducted using the detailed flow model and reactive transport modeling utilities to evaluate natural attenuation mechanisms in the aquifer.

4.3.1 Vadose Zone Evaluation Using Soil Vapor Monitoring Points

Seven out of 20 USTs were fitted with SVMPs during the pilot study. SVMPs from 5 of the 7 USTs showed elevated petroleum vapor, greater than 250 $\mu g/m^3$ of total VOCs. Based on these measurements, the soil vapor transport pathway is evaluated in the risk assessment. In addition, these results indicate that SVMPs may be useful as leak detection devices.

4.3.2 Groundwater Evaluation Using Monitor Wells

One existing well (RHMW01) and two new wells (RHMW02 and RHMW03) were installed into the basal aquifer within the lower access tunnel of the Facility. Petroleum was observed in samples from each well, with the highest concentrations measured at RHMW02, located adjacent to Tanks 5 and 6. No petroleum concentrations measured was at the solubility limit of JP-5 (approximately 5 mg/L), which would indicate the presence of LNAPL; however TPH from groundwater at RHMW02 was consistently greater than 2.5 mg/L. Low concentrations observed at the assumed down-gradient well (RHMW01) indicates that dissolved petroleum is not migrating offsite at levels of concern.

As described in detail in Section 4.3.2, methane was observed in groundwater samples from 2254-01, RHMW01, RHMW02 and RHMW03. Methane is an indicator compound for active anaerobic biodegradation of petroleum. Methane's presence can imply that microbial activity is anaerobically degrading the petroleum dissolved in groundwater, up-gradient from each of these locations. Anaerobic degradation is expected to occur only after aerobic degradation has used up all the available dissolved oxygen in the groundwater. The presence of methane can also indicate that biodegradation is an active process in the groundwater beneath the Facility.

4.3.3 Water Table Potentiometric Surfaces from Well Measurements

The water table surface is strongly influenced by pumping within the Red Hill basin. Gradients measured during the time when U.S. Navy well 2254-01 was off (May 12 to 19, 2006) were nearly directly south. When the pump was activated (May 20 to 26, 2006), the gradient shifted to the west, in the direction of the well 2254-01 (approximately 240 to 245 degrees from north). These gradients were not in agreement with the common scientific expectation, which estimates that groundwater would flow nearly parallel to the valley fill boundaries, at approximately 230 to 240 degrees from north, in both pump-on and pump-off periods.

As illustrated in Figure 4-1, the bottoms of the Tanks and the groundwater beneath the Facility are deeper than the adjacent valley floors. Releases from the tanks will not migrate to surface seeps in the vicinity of the Facility, therefore direct contact to product will not be expected from seeps to surface soil, surface water or sediments in nearby streams.

4.3.4 Groundwater Flow Characteristics from the Numerical Flow Model

The localized flow model was calibrated to regional recharge and groundwater flow assumptions from Giambelluca (1983) and Shade and Nichols (1996), and updated for current land use (Rotzoll and El-Kadi, 2006). Flow characteristics simulated those presented in the literature (Nichols et. al, 1996 [USGS Professional Paper 1412-A]; Oki, 1998 [WRIR 97-4276]) illustrated in Figure 1-9. However, these flow vectors were based on estimates in the vicinity of the Facility, since previously there were no monitoring points available there. The simulated groundwater contours are provided in Figure 2-7, based on average recharge and pumping between 1996 and 2005. The groundwater particle velocity in the basal aquifer beneath the Facility in the simulations was approximately 9.2 ft/day near the water table and increased near the infiltration gallery.

Figure 4-2 illustrates the local model simulated ten-year capture zones for area potable water wells. For the U.S. Navy well 2254-01, all groundwater is collected from within the South Halawa Valley fill and Moanalua Valley fill, according to these simulations. For HBWS Halawa Shaft (2254-01), groundwater particles are collected from west of the North Halawa Valley fill, and for HBWS Moanalua wells (2153-10, -12 and -22), groundwater particles are collected from east of the Moanalua Valley fill. Figure 4-1, the CSM illustrates how the valley fills are barriers to groundwater flow.

4.3.5 Evaluation of Fuel Sources

According to records, the main fuel types stored at the Facility have been diesel oil, NSFO, ND, JP-5, JP-8 and F-76; except for Tank 17, which contained AVGAS and MOGAS between 1964 and 1969; and Tank 18, which contained AVGAS between 1964 and 1968. AVGAS and MOGAS are highly volatile fuels, which present potential explosion concerns within the enclosed tunnels of the Facility. AVGAS and MOGAS are gasoline-based fuels which have a much higher concentration of highly soluble and mobile compounds known as aromatic hydrocarbons, than do kerosene- and diesel-based fuels. BTEX are examples of aromatic hydrocarbons that can be easily degraded in groundwater at low concentrations, but will migrate large distances at higher concentrations. The U.S. Navy does not have current plans to store AVGAS or MOGAS at the Facility in the future. Currently, JP-5, which is a kerosene-based fuel, is the most volatile and mobile fuel stored at the Facility.

According to the TPH Criteria Working Group Series, Volume 2 (TCWG, 1998), gasoline contains approximately 35% aromatic hydrocarbons, of which 19% is BTEX. Comparatively, JP-5 contains approximately 6.8% aromatic hydrocarbons, less than 1% BTEX, and less than 0.02% benzene and diesel-based fuels contain even less aromatic hydrocarbons. In addition, diesels and JP fuels do not contain lead or MtBE. An important mechanism is the solubility limit of a fuel at standard temperature and pressure, which is the highest concentration of petroleum hydrocarbons one can expect to dissolve in water. The solubility limits for gasoline and JP-5 are 93 mg/L and 4.5 mg/L, respectively. The solubility limit for benzene in JP-5 is 0.75 mg/L. These concentrations will only be reached if these fuels are in direct contact and at equilibrium with the groundwater table. The lower dissolved concentration resulting from JP-5 allows the fuel to be degraded by natural attenuation mechanisms, such as by the metabolism of natural microbes in the groundwater.

4.3.5.1 Reactive Transport Simulations

Natural attenuation mechanisms were simulated using the localized MODFLOW groundwater model and RT3D 3-D transport model utility. RT3D simulates the degradation of hydrocarbons based on the availability of aerobic and anaerobic electron acceptors within the aquifer and the stoichiometry required for natural microbial degradation. Details of these simulations are provided in Appendix M of this report. The main electron acceptors evaluated are dissolved oxygen, nitrate, ferric iron and sulfate. In addition, a process of anaerobic metabolism called methanogenesis was simulated, in which estimates of petroleum degraded can be made based on the amount of methane produce in the degradation process.

Measurements of dissolved oxygen, nitrate, sulfate, ferrous iron (a byproduct of ferric iron utilization) and methane were collected in the inflow groundwater from the up-gradient background well (RHMW04) and from the lower access tunnel wells (RHMW03, RHMW02 and RHMW01) to determine the availability of these natural attenuation parameters (NAPs). Petroleum constituent degradation rates for each NAP are considered site-specific characteristics that can be measured in the case of a large fuel release if sufficient monitoring points exist within the plume. However, measurable concentrations of petroleum constituents were limited to RHMW02, due to the limited number of wells beneath Facility and the distance between them. For this reason, literature values were used for degradation rates, based on a case study conducted at Hill Air Force Base (Guoping et. al., 1999) modeling BTEX degradation. Actual NAP concentrations were used to determine the amount of each available for biodegradation. The current simulations modeled the fate and transport of benzene, and TPH using the RT3D utility to evaluate natural attenuation (Appendix M).

In addition to natural attenuation, RT3D accounts for natural retardation and mixing due to hydrodynamic diffusion. In general, retardation is attributed to equilibrium partitioning of chemicals between the solid and liquid phase, and these mechanisms are driven by organic carbon content and clay content within the aquifer matrix. Since the aquifer of concern is within a fractured basalt matrix, retardation was not included in the simulation. Hydrodynamic diffusion was calculated by estimating the dispersivity of similar basalt cores from Central Oahu, and comparing the results to the literature value (Souza and Voss, 1987). Taking the geometric mean of these measurements gave a longitudinal dispersivity of 112 ft. The transverse and vertical dispersivities were 11.2 ft and 1.12 ft, respectively.

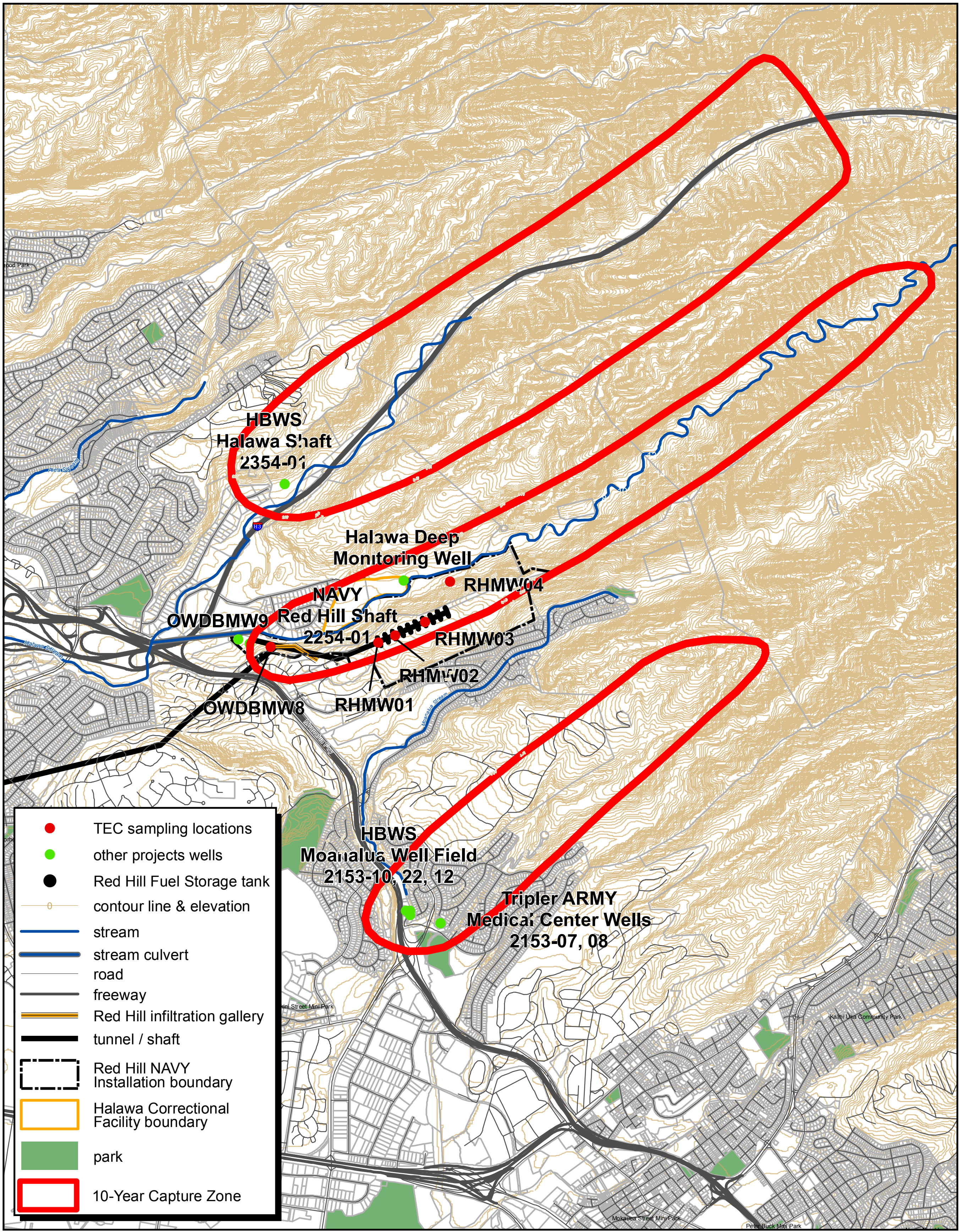
Simulations were conducted for benzene and TPH, with the goal of estimating the concentrations of these in the Facility monitoring wells that would result in exceedences of health based action levels at the down-gradient infiltration gallery of well 2254-01.

One set of simulations assumed that infiltrating groundwater from precipitation recharge contained the maximum concentration of benzene (0.75 mg/L) for a JP-5 fuel source. This fuel plume did not exceed the facility boundary. Figure 4-3 shows the simulated concentration contours for benzene for this scenario under static equilibrium conditions.

Another set of simulations assumed a constant source of dissolved petroleum of varying lengths and widths in the upper 20 feet of the water table. These were meant to represent fuel on groundwater with maximum solubility concentrations within the first 20 ft of the water table beneath the product. The result of these simulations indicated that a source consisting of product on groundwater directly beneath tank 1 would need to get within 500 ft of the infiltration gallery before the TPH concentrations would exceed 100 μg/L within the infiltration gallery; and within 1,099 ft before benzene concentrations exceed 5 μg/L within the infiltration gallery. Figure 4-4 and 4-5 show the simulated concentration contours for TPH and benzene, respectively for these exceedance scenarios under static equilibrium conditions.

These simulations indicated that:

- JP-5 dissolved in infiltrating leachate from the Facility will not impact the U.S. Navy well 2254-01 due to natural attenuation and hydrodynamic dispersion;
- Evidence of product on groundwater may indicate future degradation of the U.S. Navy well 2254-01;
- Evidence may include measurements of free-product in wells, dissolved concentrations of TPH exceeding 5 mg/L; or absence of nitrate, sulfate, dissolved oxygen and increasing concentrations of methane and ferrous iron concentrations.



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TEC inc

Figure 4-2
Local Model Ten-Year Capture Zones for Area Wells
Red Hill Fuel Storage Facility
Oahu, Hawaii

Meters
0 500 1,000
0 750 1,500 3,000
Feet

N

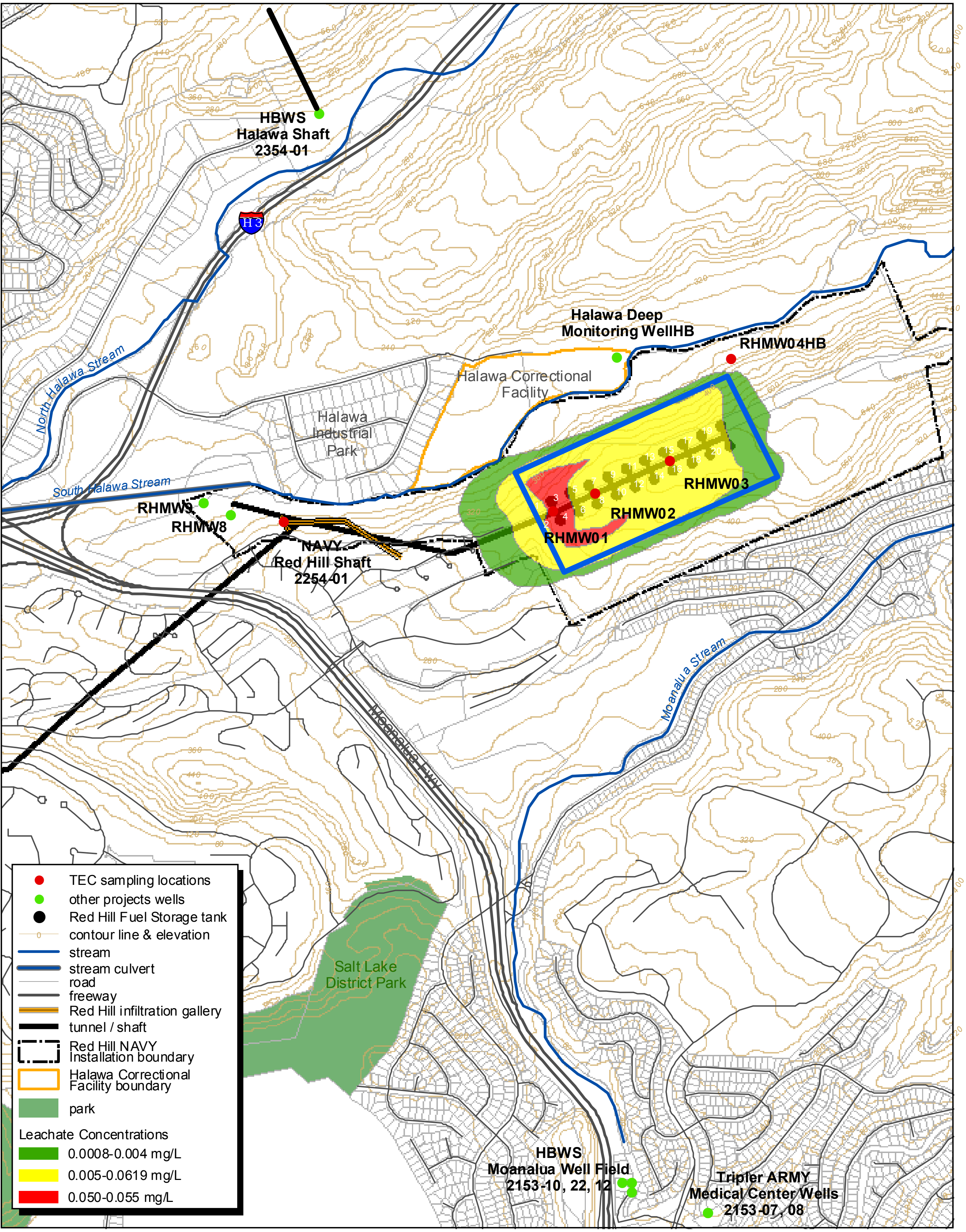

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Figure 4-3
Benzene Contours for the Maximum Leachate Scenario
Red Hill Fuel Storage Facility
Oahu, Hawaii

Meters
0 255 510
0 380 760 1,520
Feet

N

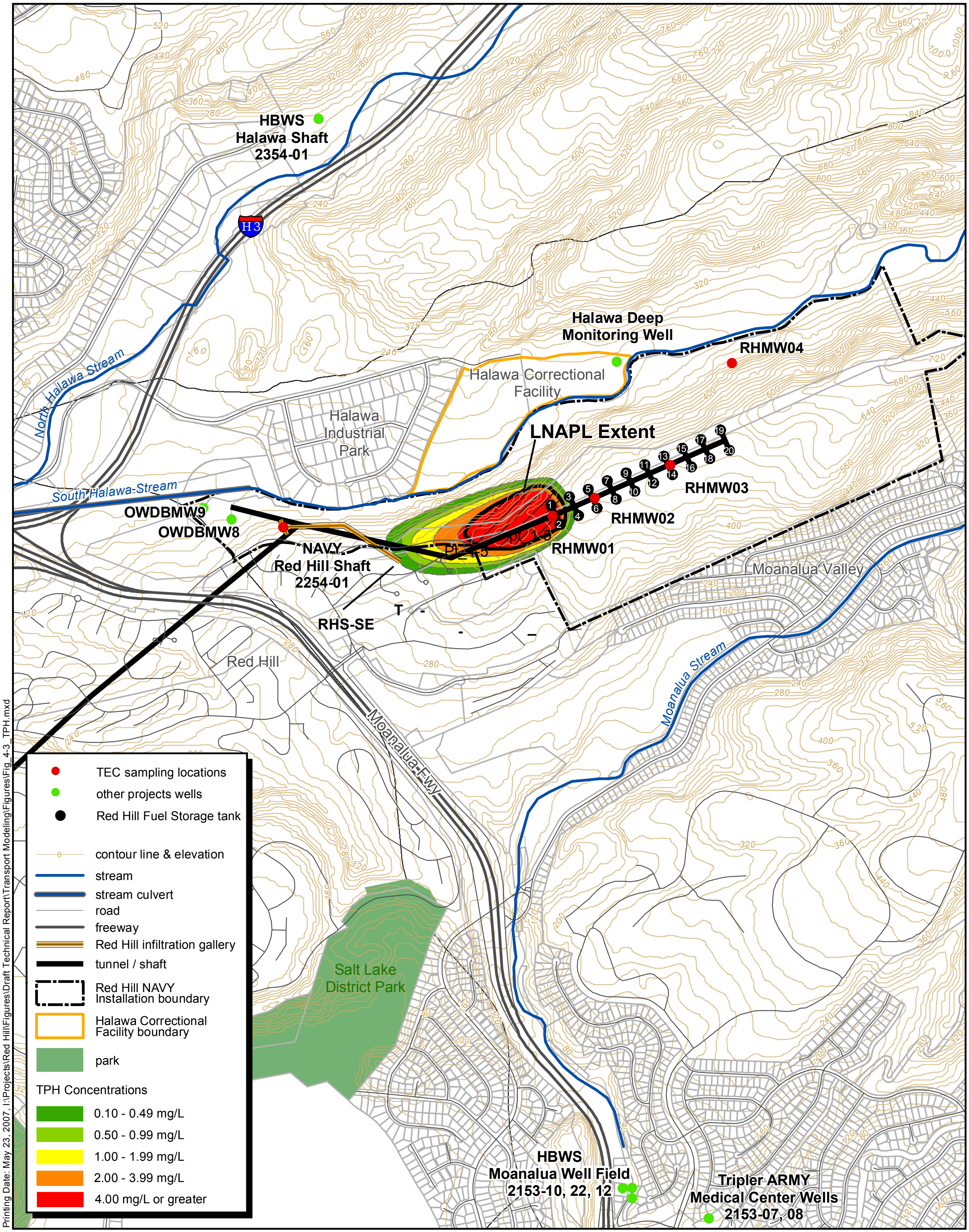

Figure 4-4
TPH Contours for the Exceedance Scenario
Red Hill Fuel Storage Facility
Oahu, Hawaii

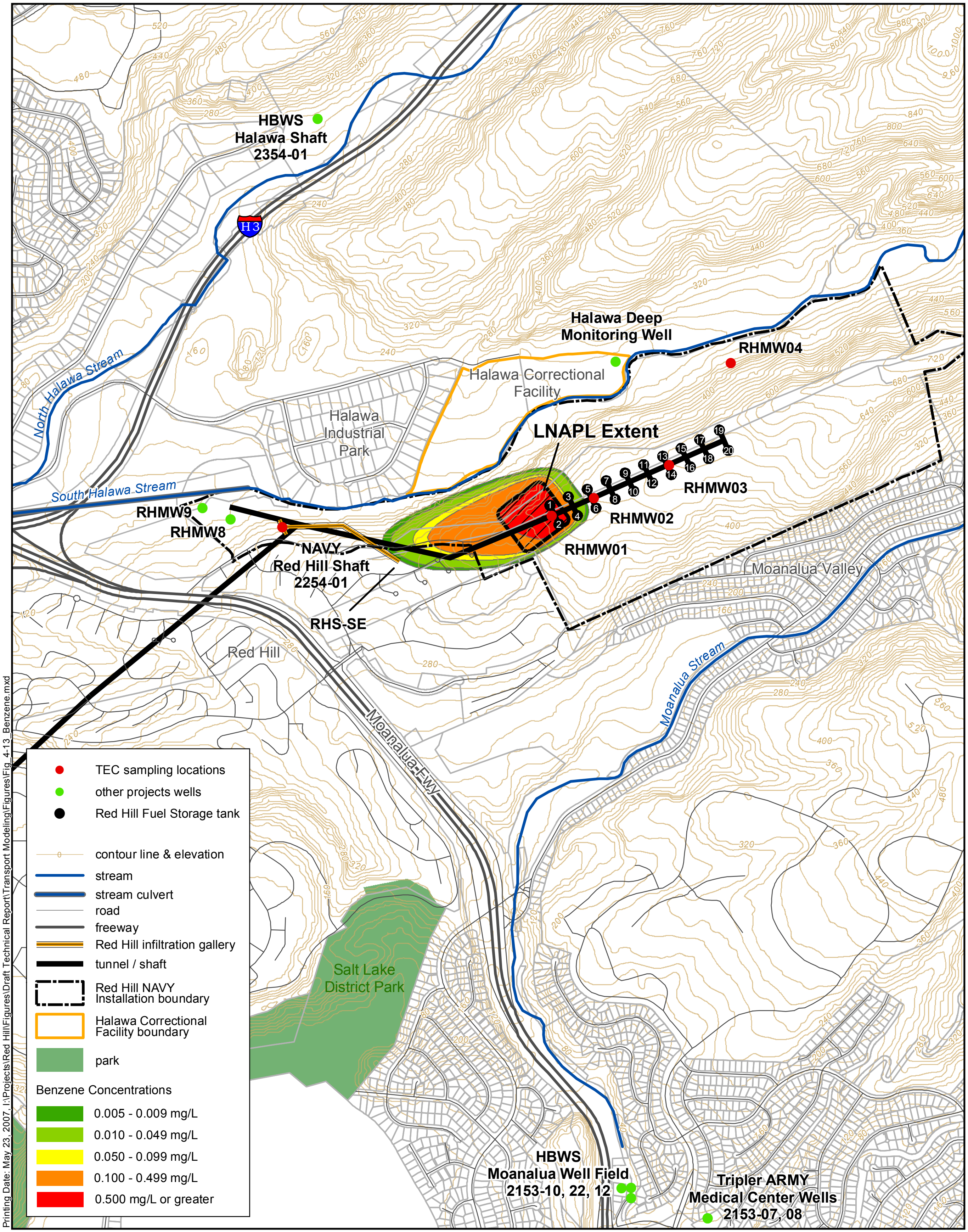

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Figure 4-5
Benzene Contours for the Exceedance Scenario
Red Hill Fuel Storage Facility
Oahu, Hawaii

TEC inc

Meters
0 245 490
0 370 740 1,480
Feet
N

SECTION 5
APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS AND TO-BE-CONSIDERED GUIDANCE

5.1 Definitions

Applicable or Relevant and Appropriate Requirements (ARARs). Applicable requirements refer to standards and other substantive environmental protection requirements promulgated under U.S. federal or Hawaii state laws that specifically address a circumstance at a hazardous waste site such as the presence of a hazardous substance, pollutant, contaminant, remedial action, or location. “Applicability” implies that the circumstances at the Facility satisfy all of the jurisdictional prerequisites of a requirement and are legally applicable for the Facility. Relevant and appropriate requirements refer to standards and other substantive environmental protection requirements promulgated under U.S. Federal or state law that are not legally applicable to a site but address situations sufficiently similar to be of use in evaluating the Facility. “Relevance” implies that the requirement regulates or addresses situations sufficiently similar to those found at the hazardous waste site. “Appropriateness” implies that the circumstances of a release or threatened release of chemicals are such that use of the standard is suitable. A requirement may be relevant but not appropriate for a site and therefore would not be an ARAR.

It is U.S. Navy policy that environmental investigations and removal actions be conducted in accordance with all applicable federal and state ARARs. TBCs may also be used as guidance for evaluating chemicals without ARARs or in situations where ARARs are not sufficiently protective of human health and the environment. ARARs/TBCs are used to determine the scope and extent of cleanup for a site. They help to formulate remedial action alternatives as well as govern the implementation and operation of a selected action.

To-Be Considered (TBC) Benchmarks. TBCs are non-promulgated advisories, guidances or benchmarks that are not generally enforceable. Where no specific ARARs exist for a chemical or situation, or where such ARARs are not sufficient to be protective, guidance documents or advisories may be considered in determining the necessary cleanup level for the protection of human health or the environment. Levels of concern developed during a risk assessment are considered TBCs.

5.2 ARARs and TBCs for the Facility

Based upon the current knowledge of the Facility and the CSM (Section 4), the state and Federal ARARs that apply to the Facility include those relating to drinking water, potable water systems, environmental response and contingency plans, and USTs. They are described in the paragraphs below.

5.2.1 Description of ARAR Regulations

Drinking Water

Title 40 of the Code of Federal Regulations (CFR), Part 141, *The National Primary Drinking Water (NPDW) Regulations*, carry out provisions of the United States, Safe Drinking Water Act

(SDWA). The SDWA and NPDW regulations establish maximum contaminant levels (MCLs) for various substances in potable water.

The HDOH, SDWB implement the HAR, Title 11, Chapter 20, Rules Relating to Potable Water Systems. The Rules establish MCLs for certain chemicals in public and private drinking water systems. These MCLs are analogous to the NPDW regulations.

Environmental Response Law and State Contingency Plan

The HERL (HAR, Title 19, Chapter 128D) and the SCP (HAR, Title 11, Chapter 451) are intended to identify releases and other situations that may endanger public health or welfare, the environment, or natural resources; prescribe notification requirements; and establish methods to address such releases. The SCP is intended to address contaminants and releases not addressed by other State of Hawaii Laws and Rules. The SCP establishes reportable quantities for hazardous substances, pollutants and contaminants for release purposes. The HERL definition of a hazardous substance includes petroleum.

Methods and criteria for investigations and response actions conducted under the SCP are described in the *Technical Guidance Manual (TGM) for the Implementation of the Hawaii SCP (HDOH, 1997)*. The TGM indicates that the following four criteria should be evaluated to determine whether further action is necessary for a site:

- There has been no release of a hazardous substance, pollutant, or contaminant to the environment.
- There is no threat of release of a hazardous substance, pollutant, or contaminant to the environment.
- The Facility is adequately characterized, and no hazardous substances remain on site, or no significant threat to human health or the environment exists.
- Response actions are complete, and adequate measures have been taken to protect human health and the environment.

The State of Hawaii UST Regulations

The Resource Conservation and Recovery Act (RCRA), established in 1979 and amended with the Hazardous and Solid Waste Amendments of 1984, established a comprehensive regulatory program for USTs. The State of Hawaii adopted its own UST statutes and regulations (Hawaii Revised Statutes [HRS], Title 19, Chapter 342L and HAR, Title 11, Chapter 281, Subchapters 1 through 10) to implement these laws in Hawaii. Owners and operators of USTs that contain regulated substances, such as petroleum are required to take specific actions when investigating releases from their USTs. Petroleum is specifically excluded from the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) definition of a hazardous substance (42, United States Code 9601(14)), therefore CERCLA is not applicable for the Facility, unless there is a release of a hazardous substance that is not petroleum-related. The TGM-UST (March, 2000), implements the UST regulations.

The 20, 12.5-Mgal USTs are deferred from subchapters 1 through 6 and 8 through 10 of HAR, Title 11, Chapter 281 because they are field constructed tanks. Subchapter 7, Release Response Action is not deferred. The U. S. Navy's current response actions are based on direct consultation with the HDOH Solid and Hazardous Waste Branch, UST Section, in order to comply with the requirements of Subchapter 7. These include the following:

- **Immediate Response Actions**, such as reporting the release; mitigating immediate safety hazards; removing the source of the release; and minimizing the spread of contaminants.
- **Initial Abatement Measures and Site Assessment,** such as removal of the source as necessary, prevent spreading to surrounding environment and monitor and remedy hazards from the release, investigate for free product and remove as practical; conduct an investigation of surrounding migration pathways for possible migration offsite, dispose of contaminated material in accordance with local, State and Federal requirements.
- **Initial Site Characterization**, including nature and extent of contamination; potential receptors, land and water usage, climate, geology, and hydrology, results of free-product investigation, and other information to assist in the evaluation of risk.
- **Free-Product Removal**, to the extent practical, in a manner that minimizes spread of contamination and maximizes removal, using methods appropriate to the site hydrogeology and safety conditions, document in quarterly reports.
- **Develop Clean Up Criteria,** Default Tier 1 Standards are documented in HAR section 11-281-80 or 2005 EAL Standards for Tier 1 Cleanups or site-specific standards derived from Tier 3 fate and transport analysis and risk assessment.
- **Public Notification of Confirmed Releases,** within 90-days of confirmation of release directly affected members of the public shall be notified of the release and the proposed response action with a letter and fact sheet.
- **Corrective Action Plan,** may be required if the release is to groundwater or surface water that is a drinking water supply, air or soil that poses a direct contact hazard to the public, or adverse impact to natural resources, or danger of fire or explosion, or risk to public health or the environment. Upon approval of the plan, the plan must be implemented along with any modifications from the UST division of HDOH, and implementation must be monitored with quarterly reporting requirements.
- **Public Participation in Corrective Action Plan,** may be required when proposed plan is controversial or cleanup goals have not been achieved and termination of clean up activities are proposed, and costs shall be paid by the owner/operator.
- **Reporting and recordkeeping,** a Release Response Action Report must be submitted within 90 days of confirmation of release along with description of future actions anticipated, and quarterly reports must follow on 90-day intervals. Quarterly Reports are not required if response actions have met the requirements of this subchapter and a final Quarterly Report has been submitted.

5.2.2 Description of TBC Guidance

USEPA Preliminary Remediation Goals

According to USEPA (2006) Preliminary Remediation Goals (PRGs) are:

> *tools for evaluating and cleaning up contaminated sites. They are risk-based concentrations that are intended to assist risk assessors and others in initial screening-level evaluations of environmental measurements. The PRGs contained in the Region 9 PRG Table are generic; they are calculated without site specific information. However, they may be re-calculated using site specific data.*

and

> *PRGs should be viewed as Agency guidelines, not legally enforceable standards. They are used for site "screening" and as initial cleanup goals if applicable. PRGs are not de facto cleanup standards and should not be applied as such. However, they are helpful in providing long-term targets to use during the analysis of different remedial alternatives.*

Screening for Environmental Concerns at Sites with Contaminated Soils and Groundwater (HDOH, 2005)

TBC guidance is considered in determining the necessary level of cleanup to protect human health or the environment where no specific regulatory standards exist for a chemical or situation, or where such standards are insufficiently protective. Under the risk assessment process conducted in support of a UST site characterization, EALs, rather than the 1995 action levels in HAR, Title 11, Chapter 281, subchapter 78 can be used to screen for COPC as described in *Screening For Environmental Concerns At Sites With Contaminated Soil and Groundwater* (HDOH, 2005b) while the 1995 action levels in HAR, Title 11, Chapter 281, subchapter 78 are being updated (HDOH, 2005b).

According to the HDOH (2005b):

> *The EALs are considered to be conservative. Under most circumstances, and within the limitations described, the presence of a chemical in soil, soil gas or groundwater at concentrations below the corresponding EAL can be assumed to not pose a significant, long-term (chronic) threat to human health and the environment. Additional evaluation will generally be necessary at sites where a chemical is present at concentrations above the corresponding EAL. Active remediation may or may not be required, however, depending on site-specific conditions and considerations.*

and

> *The EALs are intended to serve as an update and supplement to the HDOH document Risk-Based Corrective Action and Decision Making at*

> *Sites With Contaminated Soil and Groundwater (June 1996). The change in terminology from "Risk-Based Action Levels" to "Environmental Action Levels" is intended to better convey the broad scope of the document and clarify that some action levels are not "risk-based" in a strict toxicological definition of this term. Use of the EALs is recommended not mandatory.*

The HDOH action levels consider numerous criteria from various sources. As stated by the HDOH (2005) the EALs expand the screening of USEPA Region 9 PRGs by:

- Addition of soil and groundwater action levels for indoor-air impact concerns;
- Addition of groundwater action levels for the protection of aquatic habitats/surface water quality;
- Use of a more rigorous leaching model to develop soil action levels for protection of groundwater quality;
- Addition of soil action levels for urban area, ecological concerns;
- Addition of soil and groundwater "ceiling levels" to address gross contamination and general resource degradation concerns;
- Addition of soil and groundwater action levels for TPH; and
- Addition of direct-exposure action levels for construction and trench workers' exposure to subsurface soils.

5.3 Comparison of Site Chemical Concentrations to ARARs and TBCs

In addition to comparing results to ARARs and TBCs, results exceeding one-tenth of direct exposure EALs are listed so that they can be evaluated for cumulative toxicity concerns. Any results exceeding these values are retained for analysis in the risk assessment.

5.3.1 Soil Gas

No quantitative ARARs were found to apply to soil gas at the Facility. There are TBCs as follows:

- HDOH EALs for shallow soil gas for the evaluation of potential vapor intrusion concerns (commercial/industrial land use).

No TBC for soil gas was exceeded. However, for some compounds there were no EALs. These results are shown in Table 5-1. These substances will be retained for analysis in the risk assessment.

5.3.2 Soil

No quantitative ARARs were found to apply to soils at the Facility. There are TBCs and they were used to evaluate several different exposure scenarios for soil:

- USEPA Region 9 PRGs for Residential Soil - Exposure to soil contaminants (situated from zero to ten (10) feet bgs) considering inhalation, dermal absorption, and ingestion;
- HDOH EALs for Soil Contaminants Leaching to Groundwater that is a Source of Drinking Water or that is Not a Source of Drinking Water.

No TBC for soil was exceeded. Comparisons of measured concentrations to TBCs can be found in Appendix O (Risk Assessment).

5.3.3 Groundwater

Groundwater classification to determine potential uses of groundwater has been discussed in Section 3.2.2.1. Specific quantitative ARARs and TBCs were used to evaluate several different exposure scenarios for groundwater. These include the following:

- USEPA Region 9 PRGs for Residential Exposure to Tapwater (TBC) – Exposure to tapwater considering inhalation, dermal absorption, and ingestion;
- National Primary Drinking Water Regulations as MCLs (ARAR);
- Hawaii Potable Water Standards (ARAR);
- HDOH EALs (in addition to those drinking water standards listed above) for groundwater that is a potential source of drinking water and for which a surface water body is not located within 150 meters of the Facility and rainfall is less than 200 cm/year (TBCs).

Instances where detected concentrations of contaminants in groundwater sampled at the Facility exceed the relevant quantitative ARAR/TBCs or one-tenth the direct exposure levels for groundwater are shown in Table 5-2. These substances will be retained for analysis in the risk assessment.

Table 5-1. Soil Gas Screening Tables
Red Hill Fuel Storage Facility
Oahu, Hawaii

						ARARS or TBCs			Other
Method	**Substance**	**Location**	**Sample Conc.**	**Q**	**Units**	**Table C-2 Lowest Residential Soil Gas[1]**	**Table C-2 Lowest Comm_Ind Soil Gas[2]**	**EPA PRG for Air[3]**	**One-tenth Lowest Residential Soil Gas in Table C-2**
TO-15	1,1,2,2-TETRACHLOROETHANE	RHSV06-15-35	29		µg/m^3	34	140	**0.033**	**3.4**
TO-15	1,2,4-TRIMETHYLBENZENE	RHSV06-15-35	105.5		µg/m^3				
TO-15	1,2,4-TRIMETHYLBENZENE	RHSV06-40-56	6.5		µg/m^3				
TO-15	1,2,4-TRIMETHYLBENZENE	RHSV11-13-30	12		µg/m^3				
TO-15	1,2,4-TRIMETHYLBENZENE	RHSV11-40-131	49		µg/m^3				
TO-15	1,2,4-TRIMETHYLBENZENE	RHSV12-15-40	40		µg/m^3				
TO-15	1,2,4-TRIMETHYLBENZENE	RHSV14-46-73	9		µg/m^3				
TO-15	1,2,4-TRIMETHYLBENZENE	RHSV14-79-110	5.4		µg/m^3				
TO-15	1,2,4-TRIMETHYLBENZENE	RHSV16-15-40	3.4		µg/m^3				
TO-15	1,3,5-TRIMETHYLBENZENE	RHSV06-15-35	87		µg/m^3			**6.2**	
TO-15	1,3,5-TRIMETHYLBENZENE	RHSV11-40-131	14		µg/m^3			**6.2**	
TO-15	1,3,5-TRIMETHYLBENZENE	RHSV12-15-40	11		µg/m^3			**6.2**	
TO-15	1,3,5-TRIMETHYLBENZENE	RHSV14-46-73	42		µg/m^3			**6.2**	
TO-15	1,4-DICHLOROBENZENE	RHSV06-15-35	5.5	U	µg/m^3	310	1300	**0.31**	31
TO-15	1,4-DICHLOROBENZENE	RHSV11-13-30	5.6		µg/m^3	310	1300	**0.31**	31
TO-15	1,4-DICHLOROBENZENE	RHSV11-40-131	14		µg/m^3	310	1300	**0.31**	31
TO-15	1,4-DICHLOROBENZENE	RHSV14-79-110	7.6		µg/m^3	310	1300	**0.31**	31
TO-15	1,4-DICHLOROBENZENE	RHSV16-15-40	4		µg/m^3	310	1300	**0.31**	31
TO-15	4-ETHYLTOLUENE	RHSV06-15-35	69		µg/m^3				
TO-15	4-ETHYLTOLUENE	RHSV06-40-56	3.8		µg/m^3				
TO-15	4-ETHYLTOLUENE	RHSV11-13-30	7.1		µg/m^3				
TO-15	4-ETHYLTOLUENE	RHSV11-40-131	31		µg/m^3				
TO-15	4-ETHYLTOLUENE	RHSV12-15-40	28		µg/m^3				
TO-15	4-ETHYLTOLUENE	RHSV14-46-73	45		µg/m^3				
TO-15	BENZENE	RHSV06-15-35	3.4	U	µg/m^3	250	1100	**0.25**	25
TO-15	BENZENE	RHSV12-15-40	2.6		µg/m^3	250	1100	**0.25**	25
TO-15	BENZENE	RHSV14-46-73	16		µg/m^3	250	1100	**0.25**	25
TO-15	BENZENE	RHSV16-15-40	2.1		µg/m^3	250	1100	**0.25**	25
TO-15	BENZENE	RHSV16-46-73	3.6		µg/m^3	250	1100	**0.25**	25
TO-15	BENZYL CHLORIDE	RHSV06-15-35	12	U	µg/m^3			**0.04**	
TO-15	CYCLOHEXANE	RHSV06-15-35	7.6		µg/m^3				
TO-15	CYCLOHEXANE	RHSV12-15-40	6.2		µg/m^3				
TO-15	CYCLOHEXANE	RHSV14-46-73	4.4		µg/m^3				
TO-15	ETHANOL	RHSV02-79-110	36		µg/m^3				
TO-15	ETHANOL	RHSV11-40-131	8		µg/m^3				
TO-15	ETHANOL	RHSV14-46-73	11		µg/m^3				
TO-15	ETHANOL	RHSV14-79-110	12		µg/m^3				
TO-15	ETHANOL	RHSV16-15-40	91		µg/m^3				
TO-15	ETHANOL	RHSV16-46-73	12	UJ	µg/m^3				
TO-15	ISOPROPANOL	RHSV16-15-40	18		µg/m^3				

Table 5-1. Soil Gas Screening Tables
Red Hill Fuel Storage Facility
Oahu, Hawaii

Method	Substance	Location	Sample Conc.	Q	Units	ARARS or TBCs: Table C-2 Lowest Residential Soil Gas[1]	ARARS or TBCs: Table C-2 Lowest Comm_Ind Soil Gas[2]	ARARS or TBCs: EPA PRG for Air[3]	Other: One-tenth Lowest Residential Soil Gas in Table C-2
TO-15	n-HEPTANE	RHSV06-15-35	17		µg/m3				
TO-15	n-HEPTANE	RHSV11-40-131	4.4		µg/m3				
TO-15	n-HEPTANE	RHSV12-15-40	8.4		µg/m3				
TO-15	n-HEPTANE	RHSV14-46-73	8.6		µg/m3				
TO-15	TETRACHLOROETHYLENE(PCE)	RHSV02-46-73	7.6		µg/m3	320	1400	**0.32**	32
TO-15	TETRACHLOROETHYLENE(PCE)	RHSV16-79-110	6.6		µg/m3	320	1400	**0.32**	32
TO-15	TETRAHYDROFURAN	RHSV14-46-73	4.6		µg/m3			**0.99**	
TO-15	TETRAHYDROFURAN	RHSV14-79-110	4.7		µg/m3			**0.99**	
TO-15	TETRAHYDROFURAN	RHSV16-15-40	3.9		µg/m3			**0.99**	
TO-15	TETRAHYDROFURAN	RHSV16-79-110	9.1		µg/m3			**0.99**	

µg/m3 - micrograms per cubic meter
Q - data qualifier
U - Indicates the compound was analyzed for but not detected at or above the stated limit
J - Indicates an estimated value
UJ - Indicates the compound was analyzed for but not detected; the sample detection limit is an estimated value
1 Table C-2. Shallow Soil Gas Action Levels for Evaluation of Potential Vapor Intrusion Concerns, lowest expected Residential Exposure (HDOH, 2005)
2 Table C-2. Shallow Soil Gas Action Levels for Evaluation of Potential Vapor Intrusion Concerns, lowest expected Commercial Industrial Land Use Exposure (HDOH, 2005)
3 USEPA Preliminary Remediation Goals for Indoor Air (USEPA, 2004)
0.033- Indicates sample concentration exceeds the ARAR/TBC value

Table 5-2. Groundwater Screening Tables
Red Hill Fuel Storage Facility
Oahu, Hawii

							ARARS or TBCs			Other
Sample Round	**Method**	**Substance**	**Location**	**Sample Conc.**	**Q**	**Units**	**Table D-1B GW is DW, >150[1]**	**Basis**	**EPA PRG for Tapwater[2]**	**One_tenth Drinking Water Toxicity in Table D-2[3]**
R01	SW6010B	LEAD	RHMW01-GW01	19.6		µg/L	**15**	Drinking Water		**1.5**
R01	SW6010B	LEAD	RHMW03-GW01	8.5		µg/L	**15**	Drinking Water Toxicity		**1.5**
R01	SW8015B	TPH as DIESEL RANGE ORGANICS[a]	RHMW01-GW01	677		µg/L	**100**	Ceiling Value		**10**
R01	SW8015B	TPH as DIESEL RANGE ORGANICS[a]	RHMW02-GW01	1817.5		µg/L	**100**	Ceiling Value		**10**
R01	SW8015B	TPH as DIESEL RANGE ORGANICS	RHMW02-GW01	2660		µg/L	**100**	Ceiling Value		**10**
R01	SW8015B	TPH as DIESEL RANGE ORGANICS	RHMW03-GW01	162	J	µg/L	**100**	Ceiling Value		**10**
R01	SW8015B	TPH as DIESEL RANGE ORGANICS	RHMW04-GW01	338		µg/L	**100**	Ceiling Value		**10**
R01	SW8015B	TPH as GASOLINE RANGE ORGANICS[b]	RHMW01-GW01	77.4		µg/L	100	Ceiling Value		**10**
R01	SW8015B	TPH as GASOLINE RANGE ORGANICS[b]	RHMW02-GW01	983		µg/L	**100**	Ceiling Value		**10**
R01	SW8260B	NAPHTHALENE	RHMW02-GW01	301	J	µg/L	**6.2**	Drinking Water Toxicity	**6.2**	**0.62**
R01	SW8260B	TRICHLOROETHYLENE (TCE)	RHMW02-GW01	8.2		µg/L	**5**	Drinking Water Toxicity	**0.028**	**0.5**
R01	SW8270C	1-METHYLNAPHTHALENE	RHMW02-GW01	103		µg/L	**10**	Ceiling Value		**24**
R01	SW8270C	2-METHYLNAPHTHALENE	RHMW02-GW01	87.85		µg/L	**10**	Ceiling Value		**24**
R01	SW8270C	BENZO(a)ANTHRACENE	RHMW02-GW01	0.071		µg/L	**0.027**	Acute Aquatic Habitat Goal		**0.0092**
R01	SW8270C	BENZO(b)FLUORANTHENE	RHMW02-GW01	0.069	J	µg/L	0.092	Acute Aquatic Habitat Goal	0.092	**0.0092**
R01	SW8270C	NAPHTHALENE	RHMW02-GW01	121.5		µg/L	**6.2**	Drinking Water Toxicity	**6.2**	**0.62**
R02	SW8015B	TPH as GASOLINE RANGE ORGANICS	RHMW02-GW02	121.5	J	µg/L	**100**	Ceiling Value		**10**
R02	SW8015B	TPH as DIESEL RANGE ORGANICS	RHMW01-GW02	509		µg/L	**100**	Ceiling Value		**10**
R02	SW8015B	TPH as DIESEL RANGE ORGANICS	RHMW02-GW02	2795		µg/L	**100**	Ceiling Value		**10**
R02	SW8015B	TPH as DIESEL RANGE ORGANICS	RHMW03-GW02	142	J	µg/L	**100**	Ceiling Value		**10**
R02	SW8260B	METHYLENE CHLORIDE	RHMW02-GW02	24.9	J	µg/L	**4.3**	Drinking Water Toxicity	**4.3**	**0.43**
R02	SW8260B	NAPHTHALENE	RHMW02-GW02	339		µg/L	**6.2**	Drinking Water Toxicity	**6.2**	**0.62**
R02	SW8270C	NAPHTHALENE	RHMW02-GW02	175.5		µg/L	**6.2**	Drinking Water Toxicity	**6.2**	**0.62**
R02	SW8270C	1-METHYLNAPHTHALENE	RHMW02-GW02	137.5		µg/L	**10**	Ceiling Value		**24**
R02	SW8270C	2-METHYLNAPHTHALENE	RHMW02-GW02	66.45		µg/L	**10**	Ceiling Value		**24**

µg/L - micrograms per liter
Q - data qualifier
J - Indicates an estimated value
15 Bold value indicates an ARAR (Hawaii drinking water MCLs); other values are TBCs.

[a] The value for TPH-DRO was obtained by adding the results for the following extractable fractions: C9-C18 aliphatics, C19-C36 aliphatics, and C11-C22 aromatics; when one fraction was non-detect, one-half the RL was used to estimate its concentration.

[b] The value for TPH-GRO was obtained by adding the results for the following volatile fractions: C5-C8 aliphatics, C9-C12 aliphatics, and C9-C10 aromatics; when one fraction was non-detect, one-half the RL was used to estimate its concentration.

1 Table D-1B Grooundwater Action Levels (Groundwater is a Current or Potential Drinking Water Resource, Surfacce Water is not Located Within 150 m of the Release Site (HDOH, 2005)
2 USEPA Regin 9 Preliminary Remediation Goals for Tapwater (USEPA, 2004)
3 Table D-2 Summary of Driniking Water Action Levels for Human Toxicity (HDOH, 2005)
1.5 - Indicates sample concentration exceeds the ARAR/TBC value

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SECTION 6
RISK ASSESSMENT

6.1 Introduction

This Human Health Risk Assessment was conducted to assist risk managers with the decision-making process. This risk assessment was conducted in accordance with HDOH and USEPA guidance (HDOH, 2005; USEPA 1989). Other sources are cited where appropriate.

This risk assessment uses the terminology of Tiers as used by HDOH (2005). Thus, Tier 1 is the first level of screening, and the methodology (comparison to EALs) and results of this analysis have already been described in Section 5. This Section describes the Tier 2 and Tier 3 risk assessment that were completed for the Facility.

Information about the background of the Facility and the surrounding area and potential receptors are available in Section 1.1 (Location and Environmental Setting) and Section 4.1 (Conceptual Site Model) of this report.

6.2 Previous Risk Evaluation

A preliminary risk evaluation was completed for Red Hill by AMEC in February 2005 (TEC and AMEC, 2005). This risk evaluation is summarized below.

An initial risk screening conducted as part of an SI Report indicated that ethylbenzene, methylene chloride, 2-methylnaphthalene, naphthalene, phenanthrene, TPH (in the Carbon 10 to 28 range) and an unknown hydrocarbon were present in core samples at levels that constitute a potential concern (Ogden, 2002).

The exposure setting included the following information:

- Land uses in the vicinity of the Facility include military, residential, commercial and forest land.
- The Facility is located above the Underground Injection Control (UIC), which prohibits the use of injection wells.
- The Facility is located upgradient from a drinking water production well, U.S. Navy well 2254-01.
- Other wells in the area (from Halawa, Aiea and Kalihi) and were noted to have contained chlordane and dieldrin.

A conceptual site exposure model was developed which summarized the results of the refined exposure assessment. Major potential exposure pathways identified were:

- Use of potable water from the U.S. Navy Well 2254-01 by residential and occupational users; and
- Inhalation of volatile constituents in air in Facility tunnels by occupational users.

It was recommended in the preliminary risk evaluation that fate and transport analyses be conducted to further define the potential human health exposure pathways identified, especially those associated with the U.S. Navy well 2254-01, which provides between 4 and 16 mgd to the U.S. Navy for public consumption.

The preliminary risk evaluation concluded that there were no significant exposure pathways for ecological receptors and no sensitive species were noted in the immediate vicinity of the Facility (see Section 1.1 for additional description of biological resources). Groundwater containing dissolved petroleum constituents would not be released to surface water bodies because the groundwater table is approximately 80 feet below the streambeds in the adjacent valleys. Therefore, no additional ecological risk assessment has been performed in this document.

6.3 Selection of COPCs

6.3.1 Data Evaluation

Definitive data is defined as results from rock, soil gas and groundwater samples that were analyzed using USEPA analytical methods and underwent 100 percent data review and validation. All definitive data not qualified as unusable were used in this risk assessment. Although there were some matrix interference issues for soil, and groundwater, it was determined that additional sampling was unlikely to yield better results, so these results were deemed usable for this risk assessment. In addition to this data, enough other supporting data was available to make reliable risk conclusions.

For tallies and quantification purposes, the only modifications to the validated raw data were in cases where duplicate samples were taken. In cases where both samples had detects, the average of the samples were calculated and this value was used. In cases where a chemical was detected in one of the duplicate pair and not detected in the other, the detected value was used. Where the chemical was not detected in either of the duplicate pairs, the sample result with the highest reporting limit was used as the estimated value.

6.3.2 Selection of Final COPCs

The results of the ARAR and TBC screening in Section 5 were modified to remove ecological risk components and the results are the COPCs for human health risk. Those results exceeding the human health ARARs and TBCs are shown in Tables 5-1 and 5-2.

These COPCs are:

- Soil – none
- Air – none
- Groundwater – naphthalene, TPH-GRO, TPH-DRO, benzene, tetrachloroethylene, 1,2, dichloroethylene, trichloroethyelene, and lead.

The results of the risk screening of samples from the current investigation indicate that under the current scenario, the exposure concerns for soil and soil vapor are insignificant, since no compounds were observed above the Tier 1 Action Levels. However, several VOCs were observed in groundwater samples above the Tier 1 Action Levels, indicating that a site-specific evaluation should be conducted.

The maximum detected concentrations of these substances and their frequency of detection in the various media are shown in Table 3-1.

6.4 Tier 2 Risk Assessment

6.4.1 Risk Assessment Conceptual Site Model: Exposure Pathways and Receptors

6.4.1.1 Exposure Pathway Designations

The four elements of an exposure pathway are: contaminant source, transport mechanism, exposure medium and route, and receptor. The Conceptual Site Exposure Model (CSEM) in Figure 6-1 visually depicts the potential current and future exposure pathways at the Facility. Potential exposure pathways are designated as complete or potentially complete (major), complete or potentially complete (minor or insignificant), or incomplete. These designations are defined by the following criteria:

Complete (major) - All four elements of the exposure pathway are present, and the presence of contamination throughout the exposure pathway has been documented. Complete pathways are further evaluated.

Potentially Complete (major) – The first three elements of the exposure pathway may be present, depending on how the land or water resources are used in the future. The fourth element will depend on the types of future receptors that may use the Facility, or may be potentially exposed to the Facility contaminants. Potentially complete pathways are further evaluated.

Complete or Potentially Complete (minor or insignificant) - Based on previous assessments of similar scenarios, or where circumstances clearly indicate so, the risk associated with this type of complete pathway is insignificant in comparison with the pathways evaluated. Insignificant pathways are not evaluated any further.

Incomplete – At least one of the four elements of the exposure pathway (source, transport mechanism, exposure route, or exposure point), isn’t present. Incomplete pathways are not evaluated any further.

The following sections describe the CSEM and identifies complete exposure pathways. The description includes the sources and the environmental media to which potential exposure could occur, i.e., air, soil, and groundwater.

6.4.1.2 Current Pathways and Receptors

Vapor Migration

The number of workers in the tunnels at any time varies considerably. For fuel operations there are 1 to 2 people always on duty in 8 hour shifts. Depending on the type of maintenance activity, there may be one or more contractors working in the tunnels at any given time. Typically there are 10 to 20 workers and at times there are more than twice that many (Al Hoyle, personal communication). Volatile hydrocarbons have been measured in groundwater, rock and soil vapor in SVMPs adjacent to the lower access tunnel; however, the current concentrations did not exceed Tier 1 Action Levels.

Groundwater

Groundwater is not used directly beneath the Facility. Several potable water production wells are located down-gradient or cross-gradient from the Facility. HBWS Halawa Shaft (2354-01) is located hydraulically cross-gradient of the Facility approximately 5,000 feet to the northwest of the Facility. HBWS Moanalua wells (2153-10, -11 and -12) are located nearly directly south of the Facility. The potential for groundwater beneath the Facility to migrate to these wells is insignificant based on the ten-year capture zones derived from MODPATH simulations using the local groundwater flow model (see Section 4.3.4).

The U. S. Navy drinking water well 2254-01 is located approximately 3,000 feet to the west and hydraulically down-gradient from the Facility. The MODPATH ten-year capture zone indicated that well 2254-01 and the associated infiltration gallery intercepted a significant portion of the groundwater that passes beneath the Facility (see Section 4.3.4). Sample results from well 2254-01 did not indicate that this pathway is currently complete.

6.4.1.3 Future Pathways and Receptors

Soil and Groundwater Volatilization to Indoor Air Pathway

The Facility is scheduled to remain in operation for the foreseeable future. There are no plans known for any changes in use of the Facility. Use of the tunnels by workers is anticipated to be similar to its current use.

If additional releases were to occur in the future, hydrocarbon concentrations may exceed soil vapor action levels. Future hydrocarbons in the soil vapor can migrate into the Facility tunnels where workers would be exposed. The number of workers is not expected to change substantially from current numbers.

Volatile constituents measured in the SVMPs may be partitioning from LNAPL, hydrocarbons adsorbed to fractured rock, or from hydrocarbons dissolved in groundwater. LNAPL and hydrocarbons dissolved in groundwater may migrate to a distant location and volatilize. Vapor could then migrate into the Facility tunnels where workers would be exposed.

The potential for toxic compounds in soil gas originating from beneath the USTs and pipelines to migrate to nearby surface residential areas is extremely remote and considered insignificant. Nearest residents are more than 700 feet away from the USTs. Volatile compounds would be diluted, would partition to soil and soil moisture, and would be degraded prior to reaching these locations at concentrations of concern. Terrestrial receptors are not expected to be impacted by soil vapor based on similar rationale.

Future Installation of a Potable Water Well in the Vicinity of the Facility

The Facility will remain in the Pacific Fleet fuel reserve for the foreseeable future. Currently, groundwater directly beneath the Facility is not used, nor are there plans for future use. This Tier 2 risk assessment scenario was conducted assuming that the water under the site was developed as a residential drinking water source in order to evaluate the least restrictive land use as suggested by HDOH policy (HDOH 2005). The residential scenario incorporates child and adult exposure factors, and assumes an exposure duration of 30 years. Residents are typically the most highly exposed receptor in a risk evaluation.

Groundwater Migration Pathway to U.S. Navy Well 2254-01

Modeling indicated that LNAPL must migrate from the USTs in sufficient quantity to produce a large secondary source of LNAPL on the groundwater table in order for petroleum to degrade the drinking water at U.S. Navy well 2254-01. In this potential future scenario, once LNAPL reaches the water table soluble constituents will dissolve at concentrations near or at their maximum equilibrium solubility limit. These maximum concentrations (4.5 mg/L TPH and 0.75 mg/L benzene for JP-5) will migrate further, based on advection, hydrodynamic dispersion, retardation, and degradation mechanisms within the aquifer. A large LNAPL plume would overcome the natural degradation processes, known as the assimilative capacity of the aquifer, and degrade the groundwater entering the U.S. Navy well 2254-01 infiltration gallery and putting consumers of that water at risk.

6.4.2 Final Pathways Selected for Analysis

Current and future human health exposure pathways considered potentially complete and significant are listed below (see Figure 6-1).

6.4.2.1 Pathway A: Soil Vapor to Indoor Air - Current Industrial Exposure

This pathway consisted of the migration of contaminated soil vapor currently beneath USTs into the Facility access tunnels where workers may be exposed. Petroleum contaminants were observed in cores and soil vapor samples collected from beneath several USTs during the previous and current SI.

6.4.2.2 Pathway B: Soil Vapor to Indoor Air - Potential Future Industrial Exposure

This pathway consisted of the migration of contaminated soil vapor from hypothetical future releases beneath USTs into the Facility access tunnels where workers may be exposed. This pathway included evaluating potential for increased concentrations in soil vapor for possible future releases.

6.4.2.3 Pathway C: Basal Groundwater to Direct Contact – Current Residential or Industrial Exposure

This pathway consisted of the direct contact to contaminated basal water currently beneath the Facility and exposure through a Residential or Industrial Tapwater scenario. The USEPA Tapwater scenario includes ingestion from drinking, inhalation of volatiles, and dermal absorption from bathing (USEPA, 2002). Petroleum contaminants were observed in groundwater above the HDOH EALs in three groundwater monitoring wells located within the Facility access tunnel and in the background well. Petroleum contaminants were not observed in the U.S. Navy well 2254-01 during the SI or quarterly groundwater sampling events. In this exposure scenario, there were no extraction wells located within the contaminated groundwater plume.

6.4.2.4 Pathway D: Basal Groundwater to Direct Contact – Potential Future Residential or Industrial Exposure for a Well at the Facility

This pathway consisted of future direct contact to contaminated basal water currently beneath the Facility. This future scenario would require a groundwater production well to be installed into the groundwater plume beneath the Facility and exposure through a Residential or Industrial Tapwater scenario. This exposure scenario assumed the current petroleum concentrations for the purpose of calculating risk.

6.4.2.5 Pathway E: Basal Groundwater to U.S. Navy Well 2254-01 – Future Potential Residential Exposure

This pathway consisted of future migration of contaminated basal groundwater beneath the Facility to the U.S. Navy well 2254-01 and exposure through a Residential or Industrial Tapwater scenario. The USEPA Tapwater scenario includes ingestion from drinking, inhalation of volatiles, and dermal absorption from bathing. This future scenario evaluated:

1. Migration of current contaminated groundwater to U.S. Navy well 2254-01;
2. Migration of current and future contaminated leachate from infiltrating rainwater to groundwater, then migration of contaminants dissolved in groundwater to U.S. Navy well 2254-01; and
3. Migration of an hypothetical future release of LNAPL to the water table, dissolution into the basal aquifer at maximum solubility levels, then migration of contaminants dissolved in groundwater to U.S. Navy well 2254-01.

The hypothetical future release cases were evaluated to estimate site-specific risk based levels in the monitoring wells at the Facility. All three cases were evaluated using Tier 3 numerical modeling, including natural attenuation mechanisms.

6.4.3 Description of Tier 2 Criteria Used

Carcinogenic and noncarcinogenic effects of COPCs were incorporated in the Tier 2 evaluation based on HDOH EALs and USEPA Region IX Preliminary Remediation Goals (PRGs). EALs and PRGs are conservative screening levels. Some HDOH EALs are not strictly risk-based but also consider policy issues to determine the action level. PRGs are generally set based on 10^{-6} cancer risk for carcinogens or a Hazard Index (HI) of 1 for non-carcinogens. For example, the drinking water HDOH EAL for benzene is set to the Federal maximum contaminant level of 5 μg/L, which is policy-based, whereas the PRG for benzene is set to the risk-based level of 10^{-6} cancer risk, and is 0.34 μg/L. Non-risk based EALs were not used to calculate risk.

Risk-based EALs and PRGs are “safe” chemical-specific concentrations developed using USEPA-approved potency and toxicity values, referred to as cancer slope factors (CSFs) for carcinogens and reference doses (RfD) for non-carcinogens. The more conservative toxicity values were used to evaluate risk in order to be most protective of human health.

Environmental concerns other than direct exposure were incorporated into the EALs. These other concerns are listed in Section 5.2.2. In addition, results exceeding one-tenth of direct exposure EALs were included for evaluation of cumulative toxicity concerns. According to HDOH (2005, p. 2-13) "Soil EALs are considered to be adequate for use at sites where no more than three carcinogenic chemicals are present and the total risk posed by residual concentrations of chemicals with similar noncarcinogenic health effects does not exceed a target HI of 1.0." Cumulative concerns were addressed in the analysis.

6.4.4 Determination of Applicable Site-Specific Tier 2 Action Levels

The following describe the applicable HDOH ARARs and TBCs and the resulting EAL categories that were used in the Tier 2 analysis for the exposure pathways of concern.

6.4.4.1 Soil

The HDOH EAL category for exposure pathways A and B that applies is *Soil Action Levels for Evaluation of Potential Indoor-Air Impacts, Commercial/Industrial Receptors*. All measured concentrations in the present study were non-detect, but future measurements should be compared to these EALs.

6.4.4.2 Soil Vapor

The HDOH EAL category for exposure pathways A and B that applies is *Shallow Soil Gas Action Levels for Evaluation of Potential Indoor Air Impacts, Commercial/Industrial Receptors*. USEPA Region 9 PRGs were also used as TBCs, with modification (see Table 6-1), since some substances had no HDOH EALs.

6.4.4.3 Groundwater

The HDOH EAL category for exposure pathways A and B that applied was *Groundwater Action Levels for Evaluation of Potential Indoor Air Impacts, Commercial/Industrial Receptors.* The HDOH EAL category for exposure pathways C and D and E that applied was *Drinking Water Action Levels for Human Toxicity*. USEPA Region 9 Tapwater PRGs also were applicable TBCs for pathways C, D, and E. HDOH EAL *Groundwater Gross Contamination Ceiling Levels* were applicable for all groundwater.

6.4.5 Comparison of Sample Results or Exposure Estimates to Site-Specific EALs

Comparisons for Pathways A through D are described here. Pathway E was evaluated in the Tier 3 risk assessment.

6.4.5.1 Pathway A: Soil Vapor to Indoor Air - Current Industrial Exposure

Soil gas measurements were collected from 7 angle borings beneath USTs, each at multiple depths. Soil gas measurements were compared to HDOH EALs that were established for protection against volatilization to building air and exposure to commercial/industrial receptors, or to USEPA PRGs for Air (Table 6-1). For some substances Tier 2 screening criteria were not available and surrogate compounds were used for the comparisons. No measured values exceeded these Tier 2 screening criteria. One measurement for 1,1,2,2-Tetrachloroethane exceeded one-tenth the AL and was therefore identified for consideration of cumulative effects. Based on all the results obtained for this UST, it was determined that it was not a cumulative risk.

6.4.5.2 Pathway B: Soil Vapor to Indoor Air - Potential Future Industrial Exposure

The future exposure scenario for receptors was assumed to be similar to the current scenario. Although current measured values of COPCs were lower than Tier 2 screening criteria, future concentrations could exceed these criteria because of new leaks or for USTs for which no measurements were obtained in the present study. No attempt was made to predict future concentrations of soil vapor. Any future measurements should be compared to the applicable site-specific EALs identified in Section 6.4.4.

6.4.5.3 Pathway C: Basal Groundwater Direct Exposure – Current Residential or Industrial Exposure

Pathway C was insignificant since there were no wells located in the portion of the aquifer that was contaminated. No receptors were using contaminated water from the Facility in the current scenario. Groundwater from the U.S. Navy well 2254-01, which is used for Tap water, did not contain petroleum compounds.

6.4.5.4 Pathway D: Basal Groundwater Direct Exposure – Potential Future Residential or Industrial Exposure

This pathway evaluated potential future receptors under a residential scenario for a drinking water well installed at the Facility. This unlikely scenario evaluated the least restrictive land use for the area, as explained in Section 6.4.2. Table 6-2 compares the measured contaminant concentrations to Tier 2 screening levels. A discussion of the comparisons is provided below.

- Lead in the unfiltered sample (19.6 µg/L) slightly exceeded the applicable EAL (15 µg/L, a drinking water ARAR) in monitoring well RHMW01 in Round 1 only. A filtered sample in Round 2 was non-detect. All other monitoring wells had non-detect results for filtered samples. Based on this information, lead was not evaluated further in the risk assessment.

- TPH-DRO exceeded the applicable EAL (100 µg/L, a drinking water TBC) in all 4 of the monitoring wells in at least 1 of the sample rounds. The TBC exceeded was for both toxicity concerns and taste/odor. The highest concentration was in monitoring well RHMW02 in Round 2 (2,800 µg/L).

- TPH-GRO exceeded the applicable EAL (100 µg/L, a drinking water TBC) in RHMW02 in Round 2 (124 µg/L) sample rounds. The TBC exceeded was for both toxicity concerns and taste/odor.

- Naphthalene exceeded the applicable EAL (6.2 µg/L, a drinking water TBC) in RHMW02 in both sampling rounds. The TBC exceeded was for drinking water toxicity. The highest concentration was in monitoring well RHMW02 in Round 2 (343 µg/L).

- The methylnaphthalenes exceeded the applicable EALs (a TBC), which were a ceiling value for taste and odor (10 µg/L), and one-tenth of the direct exposure drinking water toxicity Action Level (24 µg/L) in RHMW02 in both sampling rounds. The highest concentration was in monitoring well RHMW02 in Round 2 (137 µg/L).

- Benzo(a)anthracene (0.071 μg/L) and benzo(b)fluoranthene (0.069 μg/L) exceeded one-tenth the direct exposure drinking water toxicity EAL (0.0092 μg/L) in RHMW02.

Subsection 6.4.6 provides further evaluation of direct risks associated the Pathway D.

6.4.6 Direct Exposure Risk for Pathway D, Groundwater Direct Exposure

Based on the results of the comparison of sample results to Tier 2 EALs, the following substances in groundwater were evaluated further in this section for future risk to residents: TPH-GRO, TPH-DRO, methylene chloride, naphthalene, 1-methylnaphthalene, 2-methylnaphthalene, benzo(a)anthracene, benzo(b)fluoranthene, and trichloroethylene.

Appendix O provides a summary of chemical properties and toxicity constants that were used in the quantification of risk, and target health effects for these substances, obtained from HDOH EALs tables (HDOH 2005).

The petroleum-related substances degrade relatively rapidly under aerobic conditions, however degradation rates decrease when conditions become anaerobic. Section 4 of this report evaluates the fate of these substances in the environment.

6.4.6.1 Methods

The laboratory analytical results for groundwater were evaluated by comparing exposure point concentrations (EPCs) to residential potable water Action Levels. An EPC is the chemical-specific term used to estimate intake in exposure calculations. For this analysis, EPCs for groundwater are the maximum detected concentration in any sample.

Non-carcinogenic risk was determined through the calculation of the hazard quotient (HQ), which is the ratio of intake to the reference dose (RfD). The RfD is the largest daily exposure concentration that is likely to be without an appreciable risk of deleterious effects during a portion of a lifetime based on the exposure scenario. The RfDs used in this risk assessment were based on chronic exposure associated with the USEPA Region 9 Residential or Industrial scenarios. These are generally the lowest RfDs, therefore most conservative. Other RfDs, such as subchronic or acute, are based on shorter exposure times, thus potentially require higher daily doses for short-term deleterious effects. The HQ was calculated by the following equation.

HQ = CDI/RfD;

where:

HQ = Hazard quotient;

CDI = Calculated average daily intake of COPC (mg/kg-day)

RfD = Reference dose $(\text{mg/kg-day})^{-1}$

If multiple substances occur together and potentially impact similar organs or physiological functions, the HQs for these substances were then summed to provide an overall site Hazard Index. The HI represents the total risk associated with all site contaminants on a particular physiological function or organ. Noncarcinogens are believed to act only after reaching a threshold concentration. USEPA generally considers an HI of 1.0 or less to be acceptable. EALs and PRGs were developed for non-carcinogens by selecting an HI of 1.0 and then back-calculating an acceptable concentration. In practice, for this risk assessment, the HQ was calculated as the ratio of the measured concentration to the EAL or PRG.

Carcinogenic risk was calculated as an upper-bound estimate of excess lifetime cancer risk (lifetime assumed to be 70 years) for a substance. These were estimated by using the following calculation:

ELCR = CDI x CSF;

where:

ELCR = Excess lifetime cancer risk;

CDI = Calculated average daily intake of COPC (mg/kg-day)

CSF = Cancer slope factor $(\text{mg/kg-day})^{-1}$

EALs and PRGs for carcinogens were developed by selecting a target risk of one in one million (1×10^{-6}) or one in one hundred thousand (1×10^{-5}) for some substances, and then back-calculating an acceptable concentration. The target risk is based on a general consensus among the scientific and regulatory communities that an excess lifetime cancer risk of one in one million (1×10^{-6}) or less is generally considered a negligible increase in cancer risk. In practice, for this risk assessment, risks were calculated by multiplying the target risk by the ratio of the measured concentration to the EAL or PRG. Because cancer risks were assumed to be additive, risks associated with simultaneous exposures to more than one carcinogen in a given medium were aggregated to determine a total pathway cancer risk. For each exposure scenario, total cancer risks for each pathway were then summed to determine the total cancer risk for the potential receptors.

USEPA established an acceptable cancer risk range of $1\text{x}10^{-6}$ to $1\text{x}10^{-4}$ for Superfund sites in the National Oil and Hazardous Substances Pollution Contingency Plan (NCP). This risk range was used as a basis for comparing the risk estimates calculated for this site, as described in the following paragraph.

6.4.6.2 Direct Exposure Risk Results

Direct exposure risk was quantified for potential future receptors under a residential scenario for a drinking water well at the Facility and the results are shown in Table 6-3. Four substances exceeded an excess lifetime cancer risk of 1×10^{-6} or an HQ of 1.0: TPH-GRO, TPH-DRO, naphthalene, and trichloroethylene. The highest risk was 1.6×10^{-6} for trichloroethylene. The highest HQ was for naphthalene with an HQ of 55.

6.5 Tier 3 Risk Assessment for Groundwater Pathway E

6.5.1 Approach to the Tier 3 Risk Assessment

Exposure Pathway E was assessed using a Tier 3 risk assessment. The Tier 3 assessment utilized fate and transport modeling to estimate the contaminant concentrations in groundwater monitoring wells that would result in reaching or exceeding the Tier 2 screening levels for groundwater at the exposure point (well 2254-01 infiltration gallery). ARARs and TBCs were used to determine which substances were COPCs to be evaluated in the Tier 3 risk assessment.

6.5.2 Groundwater Model Results

Section 4-3 summarizes the groundwater modeling results. The modeling of contaminant migration from beneath the Facility to well 2254-01 indicated the current concentrations measured in RHMW01, RHMW02 and RHMW03 will not be observed at the well 2254-01 above the detection limit of the analysis and thus did not present a measurable risk. In addition, long-term simulations of leachate concentrations at the solubility limit of benzene for JP-5 (0.75 mg/L) did not show benzene above the detection limit of the analysis at well 2254-01; therefore, contaminants adsorbed to the bedrock in the unsaturated zone above the water table did not represent a risk to water system associated with well 2254-01.

Additional simulations did show that free petroleum product on the groundwater table could cause the petroleum concentrations at well 2254-01 infiltration gallery to exceed EALs. In particular, the modeling evaluated movement of benzene and a JP-5 fuel product. If JP-5 were present on the groundwater table, the dissolved groundwater concentrations would be at the solubility limits of benzene (7.5 mg/L) and TPH (4.5 mg/L). In addition, these simulations indicated that fresh JP-5 product must get within 1,099 feet of the infiltration gallery, for the benzene MCL to be exceeded in the gallery. The infiltration gallery is approximately 2,000 feet down-gradient of RHMW01 and Tank 1, the nearest monitoring well and UST in the Facility to the U.S. Navy well 2254-01 infiltration gallery.

Based on this assessment, LNAPL would have to be present at RHMW01, and extend approximately 2,000 feet toward the infiltration gallery before an exceedance would be observed there. This would be indicated by LNAPL in RHMW01, or groundwater concentrations of approximately 750 μg/L for benzene and 4,500 μg/L for TPH (conservative estimates of their solubility limits). These concentrations in any well would also require evaluation of cleanup to the extent practical in accordance with the HAR, Title 11, Chapter 281, subchapter 7: Free-Product Removal.

6.5.3 Comparison of Groundwater Sample Results to Site-Specific ALs

Based on the analysis above, concentrations at the Facility wells (RHMW01, RHMW02, RHMW03) below the solubility limit of TPH and benzene will not represent an unacceptable risk to the existing U.S. Navy well 2254-01 drinking water system. These solubility limits should be set as site-specific risk-based levels (SSRBLs) for the evaluation of future risk to the U.S. Navy well 2254-01 drinking water system. The concentrations in groundwater monitoring wells did not exceed the SSRBALs of 750 μg/L for benzene and 4,500 μg/L for TPH. Benzene was not detected in any groundwater sampling events and the maximum concentration detected for TPH was 2,795 μg/L TPH-DRO in monitoring well RHMW02 in the second SI sampling event (see Table 6-2). At U.S. Navy well 2254-01, HDOH EALs are the action levels.

6.6 Uncertainty

Uncertainties exist in nearly every aspect of risk assessment. Most assumptions regarding toxicity and exposure in the development of these values are intended to be conservative (i.e., protective of health).

6.6.1 RME Concentrations of COPCs

For groundwater, maximum concentrations were used to compare to EALs and PRGs and to calculate risk. Maximum concentrations were used because there is a chance that a drinking water well could be installed into groundwater with these levels. However, the plume area exceeding EALs is relatively small and there is a low likelihood that a drinking water well would ever be installed within the Facility. For this reason, the future risk for current conditions is hypothetical, and will decrease as the petroleum is degraded assuming that no future releases occur. However, the following concerns indicate that the risk of future releases to the environment should be carefully evaluated.

- The Facility is active with a total fuel capacity of approximately 250 Mgals.
- It has been in service since 1943, thus tank structures have been subject to corrosion and degradation since that time.
- It was constructed in the field, therefore is deferred from UST regulations which require certified leak detection systems.
- Evidence of releases have been observed in groundwater and soil vapor samples at the Facility.
- One or more tanks are currently out of service for maintenance reasons.
- The original tell-tale leak detection systems are no longer operational.
- The size and location of the USTs (inside the Red Hill Ridge) make detecting future releases very difficult using the existing infrastructure and standard operating procedures.

In addition, measured concentrations of total petroleum hydrocarbons show variability based on the analytical methods used. In the first SI sampling event, petroleum hydrocarbons were measured by two different methods:

1. TPH-GRO and TPH-DRO were analyzed in accordance with SW8015M based on updated guidance from HDOH (HDOH, 2005); and
2. VPH and EPH were analyzed based on previous guidance from the Massachusetts Department of Environmental Protection (MADEP).

The comparison of results is as follows:

VPH (MADEP) μg/L		EPH (MADEP) μg/L	
C5-C8 aliphatics	< 75	C11-C22 aromatics	741
C8-C12 aliphatics	549.5	C19-C36 aliphatics	274
C9-C10 aromatics	396	C9-C18 aliphatics	802.5
Total	983	Total	1817.5
TPH-GRO (SW8015M) μg/L	< 100	TPH-DRO (SW8015M) μg/L	2660

These results demonstrated a range of results possible with different methods of analysis. The current risk assessment was conducted using the action levels in the HDOH EAL guidelines using SW8015 methodology (TPH-DRO and TPH-GRO). Risk was calculated based on the HDOH EALs of 100 μg/L for both TPH-DRO and TPH-GRO are the non-cancer risk concentrations associated with a Hazard Index of 1 for these substances.

6.6.2 Exposure Pathways

The potential exposure pathways for each receptor evaluated in this risk assessment incorporates conservative assumptions. Although the Facility is not residential and groundwater beneath the Facility is not used for residential drinking water, this hypothetical future scenario was used to evaluate whether the Facility can be closed without any restrictions for future use. The Facility is likely to remain controlled Navy property for the foreseeable future since there are no plans to change its current use. A residential scenario is conservative and likely overestimates actual risk conditions in the future. This scenario is unlikely given the availability of HBWS sources of water for homes and businesses in the area.

6.6.3 Action Levels and Risk

Action Levels and risk calculations are generally based on conservative toxicity criteria and exposure assumptions. For example, the CSFs (i.e., cancer potency values) and RfDs (toxicity thresholds) utilized in developing the EALs and PRGs are typically based on extrapolations from animal studies and incorporate numerous levels of protection factors and various other conservative assumptions.

The toxicity factors for TPH-GRO and TPH-DRO are particularly uncertain and likely to be highly conservative. These values have been developed by various groups, e.g. the TPH Criteria Working Ground, the MADEP, USEPA, and the Oak Ridge National Laboratory. These groups use surrogate compounds with the highest or near highest toxicities of those which are known for the group. These toxicities may not be representative of the entire group of compounds but are used in lieu of toxicity and composition information for the complete mixture. In addition, within each mixture there is likely to be substantial component of substances that are not hydrocarbons (Lundegard and Sweeney 2004).

6.6.4 Background Contamination

Trichloroethylene (TCE) was detected in 1 of 10 samples at a concentration of 8.2 μg/L. There is no evidence of TCE use at Facility. There is a known history of TCE contamination in basal aquifer water on Oahu. The USGS detected TCE in public water supply wells and monitoring wells throughout central Oahu at concentrations up to, and in one supply well, exceeding 5 μg/L (Hunt, 2004).

6.6.5 Groundwater Modeling

Numerous assumptions and estimates are made during the groundwater modeling effort at the site. These assumptions are discussed in detail in the modeling report (Appendices L and M). There was a substantial effort to calibrate the MODFLOW 2000 regional model and localized model and there was generally good agreement between historical data and new data collected for the present study.

There is a significant uncertainty regarding degradation estimates that were based on degradation constants from Hill AFB, where similar contaminants were evaluated. The outcome of the model indicates that there would be no migration of contaminants from the Facility to the U.S. Navy well 2254-01 infiltration gallery at risk levels of concern unless there was fuel product in contact with the groundwater at a location closer to the gallery than the actual distance to well 2254-01. Consequently, using the monitoring wells at the Facility as the point of measurement would maintain an extra margin of safety.

6.7 Tier 2 Human Health Risk Summary

The primary environmental risks at the Facility were determined to be due to a future scenario in which groundwater from beneath the site was extracted for residential tapwater use, including drinking. Currently, no extraction wells lie in the vicinity of the current groundwater plume. In addition, if a future release were to produce a large secondary source of LNAPL on the water table, dissolved contaminants or free-product may result in unacceptable concentrations of petroleum in the U.S. Navy well 2254-01 potable water system, and require that the system be unavailable for an undetermined time period.

6.7.1 Pathway A: Soil Vapor to Indoor Air - Current Industrial Exposure

Negligible risk.

6.7.2 Pathway B: Soil Vapor to Indoor Air - Potential Future Industrial Exposure

Evaluation of current conditions indicated negligible risk. However, future concentrations could exceed risk-based criteria because of new leaks, or for USTs for which no measurements were obtained in the present study. No attempt was made to predict future concentrations of soil vapor. Any future measurements should be compared to the applicable site-specific EALs identified in Section 6.4.4.

6.7.3 Pathway C: Basal Groundwater Direct Exposure – Current Residential or Industrial Exposure

Negligible risk.

6.7.4 Pathway D: Basal Groundwater Direct Exposure – Potential Future Residential or Industrial Exposure for a Well at the Facility

A summary of the direct exposure risk results for this scenario assuming that the concentrations of COPCs measured currently do not change are as follows:

Substance	Non-Carcinogenic HQ (Maximum Detected Concentration)	Excess Lifetime Cancer Risk (Maximum Detected Concentration)	Number of Samples Exceeding HQ=1 or risk of 10^{-6}
TPH-GRO	10	Not applicable	3 of 10
TPH-DRO	28	Not applicable	8 of 10
Naphthalene	55	Not applicable	2 of 10
1-Methylnaphthalene	0.9	Not applicable	0 of 10
2-Methylnaphthalene	0.6	Not applicable	0 of 10
Benzo(a)anthracene	No RfD available	7.7×10^{-7}	0 of 10
Benzo(b)fluoranthene	No RfD available	7.5×10^{-7}	0 of 10
Trichloroethylene	0.9	1.6×10^{-6}	1 of 10
		Total Risk = 3.2×10-^{6}	

An excess lifetime cancer risk of one in one million (1×10^{-6}) is generally considered a negligible increase in cancer risk by regulatory agencies. Only the cancer risk for TCE exceeded this value, and this was by a small amount. TCE is not stored in the USTs and has been observed at similar concentrations throughout the Pearl Harbor Aquifer. An HQ of less than 1 is considered an acceptable risk. HQs exceeded 1 for TPH-GRO, TPH-DRO, and naphthalene. The highest HQ of 55 was for naphthalene in monitoring well RHMW02 (Round 2). All other wells had an HQ less than 1.

All substances measured were at their maximum concentration in well RHMW02, except for lead which was highest at RHMW01 and the maximum result was from an unfiltered sample. These hypothetical future risks apply only if a drinking water well is installed within the Facility and screened in the current plume of groundwater contamination. This scenario is considered unlikely but was evaluated to evaluate a scenario of unrestricted use of the area. The groundwater modeling that was conducted indicated that petroleum contaminants observed at RHMW02 will not migrate to offsite extraction wells at concentrations greater than the detection limit of the analyses. (see Section 5).

6.7.5 Pathway E: Groundwater to U.S. Navy Well 2254-01 – Future Potential Residential Exposure

According to fate and transport simulations (see Section 4.3 and Appendix M):

- An extended LNAPL plume was required on the water table downgradient of RHMW01 in order for EALs to be exceeded in the U.S. Navy well 2254-01 infiltration gallery;
- An extended LANPL plume did not exist during the SI or quarterly sampling; therefore the risk associated with current conditions was insignificant; and
- Leachate concentrations were affected by dilution as they enter the basal aquifer; therefore, maximum COPC concentrations in the basal aquifer were much less than an extended LNAPL source and the risk associated with the leachate scenario was insignificant.

Assuming the LNAPL release was JP-5, the model simulations indicated that benzene was the risk driver for an extended LNAPL source on groundwater at the Facility. Benzene is both toxic and mobile, and would be one of the first constituents to enter the infiltration gallery. While PAHs are also toxic, they are less mobile and would require a larger plume before action levels were exceeded at the infiltration gallery. In the simulations, benzene was observed in the infiltration gallery at the Federal MCL and DOH EAL of 5 μg/L when LNAPL reached within 1,099 feet of the gallery. Important considerations in the evaluation of benzene as a risk driver are provided below.

- The minimum volume of fuel estimated to generate an extended plume of this size was estimated to be as small as 16,000 gallons (Section 4.2.1.4).
- The carcinogenic PRG for benzene is 0.35 μg/L associated with a 10^{-6} cancer probability, so the carcinogenic risk associated with the simulated 5 μg/L in tapwater is 1.4×10^{-5} cancer probability.
- The U.S. Navy well 2254-01 provides up to 16 mgd to the PHWS. The PHWS supplies approximately 52,200 military consumers with potable water and approximately 24 percent of that water comes from the U.S. Navy well 2254-01 (Section 3.2.2.1).
- Simulations of an extended LNAPL source extending to within 1,099 feet of the infiltration gallery took between 5 and 6 years for groundwater concentrations at the gallery to exceed 5 μg/L of benzene (Section 4.3.5.1).
- If the LNAPL plume extended closer to the infiltration gallery, the risk would increase and the travel time would decrease proportionately. The maximum RME benzene concentration from LNAPL would be 750 μg/L, the solubility limit of benzene for JP-5. The carcinogenic risk associated with a benzene concentration of 750 μg/L in tapwater is 2.1×10^{-3} cancer probability. This would be the result of a JP-5 LNAPL plume extending to the infiltration gallery.

The results of the Tier 3 risk assessment indicated that current conditions did not present an unacceptable risk to the U.S. Navy well 2254-01. However, a hypothetical future release exceeding 16,000 gallons may result in a cancer risk of 1.4×10^{-5} for the Residential Tapwater exposure scenario. A larger release, in which LNAPL extends to the infiltration gallery would result in a cancer risk of 2.1×10^{-3} for the Residential Tapwater exposure scenario. Appendix M documents the fate and transport modeling task.

Table 6-1. Tier 2 Evaluation of Soil Gas Results
Red Hill Fuel Storage Facilty
Oahu, Hawaii

						ARARs or TBCs			Other	
Method	**Substance**	**Location**	**Sample Conc.**	**Q**	**Units**	**HDOH Comm_Ind Soil Gas[a]**	**Estimated Soil Vapor Criteria Based on USEPA R9 Air PRG[b]**	**Note**	**One-tenth HDOH Comm_Ind Soil Gas or estimated criteria[c]**	**Evaluation**
TO-15	1,1,2,2-TETRACHLOROETHANE	RHSV06-15-35	29		μg/m^3	140	33		**14**	Eliminate: No cumulative toxicity concern
TO-15	1,2,4-TRIMETHYLBENZENE	RHSV06-15-35	105.5		μg/m^3		6200	Value based on 1,3,5-TMB surrogate PRG	620	Eliminate
TO-15	1,2,4-TRIMETHYLBENZENE	RHSV06-40-56	6.5		μg/m^3		6200	Value based on 1,3,5-TMB surrogate PRG	620	Eliminate
TO-15	1,2,4-TRIMETHYLBENZENE	RHSV11-13-30	12		μg/m^3		6200	Value based on 1,3,5-TMB surrogate PRG	620	Eliminate
TO-15	1,2,4-TRIMETHYLBENZENE	RHSV11-40-131	49		μg/m^3		6200	Value based on 1,3,5-TMB surrogate PRG	620	Eliminate
TO-15	1,2,4-TRIMETHYLBENZENE	RHSV12-15-40	40		μg/m^3		6200	Value based on 1,3,5-TMB surrogate PRG	620	Eliminate
TO-15	1,2,4-TRIMETHYLBENZENE	RHSV14-46-73	9		μg/m^3		6200	Value based on 1,3,5-TMB surrogate PRG	620	Eliminate
TO-15	1,2,4-TRIMETHYLBENZENE	RHSV14-79-110	5.4		μg/m^3		6200	Value based on 1,3,5-TMB surrogate PRG	620	Eliminate
TO-15	1,2,4-TRIMETHYLBENZENE	RHSV16-15-40	3.4		μg/m^3		6200	Value based on 1,3,5-TMB surrogate PRG	620	Eliminate
TO-15	1,3,5-TRIMETHYLBENZENE	RHSV06-15-35	87		μg/m^3		6200		620	Eliminate
TO-15	1,3,5-TRIMETHYLBENZENE	RHSV11-40-131	14		μg/m^3		6200		620	Eliminate
TO-15	1,3,5-TRIMETHYLBENZENE	RHSV12-15-40	11		μg/m^3		6200		620	Eliminate
TO-15	1,3,5-TRIMETHYLBENZENE	RHSV14-46-73	42		μg/m^3		6200		620	Eliminate
TO-15	1,4-DICHLOROBENZENE	RHSV06-15-35	5.5		μg/m^3	1300	310		130	Eliminate
TO-15	1,4-DICHLOROBENZENE	RHSV11-13-30	5.6		μg/m^3	1300	310		130	Eliminate
TO-15	1,4-DICHLOROBENZENE	RHSV11-40-131	14		μg/m^3	1300	310		130	Eliminate
TO-15	1,4-DICHLOROBENZENE	RHSV14-79-110	7.6		μg/m^3	1300	310		130	Eliminate
TO-15	1,4-DICHLOROBENZENE	RHSV16-15-40	4		μg/m^3	1300	310		130	Eliminate

μg/m^3 - micrograms per cubic meter
Q - data qualifier
J - Indicates an estimated value
14 Asterisks indicated that the criteria is exceeded.

[a] Value from HDOH (2005) Table C-2.

[b] EPA Region 9 Air PRG multiplied by 1000 to account for decrease from soil gas to building air (decrease factor explained in HDOH 2005); this value is only listed if the HDOH Comm_Ind Soil Gas value has not been

[c] Value is the HDOH Comm_Ind criteria unless not available, then it is the USEPA PRG-based criteria.

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TO-15	4-ETHYLTOLUENE	RHSV06-15-35	69		µg/m^3		6200	Value based on 1,3,5-TMB surrogate PRG	620	Eliminate
TO-15	4-ETHYLTOLUENE	RHSV06-40-56	3.8		µg/m^3		6200	Value based on 1,3,5-TMB surrogate PRG	620	Eliminate
TO-15	4-ETHYLTOLUENE	RHSV11-13-30	7.1		µg/m^3		6200	Value based on 1,3,5-TMB surrogate PRG	620	Eliminate
TO-15	4-ETHYLTOLUENE	RHSV11-40-131	31		µg/m^3		6200	Value based on 1,3,5-TMB surrogate PRG	620	Eliminate
TO-15	4-ETHYLTOLUENE	RHSV12-15-40	28		µg/m^3		6200	Value based on 1,3,5-TMB surrogate PRG	620	Eliminate
TO-15	4-ETHYLTOLUENE	RHSV14-46-73	45		µg/m^3		6200	Value based on 1,3,5-TMB surrogate PRG	620	Eliminate
TO-15	BENZENE	RHSV06-15-35	3.4		µg/m^3	1100	250		110	Eliminate
TO-15	BENZENE	RHSV12-15-40	2.6		µg/m^3	1100	250		110	Eliminate
TO-15	BENZENE	RHSV14-46-73	16		µg/m^3	1100	250		110	Eliminate
TO-15	BENZENE	RHSV16-15-40	2.85		µg/m^3	1100	250		110	Eliminate
TO-15	BENZYL CHLORIDE	RHSV06-15-35	12		µg/m^3		250		25	Eliminate
TO-15	CYCLOHEXANE	RHSV06-15-35	7.6		µg/m^3		210000	Value based on n-hexane surrogate PRG	21000	Eliminate
TO-15	CYCLOHEXANE	RHSV12-15-40	6.2		µg/m^3		210000	Value based on n-hexane surrogate PRG	21000	Eliminate
TO-15	CYCLOHEXANE	RHSV14-46-73	4.4		µg/m^3		210000	Value based on n-hexane surrogate PRG	21000	Eliminate
TO-15	ETHANOL	RHSV02-79-110	36		µg/m^3		1800000	Value based on methanol surrogate PRG	180000	Eliminate
TO-15	ETHANOL	RHSV11-40-131	8		µg/m^3		1800000	Value based on methanol surrogate PRG	180000	Eliminate
TO-15	ETHANOL	RHSV14-46-73	11		µg/m^3		1800000	Value based on methanol surrogate PRG	180000	Eliminate
TO-15	ETHANOL	RHSV14-79-110	12		µg/m^3		1800000	Value based on methanol surrogate PRG	180000	Eliminate
TO-15	ETHANOL	RHSV16-15-40	91		µg/m^3		1800000	Value based on methanol surrogate PRG	180000	Eliminate
TO-15	ETHANOL	RHSV16-46-73	12	J	µg/m^3		1800000	Value based on methanol surrogate PRG	180000	Eliminate

µg/m^3 - micrograms per cubic meter
Q - data qualifier
J - Indicates an estimated value
14 Asterisks indicated that the criteria is exceeded.

[a] Value from HDOH (2005) Table C-2.

[b] EPA Region 9 Air PRG multiplied by 1000 to account for decrease from soil gas to building air (decrease factor explained in HDOH 2005); this value is only listed if the HDOH Comm_Ind Soil Gas value has not been set.

[c] Value is the HDOH Comm_Ind criteria unless not available, then it is the USEPA PRG-based criteria.

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TO-15	ISOPROPANOL	RHSV16-15-40	18		µg/m^3		1100000	Value based on isobutanol surrogate PRG	110000	Eliminate
TO-15	n-HEPTANE	RHSV06-15-35	17		µg/m^3		210000	Value based on n-hexane surrogate PRG	21000	Eliminate
TO-15	n-HEPTANE	RHSV11-40-131	4.4		µg/m^3		210000	Value based on n-hexane surrogate PRG	21000	Eliminate
TO-15	n-HEPTANE	RHSV12-15-40	8.4		µg/m^3		210000	Value based on n-hexane surrogate PRG	21000	Eliminate
TO-15	n-HEPTANE	RHSV14-46-73	8.6		µg/m^3		210000	Value based on n-hexane surrogate PRG	21000	Eliminate
TO-15	TETRACHLOROETHYLENE(PCE)	RHSV02-46-73	7.6		µg/m^3	1400	320		140	Eliminate
TO-15	TETRACHLOROETHYLENE(PCE)	RHSV16-79-110	6.6		µg/m^3	1400	320		140	Eliminate
TO-15	TETRAHYDROFURAN	RHSV14-46-73	4.6		µg/m^3		990		99	Eliminate
TO-15	TETRAHYDROFURAN	RHSV14-79-110	4.7		µg/m^3		990		99	Eliminate
TO-15	TETRAHYDROFURAN	RHSV16-15-40	3.9		µg/m^3		990		99	Eliminate
TO-15	TETRAHYDROFURAN	RHSV16-79-110	9.1		µg/m^3		990		99	Eliminate

µg/m^3 - micrograms per cubic meter
Q - data qualifier
J - Indicates an estimated value
14 Asterisks indicated that the criteria is exceeded.

[a] Value from HDOH (2005) Table C-2.

[b] EPA Region 9 Air PRG multiplied by 1000 to account for decrease from soil gas to building air (decrease factor explained in HDOH 2005); this value is only listed if the HDOH Comm_Ind Soil Gas value has not been

[c] Value is the HDOH Comm_Ind criteria unless not available, then it is the USEPA PRG-based criteria.

Table 6-2. Tier 2 Evaluation of Groundwater Results for Residential Receptors
Red Hill Fuel Storage Facilty
Oahu, Hawaii

Sample Round	Method	Compound	Location	Sample Conc.	Q	Units	Lowest Applicable EAL	Basis	Other Applicable EALs Exceeded	EPA PRG for Tapwater	One_tenth Drinking Water Human Toxicity in Table D-2_1	Evaluation
R01	SW6010B	LEAD (Unfiltered)	RHMW01-GW01	19.6		µg/L	**15**	Drinking Water Toxicity	None		**1.5**	Eliminate: Unfiltered sample; filtered samples at this well non-detect; no cumulative issues at this well
R01	SW6010B	'LEAD (Unfiltered)	RHMW03-GW01	8.5		µg/L	15	Drinking Water Toxicity	None		**1.5**	Eliminate: Same as above
R01	SW8015B	TPH as DIESEL RANGE ORGANICS[a]	RHMW01-GW01	677		µg/L	**100**	Drinking Water Toxicity	**100** Taste and Odors		**10**	Evaluate
R01	SW8015B	TPH as DIESEL RANGE ORGANICS[a]	RHMW02-GW01	1817.5		µg/L	**100**	Drinking Water Toxicity	**100** Taste and Odors		**10**	Evaluate
R01	SW8015B	TPH as DIESEL RANGE ORGANICS	RHMW02-GW01	2660		µg/L	**100**	Drinking Water Toxicity	**100** Taste and Odors		**10**	Evaluate
R01	SW8015B	TPH as DIESEL RANGE ORGANICS	RHMW03-GW01	162	J	µg/L	**100**	Drinking Water Toxicity	**100** Taste and Odors		**10**	Evaluate
R01	SW8015B	TPH as DIESEL RANGE ORGANICS	RHMW04-GW01	338		µg/L	**100**	Drinking Water Toxicity	**100** Taste and Odors		**10**	Evaluate
R02	SW8015B	TPH as DIESEL RANGE ORGANICS	RHMW01-GW02	509		µg/L	**100**	Drinking Water Toxicity	**100** Taste and Odors		**10**	Evaluate
R02	SW8015B	TPH as DIESEL RANGE ORGANICS	RHMW02-GW02	2795		µg/L	**100**	Drinking Water Toxicity	**100** Taste and Odors		**10**	Evaluate
R02	SW8015B	TPH as DIESEL RANGE ORGANICS	RHMW03-GW02	142	J	µg/L	**100**	Drinking Water Toxicity	**100** Taste and Odors		**10**	Evaluate
R01	SW8015B	TPH as GASOLINE RANGE ORGANICS[b]	RHMW01-GW01	77.4		µg/L	100	Drinking Water Toxicity	None		**10**	Evaluate
R01	SW8015B	TPH as GASOLINE RANGE ORGANICS[b]	RHMW02-GW01	983		µg/L	**100**	Drinking Water Toxicity	**100** Taste and Odors		**10**	Evaluate
R02	SW8015B	TPH as GASOLINE RANGE ORGANICS	RHMW02-GW02	121.5	J	µg/L	**100**	Drinking Water Toxicity	**100** Taste and Odors		**10**	Evaluate
R01	SW8260B	NAPHTHALENE	RHMW02-GW01	301	J	µg/L	**6.2**	Drinking Water Toxicity	**21** Taste and Odors	**6.2**	**0.62**	Evaluate
R02	SW8260B	NAPHTHALENE	RHMW02-GW02	339		µg/L	**6.2**	Drinking Water Toxicity	**21** Taste and Odors	**6.2**	**0.62**	Evaluate
R01	SW8260B	TRICHLOROETHYLENE (TCE)	RHMW02-GW01	8.2		µg/L	**5**	Drinking Water Toxicity	None	**0.028**	**0.5**	Evaluate
R02	SW8260B	METHYLENE CHLORIDE	RHMW02-GW02	24.9		µg/L	**4.3**	Drinking Water Toxicity	None	**4.3**	**0.43**	Eliminate: known lab contaminant; frequency is 1 in 10; no reason to believe it is present
R01	SW8270C	1-METHYLNAPHTHALENE	RHMW02-GW01	103		µg/L	**10**	Ceiling Value (Taste and Odor)	None		**24**	Evaluate: potential cumulative issues
R02	SW8270C	1-METHYLNAPHTHALENE	RHMW02-GW02	137.5		µg/L	**10**	Ceiling Value (Taste and Odor)	None		**24**	Evaluate: potential cumulative issues
R01	SW8270C	2-METHYLNAPHTHALENE	RHMW02-GW01	87.85		µg/L	**10**	Ceiling Value (Taste and Odor)	None		**24**	Evaluate: potential cumulative issues
R02	SW8270C	2-METHYLNAPHTHALENE	RHMW02-GW02	66.45		µg/L	**10**	Ceiling Value (Taste and Odor)	None		**24**	Evaluate: potential cumulative issues
R01	SW8270C	BENZO(a)ANTHRACENE	RHMW02-GW01	0.071		µg/L	0.092	Drinking Water Toxicity	None	0.092	**0.0092**	Evaluate: potential cumulative issues
R01	SW8270C	BENZO(b)FLUORANTHENE	RHMW02-GW01	0.069		µg/L	0.092	Drinking Water Toxicity	None	0.092	**0.0092**	Evaluate: potential cumulative issues

µg/L - micrograms per liter
Q - data qualifier
J - Indicates an estimated value

[a] The value for TPH-DRO was obtained by adding the results for the following extractable fractions: C9-C18 aliphatics, C19-C36 aliphatics, and C11-C22 aromatics.

[b] The value for TPH-GRO was obtained by adding the results for the following volatile fractions: C5-C8 aliphatics, C9-C12 aliphatics, and C9-C10 aromatics; when one fraction was non-detect, one-half the RL was used to estimate its concentration.

🟧 Substances Exceeding Initial Tier 2 Screen.

Table 6-3. Tier 2 Human Health Risk Evaluation for Direct Exposure of Potential Future Receptors for a Well at RHSF
Red Hill Fuel Storage Facilty
Oahu, Hawaii

								Carcinogens		Non-Carcinogens		
Chemical	**Sample Size [a]**	**Number of Detects**	**Frequency of Detection**	**Max EPC[b]**	**Location of Max EPC**	**95 % UCL[c]**	**RME EPC[d]**	**Carcinogen Action Level[e]**	**Risk[f]**	**Non-carcinogen Action Level[g]**	**HQ[h]**	**No. of Results Exceeding Lowest Action Level**
Basal Groundwater (2 rounds); units in µg/L												
TPH-GRO	10	3	30%	983	RHMW02-GW01	nc	983	na	na	100	10	3
TPH-DRO	10	8	80%	2795	RHMW02-GW02	nc	2795	na	na	100	28	8
Naphthalene	10	2	20%	339	RHMW02-GW02	nc	339	na	na	6.2	55	2
1-Methylnaphthalene	8	2	25%	137.5	RHMW02-GW02	nc	137.5	na	na	150	0.9	0
2-Methylnaphthalene	8	2	25%	87.9	RHMW02-GW01	nc	87.85	na	na	150	0.6	0
Benzo(a)anthracene	8	1	13%	0.071	RHMW02-GW01	nc	0.071	0.092	7.72E-07	na	nc	0
Benzo(b)fluoranthene	8	1	13%	0.069	RHMW02-GW01	nc	0.069	0.092	7.50E-07	na	nc	0
Trichloroethylene	10	1	10%	8.2	RHMW02-GW01	nc	8.2	5.000	1.64E-06	9.5	0.9	1
Estimated Upper Bound Carcinogenic Risk for well RHMW02									**3.2E-06**			

Notes:

na = no data or not applicable

nc = not calculated

[a] Two sample rounds; field duplicate results count as 1 sample

[b] Maximum exposure point concentration (EPC) is the maximum detected concentration of an analyte.

[c] The UCL is not calculated because it is not considered appropriate for groundwater

[d] The reasonable maximum exposure (RME) EPC; the minimum of either the upper confidence limit (UCL) of the arithmetic mean or the maximum EPC.

[e] Carcinogen Action Levels are from are from HDOH (2005) for drinking water.

[f] Cancer risk = 1E-06 x (RME EPC / Carcinogenic PRG); PRG is from USEPA (2004); risk is estimated upper bound excess risk above background

[g] Non-carcinogen action levels are based on HDOH Drinking Water Action Levels (HDOH 2005) except for methylene chloride and trichloroethylene which are taken from USEPA (2004 and Action Levels for the methylnaphthalenes which were calculated with the formulas from USEPA (2004) and using an oral RfD of 0.004 mg/kg-day for 2-methylnaphthalene from IRIS (USEPA 2006) (no inhalation reference concentration is reported in IRIS)

[h] HQ = RME EPC / Noncarcinogenic PRG.

[i] Calculated using a TEQ approach with benz(a)pyrene assigned a value of 1, as recommended by USEPA (2000)

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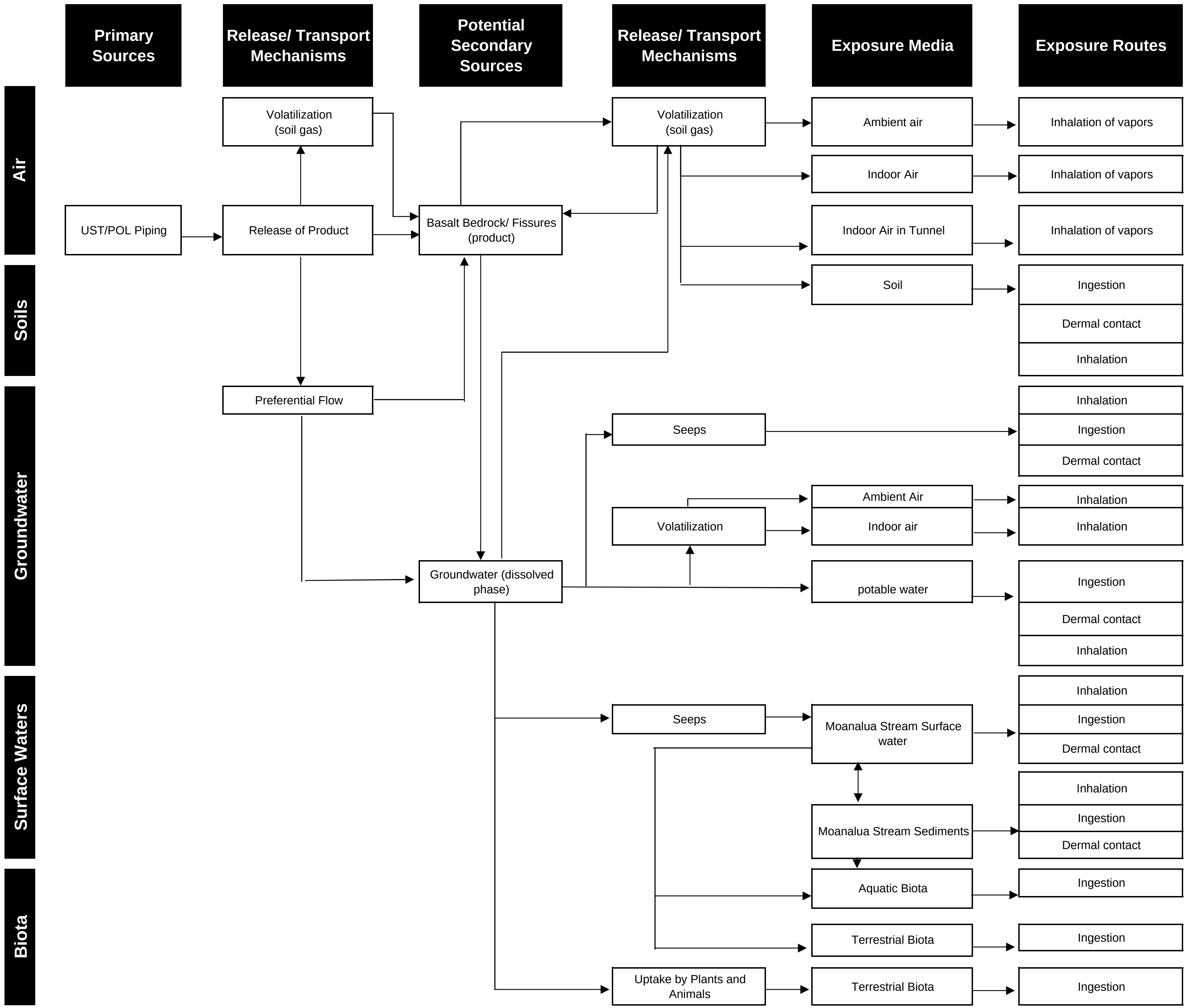

		Potential Receptors				
Exposure Media	Exposure Routes	Residential	Occupational Workers	Trespasser/ Visitor	Ecological (Aquatic)	Ecological (Terrestrial)
Ambient air	Inhalation of vapors	▨	▨	▨	○	▨
Indoor Air	Inhalation of vapors	▨	▨	▨	○	○
Indoor Air in Tunnel	Inhalation of vapors	○	●	▨	○	○
Soil	Ingestion	▨	▨	▨	○	▨
	Dermal contact	▨	▨	▨	○	▨
	Inhalation	▨	▨	▨	○	▨
Seeps	Inhalation	○	○	○	○	○
	Ingestion	○	○	○	○	○
	Dermal contact	○	○	○	○	○
Ambient Air	Inhalation	▨	▨	▨	○	▨
Indoor air	Inhalation	▨	▨	▨	○	○
potable water	Ingestion	●	●	▨	○	○
	Dermal contact	●	●	▨	○	○
	Inhalation	●	●	▨	○	○
Moanalua Stream Surface water	Inhalation	○	○	○	○	○
	Ingestion	○	○	○	○	○
	Dermal contact	○	○	○	○	○
Moanalua Stream Sediments	Inhalation	○	○	○	○	○
	Ingestion	○	○	○	○	○
	Dermal contact	○	○	○	○	○
Aquatic Biota	Ingestion	○	○	○	○	○
Terrestrial Biota	Ingestion	○	○	○	○	○
Terrestrial Biota	Ingestion	○	○	○	○	○

LEGEND

○ Exposure Pathway Evaluated and Incomplete

▨ Exposure Pathway Evaluated and Potentially Complete - Minor

● Exposure Pathway Evaluated and Potentially Complete - Major

Minor Exposure Pathway = contaminants concentrations that would reach the exposure points are very small compared to the screening action levels and therefore deemed insignificant in impacting human health and the environment.

Major Exposure Pathway = contaminants concentrations that would reach the exposure points have the potential to present an unacceptable risk to human health and the environment.

NA = Not Applicable

Figure 6-1

Human Health Risk Assessment Exposure Pathways and Receptors

Red Hill Fuel Storage Facility
Oahu, Hawaii

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SECTION 7
CONCLUSIONS AND RECOMMENDATIONS

This comprehensive SI report evaluated a full range of environmental media to assess potential risks to human health and the environment from inadvertent releases of fuel from the Facility. These media include subsurface soil (rock) groundwater, and soil vapor throughout the Facility.

7.1 Conclusions

The results of this investigation clearly indicate that petroleum has been released from Facility in the past. Soil vapor measurements from SVMPs beneath seven of the USTs show petroleum vapor thoughout the subsurface and at greater concentrations at Tanks 6, 11, 12, 14 and 16. Three groundwater monitoring wells were installed within the lower access tunnel of the Facility and samples from each have consistently detected petroleum dissolved in the groundwater beneath the site.

The results of this investigation indicate the following:

- Migration pathways for released chemicals to the ground surface or surface water are insignificant, due to the depth of the tanks beneath the ground surface, and distance from nearby streams.
- Migration pathways for released chemicals to the ground surface via soil vapor to impact indoor air of ground surface buildings are insignificant due to the low volatility of the stored fuels and the distance of the USTs and underlying groundwater from the ground surface.
- Migration pathways for released chemicals to the indoor air of the Facility lower access tunnel via soil vapor are insignificant due to the low volatility of the stored fuels and ventilation system within the Facility.
- The current level of impact to the environment exceeds the Tier 1 Action Level standard developed by the HDOH (HDOH, 2005) for groundwater that will be used as drinking water. However, the groundwater directly beneath the site is not currently being used, nor is expected to be used in the near future.
- The groundwater modeling efforts for this SI indicated that of the three nearby potable water systems (HBWS Halawa Shaft, HBWS Moanalua Wells, and U. S. Navy Pumping Station 2254-01) based on groundwater extraction, groundwater beneath the Facility is only within the 10-year capture zone of the U.S. Navy well 2254-01.
- Fate and transport simulations based on the same groundwater model indicated that current concentrations of petroleum in groundwater beneath the Facility will not result in measurable concentrations at the U.S. Navy well 2254-01.
- Fate and transport simulations indicated that infiltrating leachate from the Facility will not result in measurable concentrations at the U.S. Navy well 2254-01.

- Fate and transport simulations indicated that a hypothetical future release in which JP-5 LNAPL extended to within 1,099 feet from the U.S. Navy well 2254-01 infiltration gallery will result in an exceedance of the benzene MCL of 5 μg/L in the infiltration gallery. The dissolved-phase migration took between 5 and 6 years for this to occur. The volume of this hypothetical release could be as small as 16,000 gallons.

The Facility overlies a very valuable groundwater resource that produces approximately 4.5 to 16 mgd of potable water to the PHWS and its military consumers via U.S. Navy well 2254-01. This water resource would be very difficult to replace, considering the present limitations of the sustainable yield of the Pearl Harbor and Honolulu Aquifer Sectors.

The age of the Facility and the mission-critical requirements for its storage capacity combine to present a future risk to the underlying groundwater. The USTs are deferred from many of the State and Federal regulations, due to their field-constructed nature. A significant rule that they are deferred from is the requirement for release detection (HAR, Title 11, Chapter 281, Subchapter 5, “Release Detection”). For this reason, there is no certified release detection system operating at the Facility.

A release of JP-5 LNAPL to groundwater as small as 16,000 gallons from the Facility has the potential to remove the Red Hill sub-basin as a water resource to the PHWS without expensive well head treatment. Currently there is no effective way to quickly determine whether a release is occurring. A chronic release of 1 gallon per minute over a period of 90 days is approximately 130,000 gallons. A release of this size would have a major impact on the groundwater resource, and may not be detectable until quarterly groundwater samples are collected under the current system.

7.2 Recommendations

The associated Contingency Plan (TEC, 2007) should be implemented to ensure proper maintenance and monitoring of the Facility occurs to mitigate risk of future releases going undetected. An undetected release from the Facility may result in the loss of the groundwater resource within the Red Hill sub-basin, between North Halawa Valley and Moanalua Valley.

SECTION 8
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