NAVFAC Naval Facilities Engineering Command

NAVFAC HAWAII

Red Hill Bulk Fuel Storage Facility
AOC SOW Section 6 and Section 7

November 30 – December 4, 2015

Introduction: Safety and Facilities

- Navy wants everyone to attend these meetings and return home safely
- Location of Restrooms
- Fire Exits
- Driving on base
  - Speed limits strictly enforced
  - Watch for pedestrians
  - Use of cell phones not allowed
  - Sanctions may include loss of base privileges

Introduction: Rules of Engagement

There is much to cover this week, please try to focus on agenda topics.

Introduction: Successful Meeting

A successful meeting will:

- Clearly Identify each organizations' expectations
- Focus discussions to categorize proposed activities and decisions points as Agreed, Undecided, or Disagreed
- Reach agreement on overall framework to meet AOC-SOW requirements
- Identify the majority of issues as Acceptable
- Establish action items and assign responsibilities to resolve Undecided or Disagreed issues in the near future

Administrative Order on Consent Statement of Work (AOC-SOW) Overall Objective

“The primary objectives of the AOC and this SOW are to take steps to ensure that the groundwater resource in the vicinity of the Facility is protected and to ensure that the Facility is operated and maintained in an environmentally protective manner.”

The Parties "agree that these objectives can best be accomplished by ensuring that the Tanks and other infrastructure at the Facility deploy the best available practicable technology (“BAPT”) (as defined in Section 3) to prevent fuel releases, **developing a better understanding of the hydrogeology of the area surrounding the Facility**, and conducting an assessment of the risk to the groundwater resources that may be posed by the Facility.

Introduction: AOC-SOW Section 6 Objectives and Proposed Tasks

AOC-SOW Section 6 Objectives:

Section 6. Investigation and Remediation of Releases:

"The purpose of the deliverables to be developed and the work to be performed under this Section is to determine the feasibility of alternatives for investigating and remediating releases from the facility.

The deliverables shall include:

- The response to the January 2014 release from Tank #5; and
- An evaluation and discussion of potential remediation methods for the January 2014 Tank #5 release and any future releases"

Proposed Tasks:

1) Evaluate Subsurface Geology
2) Investigate Light Non-aqueous Phase Liquid (LNAPL)
3) Identify Chemicals of Potential Concern (COPCs)
4) Expand the Monitoring Network

Introduction: AOC-SOW Section 7 Objectives and Proposed Tasks

AOC-SOW Section 7 Objectives:

Section 7. Groundwater Protection and Evaluation:

"The purpose of the deliverables to be developed and the work to be performed under this Section is to monitor and characterize the flow of groundwater around the facility. Navy and DLA shall update the existing Groundwater Protection Plan to include response procedures and trigger points in the event that contamination from the facility shows movement toward any drinking water well. The collective work done in this Section shall be used to inform subsequent changes to the Groundwater Protection Plan. The deliverables and work to be performed under this Section may include the installation of additional monitoring wells as needed."

Proposed Tasks:

5) **Update the Existing Groundwater Model**
6) **Update Contaminant Fate &Transport (CF&T) Model and Evaluate Whether to Perform a Tracer Study**
7) **Evaluate Remedial Alternatives**

Introduction: Agenda Day 1

Day 1 – Monday, November 30, 2015

0800 – 1000	Introduction of Attendees, Meeting Procedures, and All-Tracks Discussion
1000 – 1015	Break; Separate into Different Meeting Track (Section 6 and Section 7)
1015 – 1115	Introductions, Review Meeting Agenda, State AOC-SOW Section Purposes, Present Outline of Proposed Tasks to Address the AOC-SOW
1115 – 1200	Site Setting: Land Uses, Topography, Water Resources, Regional Geology
1200 – 1300	Lunch
1300 – 1515	Site Geology and Hydrogeology: Preliminary Geologic Conceptual Site Model (CSM)
1515 – 1530	Break
1530 – 1630	Task #1: Evaluate Subsurface Geology
1630 – 1700	Review of Action Items for Monday, November 30 Discussions

Introduction: Agenda Day 2

<u>Day 2 – Tuesday, December 1, 2015</u>

0800 – 1000	Previous Investigations (Pre-2014): Results, Existing Models and CSM
1000 – 1015	Break
1015 – 1200	January 2014 Release: Response, Investigations, and Results
1200 – 1300	Lunch
1300 – 1500	Task #2: Investigate the Light Non-Aqueous Phase Liquid (LNAPL)
1500 – 1515	Break
1515 – 1645	Task #2: Investigate the LNAPL (Continued)
1645 – 1700	Review of Action Items for Tuesday, December 1 Discussions

Introduction: Agenda Day 3

Day 3 – Wednesday, December 2, 2015

0800 – 0900	All-Tracks Discussion on Progress
0900 – 0915	Break; Separate into Different Meeting Track
0915 – 1015	Task #3: Identify Chemicals of Potential Concern (COPCs)
1015 – 1200	Task #4: Expand the Monitoring Network
1200 – 1300	Lunch
1300 – 1500	Task #4: Expand the Monitoring Network (Continued)
1500 – 1515	Break
1515 – 1640	AOC-SOW Section 6 Recap: Objectives and Tasks
1640 – 1700	Review of Action Items for Wednesday, December 2 Discussions

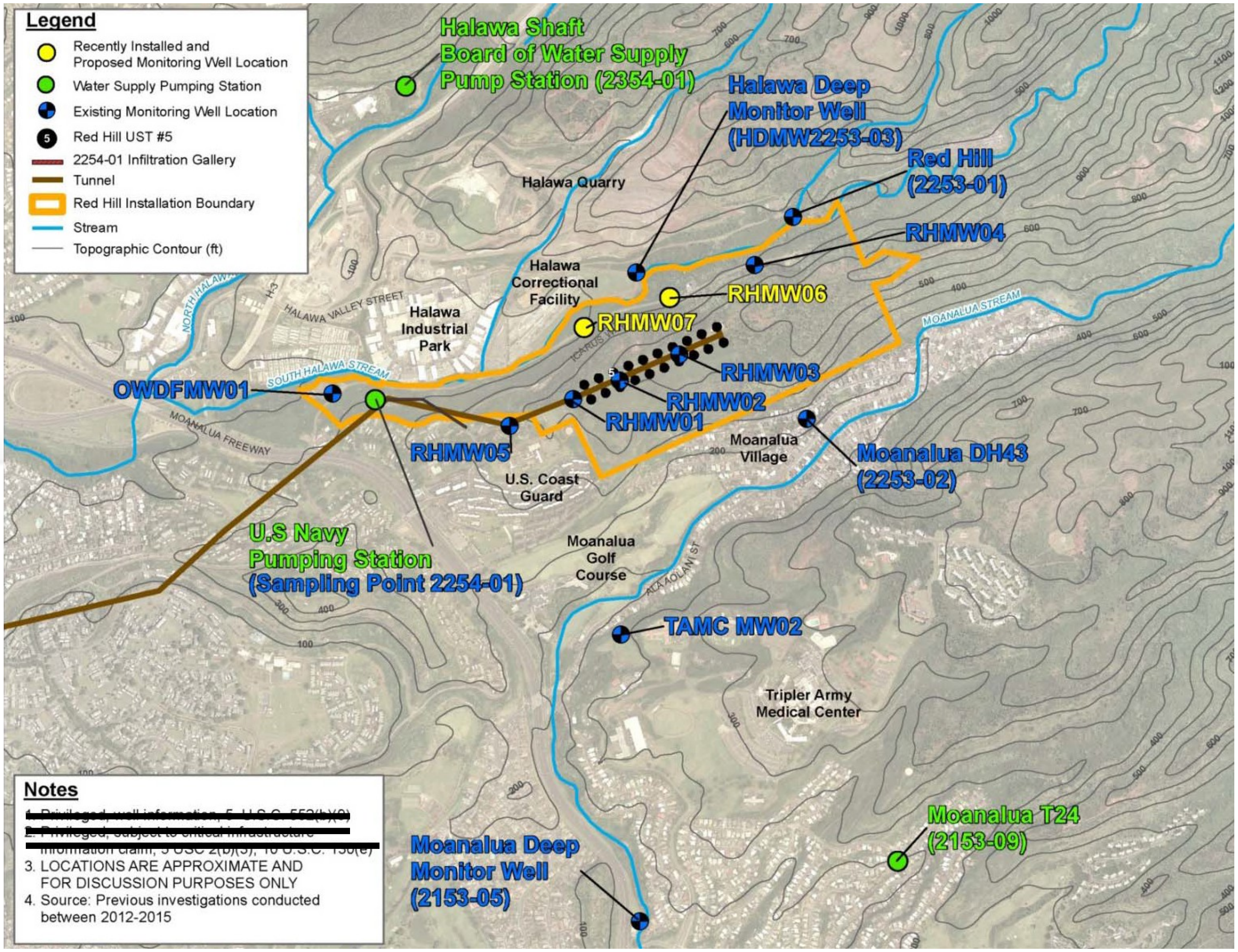
Introduction: Agenda Day 4

Day 4 – Thursday, December 3, 2015	
0800 – 1000	Task #5: Update the Existing Groundwater Model
1000 – 1015	Break
1015 – 1200	Task #5: Update the Existing Groundwater Model (Continued)
1200 – 1300	Lunch
1300 – 1445	Task #6: Update CF&T Model and Evaluate Whether to Perform a Tracer Study
1445 – 1500	Break
1500 – 1600	Task #7: Evaluate Remedial Alternatives
1600 – 1640	AOC-SOW Section 7 Recap: Objectives and Tasks
1640 – 1700	Review of Action Items for Thursday, December 3 Discussions

Introduction: Agenda Day 5

Day 5 – Friday, December 4, 2015	
0800 – 0900	All-Tracks Discussion and Closeout
0900 – 1030	Path Forward, Schedule Milestones, and Review Action Items/Decision Points
1030 – TBD	[Contingent if Section 6 and Section 7 Require More Discussions]

Site Setting: Land Uses, Topography, Water Resources, Regional Geology



Site Setting: Land Uses, Topography, Water Resources, Regional Geology

- Cursory Search of Available DOH Databases
  - Solid and Hazardous Waste Branch (SHWB) Underground Storage Tank (UST) Database
  - SHWB Leaking UST (LUST) Database
  - Office of Hazard Evaluation and Emergency Response (HEER) and Sites of Interest Databases
  - Only Confirmed Locations within Site Vicinity Mapped
  - Other Locations May Exist

Site Setting: Land Uses, Topography, Water Resources, Regional Geology

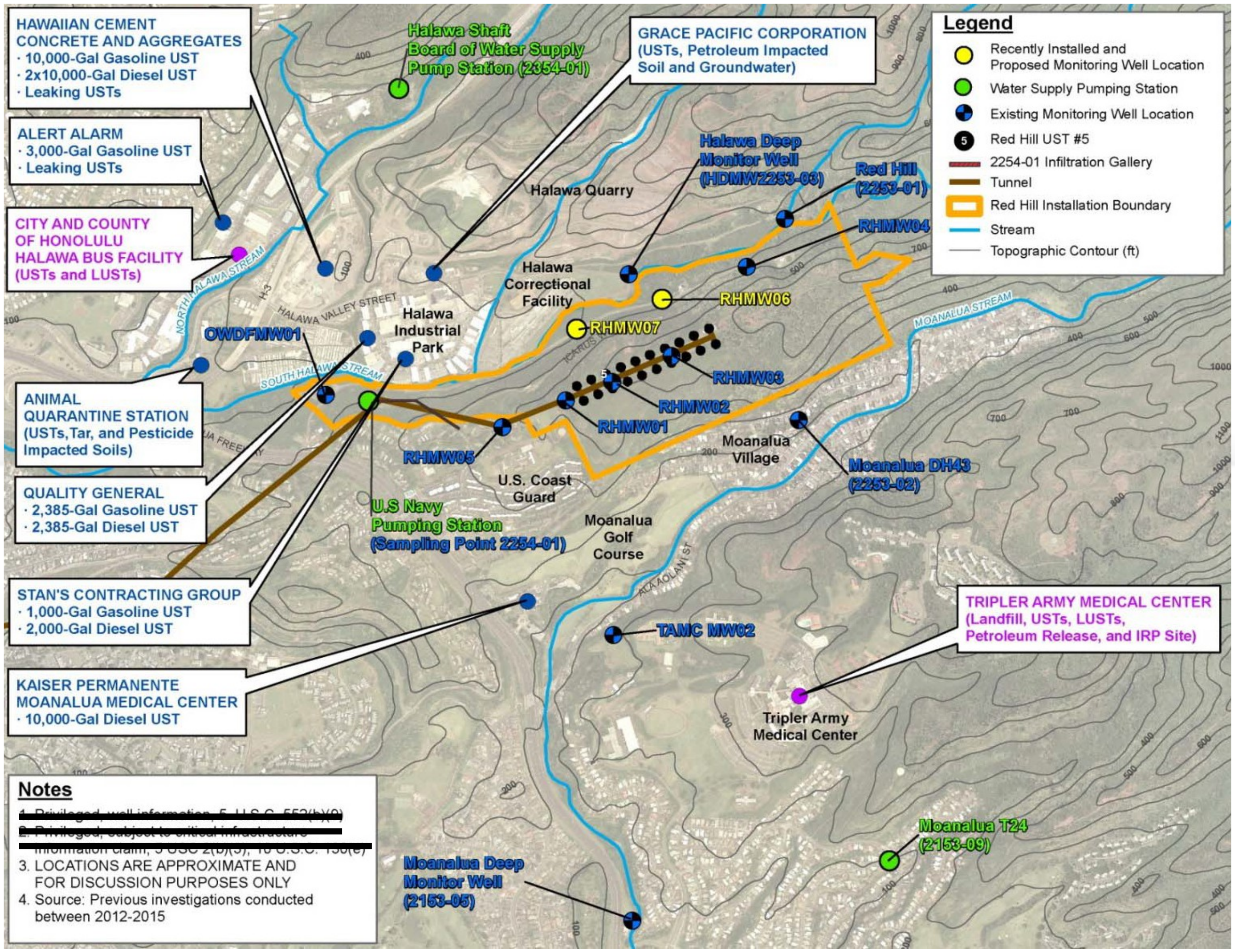
- **59 USTs between Board of Water Supply (BWS) Halawa Well and Moanalua Well**
  - **50 Permanently Out of Use**
  - **9 Active**

- **22 LUSTs**
  - **17 LUSTs with Conditional No Further Actions (NFAs)**
  - **Tripler Army Medical Center, Building 144/145 (Former Gas Station)**
    - Release from one of the tanks is being managed in place under an Environmental Health Management Plan (EHMP); COPCs: TPH-gasoline
  - **City and County of Honolulu (CCH), Halawa Bus Facility**
    - Releases from four tanks are currently being managed in place under a Exposure Prevention Management Plan (EPMP). COPCs: TPH-diesel, MtBE

Site Setting: Land Uses, Topography, Water Resources, Regional Geology

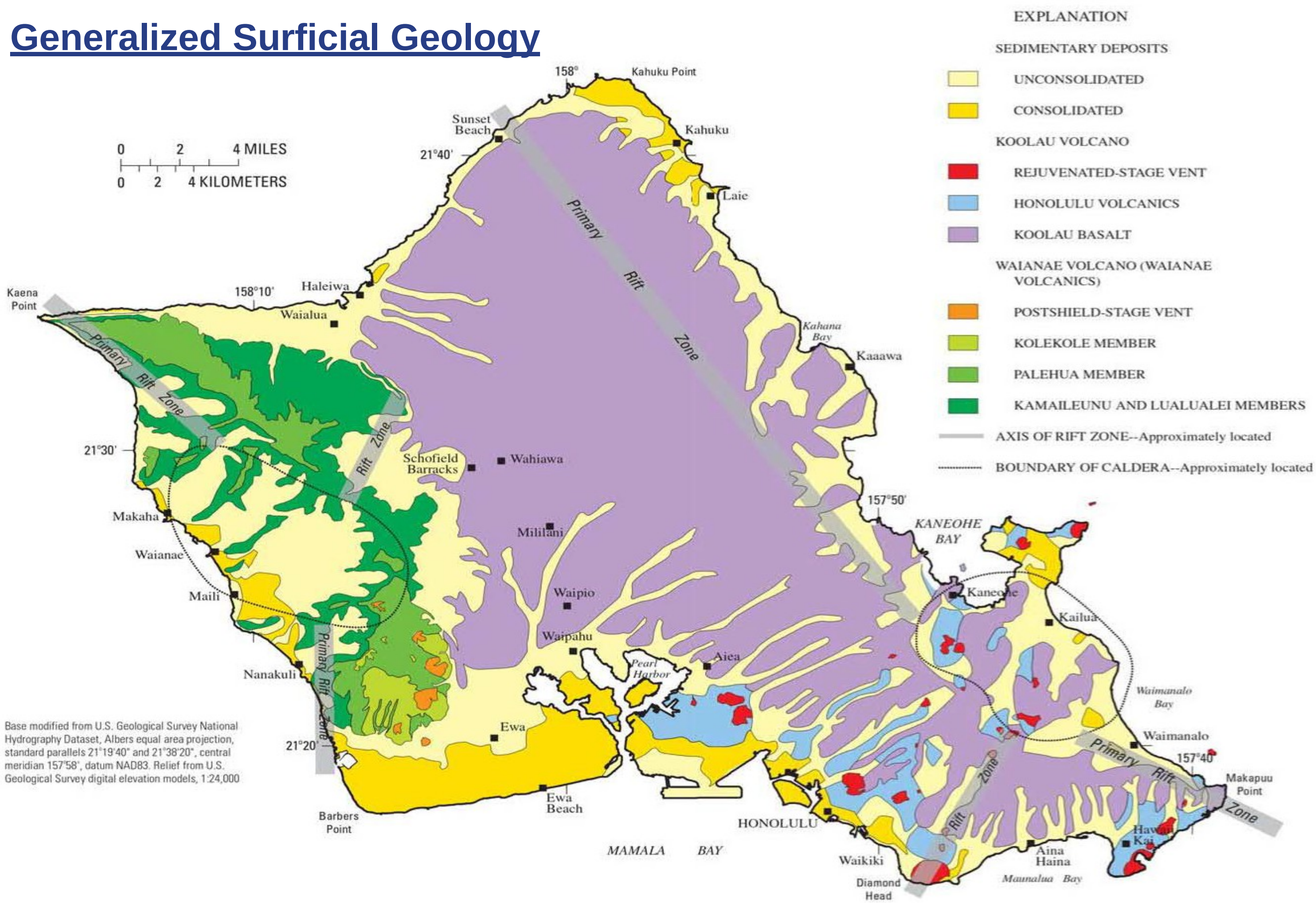
- HEER Reported Releases and Sites of Interest Databases
  - CCH Halawa Corporation Yard: diesel-contaminated soil
  - Hawaii Cement Concrete and Aggregate: petroleum releases
  - Halawa Correctional Facility: petroleum releases, fugitive dumping of paint
  - H-3 Construction: release of 1,800 gallons of diesel in the valley
  - Grace Pacific Corporation: petroleum-impacted soil and groundwater
  - Animal Quarantine Station: surfacing tar, pesticide-impacted soil
  - Tripler Army Medical Center: built over a former landfill; currently a Installation Restoration Program (IRP [Army]) site

Site Setting: Land Uses, Topography, Water Resources, Regional Geology



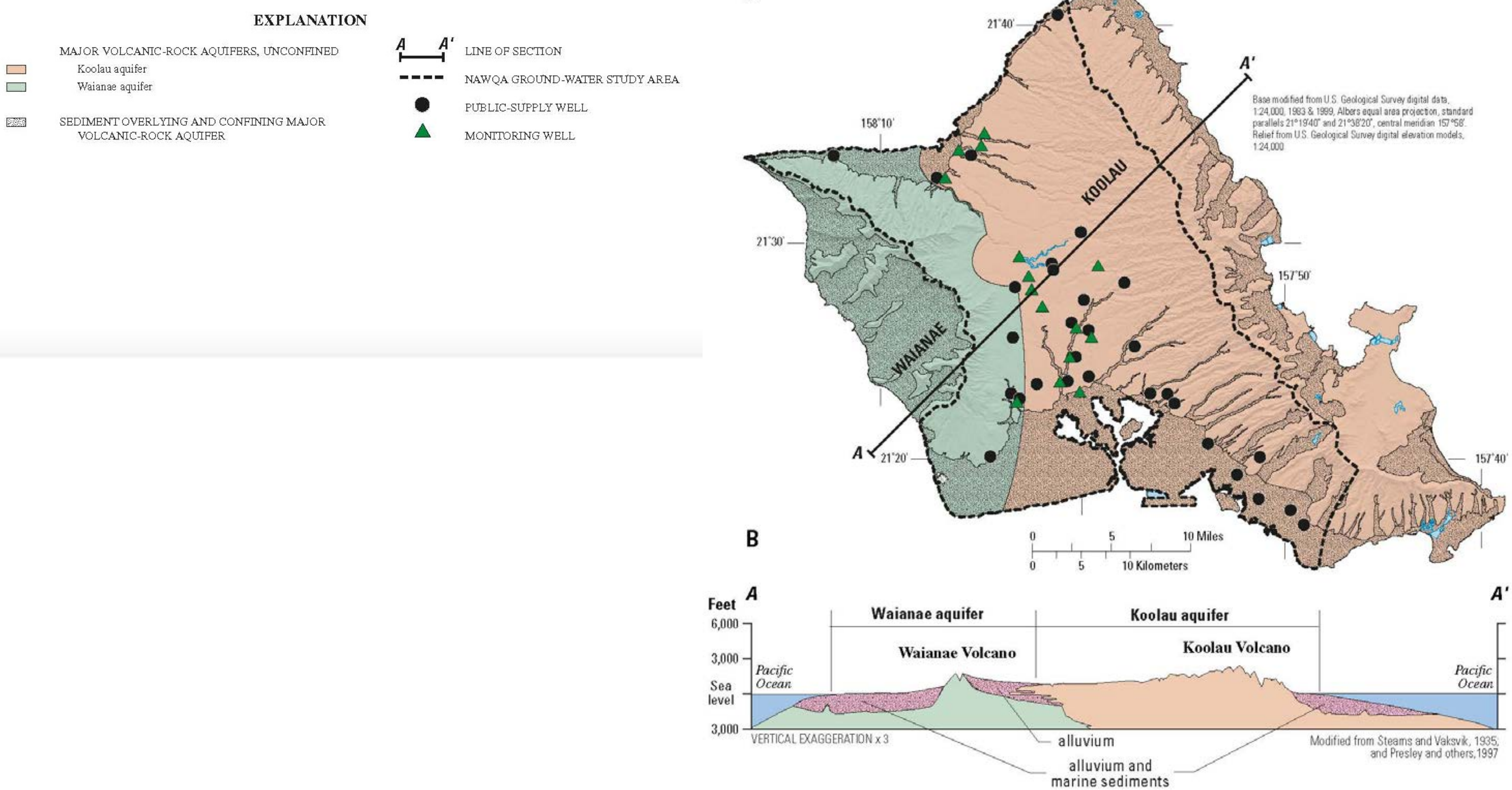
Site Geology and Hydrogeology: Regional Geology

Generalized Surficial Geology



Site Geology and Hydrogeology: Regional Geology

Waianae and Koolau volcanic-rock aquifers



Site Geology and Hydrogeology: Regional Geology

- Four major geomorphic provinces define the Island of Oahu: two volcanic mountain ranges (Waianae and Ko‘olau), the Schofield Plateau, and the Ewa coastal plain (Stearns and Vaksvik, 1935).
- The Ko‘olau Volcanic Series is made up almost entirely of tholeiitic basalts and olivine basalts.
- The southeastern third of Ko‘olau volcano’s remnant shield experienced a rejuvenation stage of volcanism. Most rejuvenation - stage volcanoes lie south of the erosional valleys carved out of the Ko‘olau shield and are interbedded with alluvial and marine sediments. These rejuvenation - stage vents and associated flows and ash deposits comprise the Honolulu Volcanic Series.

Site Geology and Hydrogeology: Vadose Zone Geology

- Volcanic formations in Hawaii can be divided into four groups, all of which may be present at Red Hill:
    1. Lava flows (extrusive)
    2. Dikes and sills (intrusive)
    3. Pyroclastic deposits (extrusive, e.g. volcanic tuff)
    4. Saprolite and weathered (soil) horizons
- These groups of rocks have markedly different physical and hydraulic properties
- Interbedded flows often result in highly heterogeneous formations

Site Geology and Hydrogeology: Vadose Zone Geology

<u>Types of Hawaiian lava flows:</u>

1. Pahoehoe

- **Less viscous flows; vesicular, smooth, ropy**
- **Smoothly undulating surface; numerous elongate voids**
  - Voids can form in the horizontal, longitudinal direction, creating preferential pathways
- **Formed as fluid, relatively rapidly flowing basaltic lavas that tend to spread out**
- **Typically thin flows with voids of various sizes; cracked and collapsed in places**
- **Lava tubes are associated with pahoehoe lava flows**

Site Geology and Hydrogeology:
Vadose Zone Geology

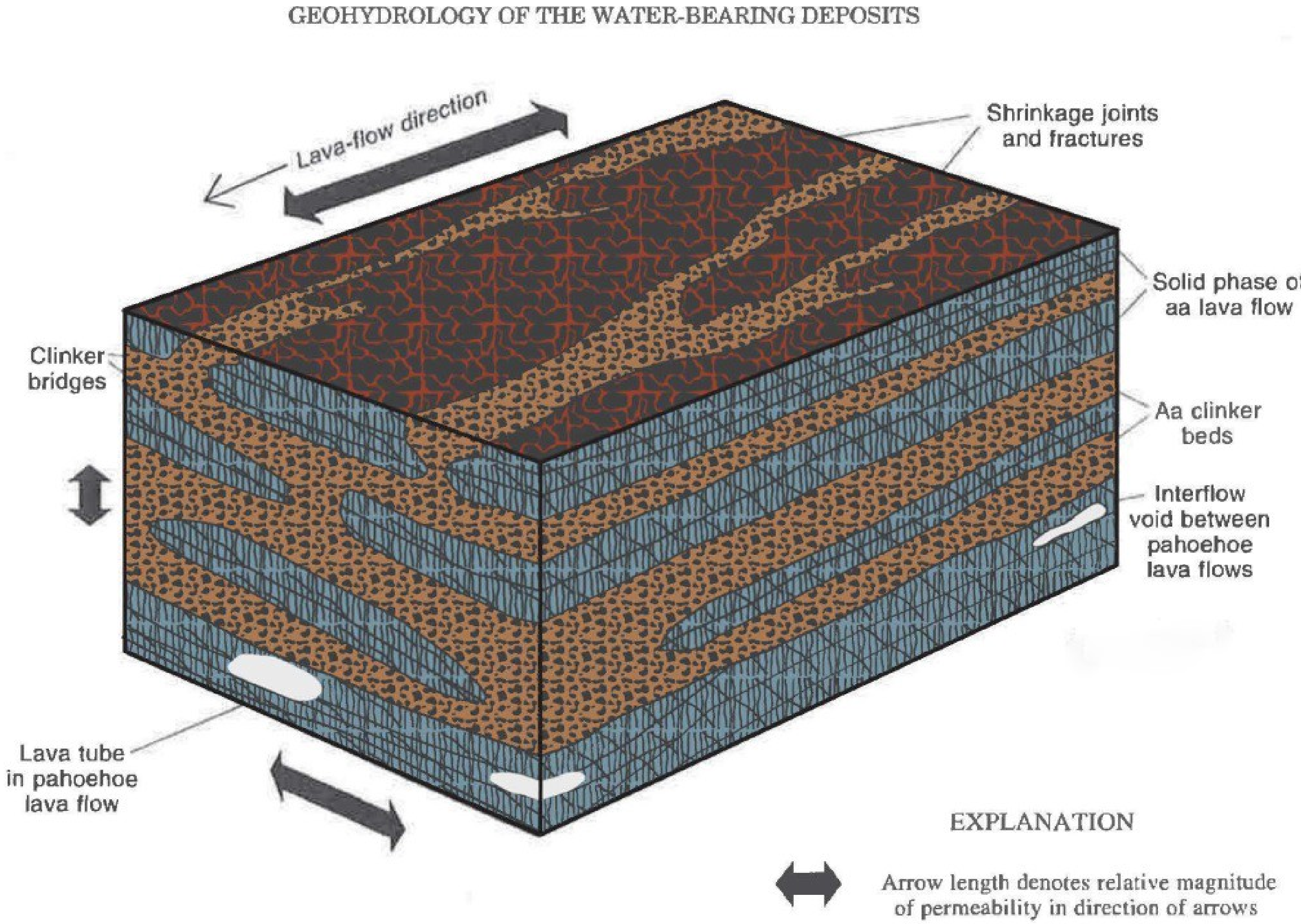
<u>Types of Hawaiian lava flows:</u>

2. A‘a

- **Solid, massive cores with top and bottom clinker zones**
- **Clinker:**
  - Like a coarse, well-sorted gravel
  - Layered sequences of flows can result in widespread beds with high hor-izontal permeability
- **The smaller effective porosity of massive a‘a cores can result in extremely low vertical permeability**
  - The principal vertical permeability of an a‘a core is imparted by wide regularly spaced cooling joints, which are typically low permeability

Site Geology and Hydrogeology: Vadose Zone Geology

Successive interbedded pahoehoe and massive a‘a often create highly irregular formations with various fractures and voids, intermixed with widespread areas of high horizontal permeability



Site Geology and Hydrogeology: Vadose Zone Geology

Dikes:

- Thin, near-vertical sheets of massive, intrusive rock
- Typically only fractures contribute to porosity and permeability
- Often no more than several feet thick, but can extend vertically thousands of feet and laterally several miles
- Where dikes intrude lava flows, they inhibit ground-water flow principally in the direction normal to the plane of the dike

Site Geology and Hydrogeology: Vadose Zone Geology

Dikes:

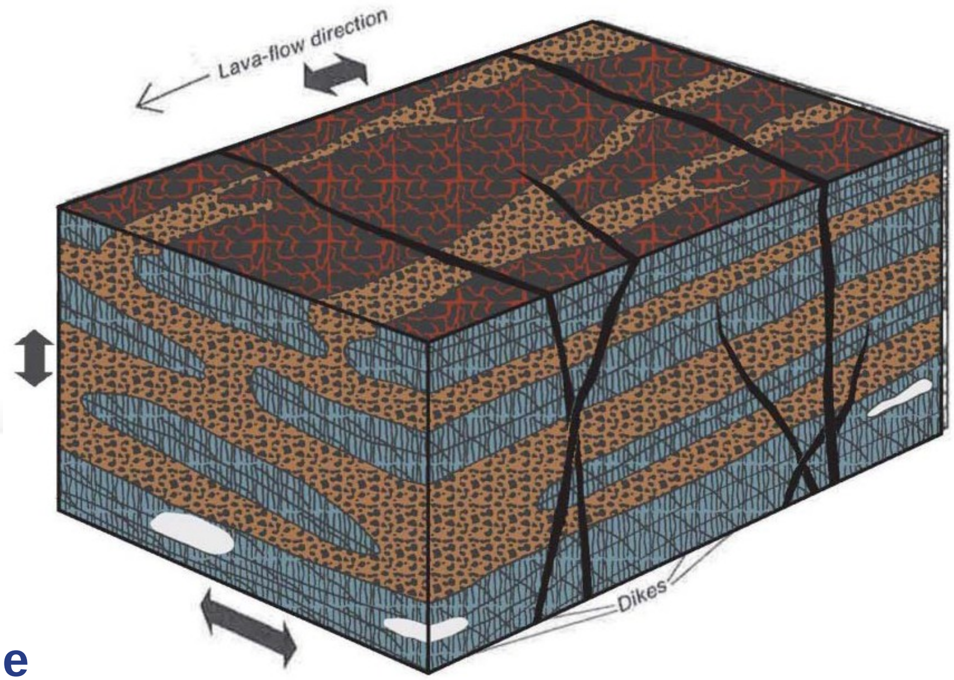
Site Geology and Hydrogeology: Vadose Zone Geology

Dike Complexes:

- Areas with numerous dikes that intersect at various angles
- Form small compartments
- Lower overall rock porosity and permeability[1]

Marginal Dike zones:

- Areas where vertical dikes are subparallel and widely scattered
- Can impound water within large compartments of more permeable lavas
- Tend to channel ground-water flow parallel to the general trend of the dikes[2]



[1] Takasaki and Mink, 1985 [2] Hirashima, 1962; Takasaki, 1971

Site Geology and Hydrogeology: Vadose Zone Geology

Pyroclastic Deposits:

- Pyroclastic (airfall) granular deposits include ash, cinder, spatter, and larger blocks
- Porosity and permeability are similar to that of granular sediments with similar grain size and degree of sorting
- Fine-grained ash is less permeable than coarse pyroclastic deposits such as cinder and spatter
- Permeability of ash may be reduced further by weathering or by compaction to tuff; weathered ash beds can act as thin confining units within lava sequences

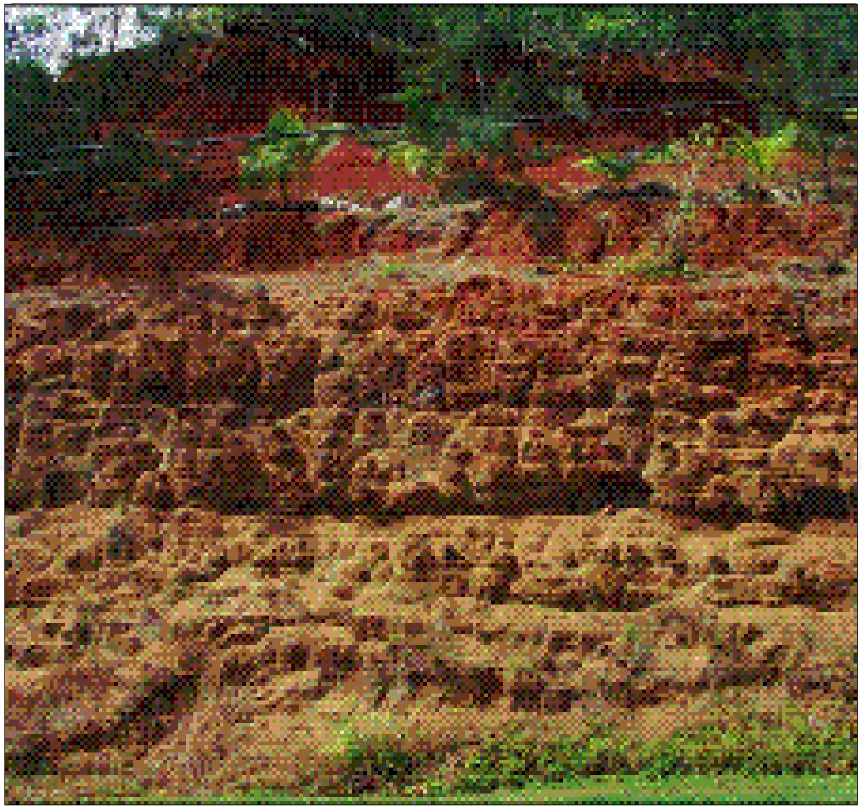
Site Geology and Hydrogeology: Vadose Zone Geology

- **Weathering between flow events ("hiatuses") can form weathered soil horizons with lower permeability.**

Site Geology and Hydrogeology: Vadose Zone Geology

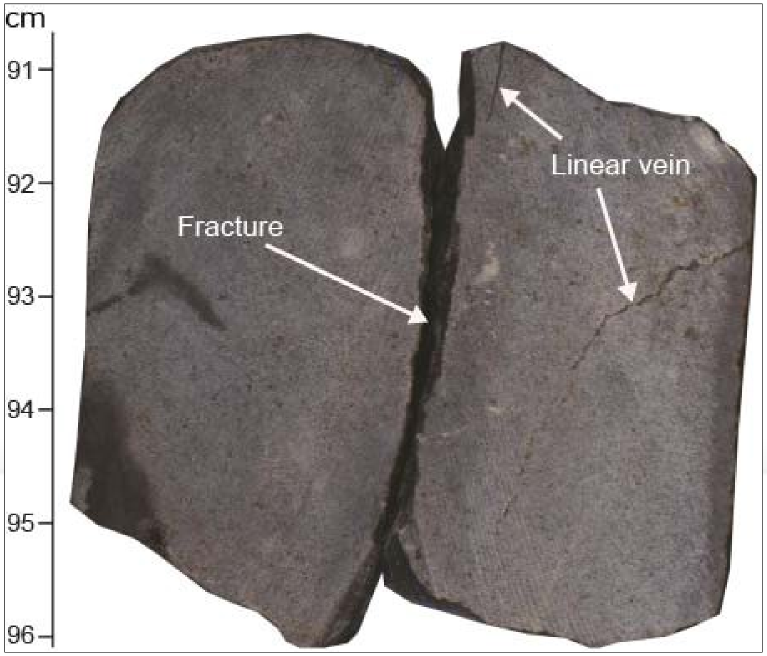
Saprolite:

- Weathered material; retains textural features of parent rock
- Can be 300 feet thick
- Percolating water beneath stream channels in valleys often significantly increases the depth of weathering
- Rocks with a high proportion of pore space and surface area, such as ash, cinder, and a‘a clinker, are weathered preferentially; weathering of massive rock proceeds more slowly
- Principal permeability in massive a’a is along vertical cooling joints; slight weathering and swelling can seal these joints, resulting in a layer of low vertical permeability



Site Geology and Hydrogeology: Porosity in Volcanic Rocks

- Fracture joints, cracks, and bedding plane separations can form during emplacement or from weathering



Site Geology and Hydrogeology: Porosity in Volcanic Rocks

- **Intergranular fragmental rocks (like clean course gravel):**

  - **Scoria/Cinder – highly vesicular lava fragments that are explosively ejected from a vent**

  - **Rubble and clinkers in an a'a flow**

Site Geology and Hydrogeology: Porosity in Volcanic Rocks

- Conduits/large openings (like limestone solution conduits):
  - Lava tubes – naturally formed tunnel in a lava flow, created by crusting of lava over the main lava channel, followed by drainage of lava, follows direction of flow
  - Interflow (typically horizontal) voids formed by cooling and expanding lava during emplacement

Site Geology and Hydrogeology: Permeability in Volcanic Rock Formation

The permeability of Hawaiian volcanic rock formation is highly variable depending on:

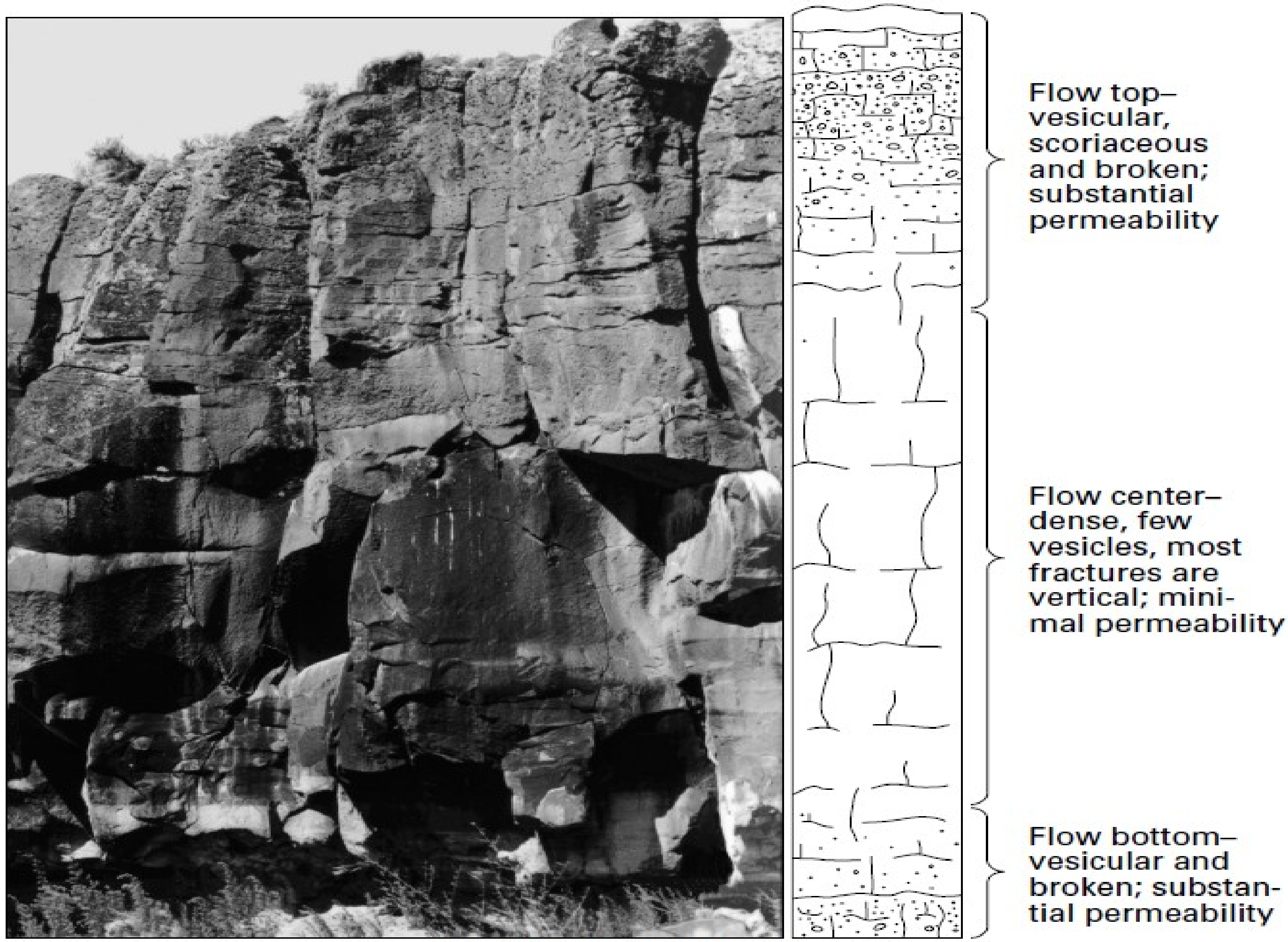
- Vesicle fraction
- Type of emplacement
  - Extrusive (lava flows)
  - Intrusive (dikes/sills)
  - Explosive/airfall (pyroclastics)
- Presence of interflow zones and voids
- Reduction in permeability by weathering

Site Geology and Hydrogeology: Permeability in Volcanic Rock Formation

- High permeability (often horizontal)
  - Thin pahoehoe flows (large number of interflow zones)
  - Vesiculated lava flow tops
  - Rubbly a‘a flow base and top (a’a clinker zones)
  - Highly fractured rocks
- Low permeability (potential confining layers) (often vertical)
  - Massive a’a flows
  - Massive unweathered intrusive rocks (dikes/sills)
  - Ash beds
  - Weathered rocks (saprolite)/soil horizons
- Net result:
  - Highly complex & variable rock type & fabric, frequently resulting in highly variable permeability and unpredictable flow patterns
  - Vertical permeability often orders of magnitude lower than horizontal
  - Horizontal permeability significantly higher in direction of flow

Site Geology and Hydrogeology: Permeability in Volcanic Rock Formation

Massive a‘a flow displays highly variable permeability

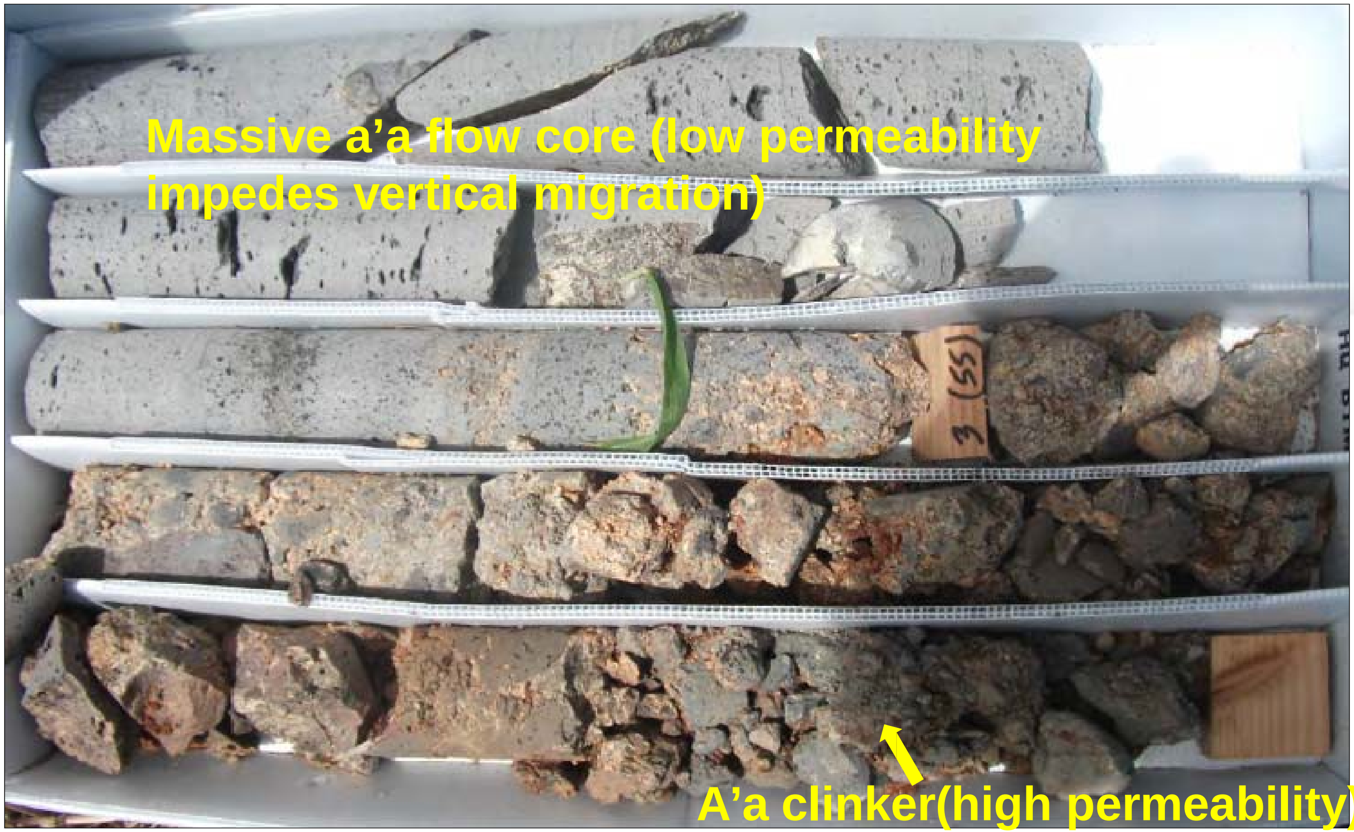


Modified from Whitehead, 1992

Site Geology and Hydrogeology: Porosity and Permeability Variability at the Site

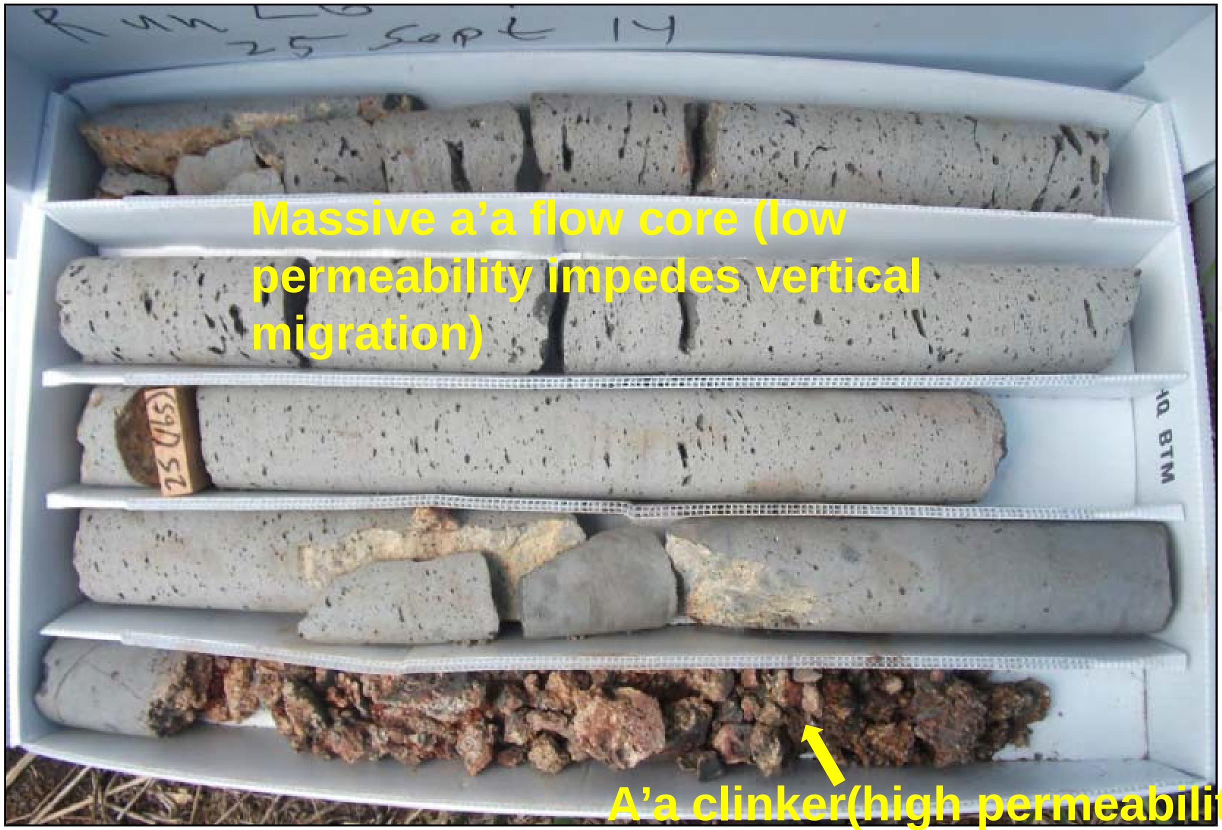
- **RHMW07 (surface elevation = 216.53 ft. msl)**

  Core interval 40 – 50 ft. bgs (166.5 – 176.5 ft. msl)



Site Geology and Hydrogeology: Porosity and Permeability Variability at the Site

- **RHMW07 (surface elevation = 216.53 ft. msl)**
  - **Core interval: 160 – 170 ft bgs (46.5 – 56.5 ft. msl)**



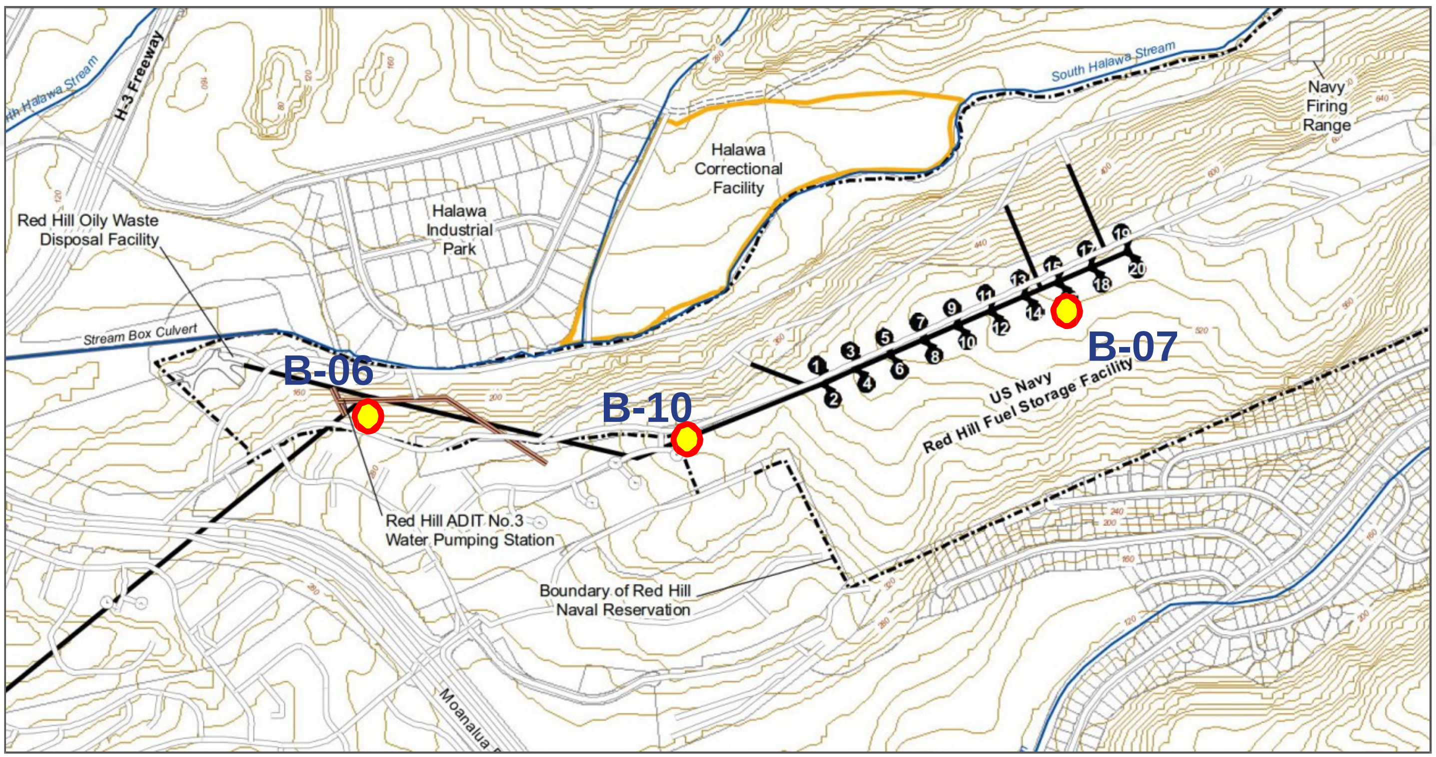
Site Geology and Hydrogeology: Porosity and Permeability Variability at the Site

Core interval 399.4 – 404.4 ft. bgs (135.6 – 141.6 ft. msl)

Pahoehoe lava (medium to high permeability due to interflow zones and fracture)

Site Geology and Hydrogeology: Vadose Zone Geology

- **Previous Red Hill investigations**
  - **Boring logs and rock cores from a previous site investigation conducted in 2012 and 2013**
    - 10 surface borings along tunnel alignment mauka to makai starting atop Red Hill
    - 2 obs in B-07 at 102' msl (slight fuel gas odor) and 92' msl (strong fuel gas odor)



Site Geology and Hydrogeology: Vadose Zone Geology

- Geologic CSM of the Red Hill vadose zone
  - Overall, the Red Hill vadose zone is highly heterogeneous and anisotropic
  - Interbedded flows of different types of lava likely flowed from different directions at different times, may have been weathered between flows (potentially forming weathered horizons and soil), resulting in the presence of sizable voids and relatively impermeable regions or zones in unpredictable locations
  - Formation of lava tubes, dikes, sills, weathering and other factors likely resulted in the formation of sizable voids that are not interconnected and relatively impermeable in the vertical direction

Site Geology and Hydrogeology: Vadose Zone Geology

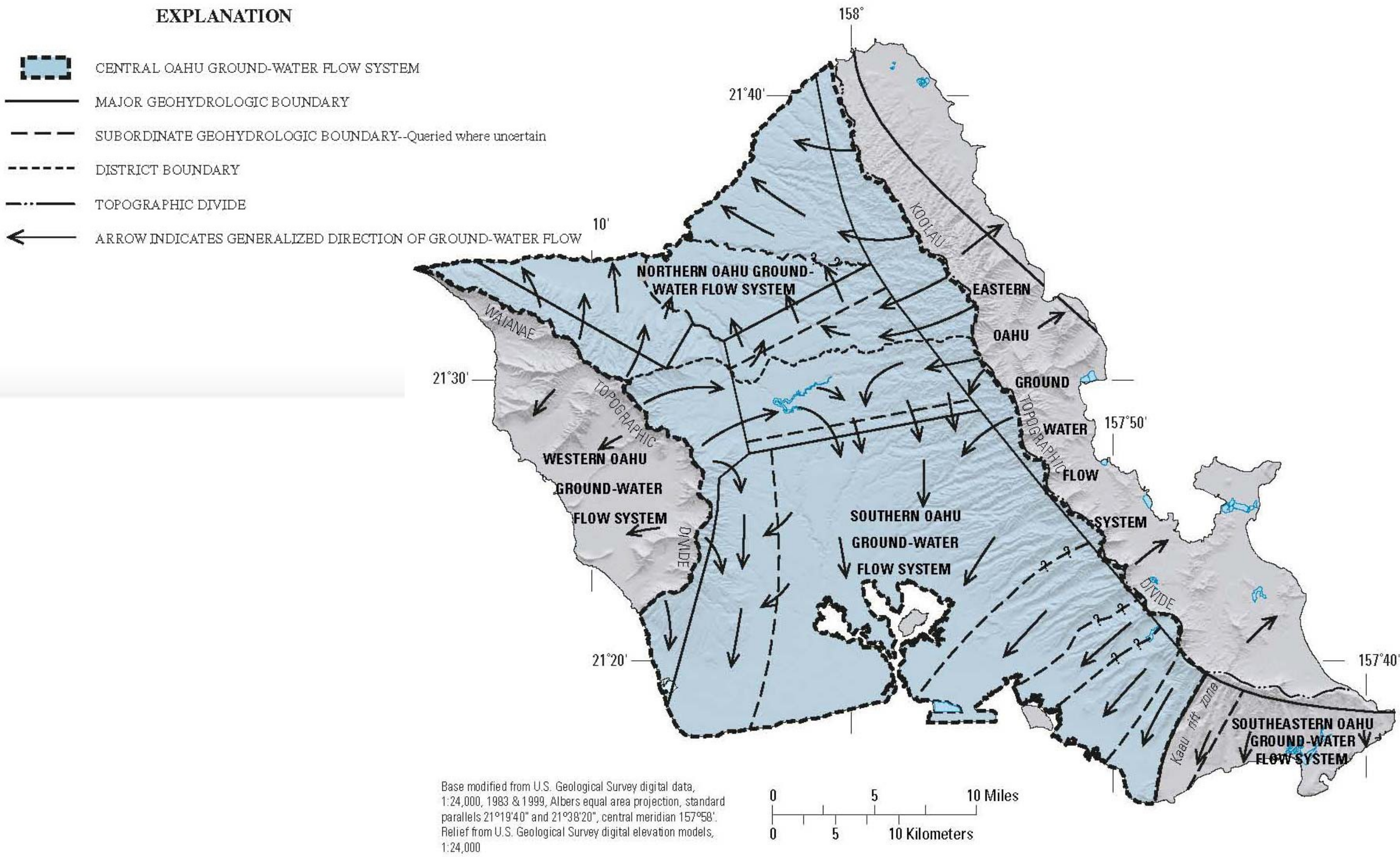
- **The Geologic CSM of the Red Hill Vadose Zone:**
  - **May explain no measurable LNAPL in monitoring wells**
    - Argues for limiting drilling near the tank farm; to avoid creating pathways through confining layers to the groundwater
    - Would make it very difficult to locate NAPL via drilling
    - Explains the difficulties and dangers that active remediation or removal of NAPL would entail
    - Suggests the formation is relatively oxygen-rich, promoting natural attenuation of petroleum products
  - **Suggests that vadose zone numerical flow modeling would not produce meaningful, reliable, or reproducible results**
    - Models developed for porous media or for fractured (mainland) bedrock would not be expected to reflect Hawaiian geology with any degree of accuracy

Site Geology and Hydrogeology: Hydrogeology

- Hydrogeology
  - Principal aquifer is comprised of high horizontal permeability (high K) zones, hydraulically interconnected at the site scale
  - Low permeability zones of unfractured basalt and dikes form barriers to groundwater flow
  - Valley fill sediments are fine grained, forming (low K) flow barriers
  - Caprock of intermediate permeability occurs west of site

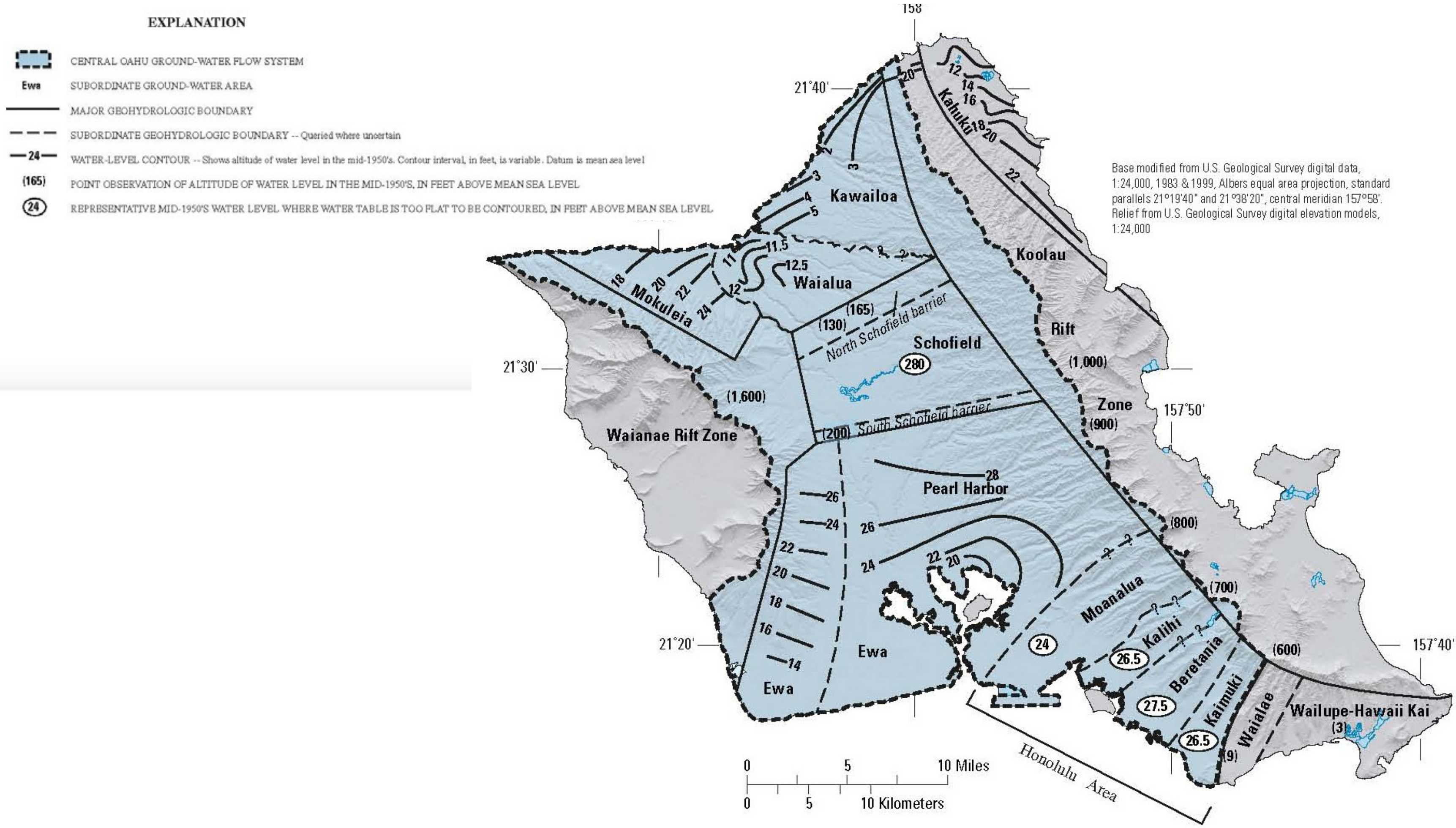
Site Geology and Hydrogeology: Hydrogeology

Groundwater Flow Systems, Oahu, Hawaii (Hunt 1996)



Site Geology and Hydrogeology: Hydrogeology

Groundwater Areas and Potentiometric Surface in the Principal Volcanic-Rock Aquifers



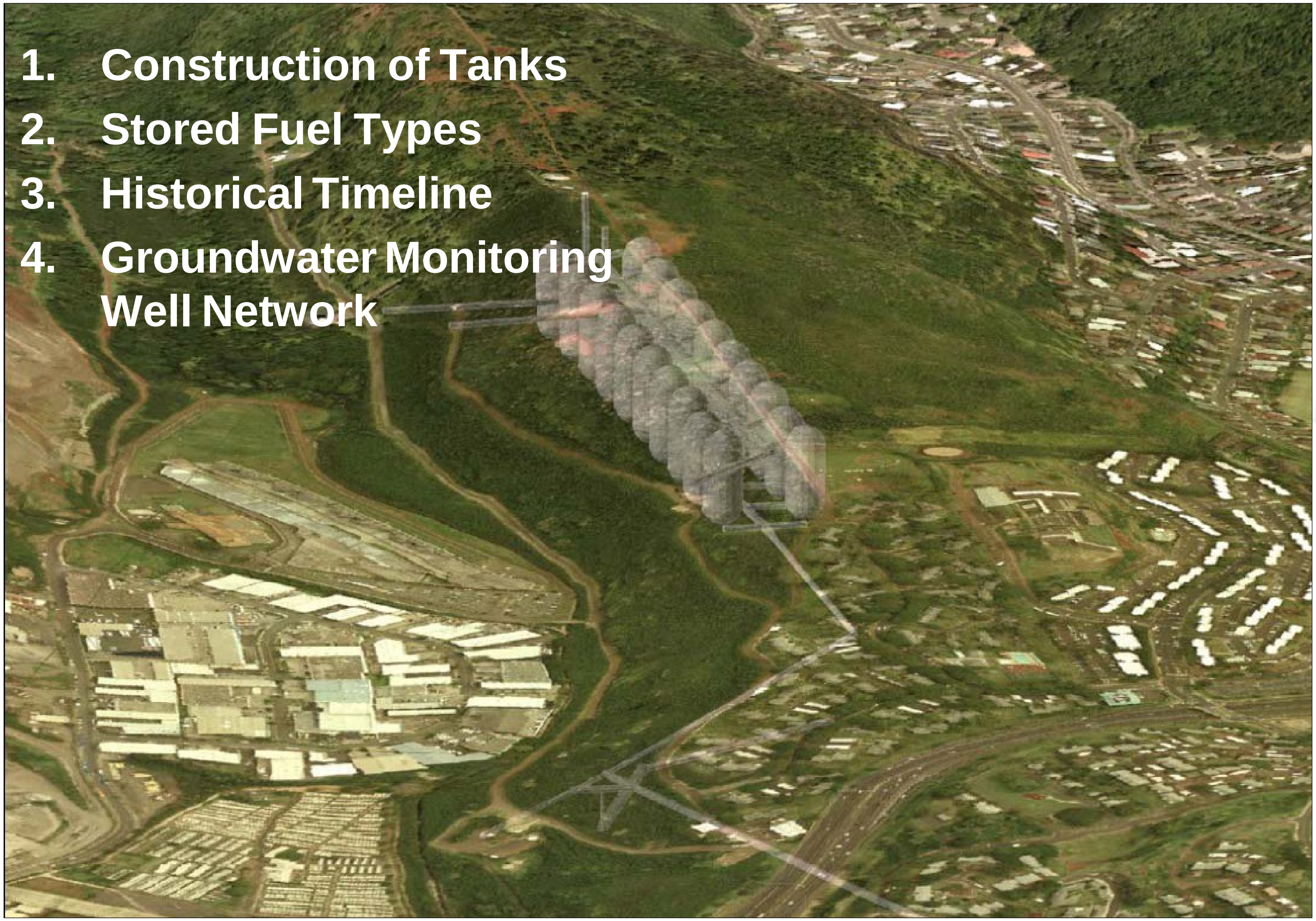
Task #1: Evaluate Subsurface Geology

- NAPL was released into complex geological formations below the tanks, however no measureable NAPL has been found in monitoring wells to date
- A better understanding of site geology would help to develop a detailed and site-specific Geological Conceptual Site Model (CSM) to help identify NAPL fate and transport mechanisms and focus subsequent analyses
- Therefore, it is recommended that we first evaluate the subsurface geology, prior to conducting other tasks

Task #1: Evaluate Subsurface Geology

- <u>**Geologic Mapping of Site Subsurface**</u>
  - **Review:**
    - literature,
    - aerial imagery, and
    - previous drilling logs and rock cores
  - **Conduct field survey to map outcrops and visual evidence of dikes**
  - **Map dips and strikes of bedding, fractures, dikes, and potential preferential pathways to the extent possible**
  - **Based on the site-specific Geological CSM:**
    - Evaluate whether modeling of potential vertical flow to the groundwater aquifer is likely to be accurate, reproducible, or reliable
    - Evaluate whether additional sampling to locate NAPL is likely to be productive and effective

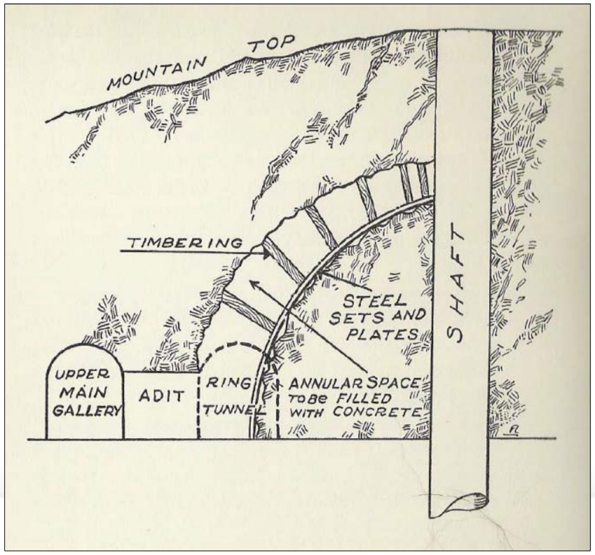
Previous Investigations: Outline

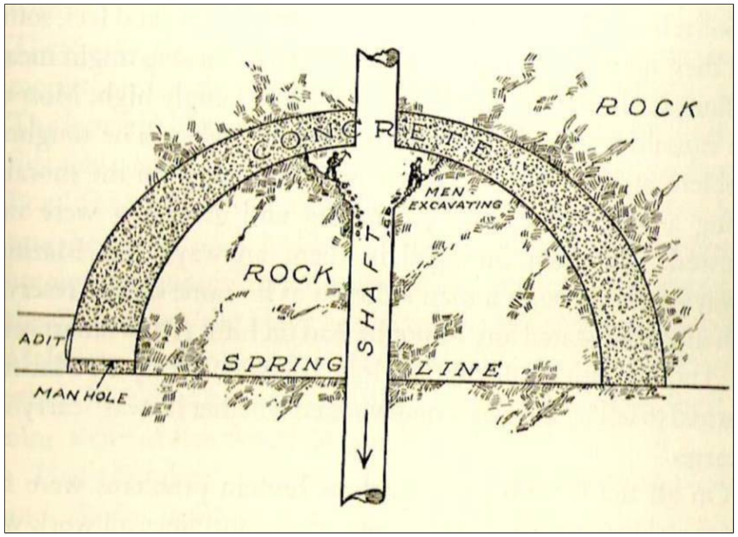


1. Construction of Tanks
2. Stored Fuel Types
3. Historical Timeline
4. Groundwater Monitoring Well Network

Previous Investigations: Construction of Tanks

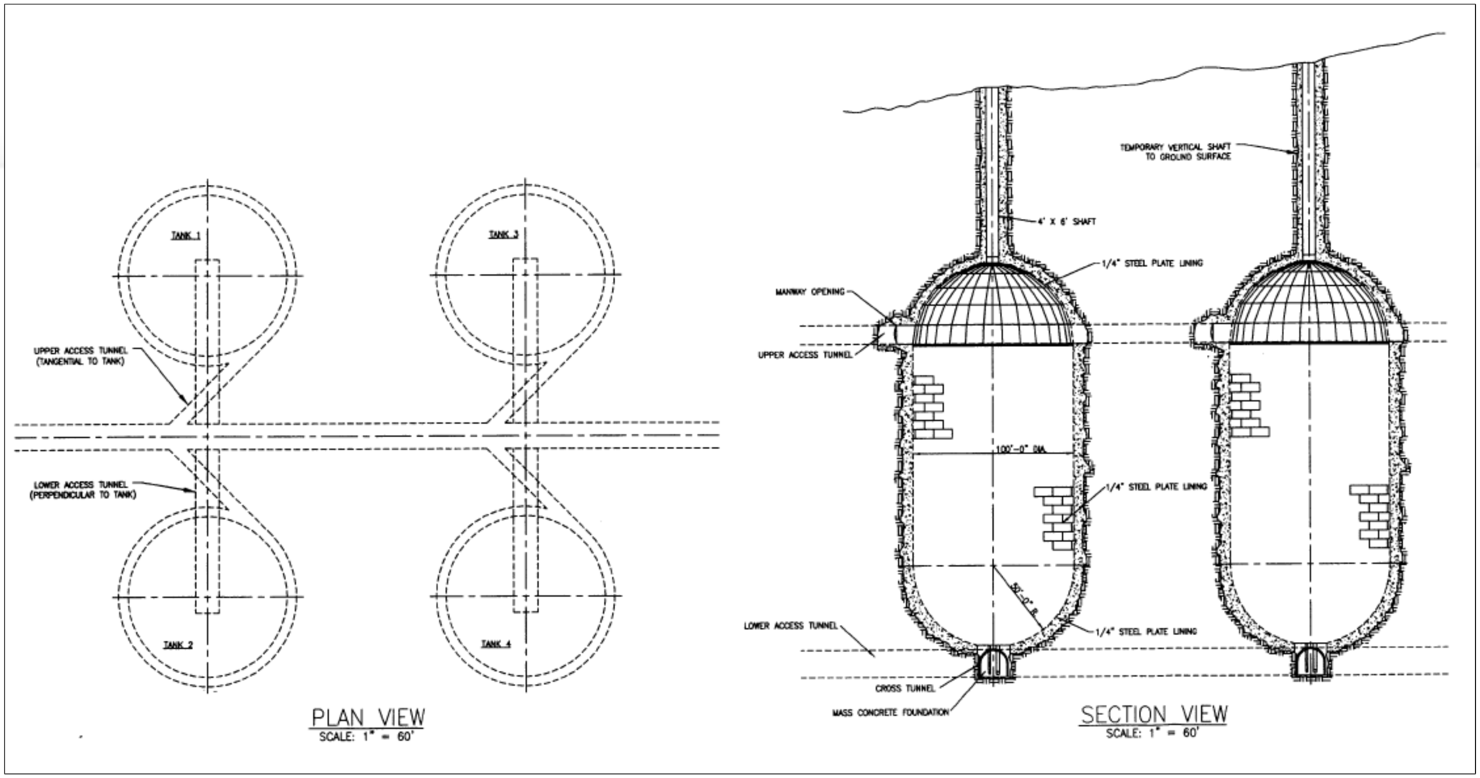
- Before the 1940's, all Navy fuel was stored in aboveground tanks
- For national security reasons, Red Hill fuel farm was installed a minimum of 100 ft underground to protect against aerial attacks
- 20 field constructed steel vertical underground storage tanks (USTs)
  - Inner tank liners constructed of welded steel plates
  - Exterior of steel liner filled with concrete



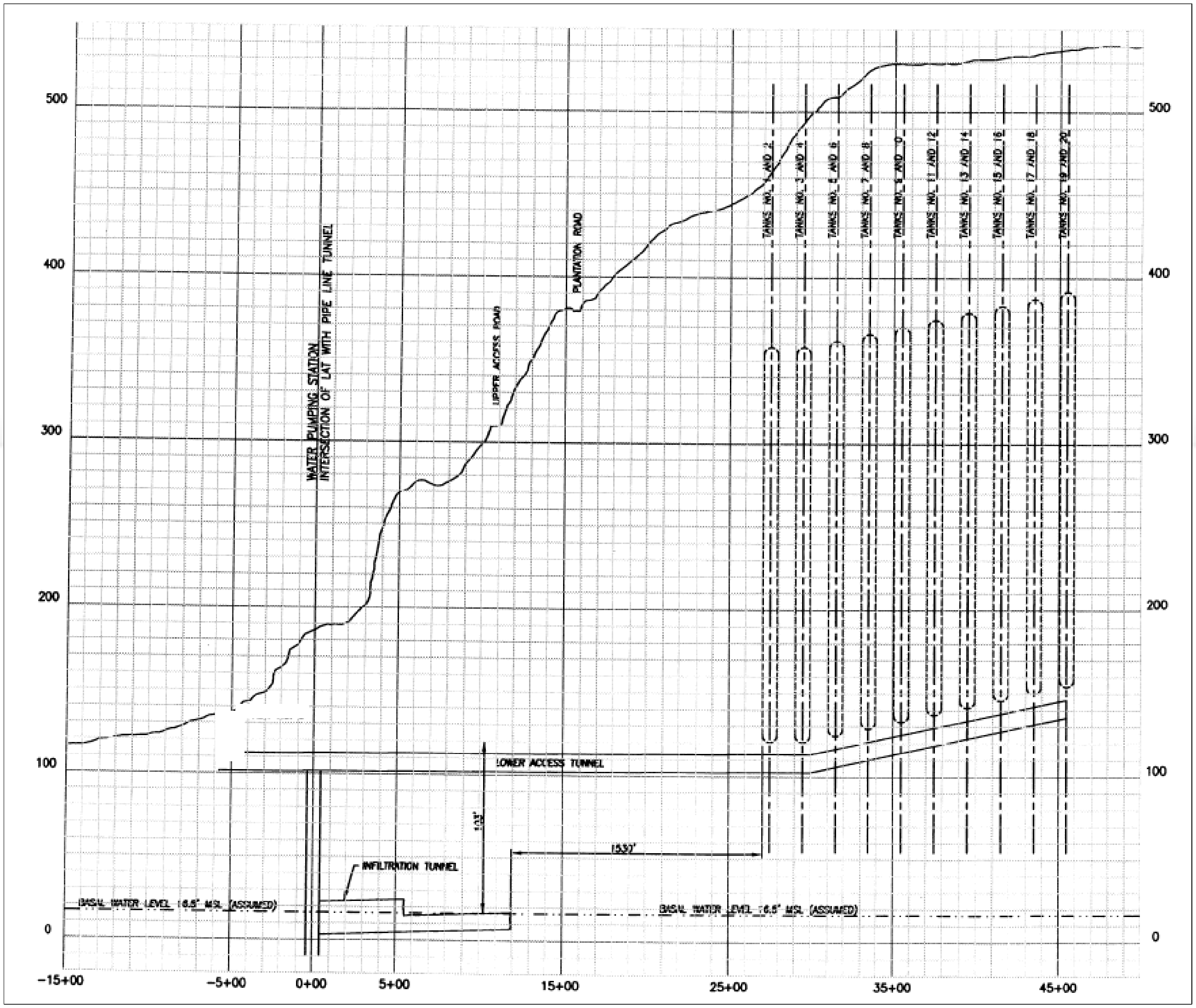


Previous Investigations: Construction of Tanks

- Each tank: 250 ft high x 100 ft diameter, 12.5 million gallons
- Tank tops: at least 100 ft underground
- Tank bottoms: approx. 100 ft or more above groundwater
- Layout: two rows with upper and lower service tunnels



Previous Investigations: Construction of Tanks



Previous Investigations: Fuel Types Stored

Fuel types:

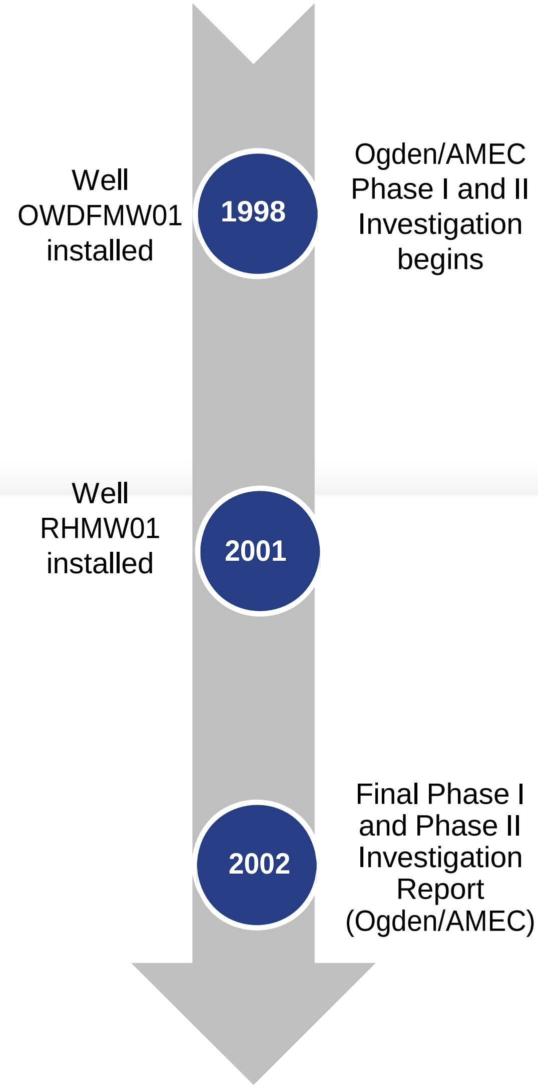
- **JP-5 (kerosene-type turbine fuel) – Tank 7-12, 17-18, 20**
- **JP-8 (kerosene-type turbine fuel) – Tanks 2-6**
- **F-76 (diesel marine fuel) – Tanks 13-16**

Tank Identification	Fuel Type	Status	Capacity
F-1	None	Inactive	12.5 million gallons
F-2	JP-8	Active	12.5 million gallons
F-3	JP-8	Active	12.5 million gallons
F-4	JP-8	Active	12.5 million gallons
F-5	JP-8	Active	12.5 million gallons
F-6	JP-8	Active	12.5 million gallons
F-7	JP-5	Active	12.5 million gallons
F-8	JP-5	Active	12.5 million gallons
F-9	JP-5	Active	12.5 million gallons
F-10	JP-5	Active	12.5 million gallons
F-11	JP-5	Active	12.5 million gallons
F-12	JP-5	Active	12.5 million gallons
F-13	F-76	Active	12.5 million gallons
F-14	F-76	Active	12.5 million gallons
F-15	F-76	Active	12.5 million gallons
F-16	F-76	Active	12.5 million gallons
F-17	JP-5	Active	12.5 million gallons
F-18	JP-5	Active	12.5 million gallons
F-19	None	Inactive	12.5 million gallons
F-20	JP-5	Active	12.5 million gallons

F-76 Marine Diesel Fuel
JP-5 Jet Fuel Propellant-5
JP-8 Jet Fuel Propellant-8

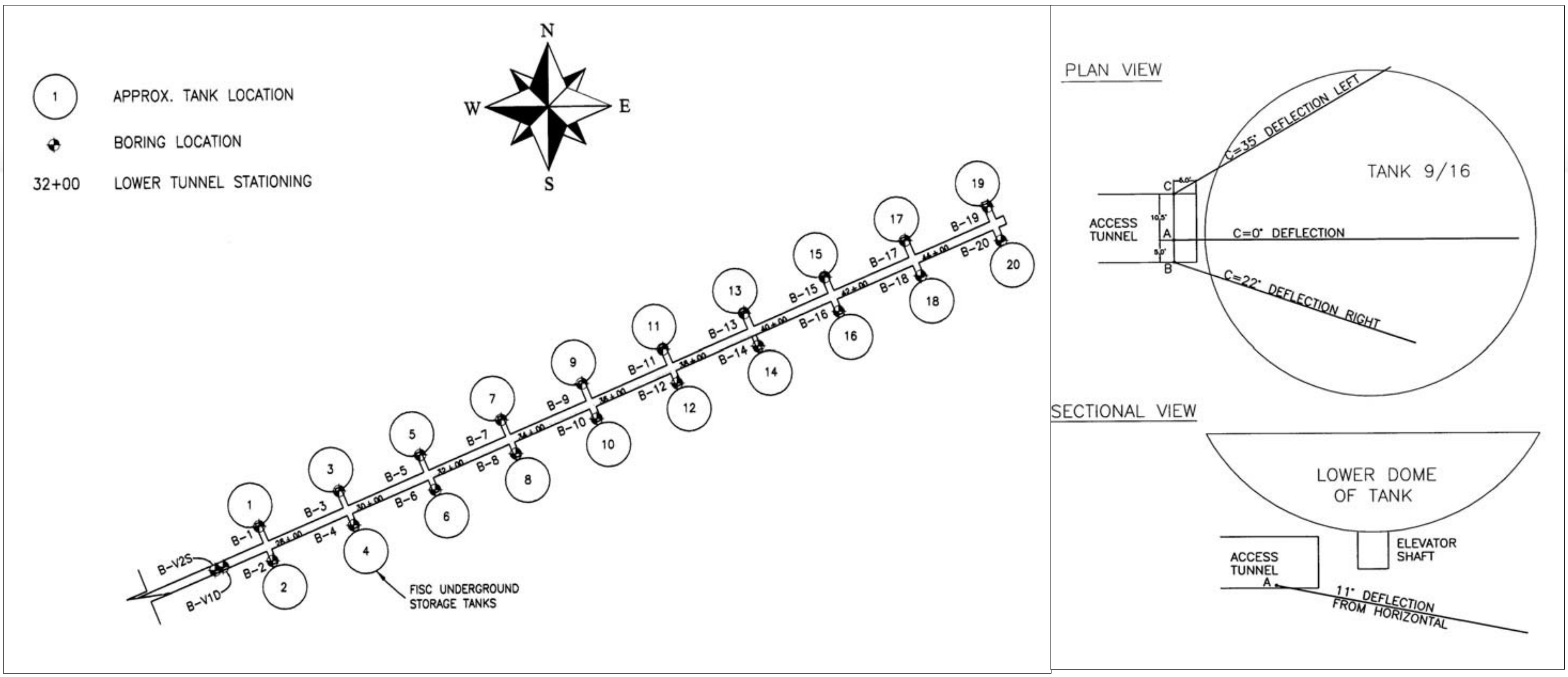
Previous Investigations: Results

- **1998-2002 – Ogden/AMEC Investigation**
  - Conducted to evaluate concerns related to historical releases
  - Included slant boreholes, installation of two monitoring wells
  - Recommended further analysis and risk assessment



Previous Investigations: Results

- **1998 – Ogden/AMEC Investigation (continued)**
  - **Slant borehole drilled at angle beneath each UST (min. 5 ft below UST), terminated 80-90 ft above groundwater level**



Previous Investigations: Results

- **1998 – Ogden/AMEC Investigation (continued)**
  - **Fluids in angled borings and one deep boring were sampled and submitted for fuel fingerprint analysis**
  - **Three types of fluids were present:**
    - LNAPL mixed with drill water (LNAPL)
    - LNAPL mixed with infiltration water (infiltration fluid)
    - One basal groundwater sample did not have product

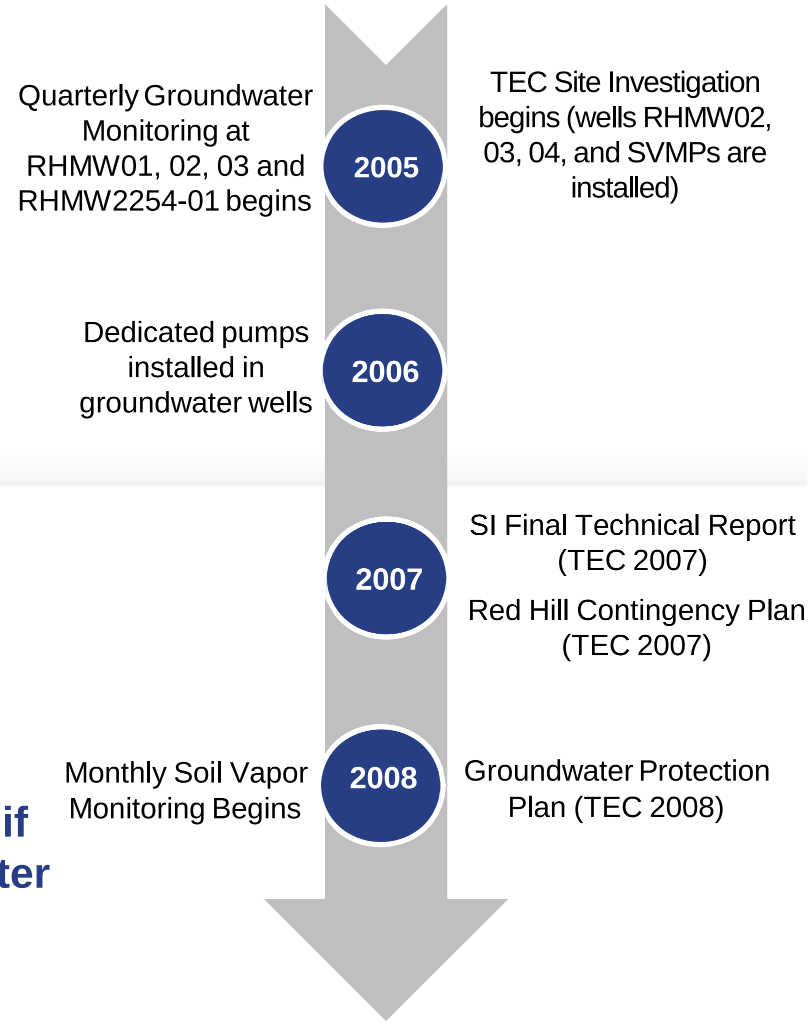
Table 3-4
Summary of Fluid Levels Detected in Monitoring Wells

Monitoring Well ID	Fluid Media	Elevation at Ground Surface	Date	Depth to Fluid Level (ft, POE)	Corrected Elevation of Fluid Level
RH-MW-1	LNAPL	102.66	03/07/01	124.20	70.52
			08/24/01	129.40	69.17
RH-MW-13	LNAPL	121.95	03/07/01	NFD	NA
			08/24/01	132.50	87.66
RH-MW-14	LNAPL	121.75	03/07/01	NFD	NA
			08/24/01	135.30	86.73
RH-MW-17	LNAPL	129.75	03/07/01	NFD	NA
			08/24/01	114.80	103.92
RH-MW-19	Infiltration Fluid	133.68	03/07/01	113.10	104.41
			08/24/01	110.52	108.81
RH-MW-V1D	GW	102.56	03/07/01	86.10	16.46
			08/24/01	86.28	16.28

LNAPL - Light phase non aqueous phase liquid (which may be mixed with drill fluid)
ft, POE - feet from boring point of entry
NA - Not applicable
NFD - No fluid detected

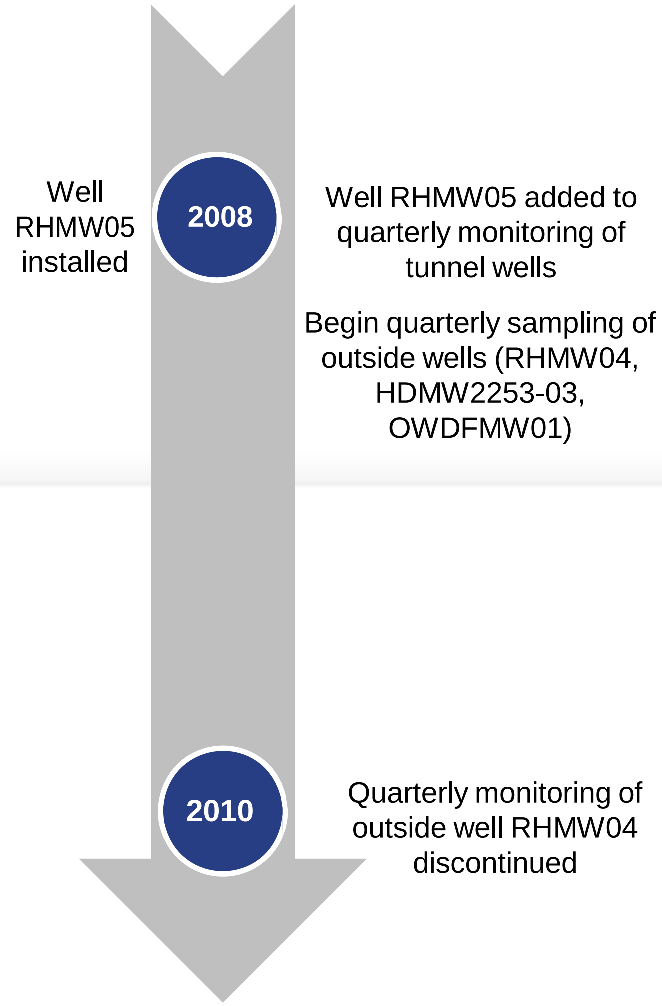
Previous Investigations Results

- **2007 – Site Investigation (TEC 2007)**
  - **Installed RHMW02, RHMW03, & RHMW04**
  - **Installed nested SVMPs in 3 slant boreholes**
  - **Conducted regional pump test**
  - **Developed MODFLOW flow model**
  - **Developed RT3D F&T model**
  - **Concluded VI pathways insignificant due to low volatility of fuels, groundwater depth, and tunnel ventilation**
- **2007, 2008 –Contingency & Groundwater Protection Plans**
  - **Quarterly GWM program and recommended responses to contaminant levels and trends**
  - **SVM program**
  - **Maintenance schedule for USTs**
  - **Actions required to remediate the basal aquifer if a large release of fuel were to migrate to the water table**



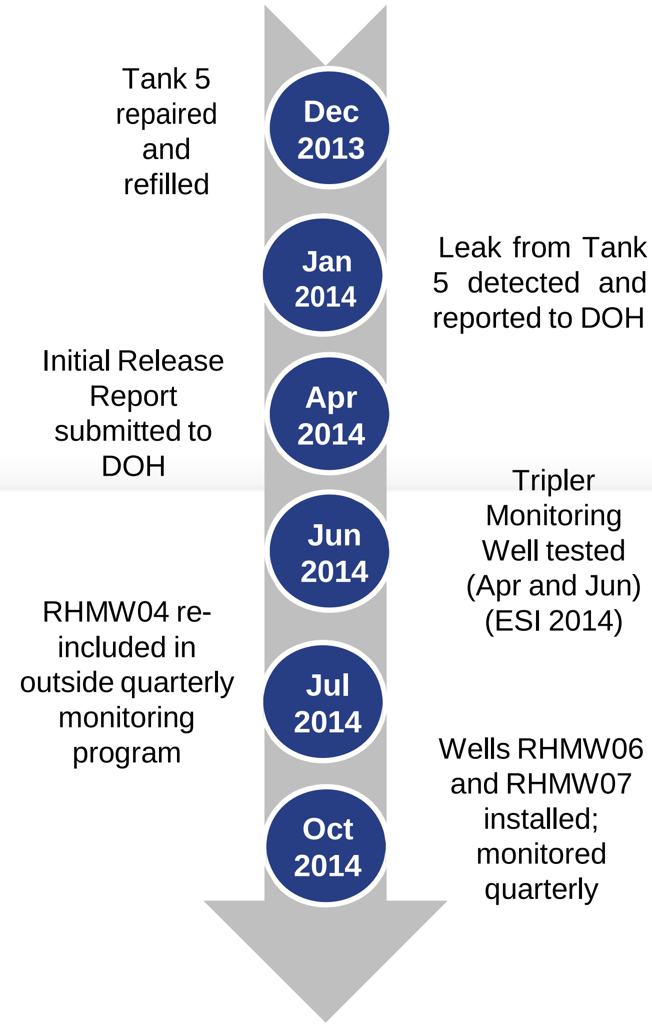
Previous Investigations Results

- **2009 – 2011 Activities Conducted under Groundwater Protection Plan and other DOH UST requirements**
  - **Install RHMW05 (based on modeling results)**
  - **Jan. 2008 – July 2010 Monthly Monitoring:**
    - **Free product well gauging:** No measurable LNAPL
    - **PID Screening of SVMPs:** General trend suggests residual contamination, not a chronic leak
  - **Quarterly groundwater monitoring well sampling**
  - **Re-evaluation of groundwater flow model**

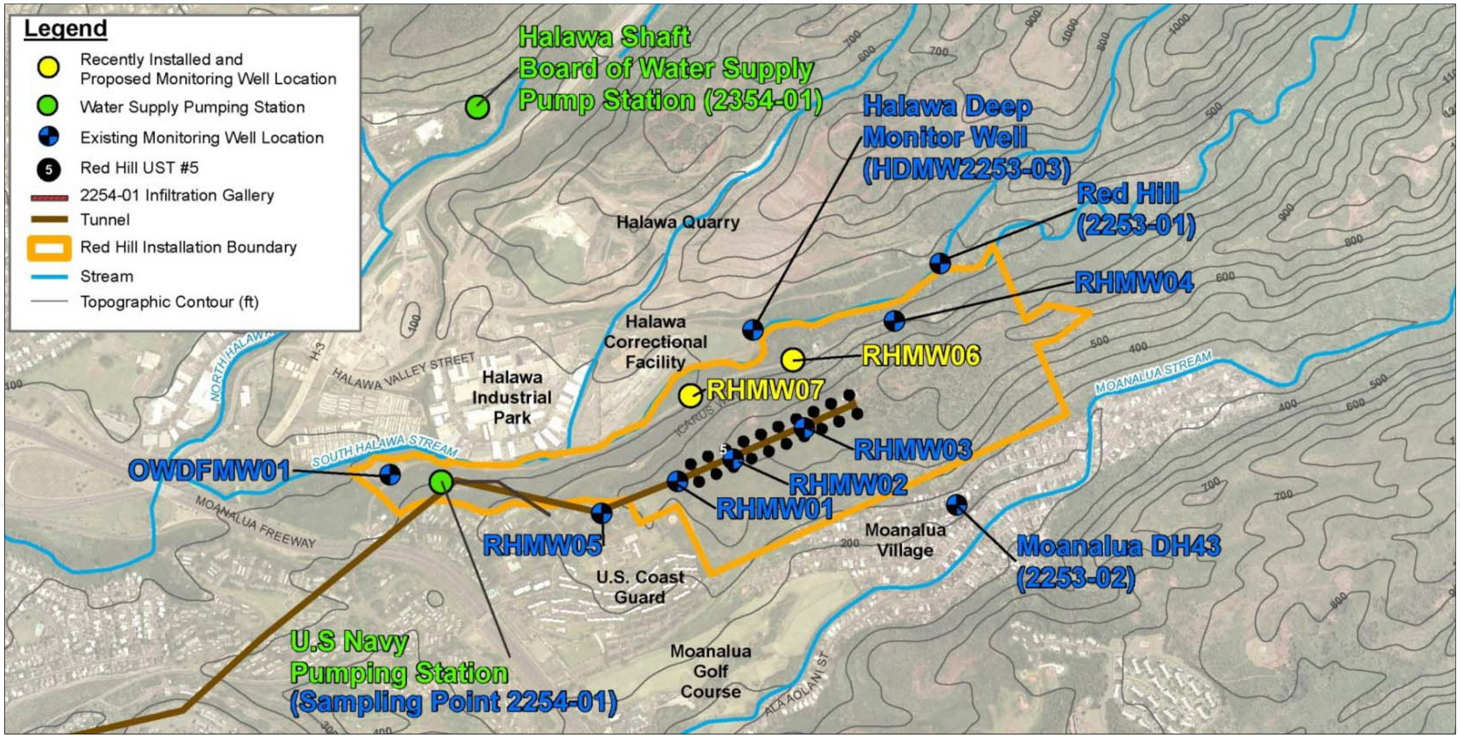


January 2014 Release: Response, Investigations

- Dec. 2013 – Jan. 2014: After repairs, tank 5 was filled with JP-8 fuel in a month-long filling process
- During tank filling, the tank flexed and the fuel level was constantly changing
- Once filled and fuel settled, a release was detected
- Jan. 13, 2014: DOH & NRC immediately notified
- Fuel immediately removed; Tank 5 emptied by Jan. 18, 2014
- April 2014 – Initial Release Response Report
  - Recommended installation of more monitoring wells and further investigation



January 2014 Release:
Current Monitoring Well Network



Well Number	RHMW01	RHMW02	RHMW03	RHMW04	RHMW05	RHMW06	RHMW07	RHMW 2254-01	HDMW 2253-03	OWDFMW 01
Description	Down-gradient of Tanks 1-20	Down-gradient of Tanks 7 -20	Down-gradient of Tanks 15-20	Back ground	Sentinel Well	Installed after release (2014)	Installed after release (2014)	Supply water sampling point	BWS monitoring well	Oily Waste Disposal Facility (IR site)

Task #2: Investigate the LNAPL

- **Potential Methods for Detecting Non-Aqueous Phase Liquid (NAPL) in the Subsurface:**
  1) **Borings and Groundwater Monitoring Wells**
  2) **Laser Induced Fluorescence Tools**
  3) **Membrane Interface Probe Dye Impregnated Liners**
  4) **Soil Gas Survey**
  5) **Geophysical Methods**
     a) Resistivity
     b) Seismic
     c) Spontaneous Potential
     d) Gravity & Magnetic
     e) Induced Polarization
     f) Ground Penetrating Radar
     g) Magnetic Resonance
     h) Electromagnetic

Task #2: Investigate the LNAPL

1. **Borings and Groundwater Monitoring Wells**
   - Effective at confirming the presence of NAPL when locations are known or plume is widespread
   - Allows determination of other subsurface properties for modeling and remediation
   - No practical depth limitation
   - May allow sampling of NAPL for laboratory analysis.
   - However
     - Only detects NAPL in borehole – can be very “hit or miss” in heterogeneous and in fractured rock formations such as Red Hill
     - Can be very expensive to complete an investigation
     - Requires relatively level and stable drilling platform
     - Can create preferential pathways for vertical migration to the groundwater
   - **Conclusion: Not recommended for implementation; evaluation of method to be included in Work Plan/SOW**

Task #2: Investigate the LNAPL

2. Laser Induced Fluorescence Tools (e.g., UVOST)

- Effective at directly detecting petroleum NAPL in the sidewalls of a borehole
- However
  - Requires direct push rig to advance the tool
  - Ineffective in bedrock formations
  - Does not detect dissolved phase contamination
  - Only detects NAPL in borehole – can be very “hit or miss” in heterogeneous and in fractured rock formations such as Red Hill
- **Conclusion: Not recommended for implementation; evaluation of method to be included in Work Plan/SOW**

Task #2: Investigate the LNAPL

3. Membrane Interface Probe (MIP)

- Effective at delineating dissolved-phase petroleum contamination
- The presence/absence of NAPL can be inferred based on the MIP data
- MIP is most effective in detecting organic chemicals with relatively low boiling points (i.e., less than 100°C)
- However
  - Requires direct-push drill rig to advance the MIP
  - Ineffective in bedrock formations
  - Detector or probe can become damaged if driven through NAPL
  - Only detects NAPL in borehole – can be very “hit or miss” in heterogeneous and in fractured rock formations such as Red Hill
  - The identified COPCs appear to have a boiling point over 100°C
- **Conclusion: Not recommended for implementation; evaluation of method to be included in Work Plan/SOW**

Task #2: Investigate the LNAPL

4. Dye Impregnated Liner (FLUTe)

- Effective at detecting NAPL presence and depth in the sidewalls of a borehole
- Can be used in bedrock
- However
  - Liner requires small diameter borehole
  - Potentially expensive as numerous boreholes would likely need to be drilled if using for delineation purposes
  - Only detects NAPL in borehole – can be very “hit or miss” in heterogeneous and in fractured rock formations such as Red Hill
- **Conclusion: Not recommended for implementation; evaluation of method to be included in Work Plan/SOW**

Task #2: Investigate the LNAPL

5. **Soil Gas Survey (Passive)**
   - Effective at detecting lighter fuels such as gasoline
   - Minimally invasive (typically installed 5-10 feet bgs)
   - Can theoretically be used in all geologic formations
   - However
     - Less effective for middle distillates and heavier fuels such as those stored at Red Hill
     - Effectiveness decreases with depth of NAPL
   - **Conclusion: Not recommended for implementation; evaluation of method to be included in Work Plan/SOW**

Task #2: Investigate the LNAPL

6. Geophysical Surveys

a) Resistivity

- Electrical resistivity tomography measures resistivity of formations, sensitive to pore fluids such as NAPL
- Can be collected as 3-D data and through time to document changes
- Minimally invasive to install electrodes
- Depth of investigation is adjustable
- Useful for leak detection, plume mapping, and hydraulic characterization
- **Conclusion: Potentially feasible; evaluation of method to be included in Work Plan/SOW**

b) Seismic

- Measures acoustic velocity and includes reflection and refraction methods
- Most commonly used for mapping bedrock, including faults/fractures at various depths
- Can detect groundwater surface, perched groundwater, and voids
- Not generally used for environmental investigations
- Effectiveness at detecting NAPL not well-documented
- **Conclusion: Not recommended for implementation; evaluation of method to be included in Work Plan/SOW**

Task #2: Investigate the LNAPL

c) Spontaneous Potential (SP)

- Measures the natural voltage difference between two points
- Can identify where water is flowing in the subsurface
- Used primarily for investigating the integrity of earthen dams/dikes
- Effectiveness at detecting NAPL not well-documented
- **Conclusion: Not recommended for implementation; evaluation of method to be included in Work Plan/SOW**

d) Gravity & Magnetic

- Measures changes in either the gravity field or magnetic field (natural or induced)
- Can be quickly and easily performed over large areas
- Used in the exploration of large ore bodies and sometimes petroleum exploration, usually to identify smaller areas of interest
- Effectiveness at detecting NAPL not well-documented
- **Conclusion: Not recommended for implementation; evaluation of method to be included in Work Plan/SOW**

Task #2: Investigate the LNAPL

e) Induced Polarization (IP)

- Secondary resistivity method that measures the charge storage capacity of materials
- Can use same equipment as resistivity survey
- Used to investigate landfills and petroleum NAPLs, and map lithologies
- Can be combined with electrical resistivity tomography
- Further research required to determine whether this is likely to be effective at Red Hill
- **Conclusion: Potentially feasible; evaluation of method to be included in Work Plan/SOW**

f) Ground Penetrating Radar (GPR)

- High resolution acoustic method uses frequencies from 10-1000 MHz
- Shallow depth of investigation (< 20 feet)
- Used to image shallow structures such as tanks, utilities, and voids
- **Conclusion: Not recommended for implementation; evaluation of method to be included in Work Plan/SOW**

Task #2: Investigate the LNAPL

g) Magnetic Resonance

- Direct detection of groundwater
- Used to estimate depth to groundwater, permeability, and water content
- Sensitive to interference from power lines
- Poorly suited for volcanic rock terrains
- **Conclusion: Not recommended for implementation; evaluation of method to be included in Work Plan/SOW**

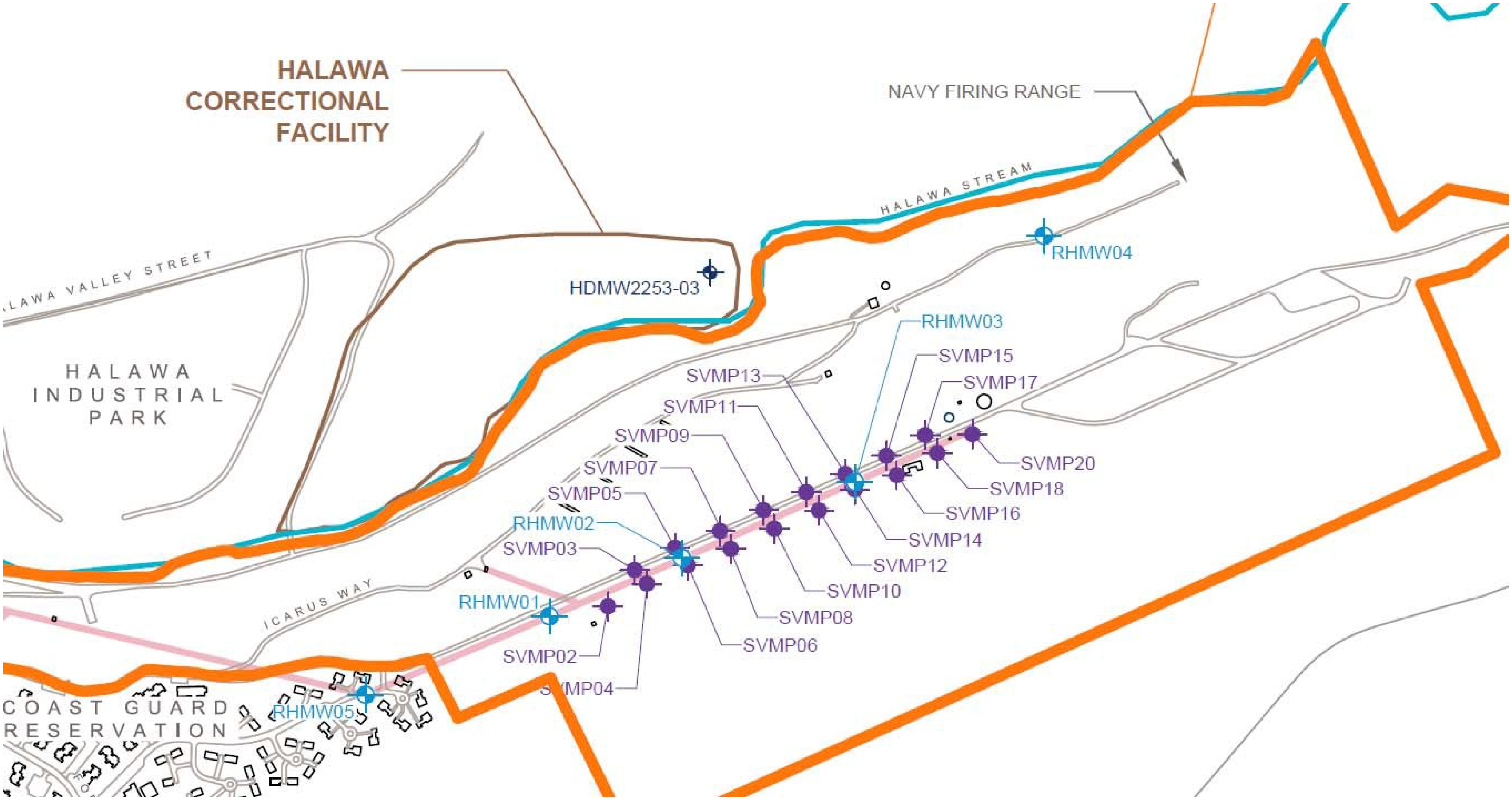
h) Electromagnetic (EM)

- Multiple EM methods are available
- Used to map landfills and other conductive soil and groundwater contamination, characterize subsurface hydrogeology, map conductive faults/fracture planes, and map geologic structures
- Further research required to determine whether this is likely to be effective at Red Hill
- **Conclusion: Potentially feasible; evaluation of method to be included in Work Plan/SOW**

Task #2: Soil Vapor Considerations

- **Soil Vapor Sampling Monitoring Analysis (2010)**
  - **a) Vapor sampling at soil vapor monitoring points (SVMP) under active fuel tanks at that time**
    - SV02, SV03, SV06, SV11, SV14, and SV17
    - BTEX and TPH
  - **b) Evaluate if soil vapor concentrations measured during the monthly rounds are indicative of a new fuel release**
    - Correlated PID measurements with analytical TPH data
    - Established three benchmark concentrations via field measurements and phase partitioning calculations
    - Modeled diffusion as the critical transport process for subsurface vapor to calculate temporal vapor concentration increases at set distances (10, 50, 100 feet)
    - Relationship to rain events

Task #2: Soil Vapor Considerations



Task #2: Soil Vapor Considerations

- **Soil Vapor Sampling Monitoring Analysis Letter Report (2010)**
  a) **Conclusions**
    - Low vapor concentrations measured and apparent mobilization of vapors due to water recharge (i.e., rain events) indicate current source of vapors observed were residual or of a small release
    - Indications of a minor release less likely due to the general trend of vapor concentrations (downward trend)
    - Soil vapor readings taken on a regular basis (i.e., monthly) provides an "excellent indicator of potential fuel releases"
    - Diffusion calculations show vapors are very mobile making detection of a leak probably within a few weeks following a small release

  b) **Recommendations**
    - Soil vapor concentrations approaching 280 ppmv in SVMPs beneath the tanks containing jet fuels warrant special attention
    - Vapor concentrations approaching 14 ppmv in SVMPs beneath tanks containing diesel fuel also warrant special attention
    - Validating/Updating maximum soil vapor calculations
    - Partitioning studies to develop a fingerprint baseline to differentiate between fresh and weathered contaminants

Soil Vapor Considerations

- **Soil Vapor Sampling Monitoring Analysis (2010)**
  - **a) Vapor sampling at soil vapor monitoring points (SVMP) under active fuel tanks at that time**
    - SV02, SV03, SV06, SV11, SV14, and SV17
    - BTEX and TPH
  - **b) Evaluate if soil vapor concentrations measured during the monthly rounds are indicative of a new fuel release**
    - Correlated PID measurements with analytical TPH data
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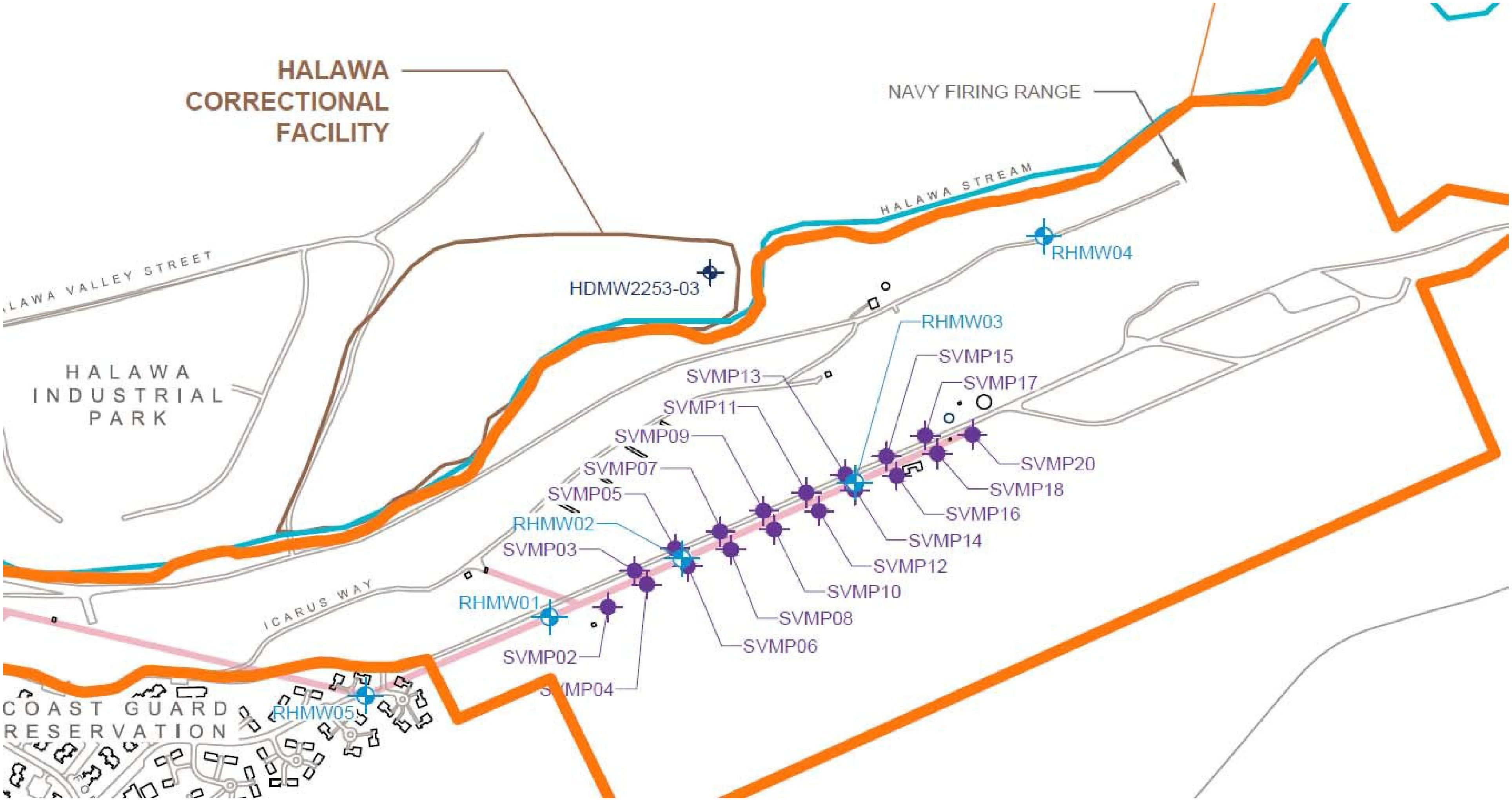
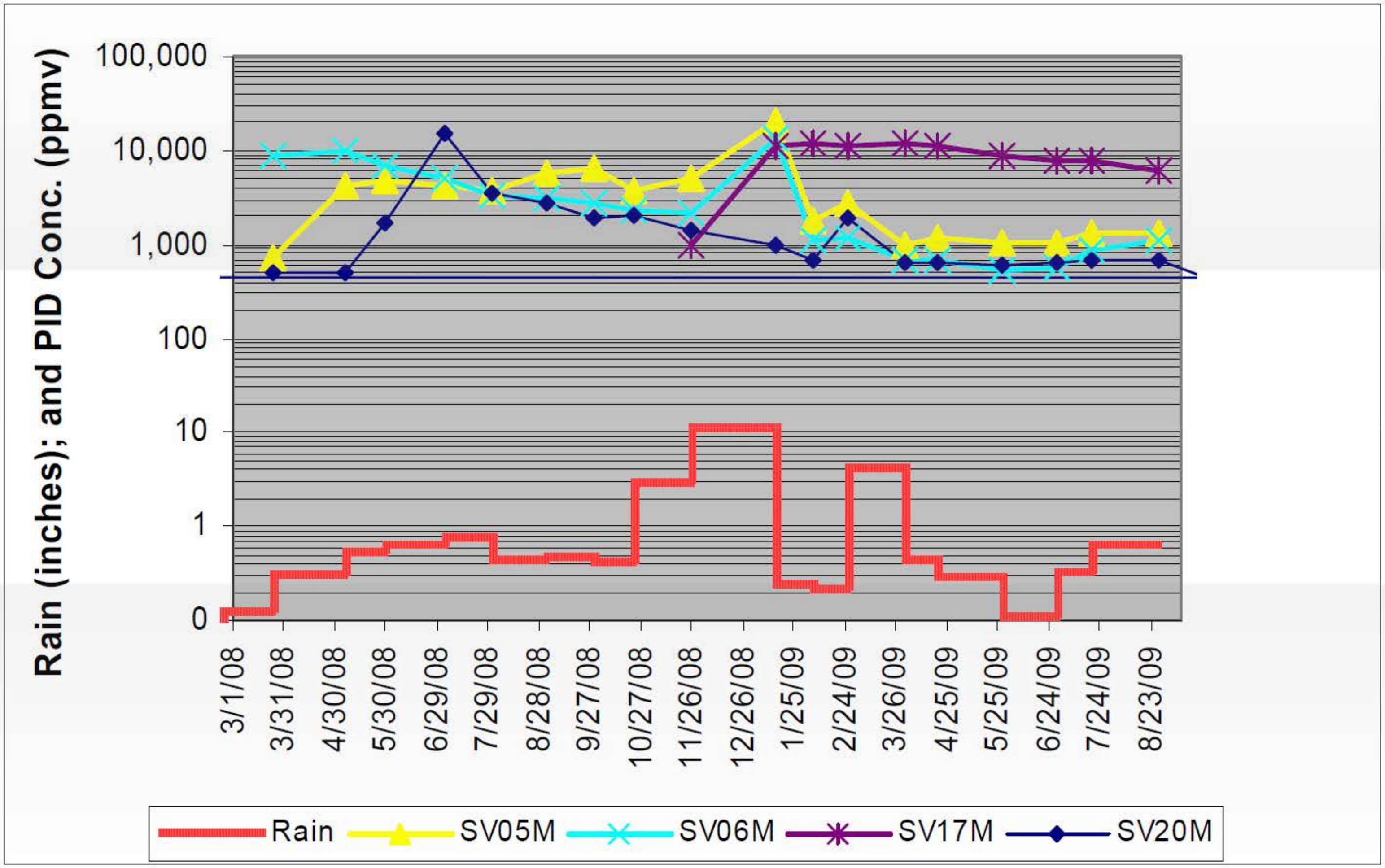
    - Relationship to rain events

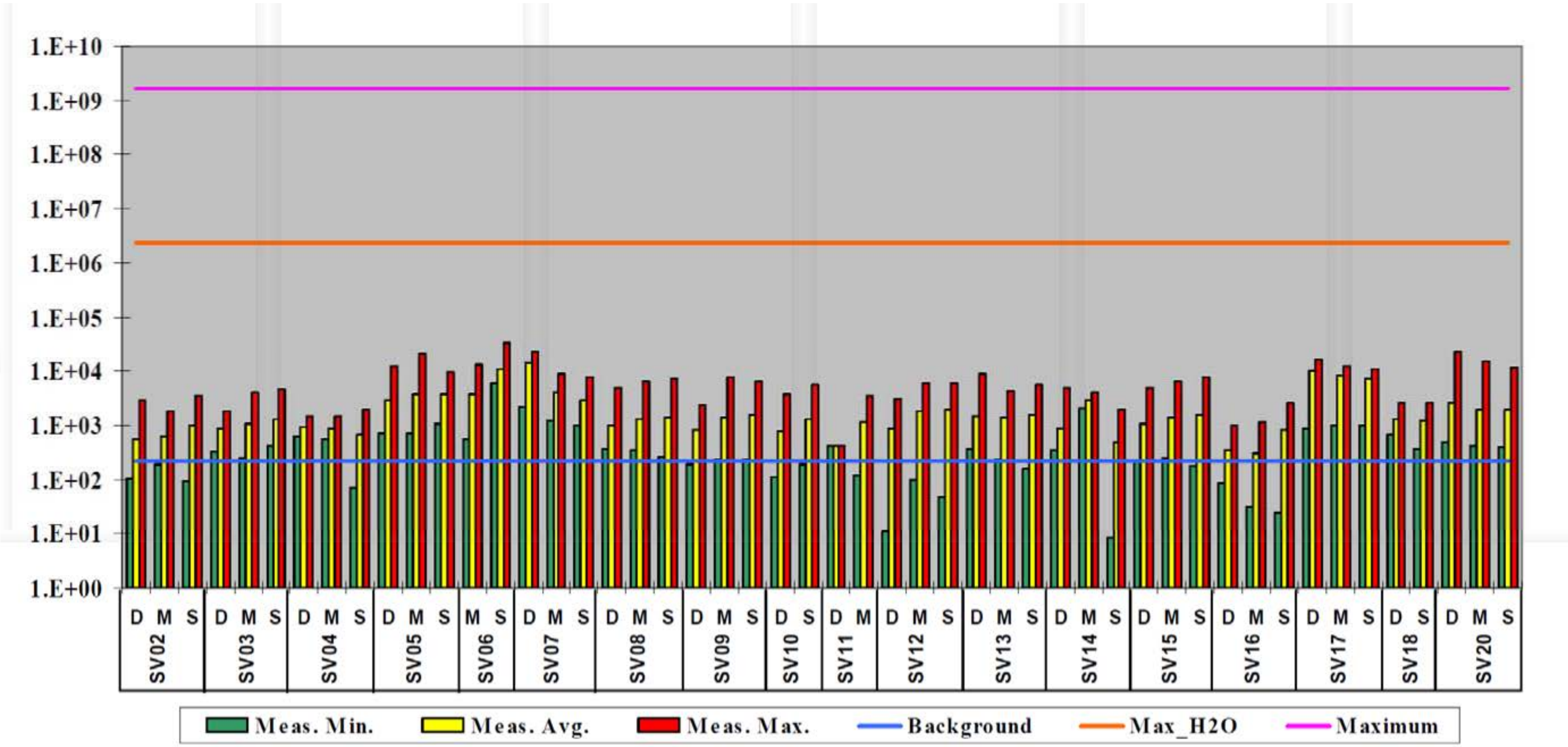
Soil Vapor Considerations



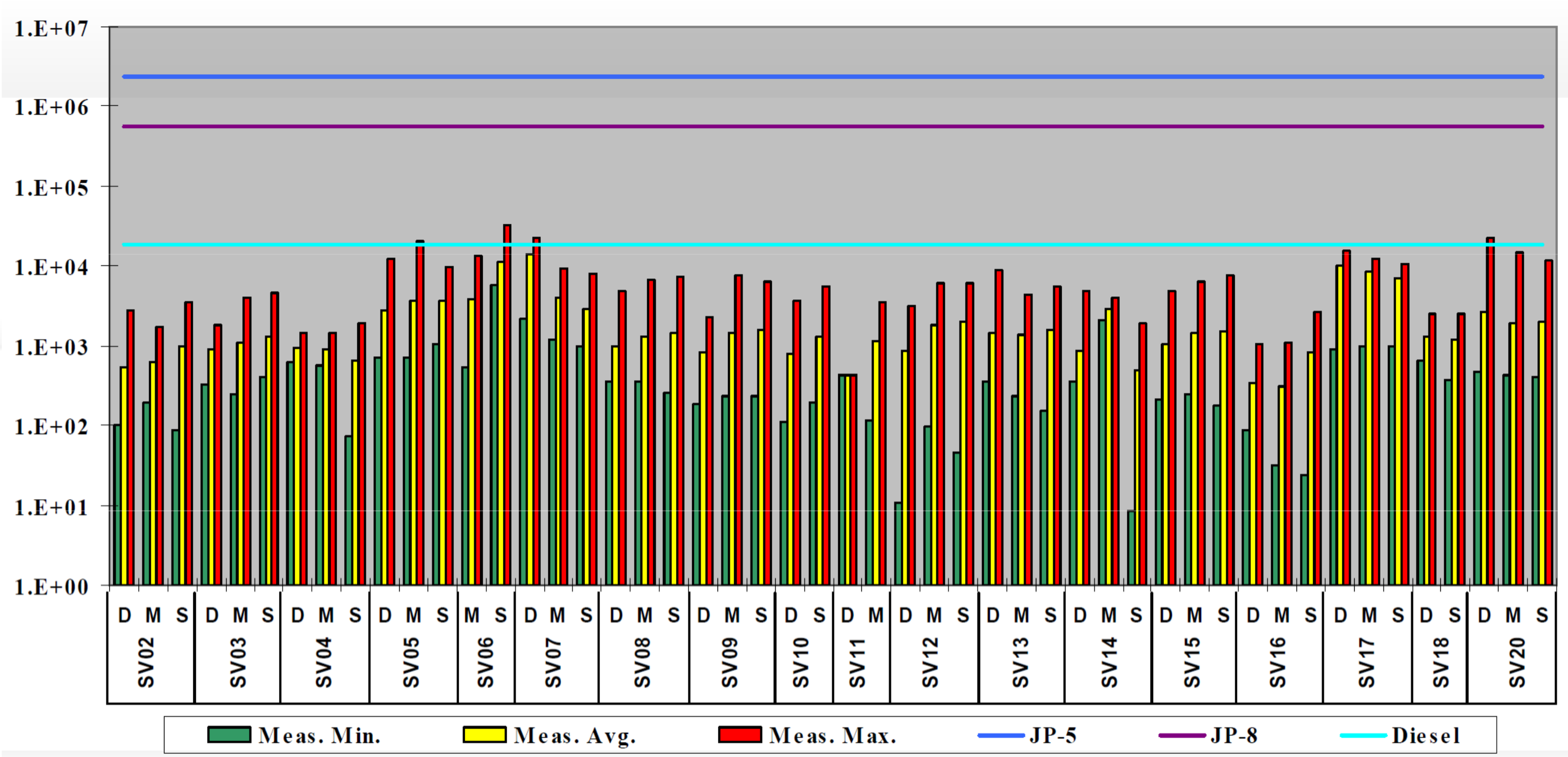
Soil Vapor Considerations



Soil Vapor Considerations



Soil Vapor Considerations



Soil Vapor Considerations

- **Soil Vapor Sampling Monitoring Analysis Letter Report (2010)**

  a) Conclusions

  – Low vapor concentrations measured and apparent mobilization of vapors due to water recharge (i.e., rain events) indicate current source of vapors observed were residual or of a small release

  – Indications of a minor release less likely due to the general trend of vapor concentrations (downward trend)

  – Soil vapor readings taken on a regular basis (i.e., monthly) provides an "excellent indicator of potential fuel releases"

  – Vapors are very mobile making detection of a leak probably within a few weeks following a small release

  b) Recommendations

  – Soil vapor concentrations approaching 280 ppmv in SVMPs beneath the tanks containing jet fuels warrant special attention

  – Vapor concentrations approaching 14 ppmv in SVMPs beneath tanks containing diesel fuel also warrant special attention

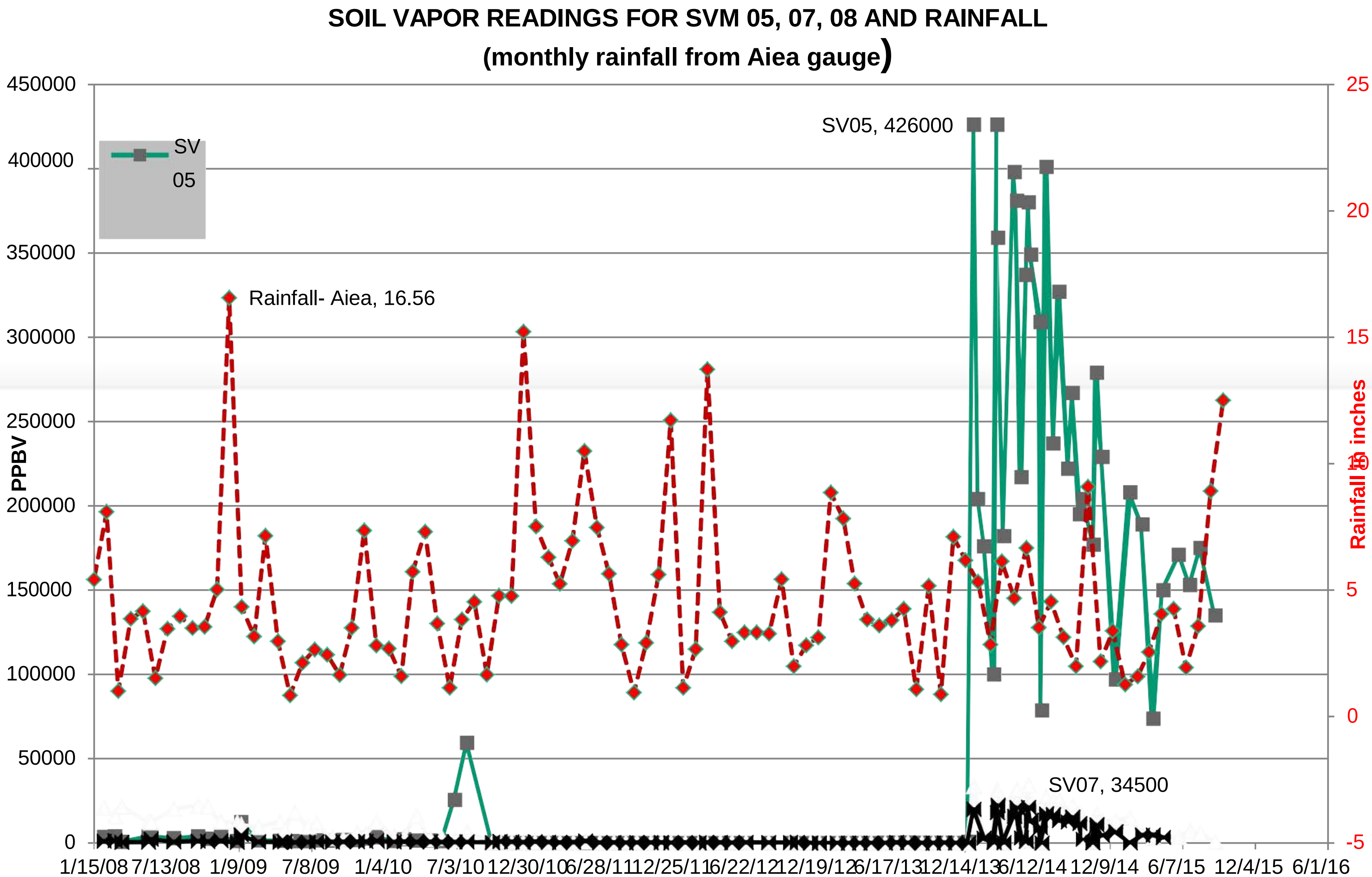
  – Validating/Updating maximum soil vapor calculations

  – Partitioning studies to develop a fingerprint baseline to differentiate between fresh and weathered contaminants

Soil Vapor Considerations

- **Update Evaluation of Soil Vapor Concentration Trends**
  - **a) Determine if sampling frequency is still sufficient for detecting a release**
    - Re-evaluating the feasibility of improving the soil vapor monitoring program
  - **b) Confirm whether the benchmark PID concentrations recommended in the 2010 report are still sufficient as field screening levels to use for release detection**

Soil Vapor Considerations



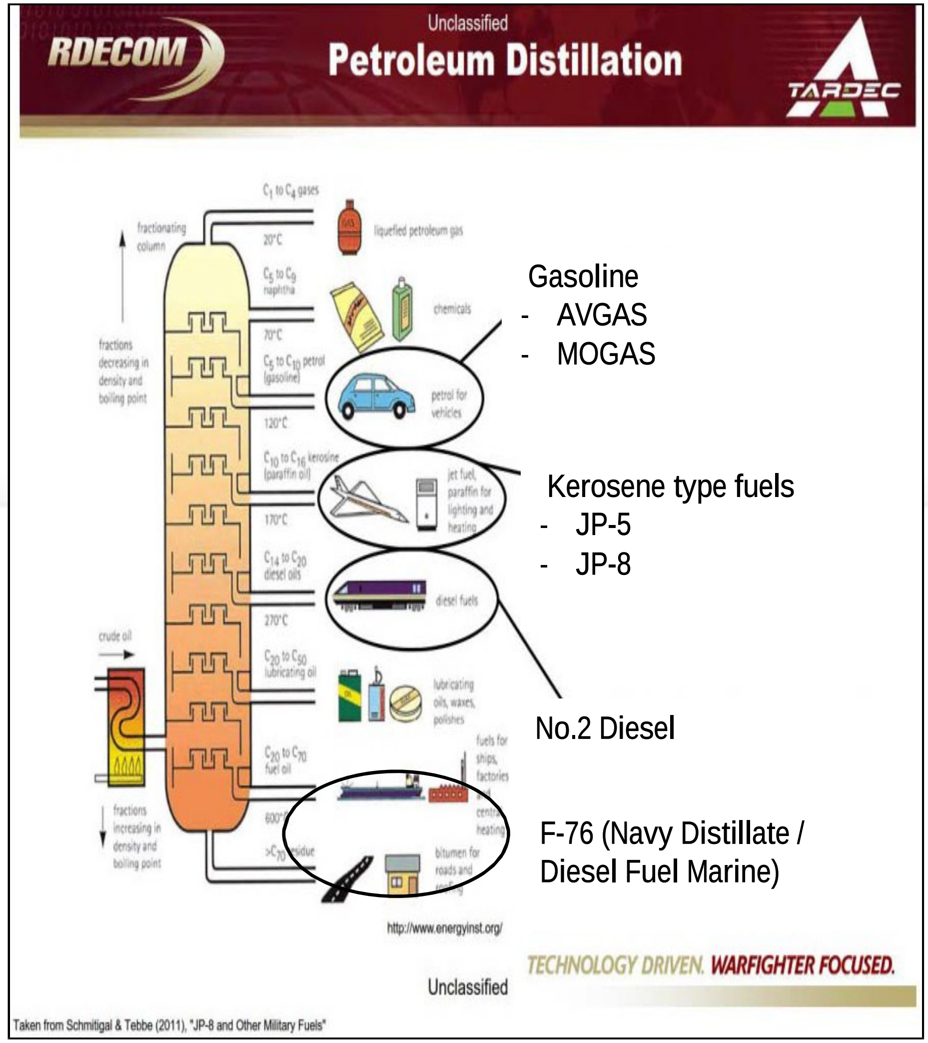
Task #3: Identify Chemicals of Potential Concern

- **Outline:**
  1. Fuel types
  2. Environmental sampling and analysis
  3. COPCs
  4. Geochemistry

Task #3: Identify Chemicals of Potential Concern: Fuel Types

Three fuels are still stored at the facility:

- **JP-8 (“NATO F-34”)**
  - Kerosene-type turbine fuel with additives
  - Similar to JP-5 (which was investigated in 2007 & 2010)
- **JP-5 (“NATO F-44”)**
  - Kerosene-type turbine fuel with additives
  - Similar to JP-8
- **NATO F-76 (“Naval Distillate Fuel”)**
  - Heavy fuel used in ships



Task #3: Identify Chemicals of Potential Concern: Fuel Types

- Heavy fuels (F-76) and kerosene-type fuels (JP-5 and JP-8) can contain the following chemicals:
  - Total petroleum hydrocarbons (TPH)
  - Polynuclear aromatic hydrocarbons (PAHs)
  - Volatile organic compounds (VOCs)
- "There is no standard formula for jet fuels. Their exact composition depends on the crude oil from which they were refined."[1]
- VOC and PAH content will differ depending on the source of crude oil.

[1] ASTDR 2011

Task #3: Identify Chemicals of Potential Concern: Fuel Types

- **The OSHA chemical profile for kerosene (the base of JP-5 and JP-8 fuels) shows that benzene is a very small component of kerosene.**
- **This is consistent with quarterly groundwater results, which show very low detections of benzene and other VOCs.**

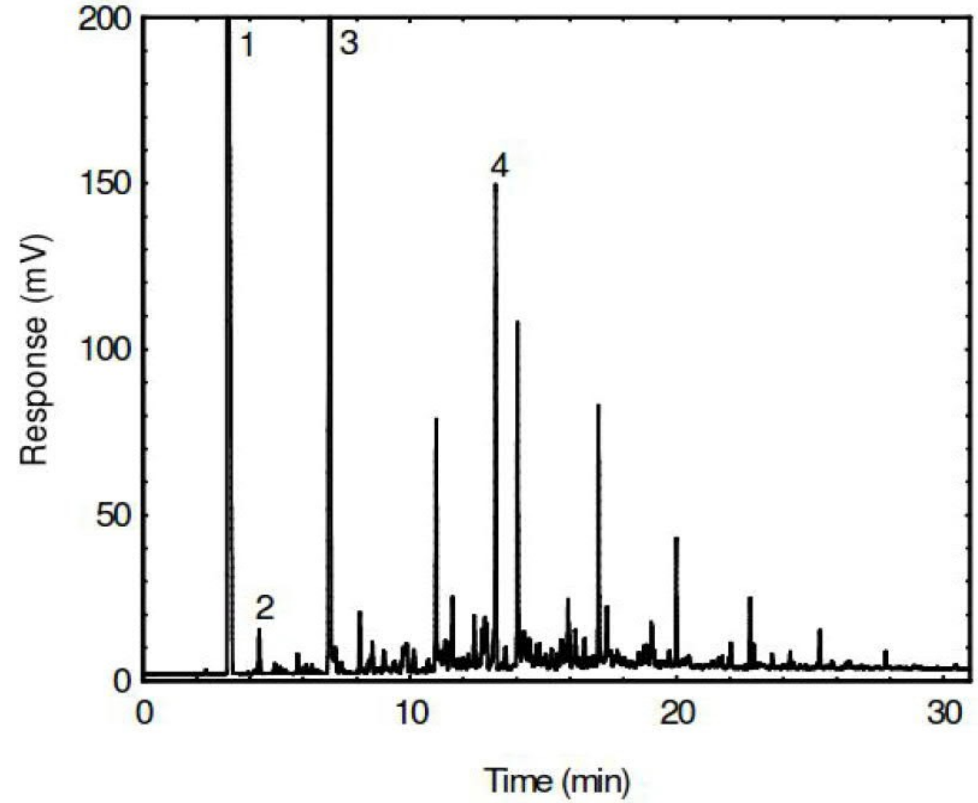


Figure 3.5.1 Chromatogram of 2.0 mg/mL kerosene in the extraction solvent. (key: (1) CS_2, (2) benzene, (3) DMF, (4) p-cymene)

Image taken from Yogi C. Shah (2004) OHSA Industrial Hygiene Chemistry Division

Task #3: Identify Chemicals of Potential Concern: Environmental Sampling and Analysis

- In 2003, DOH requested the following target analytes:
  - TPH-G, TPH-D, TPH-O
  - benzene, toluene, ethyl-benzene, xylenes (BTEX)
  - MtBE
  - benzo(a)pyrene, acenaphthene, fluoranthene, naphthalene
  - Total and dissolved lead
- The requested analyses include the recommended target analytes for general petroleum releases in the HDOH Technical Guidance Manual (TGM), plus others.

Table 9-5 Target Analytes for Releases of Petroleum Products

Petroleum Product	Media	[1]Recommended Target Analytes
Gasolines	Soil	TPH, BTEX, naphthalene, MTBE and appropriate additives and breakdown products (e.g., TBA, lead, ethanol, etc.)
	Soil Vapor	TPH, BTEX, naphthalene and MTBE plus other volatile additives and methane
	Groundwater	Same as soil
Middle Distillates (diesel, kerosene, Stoddard solvent, heating fuels, jet fuel, etc.)	Soil	TPH, BTEX, naphthalene, and methylnaphthalenes (1- and 2-)
	Soil Vapor	TPH, BTEX, naphthalene, and methane
	Groundwater	Same as soil
Residual Fuels (lube oils, hydraulic oils, mineral oils, transformer oils, Fuel Oil #6/Bunker C, waste oil, etc.)	Soil	TPH, [2]VOCs, naphthalene, methylnaphthalenes (1- and 2-), the remaining 16 priority pollutant PAHs, PCBs, and heavy metals unless otherwise justified
	Soil Vapor	TPH, VOCs, naphthalene, and methane
	Groundwater	same as soil

1. Include any additional volatile additives in soil vapor samples if suspected to be present.
2. VOCs includes BTEX and chlorinated solvent compounds.

Task #3: Identify Chemicals of Potential Concern: Environmental Sampling and Analysis

- **The Groundwater Long Term Monitoring Plan (2008, interim update in 2014) for the Facility specifies the following methods for analysis of chemicals of potential concern:**
  - **TPH by EPA SW-846 8015**
  - **PAHs by EPA SW-846 8270 SIM**
  - **VOCs by EPA SW-846 8260**
  - **Total and dissolved Lead by EPA SW-846 6010**
    - Of the fuels stored at the Facility, only AVGAS (last stored prior to 1968) contained tetraethyl lead as an additive.
- **Drinking Water methods (EPA methods 418.1, 525, and 524) are not recommended because detection limits are usually higher than the EAL, and TPH types are not differentiated.**

Task #3: Identify Chemicals of Potential Concern: Environmental Sampling and Analysis

Table 4-1. Action Levels		
Chemical	**EAL (µg/L)**	**SSRBL (µg/L)**
Volatiles		
Benzene	5	750
Ethylbenzene	700	NA
Methyl Tert Butyl Ether	*12*	NA
Toluene	1,000	NA
Xylenes	10,000	NA
Semi-volatiles		
Acenaphthene	*370*	NA
Benzo(a)pyrene	0.2	NA
Fluoranthene	*1,500*	NA
Naphthalene	*17*	NA
Lead		
Total	Not set	Not set
Dissolved	15	NA
Other		
TPH *(gasoline range)*	100	*NA*
TPH (diesel range)	*100*	*4,500*

NA – Not applicable or not determined

SSRBLs are applicable at RHMW01, RHMW02, RHMW03, and *RHMW05*

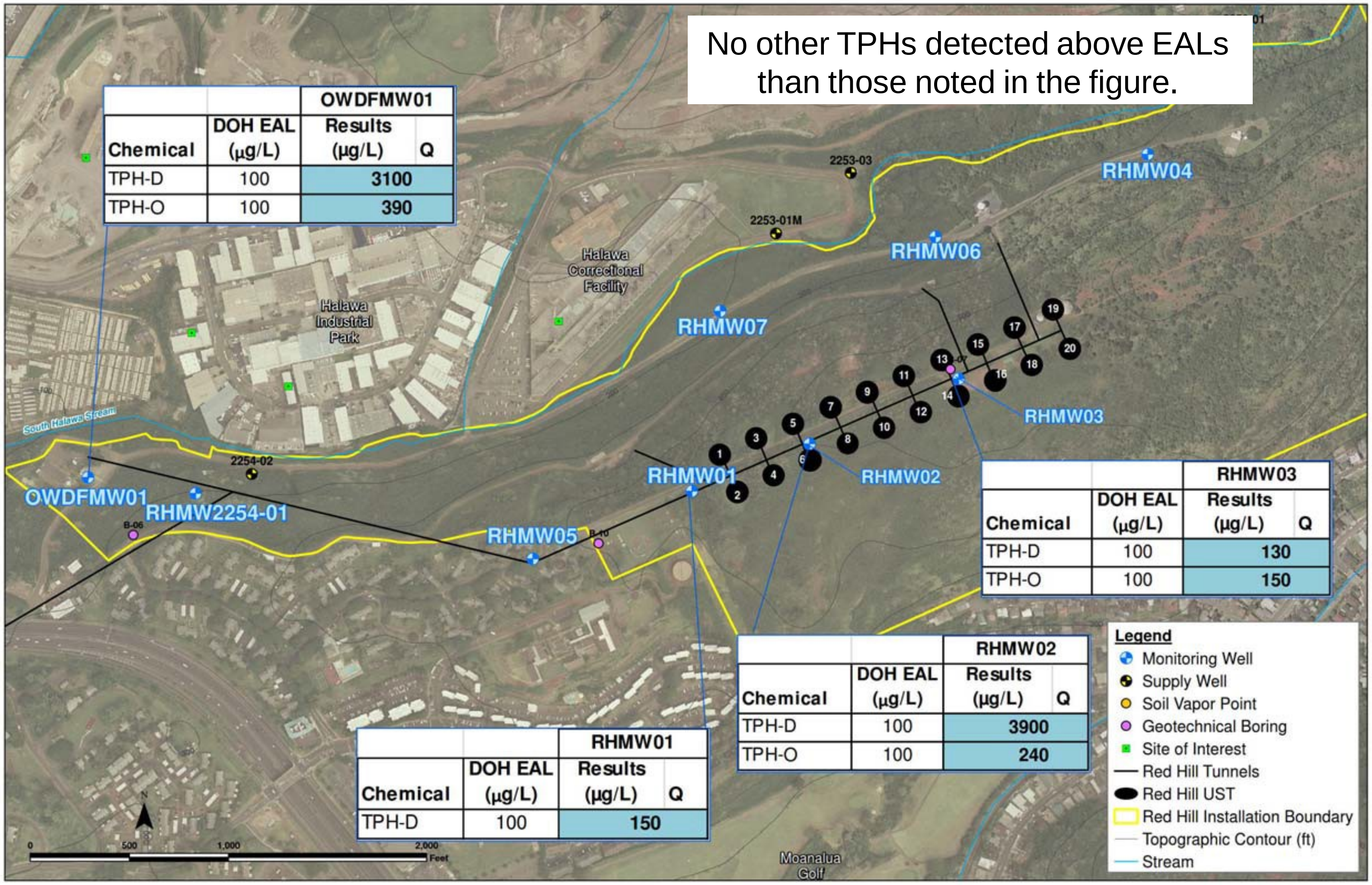
EALs are applicable at U.S. Navy well 2254-01

Taken from "Interim Update, Red Hill Bulk Fuel Storage Facility, Final Groundwater Protection Plan" (August 2014)

Task #3: Identify Chemicals of Potential Concern: Environmental Sampling and Analysis

- **The following analytes were detected above the EALs in groundwater below the tanks at least once in the last 5 years:**
  - **TPH-G**
    - last detected above EAL in 2013-Q1 in RHMW02
  - **TPH-D**
    - last detected above EAL in RHMW01-02-03 in 2015-Q3
  - **TPH-O**
    - last detected above EAL in RHMW02 and RHMW03 in 2015-Q3
  - **1-Methylnaphthalene**
    - last detected above EAL in RHMW02 in 2015-Q3
  - **2-Methylnaphthalene**
    - last detected above EAL in RHMW02 in 2015-Q3
  - **Naphthalene**
    - last detected above EAL in RHMW02 in 2015-Q3

Task #3: Identify Chemicals of Potential Concern: 2015-Q3 Groundwater Monitoring Results (TPH)



Chemical	DOH EAL (µg/L)	OWDFMW01 Results (µg/L)	Q
TPH-D	100	3100	
TPH-O	100	390	

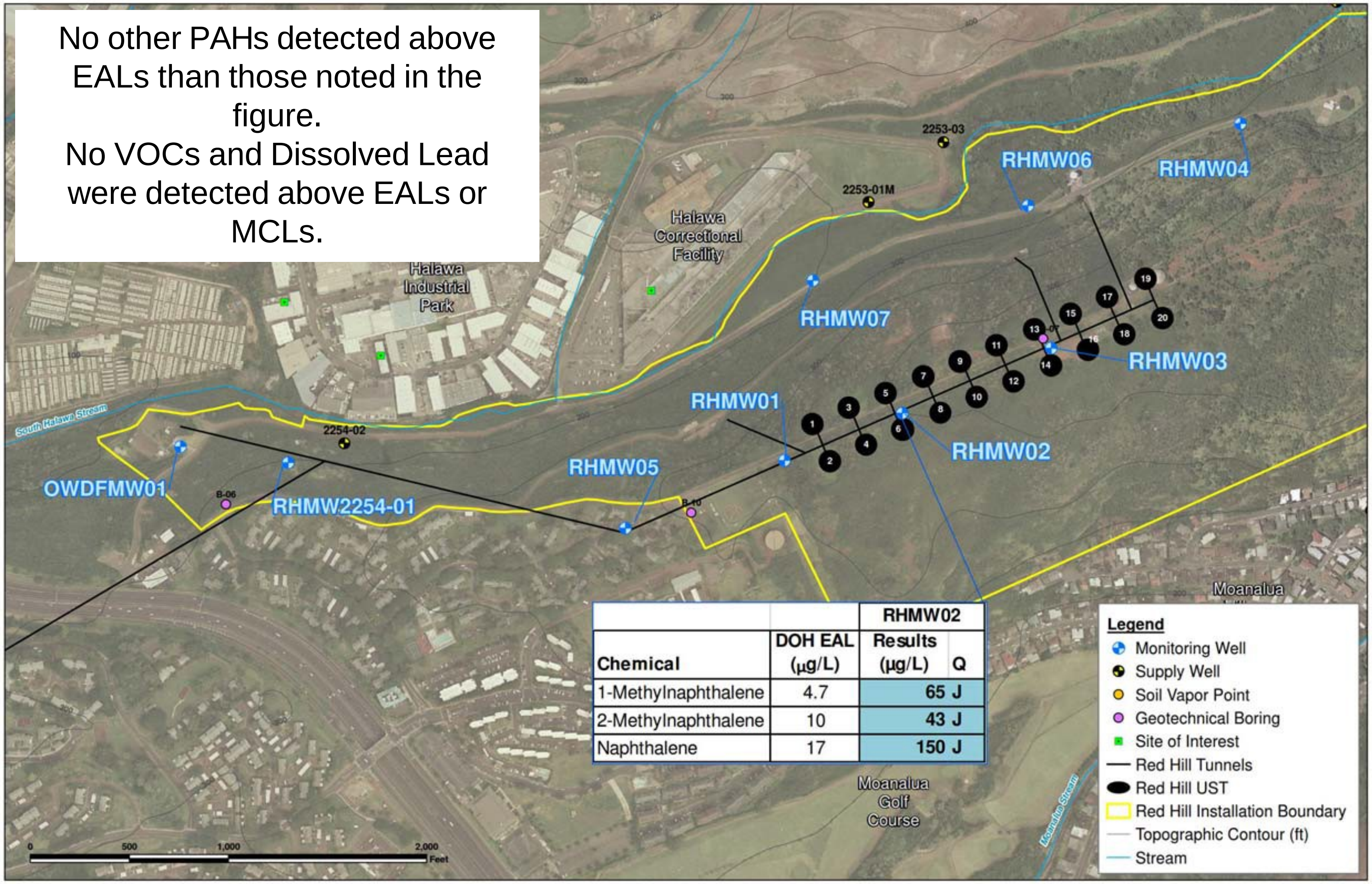
Chemical	DOH EAL (µg/L)	RHMW03 Results (µg/L)	Q
TPH-D	100	130	
TPH-O	100	150	

Chemical	DOH EAL (µg/L)	RHMW02 Results (µg/L)	Q
TPH-D	100	3900	
TPH-O	100	240	

Chemical	DOH EAL (µg/L)	RHMW01 Results (µg/L)	Q
TPH-D	100	150	

Task #3: Identify Chemicals of Potential Concern: 2015-Q3 Groundwater Monitoring Results (PAHs)

No other PAHs detected above EALs than those noted in the figure.
No VOCs and Dissolved Lead were detected above EALs or MCLs.



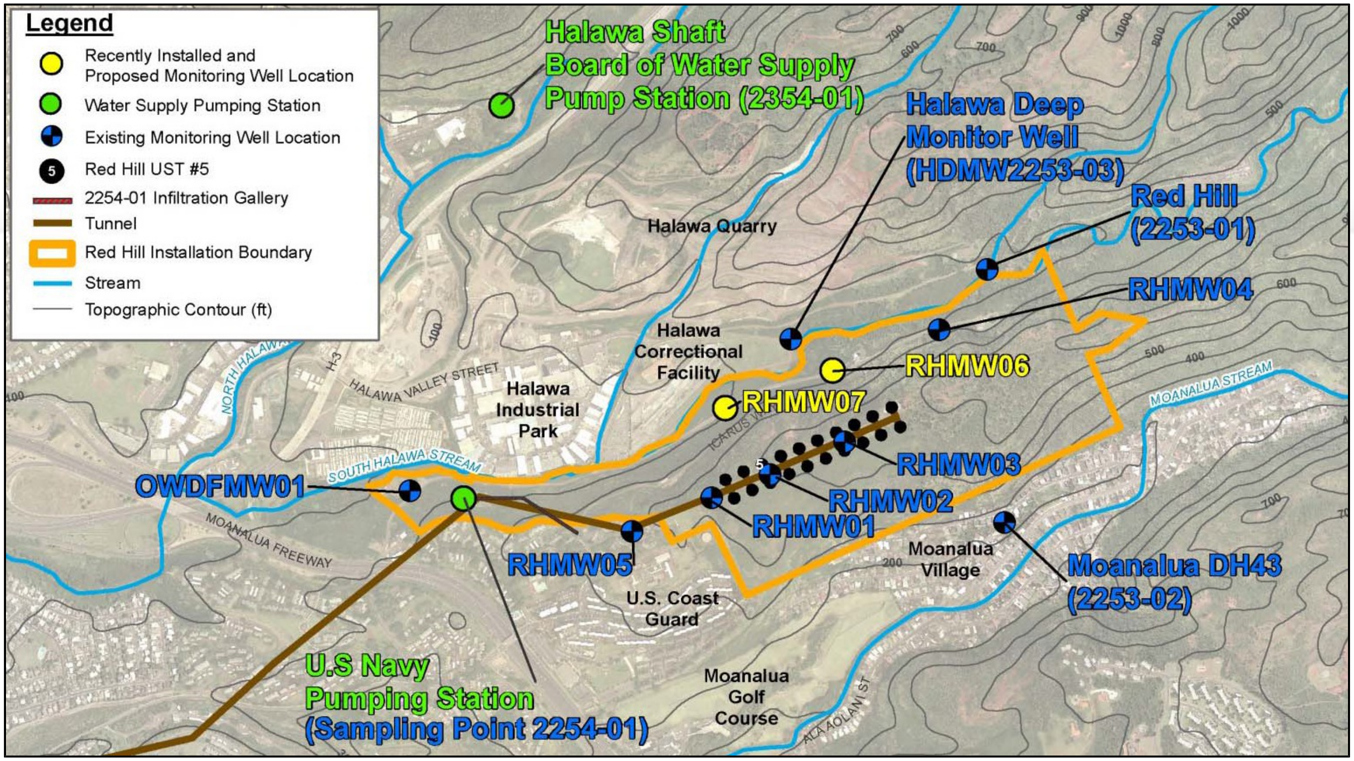
Chemical	DOH EAL (µg/L)	RHMW02 Results (µg/L)	Q
1-Methylnaphthalene	4.7	65	J
2-Methylnaphthalene	10	43	J
Naphthalene	17	150	J

Task #3: Identify Chemicals of Potential Concern: COPCs

- TPHs and select PAHs have been detected in wells RHMW01, RHMW02, and RHMW03.
- No analytes have been detected above the DOH EALs at RHMW2254-01 (groundwater infiltration gallery supply or monitoring well).
- BTEX, MtBE, and Dissolved Lead have not been detected above EALs or MCLs in the groundwater monitoring wells.
  - Because these chemicals are also not present in current and recent fuels stored, consider removing from analyte list.
- The current long-term monitoring groundwater analyte list is protective.

Task #3: Identify Chemicals of Potential Concern: COPCs

- **Based on the results of the groundwater monitoring, the following are recommended as COPCs for further investigation and groundwater modeling:**
  - TPH-G
  - TPH-D
  - TPH-O
  - 1-Methyl-naphthalene
  - 2-Methyl-naphthalene
  - Naphthalene



Task #3: Identify Chemicals of Potential Concern: Geochemistry

- 2007 Technical Report indicated aerobic degradation have occurred based on the depleted dissolved oxygen (DO) in the groundwater.
- DO was highest in the background well and wells downgradient of the fuel tanks.
  - RHMW04, RHMW05, and RHMW2254-01 are likely to undergo aerobic degradation under current conditions.
- Facility wells depleted of DO include RHMW01, RHMW02, and RHMW03.
  - Least amount of DO was detected in RHMW02, which had the highest COPC concentrations.

Parameter	RHMW04 Background (mg/L)	RHMW03 Up Plume (mg/L)	RHMW02 Central Plume (mg/L)	RHMW01 Down Plume (mg/L)	RHMW05 Sentinel (mg/L)*	RHMW2254-01 Down Gradient (mg/L)
Dissolved Oxygen	8.0	1.8	1.2	1.9	7.7	8.3

mg/L – milligrams per liter
*RHMW05 not included in the 2007 natural attenuation study; 2015-Q3 DO concentrations for RHMW05 included for comparison.

Task #3: Identify Chemicals of Potential Concern: Geochemistry

- **2007 Technical Report also indicated favorable conditions for anaerobic degradation within the basal aquifer.**
  - **Concentrations of anaerobic natural attenuation parameters (NAPs) is indicative of anaerobically degrading plume,**
  - **Nitrate and sulfate decreased as plume flowed downgradient,**
  - **Ferrous ion increased as plume flowed downgradient, and**
  - **Methane (petroleum breakdown by-product) is highest in the central plume where largest mass of petroleum is expected (consistent with groundwater results showing highest TPH concentrations at RHMW02).**

Parameter	RHMW04 Background (mg/L)	RHMW03 Up Plume (mg/L)	RHMW02 Central Plume (mg/L)	RHMW01 Down Plume (mg/L)	RHMW05 Sentinel (mg/L)*	RHMW2254-01 Down Gradient (mg/L)
Dissolved Oxygen	8.0	1.8	1.2	1.9	7.7	8.3
Nitrate	0.5	1.1	0.2	0.0	NT	0.6
Ferrous Iron	0.03	0.9	2.5	3.1	NT	0.1
Sulfate	9.6	27.8	12.5	0.5	NT	NT
Methane	0.0	0.0	1.4	.08	NT	NT
Attenuation	Aerobic	Anaerobic	Anaerobic	Anaerobic	Likely Aerobic	Aerobic
Notes: NT - not tested; * Parameter concentrations from the 3rd Quarter 2015 Groundwater Long Term Monitoring event.						

Task #3: Identify Chemicals of Potential Concern: Geochemistry

- Recommend analyzing for the following NAPs to evaluate current attenuation conditions:
  - Dissolved Oxygen
  - Nitrate
  - Ferrous Iron
  - Sulfate
  - Methane
  - Chloride
- Additionally, groundwater samples should be analyzed for the following indicator parameters:
  - pH
  - Specific Conductance
  - Turbidity
  - Temperature
  - Oxidation Reduction Potential

Task #4: Expand the Monitoring Network

- **Monitoring well locations will be recommended in the Scope of Work (work plan), which will be submitted for regulator review**
- **The proposed well locations fulfill the following objectives:**
  - **Sentinels:** Provide monitoring points between the Red Hill tanks and receptors potentially exposed via the drinking water supply system and vapor intrusion pathways, and to guard against VI for offsite residences
  - **Characterize Flow:** Provide additional groundwater elevation data to evaluate groundwater flow patterns in the vicinity of the Red Hill Facility and refine and calibrate the groundwater flow model
  - **Characterize Groundwater Chemistry:** Provide water quality data and evaluate COP concentrations and NAPs
  - **Characterize Matrix:** Further characterize the stratigraphy and properties of the Valley Fill, caprock, and saprolite layers
  - **Other Uses:** Provide potential monitoring and access points for other activities, such as a tracer study or augmentation, if warranted upon completion of other field activities

Task #4: Expand the Groundwater Monitoring Network

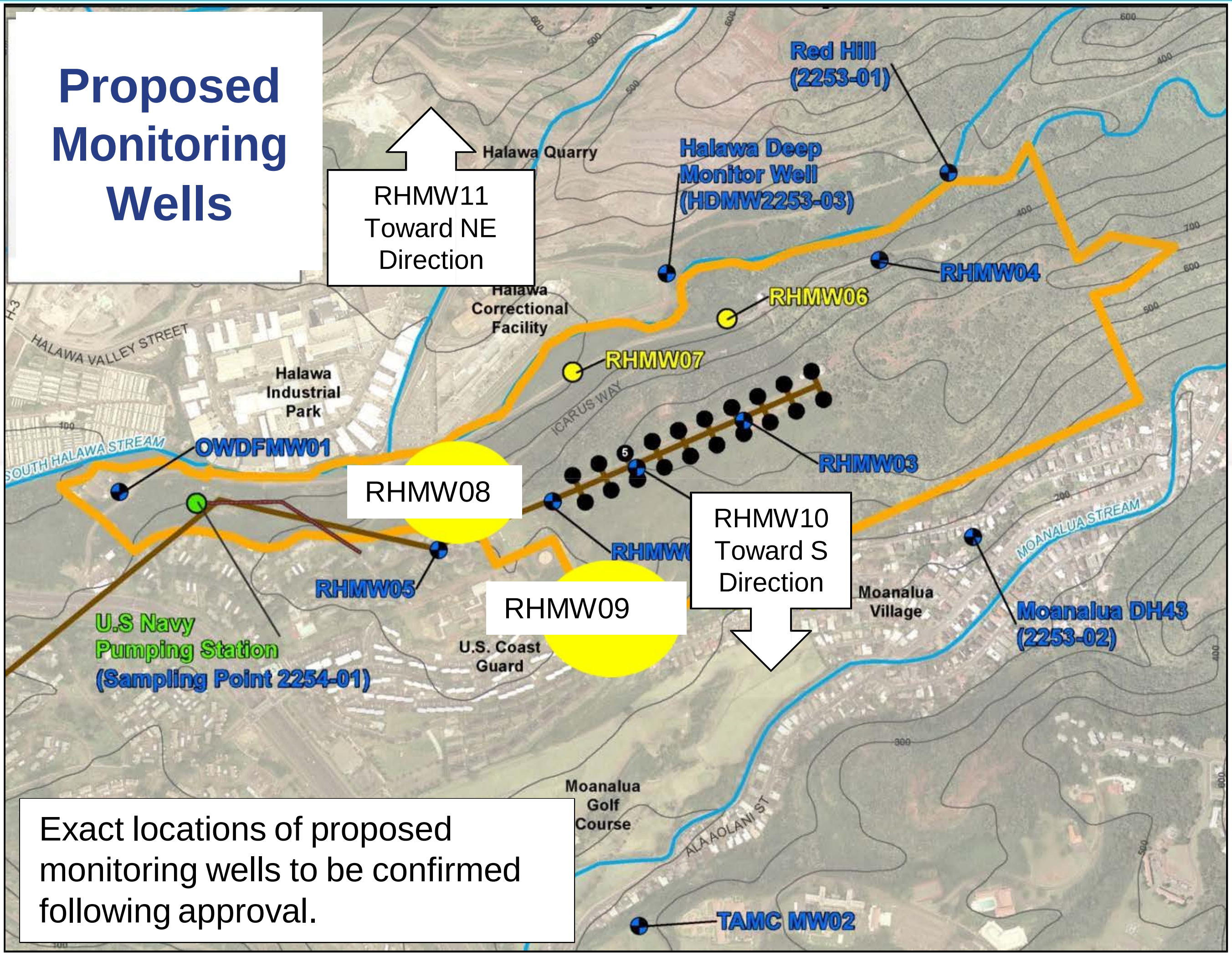
New and Proposed Well and Objectives Matrix

Well ID	Objective 1: Sentinels	Objective 2: Characterize Flow	Objective 3: Characterize Chemistry	Objective 4: Characterize Matrix	Objective 5: Other Uses
Recently Installed Monitoring Wells					
RHMW06	✓	✓	✓		✓
RHMW07			✓	✓	✓
Proposed New Monitoring Wells					
RHMW08	✓	✓	✓		✓
RHMW09	✓	✓	✓		✓
RHMW10	✓	✓	✓		✓
RHMW11	✓[1]	✓	✓	✓[2]	✓

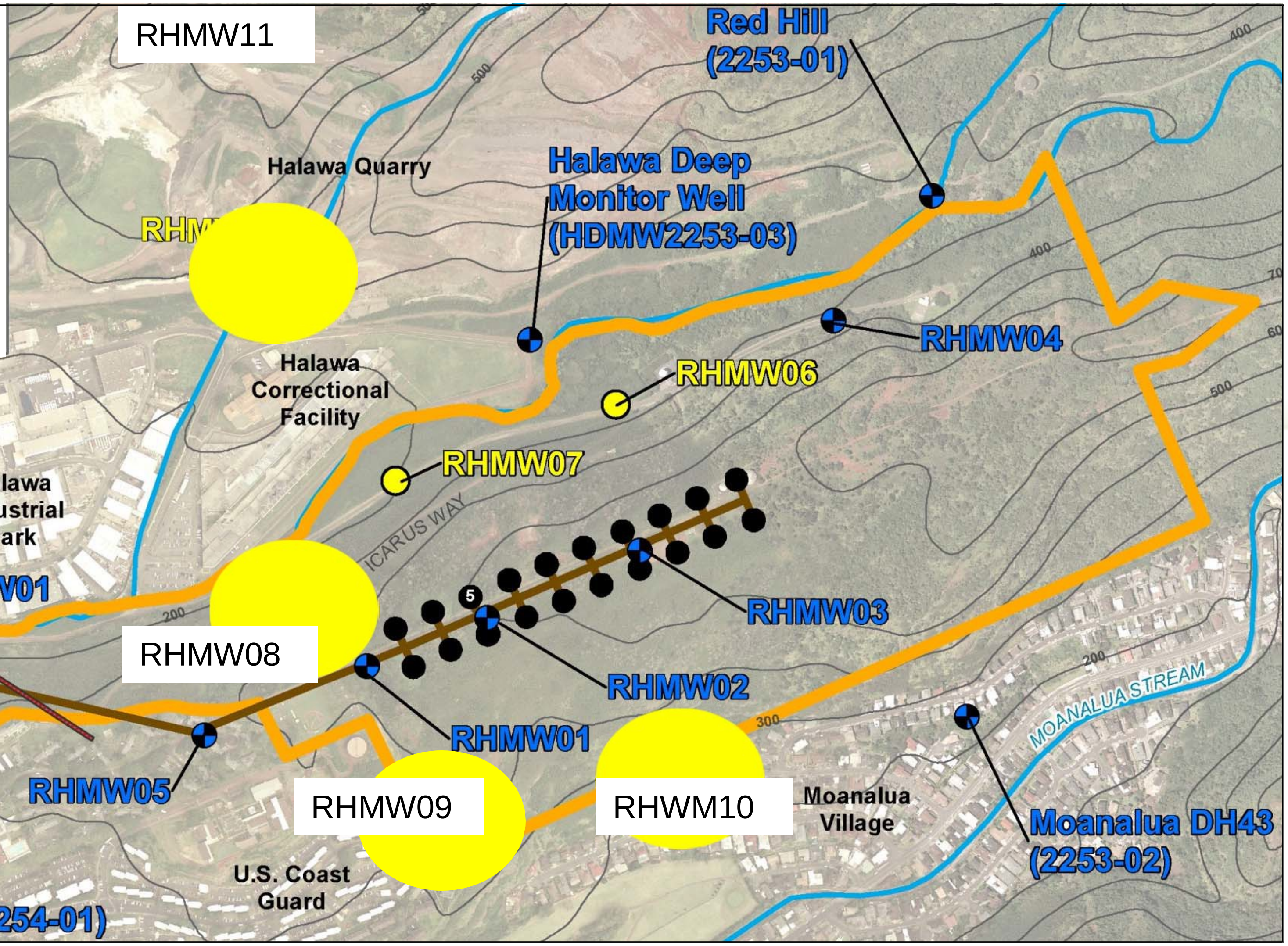
[1] Contingent if groundwater flow direction is towards the Board of Water Supply Halawa Shaft.

[2] Intend to collect subsurface data (i.e., evaluate flow paths, potential valley fill strata, etc.).

Task #4: Expand the Monitoring Network



Proposed Monitoring Wells General Locations (close-up)



Task #5: Update the Existing Groundwater Model

- **Overall Modeling Objectives:**
  - **Leverage considerable effort expended by local experts to develop flow (and fate and transport [F&T]) models**
  - **Refine existing flow model to improve understanding of flow in the vicinity of the facility**
  - **Improve models for use as planning tools:**
    - Re-evaluate SSRBLs
    - Support alternatives analysis
    - Inform the contingency planning

Task #5: Update the Existing Groundwater Model

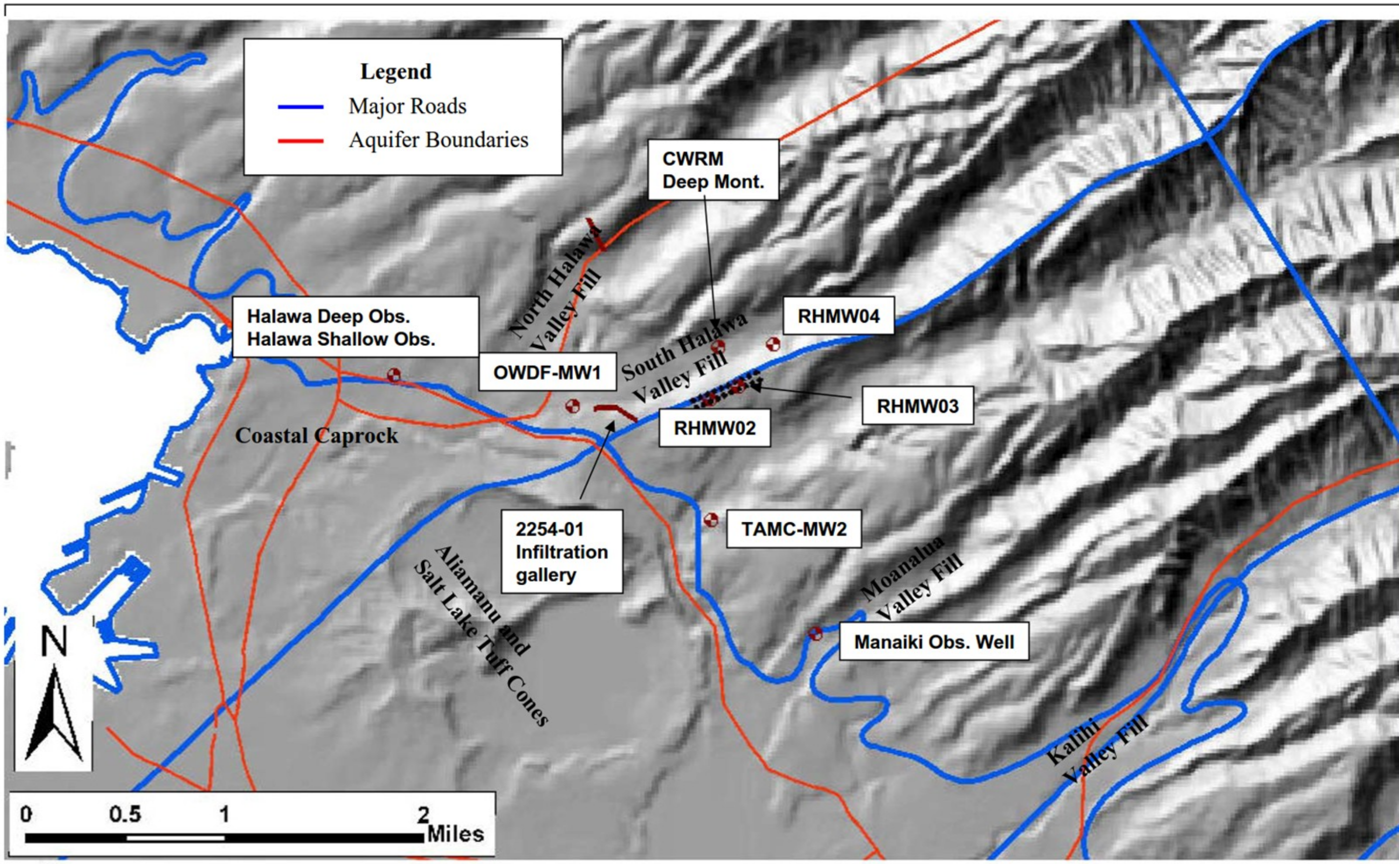


Figure 10
Locations of Monitoring and Observations Wells, and the Locations of Potential Barriers to Groundwater Flow
Groundwater Gradient Study Red Hill Bulk Fuel Storage Facility, Pearl Harbor, Hawaii

Task #5: Update the Existing Groundwater Model

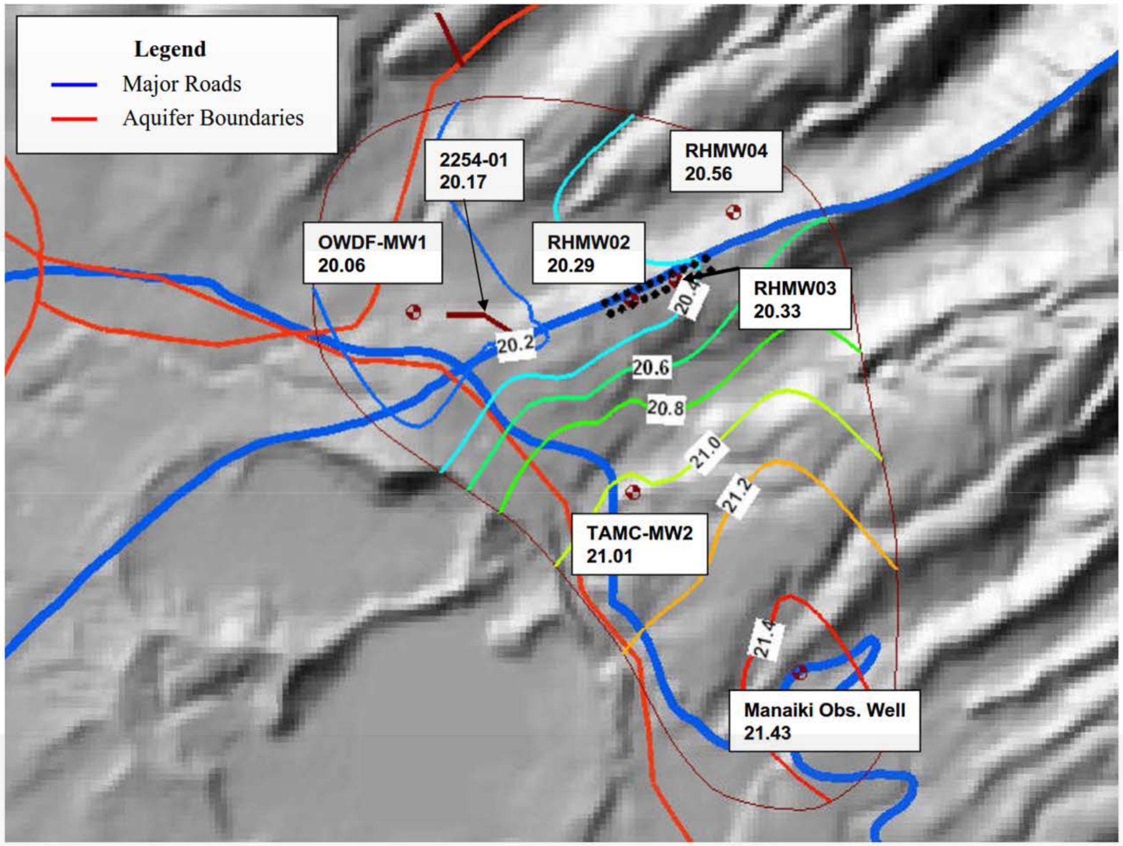


Figure 6.
Groundwater Elevation Contours Based on Water Levels Measured On May 18, 2006 (contour labels and groundwater elevations at each well shown in ft above mean tidal datum)
Groundwater Gradient Study Red Hill Bulk Fuel Storage Facility, Pearl Harbor, Hawaii

Task #5: Update the Existing Groundwater Model

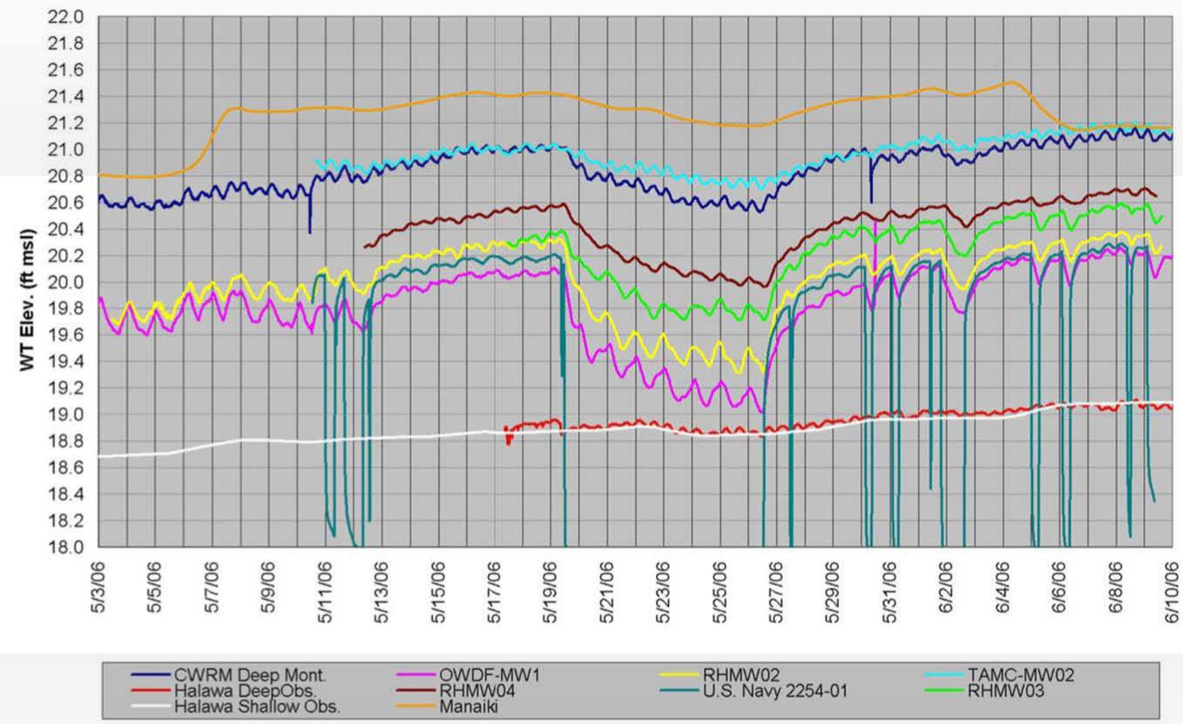


Figure 9.
Recorded Water Levels in Wells Monitored During the May 2006 Aquifer Test at Red Hill Updated Using New TOC Elevations
Groundwater Gradient Study Red Hill Bulk Fuel Storage Facility, Pearl Harbor, Hawaii

Task #5: Update the Existing Groundwater Model

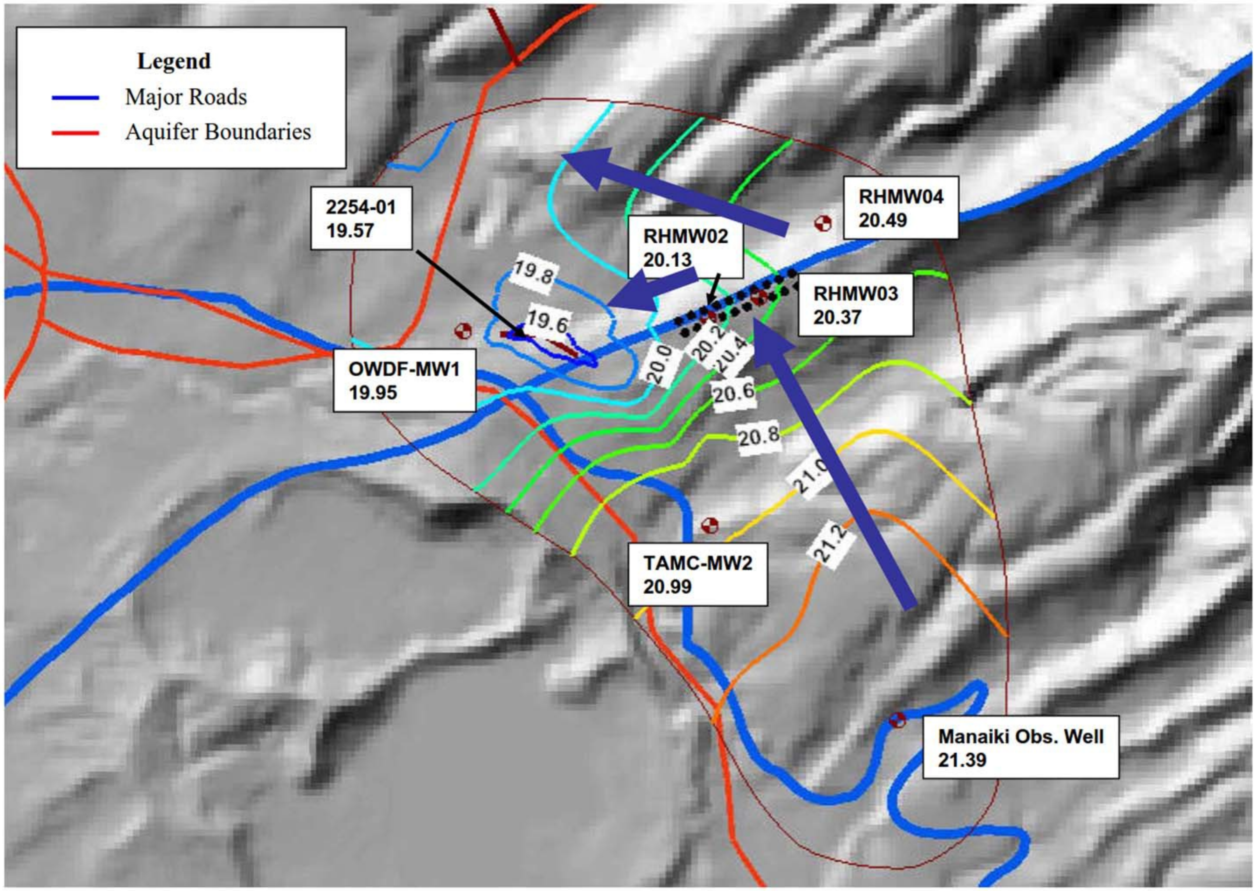


Figure 8.
Groundwater Elevation Contours Based on Water Levels Measured On May 30, 2006 (contour labels and groundwater elevations at each well shown in ft above mean tidal datum) (Blue arrows show interpreted groundwater flow directions)
Groundwater Gradient Study Red Hill Bulk Fuel Storage Facility, Pearl Harbor, Hawaii

Q

Task #5: Update the Existing Groundwater Model

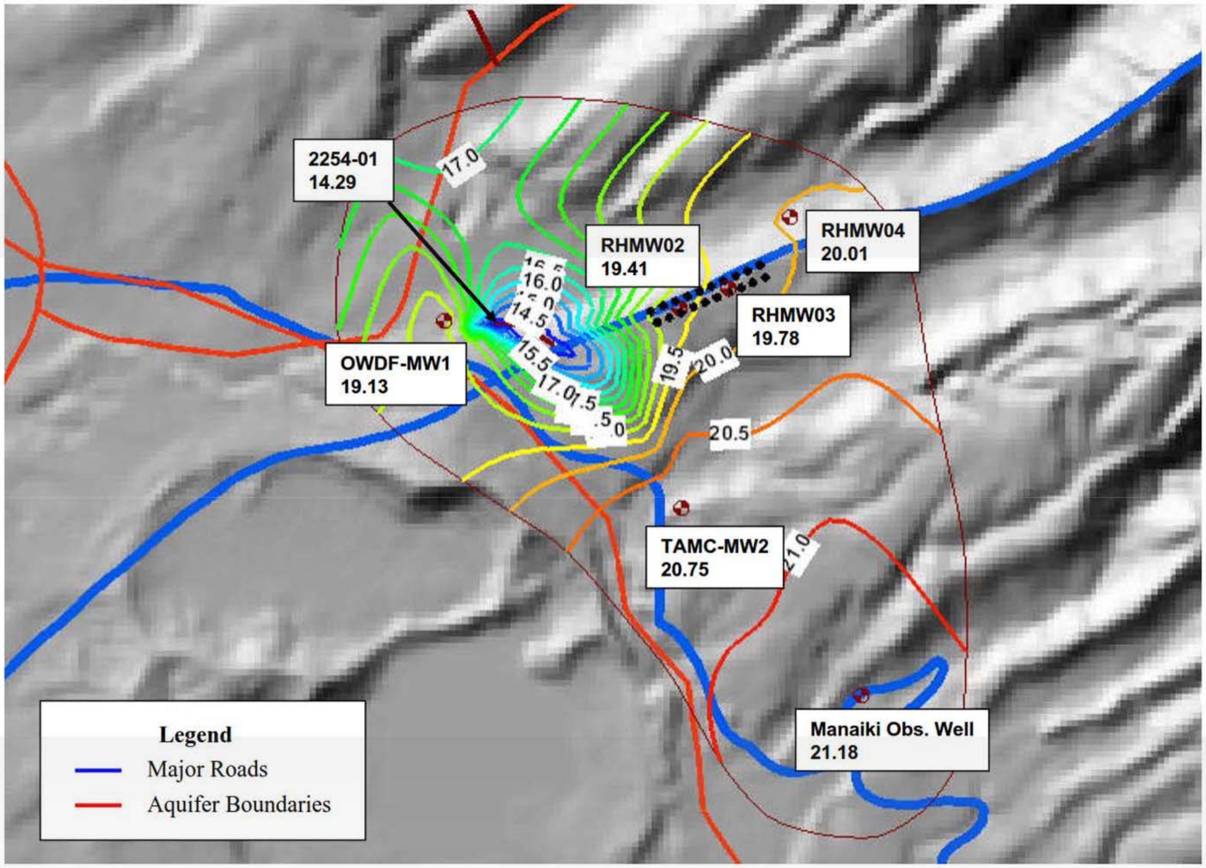


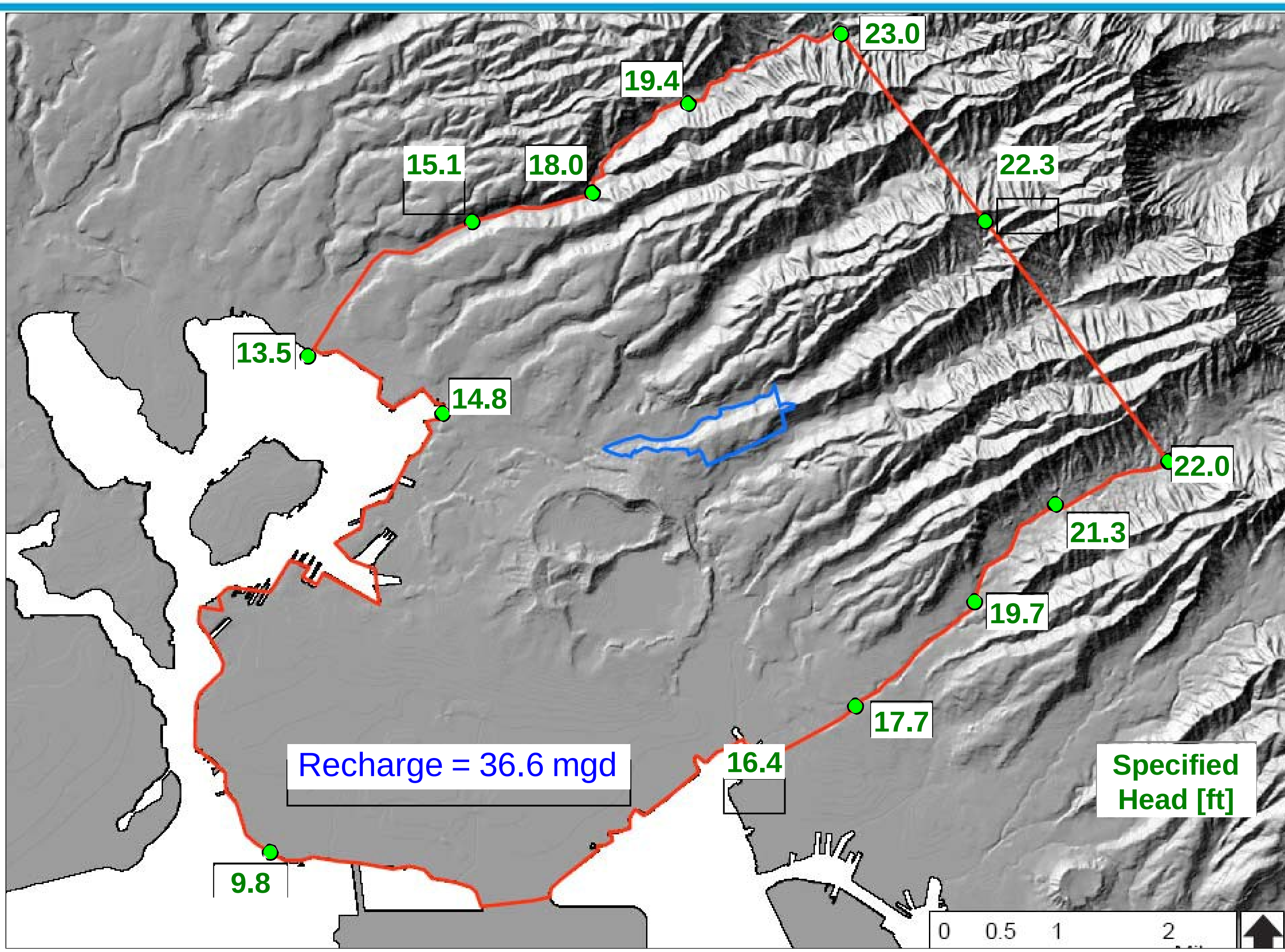
Figure 7.
Groundwater Elevation Contours Based on Water Levels Measured On May 25, 2006 (contour labels and groundwater elevations at each well shown in ft above mean tidal datum)
Groundwater Gradient Study Red Hill Bulk Fuel Storage Facility, Pearl Harbor, Hawaii

Q

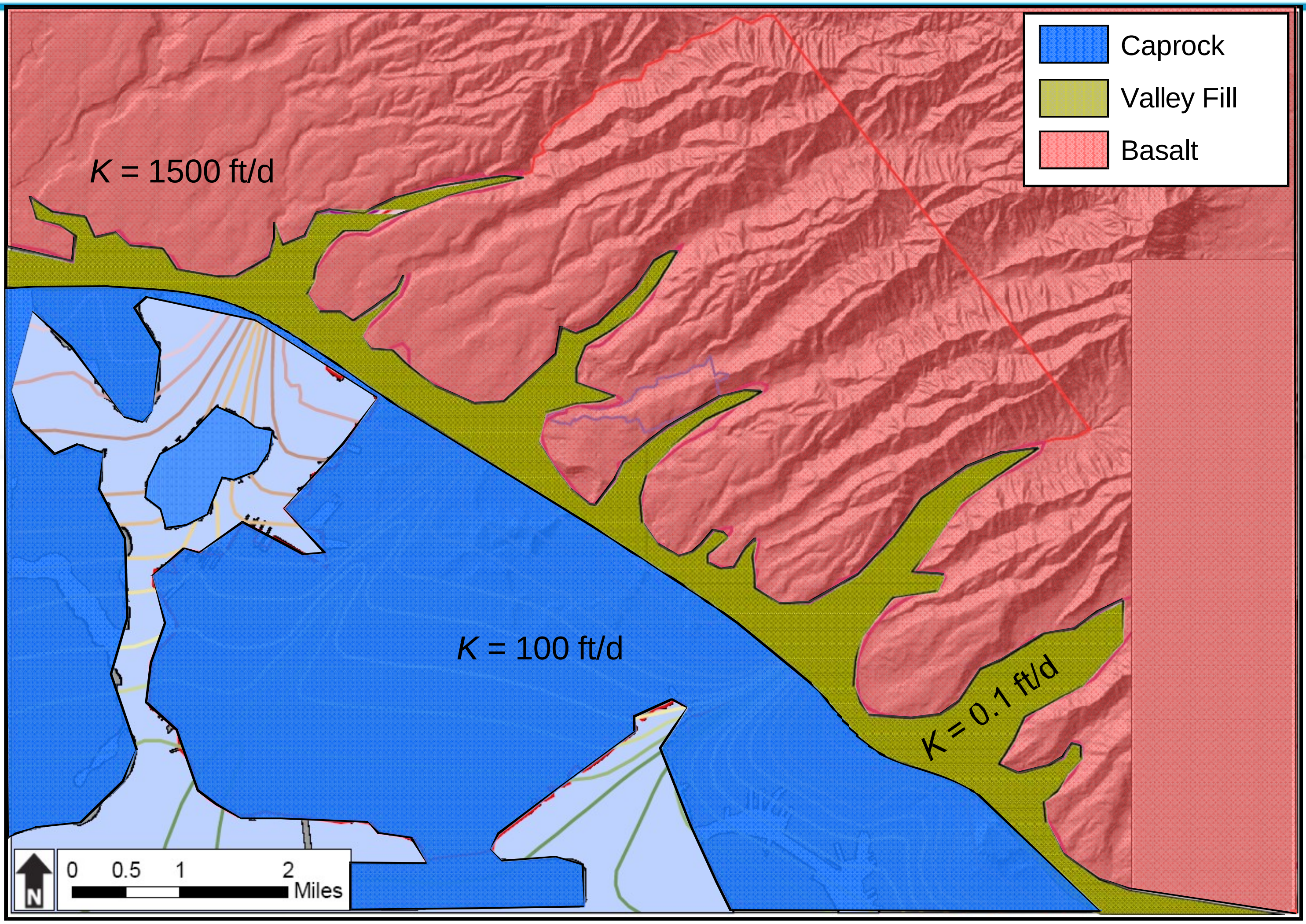
Task #5: Update the Existing Groundwater Model

- Previous Modeling Methodology (TEC 2007)
  - Multi-layer MODFLOW model (industry standard)
  - Calibrated steady-state flow model based on the island-wide SWAP model
  - Boundary conditions (specified head on sides, saline water interface at bottom boundary)
  - Calibrated transient flow model with a 18-day aquifer test of RHS
  - Delineated Capture Zones of Municipal Groundwater Sources
- Following slides are taken from presentation by Kolja Rotzoll

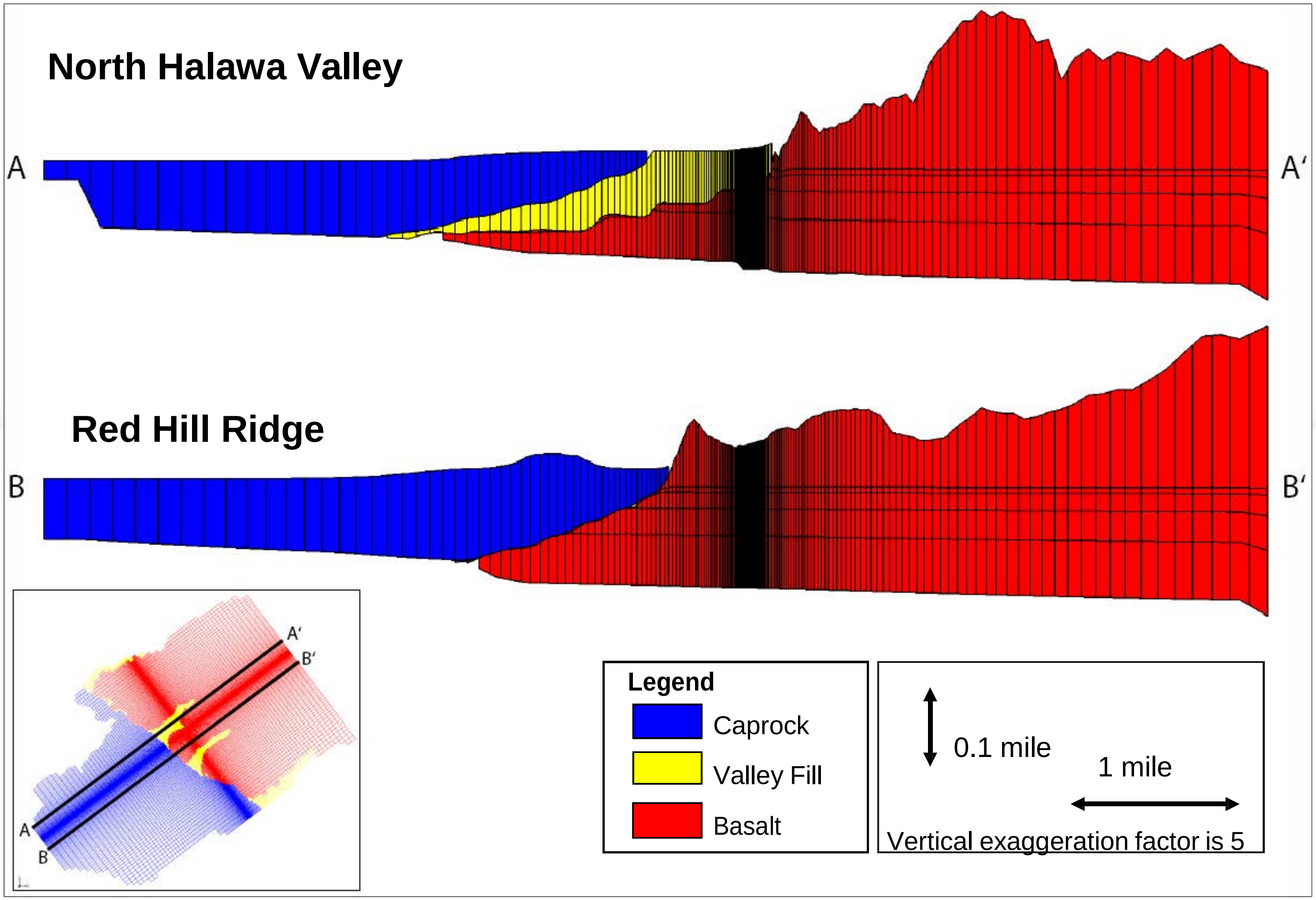
Task #5: Update the Existing Groundwater Model Boundary Conditions



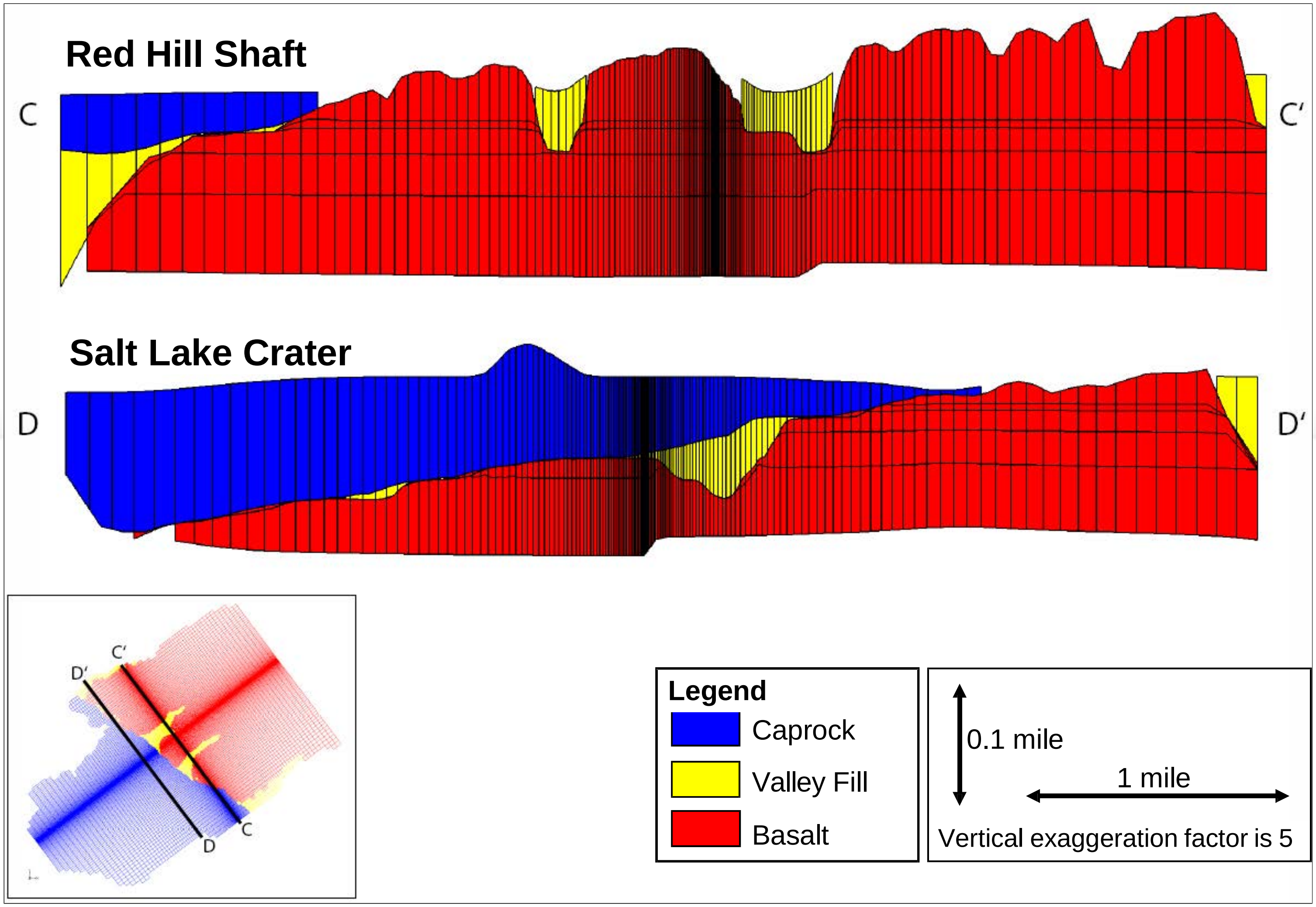
Task #5: Update the Existing Groundwater Model Simplified Surface Geology



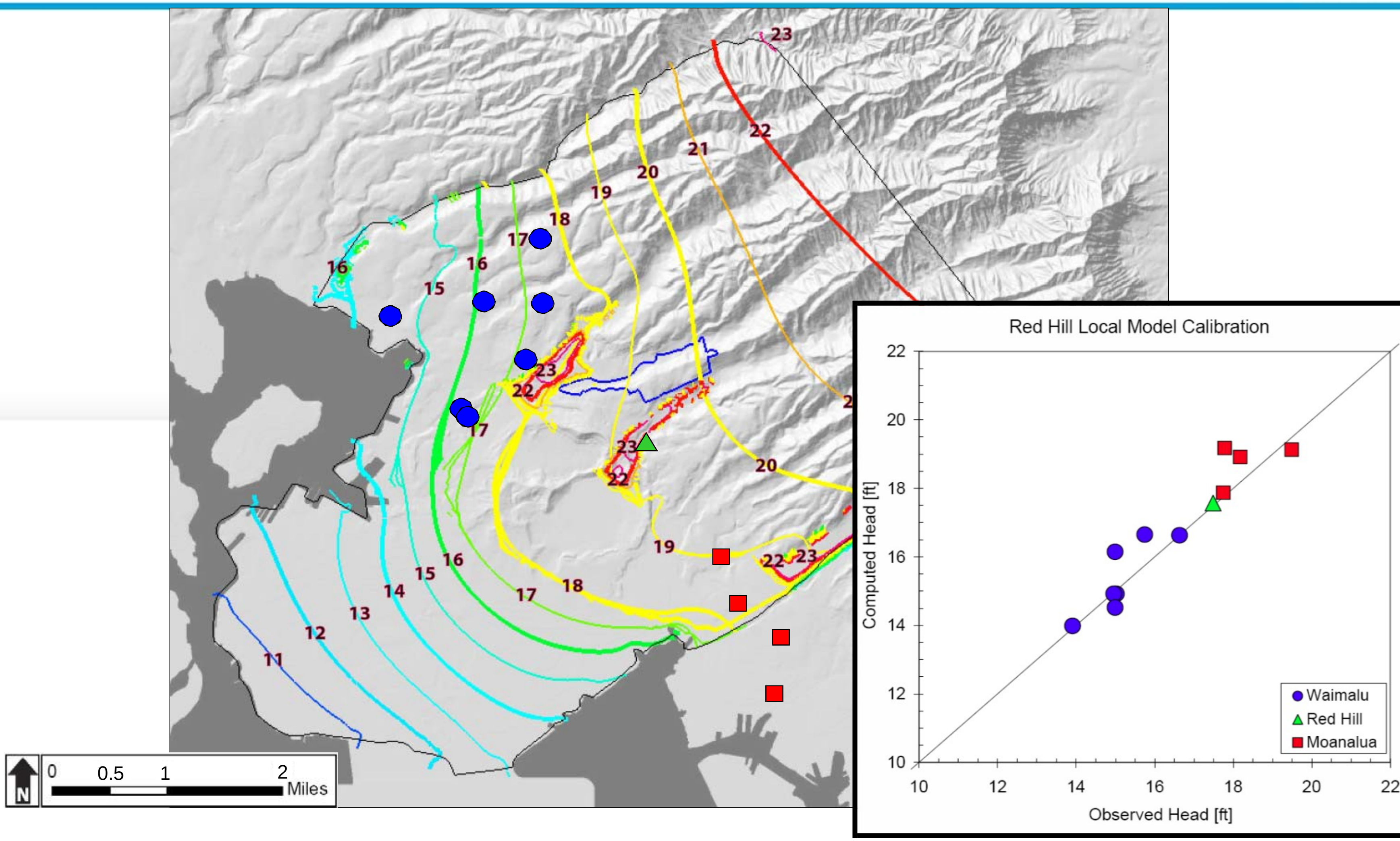
Task #5: Update the Existing Groundwater Model
7-Layer Modflow Model Grid



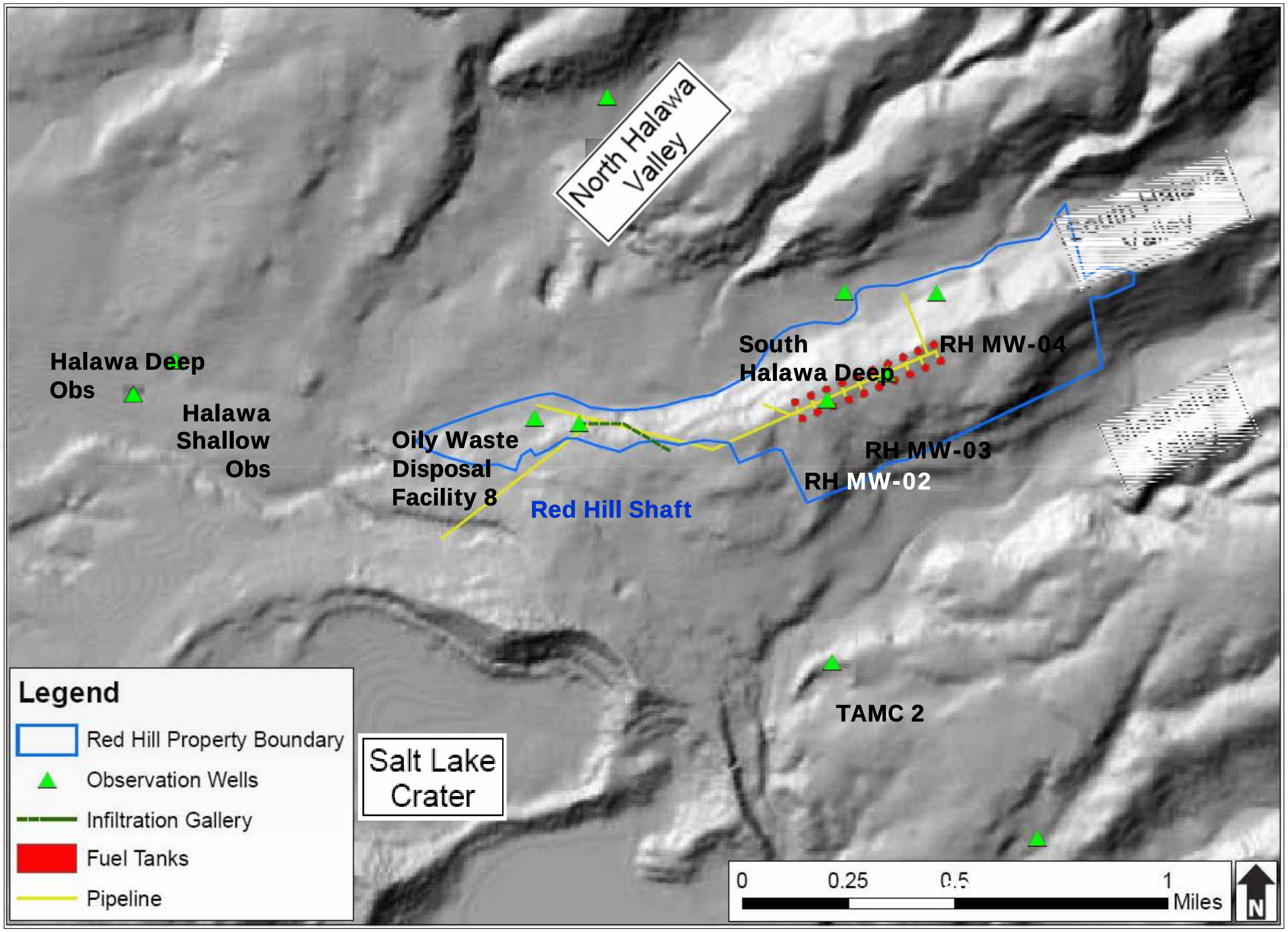
Task #5: Update the Existing Groundwater Model
7-Layer Modflow Model Grid



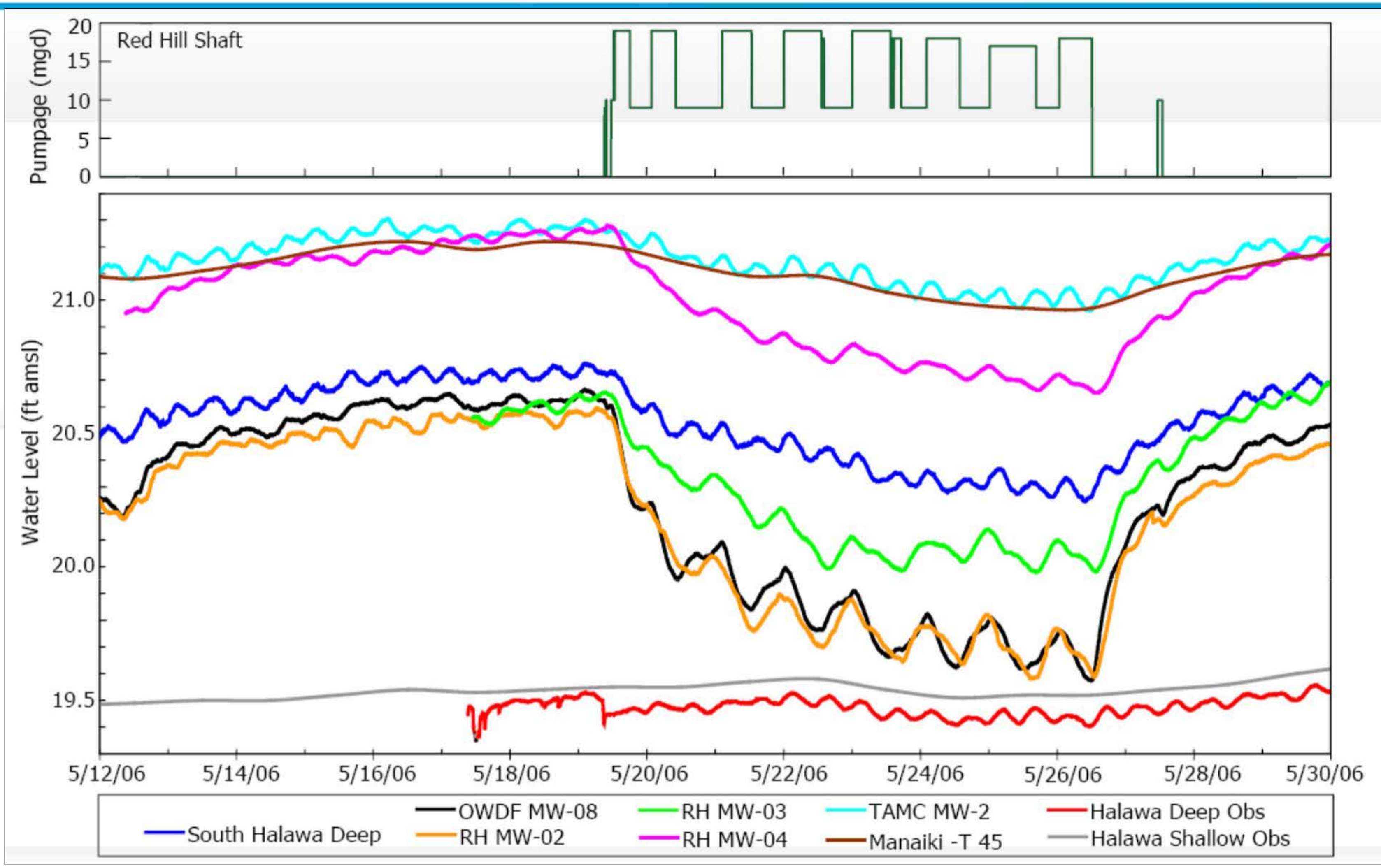
Task #5: Update the Existing Groundwater Model
Modeled Water Levels



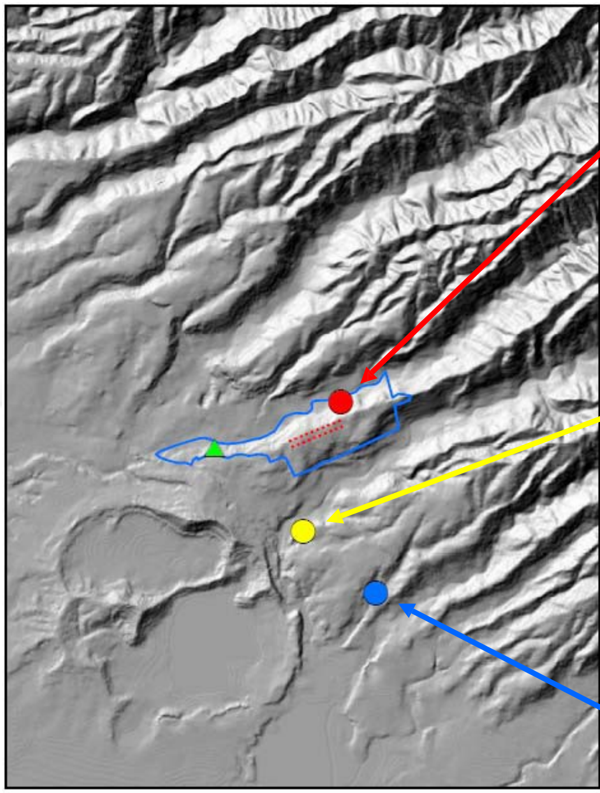
Task #5: Update the Existing Groundwater Model Observation Wells

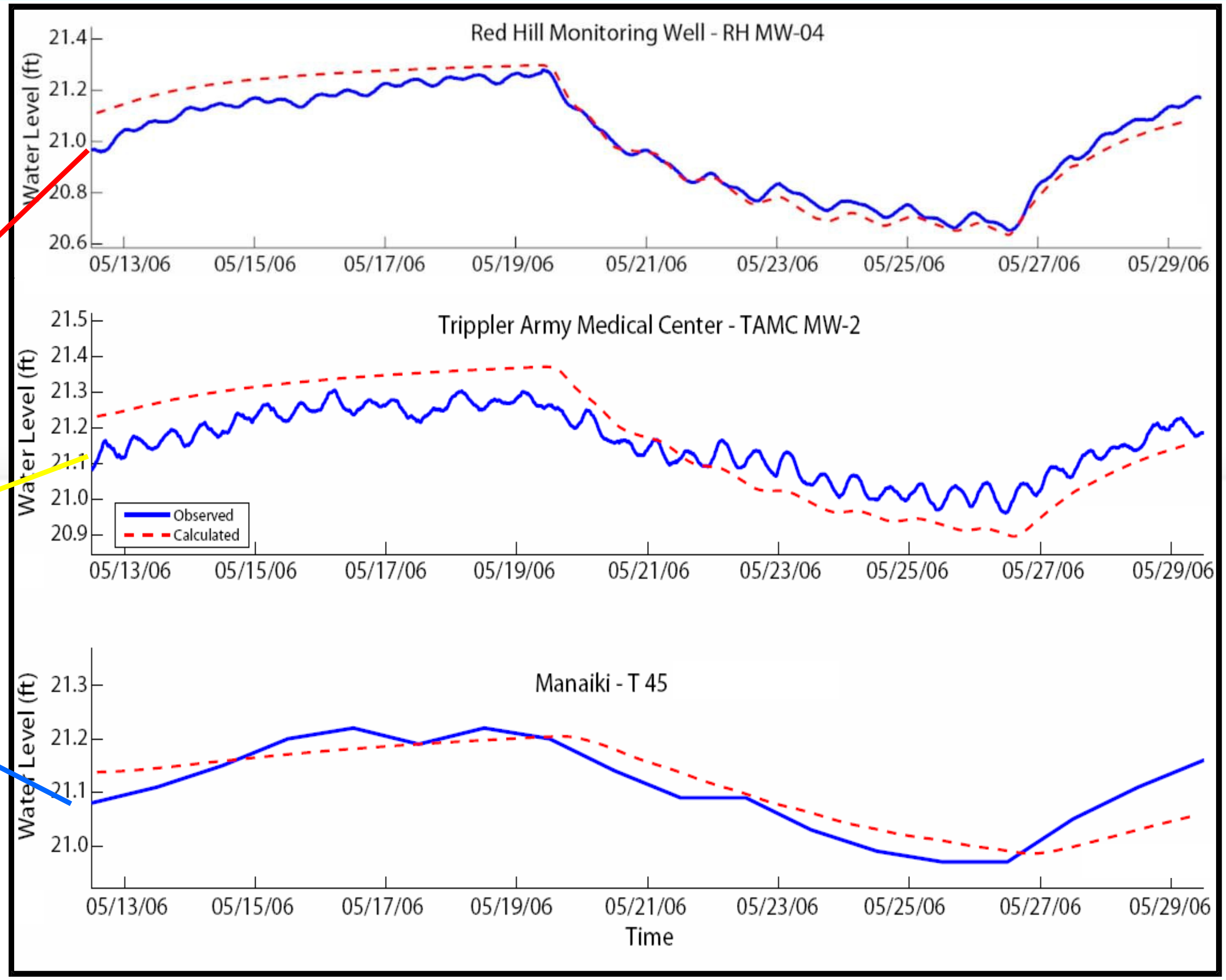


Task #5: Update the Existing Groundwater Model Red Hill Shaft Pump Test



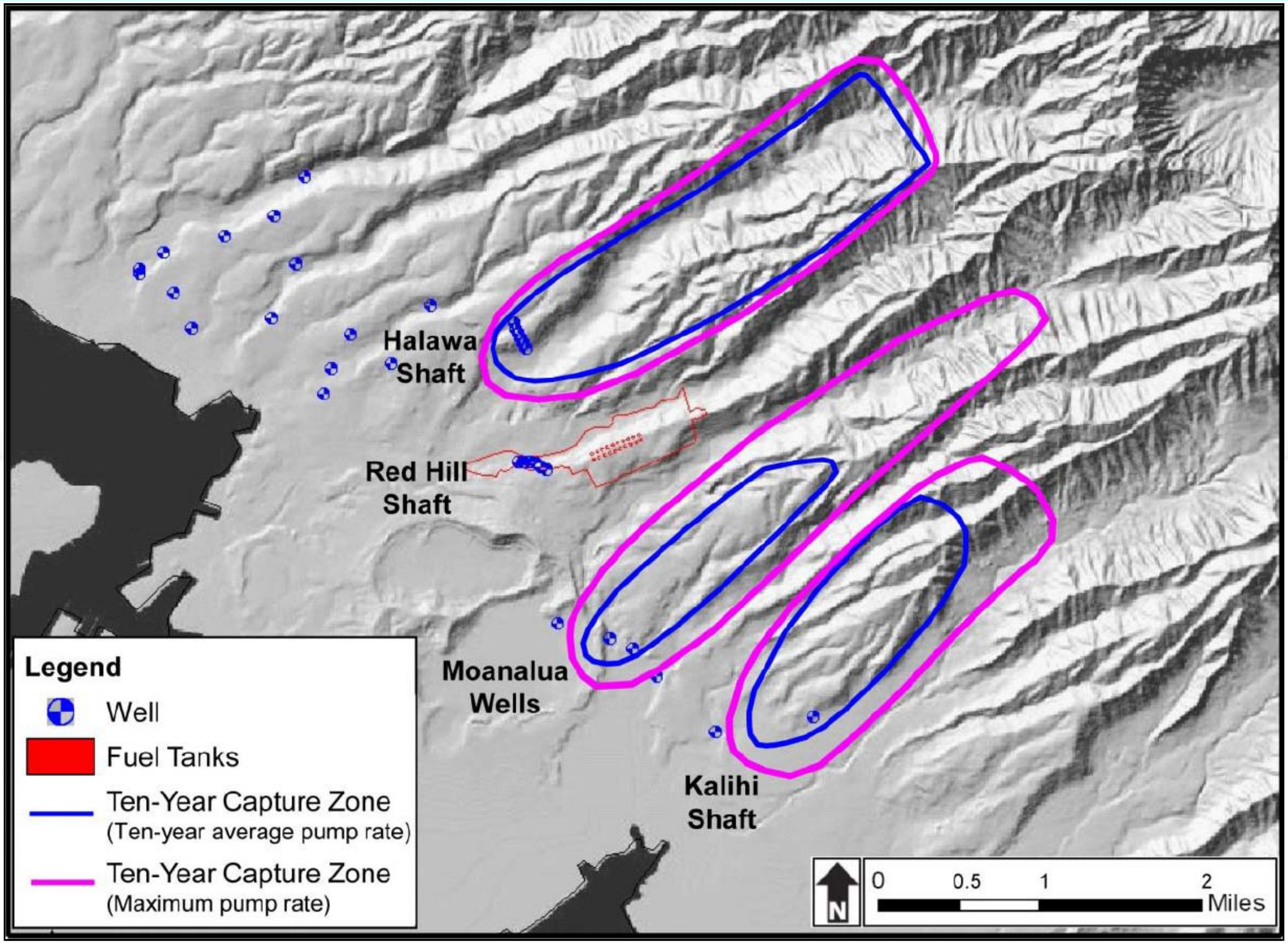
Task #5: Update the Existing Groundwater Model
Red Hill Shaft Pump Test



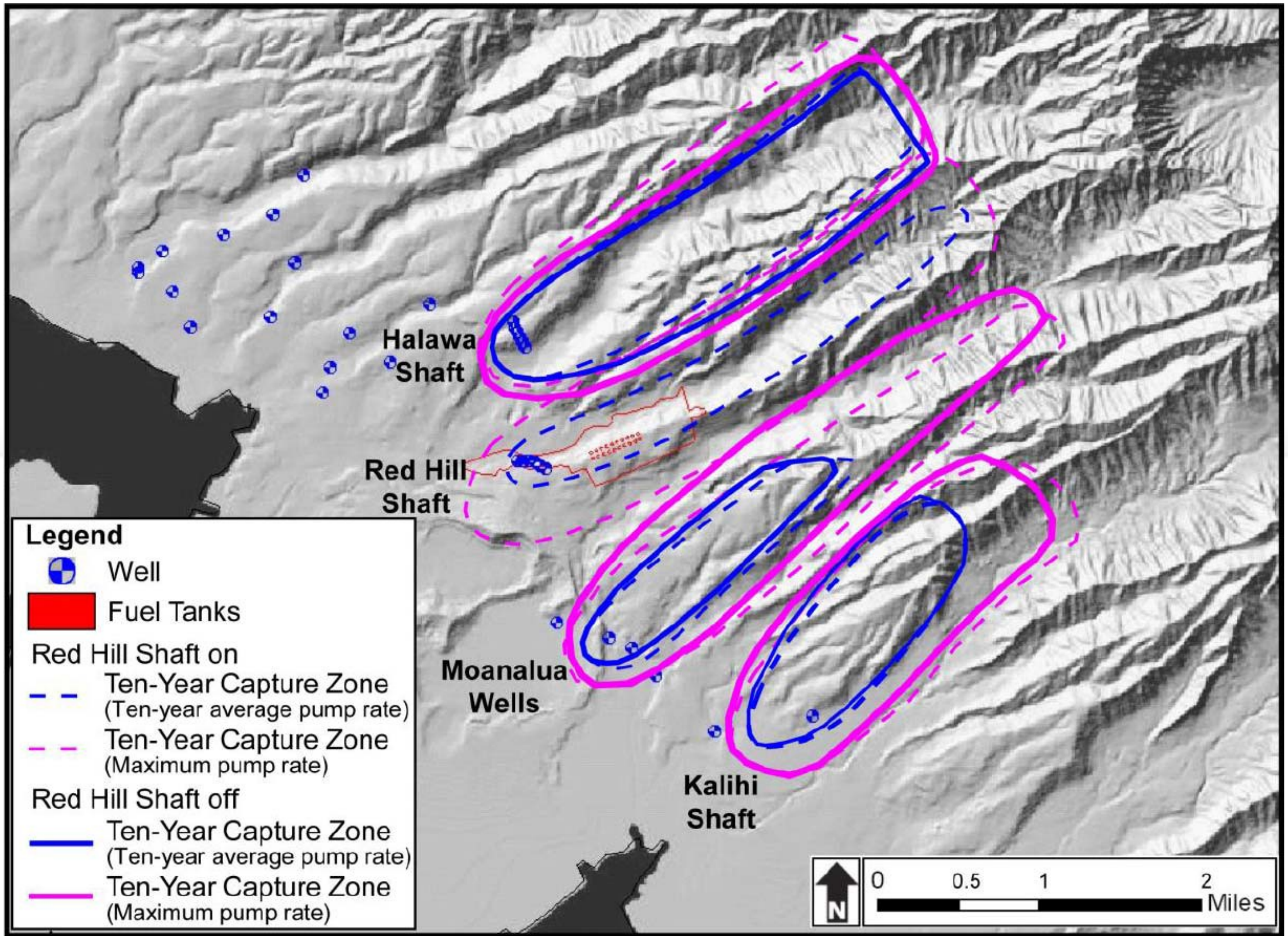


Specific Yield = 0.03

Task #5: Update the Existing Groundwater Model Capture Zone Delineation, Red Hill Shaft Off



Task #5: Update the Existing Groundwater Model Capture Zone Delineation, Both



Task #5: Update the Existing Groundwater Model Flow Model Strengths, Data Gaps

- Existing Flow Model Strengths
  - MODFLOW is the industry-standard flow model, tried and tested at countless sites
  - Significant effort expended by local experts to develop site model and calibrated with site data and pump test
  - Reasonably simulates transient drawdown from Red Hill Shaft
  - Supports concept of aquifer as porous medium
- Recommendations for Flow Model Improvement
  - Gather more site geologic, hydrogeologic, and hydraulic data
  - Gather more widespread hydraulic head data
  - Better define stratigraphy and properties of relatively low-permeability valley-fill barrier
  - Add saprolite layer beneath valley fill

Task #6: Update the CF&T Model and Evaluate Whether to Perform Tracer Study

- Previous Contaminant Fate and Transport Modeling performed by Bob Whittier, using RT3D (TEC 2007)
- Modeling purpose: Conduct Tier 3 risk assessment
  - Establish site-specific risk-based level (SSRBL) for selected compounds
  - DOH EALs: Benzene: 0.005 mg/L; Total Petroleum Hydrocarbons (TPH): 0.100 mg/L
  - Must show compliance with MCL at drinking water source
- Modeling Question:
  - "How close can a hypothetical LNAPL plume get to the Red Hill Shaft without exceeding MCL or EAL?"
    - Note: NAPL has never been detected at the groundwater surface

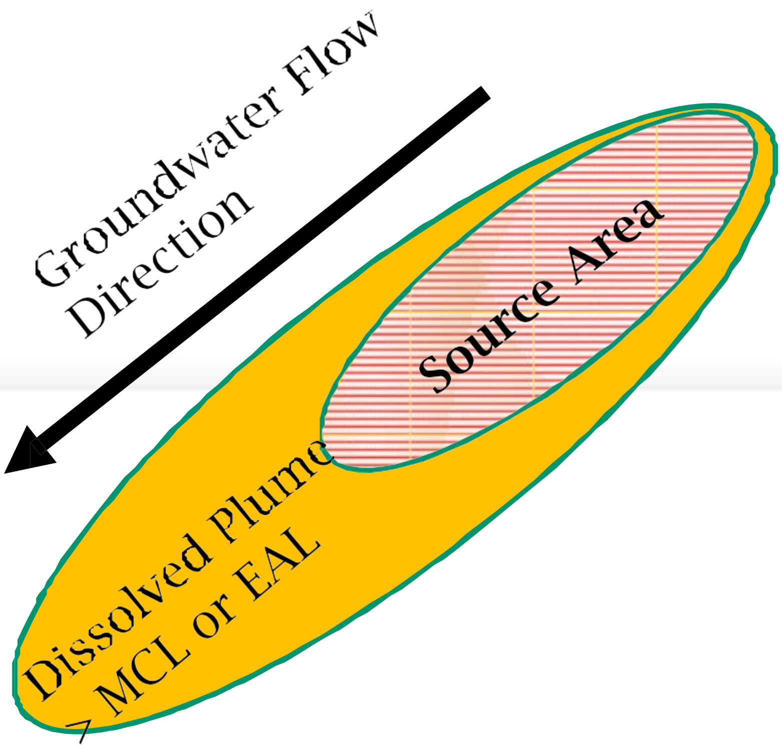
Task #6: Update the CF&T Model and Evaluate Whether to Perform Tracer Study

- **What this model DOESN'T do:**
  - **Simulate the LNAPL migration in the vadose zone**
    - Geologic CSM suggests NAPL is not migrating to the water table
  - **Simulate potential LNAPL migration along the water table**
    - NAPL has not been detected on the groundwater surface
- **What the model DOES do:**
  - **Estimate the degradation rate of dissolved contamination**
  - **Provide the foundation for Site Specific Risk Based Risk Based Level (SSRBL)**

Task #6: Update the CF&T Model and Evaluate Whether to Perform Tracer Study

- **Modeling Approach**
- **Select modeling code**
  - **Compatible with MODFLOW**
    - MODPATH, MT3D, RT3D
  - **MODPATH**
    - Particle tracking, good for delineating zones of contribution and estimating groundwater velocity
    - No dispersion
  - **MT3D**
    - Simultaneously simulate transport of multiple species
    - Include dispersion, sorption, first order decay
    - Some challenges in acquiring needed parameters
  - **RT3D**
    - Similar to MT3D, but can simulate biodegradation
    - Very challenging to get required parameters!

Task #6: Update the CF&T Model and Evaluate Whether to Perform Tracer Study



- **Modeling Approach**
  - Modeled source area as an immobile LNAPL Plume
  - Simulated microbial mediated degradation in the dissolved plume
  - Estimated distance dissolved plume travels prior to degrading to < MCL or EAL

Task #6: Update the CF&T Model and Evaluate Whether to Perform Tracer Study

- **RT3D required parameters**
  - **Dispersivity**
    - Estimated from rock core logs (50 ft) and USGS reports (250 ft)
    - Geometric mean 112 ft
    - Estimated Lahaina Tracer Test Value - 82 ft (for comparison)
  - **Sorption**
    - Assumed to be zero
    - Conservative assumption (probably not true)
  - **Natural Attenuation Parameters (NAPs)**
    - Concentrations
    - Consumptive rate
    - Reaction rates and coefficients

Task #6: Update the CF&T Model and Evaluate Whether to Perform Tracer Study

- **Model Simulations**
  - **Base – estimate proximity of LNAPL to RHS and still be compliant at the Red Hill Shaft**
    - TPH
    - Benzene
  - **Plume size**
    - Step-wise increase in width and length
  - **Infiltration only**
    - Simulate the impact on groundwater of recharge moving through contamination in the unsaturated zone
  - **Reaction rates**

Task #6: Update the CF&T Model and Evaluate Whether to Perform Tracer Study: Previous Model Results

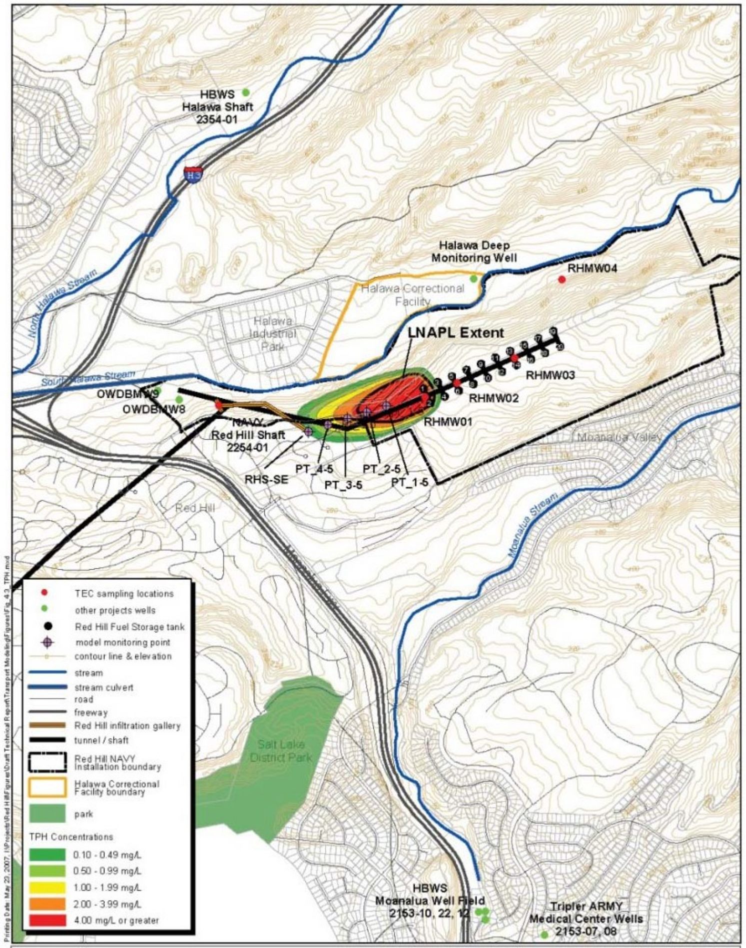


Figure 4-3
TPH Concentration Distribution When the TAL is Exceeded at the RHS

Total Petroleum Hydrocarbons

- Hypothetical LNAPL footprint: red hatched oval
- Results
  - LNAPL must extend to point mid-way between RHMW01 and RHMW05 for an exceedance to occur at the Red Hill Shaft
- TPH Dissolution Rate
  - 2.7 mg/d/ft^2
  - Compares favorably with analytical model
    - (Wiedeimerer et al 1995)

Task #6: Update the CF&T Model and Evaluate Whether to Perform Tracer Study: Previous Model Results

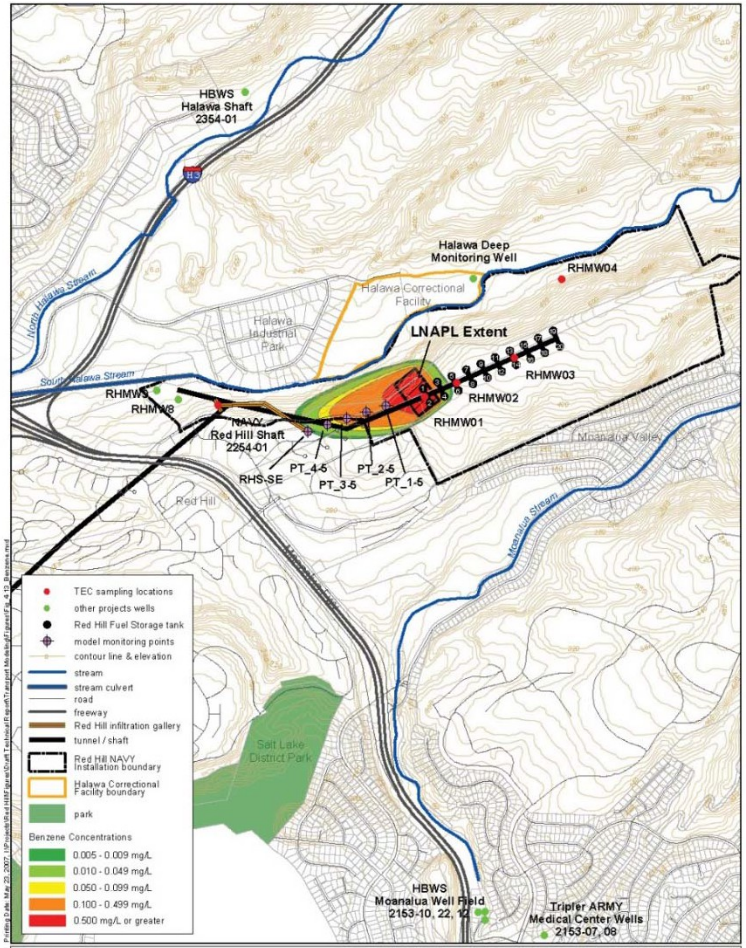


Figure 4-13
Benzene Concentration Distribution
for the Benzene Compliance Simulation

Benzene

- **Results**
  - A hypothetical LNAPL plume that reaches beyond RHMW01 could cause an exceedance at the RHS
- **Concentration must be reduced by a factor of 150**
  - TPH, only requires a 45 fold reduction
- **But only infrequent, trace benzene detections, and benzene not a major constituent of JP-8**
  - Benzene may not be the best COPC for modeling and planning purposes

Task #6: Update the CF&T Model and Evaluate Whether to Perform Tracer Study: Previous Modeling Conclusions

Modeling Conclusions

- Jet fuels (JP-5) solubility is relatively low
  - TPH solubility of ~5 parts per million (mg/L)
  - Benzene content low, 0.7 mg/L maximum
    - May be much less
- Red Hill dissolved contamination is not extremely mobile
- Natural attenuation reduces TPH concentrations to < EAL over distances of 1000 – 2000 ft
- Properly characterizing NAP reaction rates is important for RT3D modeling

Task #6: Update the CF&T Model and Evaluate Whether to Perform Tracer Study: Previous Modeling Conclusions

- **Uncertainties**
  - **Actual solubility of JP-5 and JP-8**
    - One analysis lists JP-8 solubility as 12 mg/L
  - **Stoichiometry**
    - Bulk rates of natural attenuation parameter utilization
  - **Reaction rates and coefficients**
    - Data indicate that these are particularly important parameters
  - **Groundwater flow paths**

Task #6: Update the CF&T Model and Evaluate Whether to Perform Tracer Study: Previous Model Results

- Existing CF&T Model Strengths
  - RT3D is an industry standard model developed to model petroleum hydrocarbons
  - Leverage considerable previous effort by local experts
  - Models existing site data reasonably well (e.g., concentrations of dissolved oxygen and methane beneath UST facility)
  - Supports concept of modeling natural attenuation in the aquifer
- Recommendations for CF&T Model Improvement
  - Better define geometry, stratigraphy, and hydraulic properties
  - Evaluate effective porosity and dispersivity
  - Re-evaluate evaluate COPCs for JP-8
    - consider: presence, mobility, degradation, toxicity
  - Evaluate solubility of JP-8
  - Refine degradation rates for COPCs
  - Gather additional NAP data: dissolved oxygen, nitrate, ferrous iron, sulfate, and methane

Task #6: Update the CF&T Model and Evaluate Whether to Perform Tracer Study: Previous Model Results

- **Recommendations for CF&T Model Improvement (cont'd)**
- **Gather and incorporate new data:**
  - **From USGS studies (e.g., pumping test of Halawa Shaft)**
  - **From new monitoring wells and sampling**
  - **From new well borehole stratigraphy and geochemical data**
  - **Gather additional NAP data**
    - e.g., dissolved oxygen, nitrate, ferrous iron, sulfate, and methane

Task #6: Update the CF&T Model and Evaluate Whether to Perform Tracer Study

- **Upon completion of all other tasks, and review of results, evaluate whether to perform a tracer study**
- **Purpose:**
  - **Study could refine site-specific estimates of field-scale:**
    - groundwater velocity and flow direction,
    - hydraulic conductivity,
    - effective porosity, and
    - Dispersivity
  - **Refine the SSRBLs**
  - **Inform Contingency Planning**
- **Considerations:**
  - **Does the new data suggest that contaminants are escaping the facility or otherwise pose an imminent and substantial endangerment?**
  - **Is groundwater flow regime amenable to a tracer study?**
  - **Are there suitable locations for tracer injection and monitoring?**

Task #6: Update the CF&T Model and Evaluate Whether to Perform Tracer Study

- Tracer Study Design Parameters and Required Data:
  - Detailed hydrogeologic characterization
  - Tracer: non-toxic, easily measured, non-adsorptive, resistant to biodegradation; no undesirable color or odor
  - Injection points directly upgradient of monitoring points and close enough to define the complete break-though curve
  - Recommend pumping test to better define drawdown capture zone to select a tracer injection well location directly up-gradient from monitoring wells and close enough to define the complete tracer break-though curve
  - Use refined models and existing data to evaluate suitability of existing wells
  - Additional hydraulic head distribution data

Task 7: Evaluation Remedial Alternatives for NAPL Fuels in the Vadose Zone

- **Potential Methods for Remediation of NAPL Fuels in the Vadose Zone:**
  1. Excavation
  2. Vapor Extraction
  3. Multi-Phase Extraction
  4. Bio-Venting
  5. Surfactant Flushing
  6. NAPL Recovery

Task 7: Evaluation Remedial Alternatives for NAPL Fuels in the Vadose Zone

1. Excavation

Physical removal of contaminated media via excavation; requires landfilling or additional in-situ or ex-situ treatment of the excavated spoils.

PROS

- Widely used technology with proven track record for quick removal of contamination in shallow soil.

CONS

- Limited to shallow soils.
- Potentially high cost for disposal or treatment.
- Not effective in fractured rock.

Conclusion: Not recommended for implementation; evaluation of the method to be included in Work Plan/SOW

Task 7: Evaluation Remedial Alternatives for NAPL Fuels in the Vadose Zone

2. Vapor Extraction

Application of negative air pressure (vacuum) to the unsaturated subsurface via extraction wells to stimulate in-situ volatilization and vapor removal. Can be combined with other technologies (bio-venting or NAPL recovery).

PROS

- Widely used technology with proven track record for the remediation of residual hydrocarbon contamination in the vadose zone.
- Can be effective at depth.

CONS

- Radius of influence dependent on effective porosity & media moisture content.
- Exhausted vapors may require treatment before discharge.
- Would require drilling to be effective at depth.
- May require long-term operations and maintenance.
- Short-circuiting can diminish effectiveness, especially in formations like Red Hill.

Conclusion: Potentially feasible; evaluation of the method to be included in Work Plan/SOW

3. Multi-Phase Extraction

Application of high negative pressure (vacuum) to the subsurface via extraction wells to remove both liquid and vapor-phase contaminants.

PROS

- Proven track record for the remediation of residual hydrocarbons and NAPL.

CONS

- Radius of influence depends on effective porosity.
- Depth limitations dependent on pump size.
- Requires handling or processing of liquid waste.
- Exhausted vapors may require treatment before discharge.
- Would require drilling to be effective at depth.
- May require long-term operations and maintenance.
- Short-circuiting can diminish effectiveness, especially in formations like Red Hill.

Conclusion: Potentially feasible; evaluation of the method to be included in Work Plan/SOW

Task 7: Evaluation Remedial Alternatives for NAPL Fuels in the Vadose Zone

NAVFAC

4. Bio-venting

Injection of air or oxygen into the subsurface to stimulate the growth of aerobic microorganisms capable of biodegrading the hydrocarbons. Can be enhanced by the introduction of amendments (nutrients), specialized microorganisms, or other technologies (vapor extraction).

PROS

- Petroleum compounds readily biodegradable under aerobic conditions.
- Proven track record.
- Can be effective at depth.

CONS

- Radius of influence depends on matrix, porosity, and moisture.
- Short-circuiting can diminish effectiveness, especially in formations like Red Hill.
- May require long-term operations and maintenance.
- If used with vapor extraction, exhaust may require treatment.

Conclusion: Potentially feasible; evaluation of the method to be included in Work Plan/SOW

Task 7: Evaluation Remedial Alternatives for NAPL Fuels in the Vadose Zone

5. Surfactant Flushing

Injection of bio-degradable surfactants (e.g., soaps and detergents) into the unsaturated subsurface to mobilize residual hydrocarbons for removal via extraction wells.

PROS

- Effective technology for the removal of residual hydrocarbon contamination in the vadose zone.
- Can be effective at depth.

CONS

- Radius of influence depends on matrix, porosity, and moisture.
- Requires both injection and extraction wells, the drilling of which could create preferential flow pathways through the Red Hill stratigraphy.
- Requires handling and processing of liquid waste.

Conclusion: Not recommended for implementation; evaluation of the method to be included in Work Plan/SOW

Task 7: Evaluation Remedial Alternatives for NAPL Fuels in the Vadose Zone

6. NAPL Recovery

Removal of NAPL from wells or excavations utilizing active methods (e.g., pumps, skimmers, bailers) or passive methods (e.g., absorbent materials). Can be combined with other technologies (vapor extraction or bioventing).

PROS

- Widely used technology with proven track record for removal of NAPL from known locations.

CONS

- Locations of NAPL must be known and accessible.
- Radius of influence dependent on matrix and porosity.
- Requires handling and processing of liquid waste.
- Vapors may require treatment.
- Effectiveness is limited to saturated NAPL conditions and requires additional technology (vapor extraction, bioventing, surfactant flush) to complete remediation of residual NAPL.
- Would require advancing wells in locations known to have NAPL, the drilling of which could create preferential flow pathways through the Red Hill stratigraphy.

Conclusion: Not recommended for implementation; evaluation of the method to be included in Work Plan/SOW

Task 7: Evaluation Remedial Alternatives for Hydrocarbons in Groundwater

- **Potential Methods for Remediation of Hydrocarbons in Groundwater:**
  1. Monitored Natural Attenuation
  2. Pump and Treat
  3. Air Sparging and Vapor Extraction
  4. Multi-Phase Extraction
  5. Chemical Oxidation
  6. NAPL Recovery

Task 7: Evaluation Remedial Alternatives for Hydrocarbons in Groundwater

1. Monitored Natural Attenuation

Periodic groundwater sampling and analysis for long-term monitoring of dissolved-phase hydrocarbon concentrations and geochemical parameters. Analytes include petroleum constituents, anions and cations, and dissolved gases. Can be enhanced with addition of nutrients; can be combined with bio-venting and vapor extraction.

PROS

- Low cost technology with proven track record.
- Can be effective at sites where groundwater occurs within fractured rock.
- Can be highly effective at petroleum release sites.
- Natural attenuation is already occurring at Red Hill.

CONS

- Relies on naturally occurring processes.
- Degradation rate may be relatively slow.
- Can generate methane.

Conclusion: Potentially feasible; evaluation of the method to be included in Work Plan/SOW

Recommend collection of groundwater data for NAPs: dissolved oxygen, nitrate, ferrous iron, sulfate, methane, and chloride

Task 7: Evaluation Remedial Alternatives for Hydrocarbons in Groundwater

NAVFAC

2. Pump and Treat

Pumping groundwater for ex-situ treatment (e.g., activated carbon filtration, air stripping) to remove the dissolved-phase hydrocarbons. May be combined with additional technologies such as vapor extraction.

PROS

- Proven technology.

CONS

- Efficiency is limited, resulting in high costs and requiring long treatment times to achieve remedial goals.
- Radius of influence dependent on effective porosity.
- High yield aquifers would require pumping & testing large quantities over a long time.
- Requires handling and processing of liquid waste.
- Effectiveness decreases as concentrations decrease; therefore, additional technologies (e.g., vapor extraction, air sparging) may be required to achieve remedial goals.
- Exhausted vapors may require treatment.
- Pumping costs increase with depth.
- Would require advancing wells in locations known to have NAPL, the drilling of which could create preferential flow pathways through the Red Hill stratigraphy.

Conclusion: Potentially feasible; evaluation of the method to be included in Work Plan/SOW

3. Air Sparging and Vapor Extraction

Injection of ambient air below the water table to strip volatile organic compounds from the water while providing aerobic microorganisms with oxygen to further degrade the hydrocarbons. Requires a vapor extraction system to control the migration of volatiles stripped from the groundwater.

PROS

- Widely used technology with proven track record for remediation of hydrocarbon contamination in groundwater.
- Can be effective at depth.

CONS

- Introduced oxygen may cause precipitates to form, potentially plugging well screens and inhibiting the flow of groundwater through the formation.
- Radius of influence depends on effective porosity.
- Exhausted vapors may require treatment.
- Would require advancing wells in locations known to have NAPL, the drilling of which could create preferential flow pathways through the Red Hill stratigraphy.

Conclusion: Potentially feasible; evaluation of the method to be included in Work Plan/SOW

Task 7: Evaluation Remedial Alternatives for Hydrocarbons in Groundwater

4. Multi-Phase Extraction

Application of high negative pressure (vacuum) to the subsurface via extraction wells to remove total liquids and vapor phase contaminants.

PROS

- Proven track record for the remediation of hydrocarbons and NAPL.

CONS

- Requires handling and processing of liquid waste.
- Exhausted vapors may require treatment.
- Would require advancing wells in locations known to have NAPL, the drilling of which could create preferential flow pathways through the Red Hill stratigraphy.
- Radius of influence depends on effective porosity.
- Depth limitations dependent on pump size.
- Requires handling or processing of liquid waste.
- Exhausted vapors may require treatment before discharge.

Conclusion: Potentially feasible; evaluation of the method to be included in Work Plan/SOW

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5. Chemical Oxidation

Injection of strong oxidant solutions or gas mixtures into the aquifer to oxidize dissolved petroleum constituents. Oxidants can include hydrogen peroxide, Fenton's reagent, potassium permanganate, persulfate, and ozone.

PROS

- Proven track record for the remediation of dissolved-phase hydrocarbons in groundwater.

CONS

- Requires special handling of oxidants.
- The oxidants may cause precipitates to form, potentially plugging well screens and inhibiting the flow of groundwater through the formation.
- Direct contact with LNAPL may cause a violent exothermic reaction.
- Oxidants may not be suitable for groundwater used as a drinking water source.
- Would require advancing wells in locations known to have NAPL, the drilling of which could create preferential flow pathways through the Red Hill stratigraphy.

Conclusion: Not recommended for implementation; evaluation of the method to be included in Work Plan/SOW

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6. NAPL Recovery

Removal of NAPL from wells or excavations utilizing active methods (e.g., pumps, skimmers, bailers) or passive methods (e.g., absorbent materials); can be enhanced with other technologies (vapor extraction or bioventing).

PROS

- Widely used technology with proven track record for removal of NAPL from the subsurface.

CONS

- Radius of influence depends on effective porosity.
- Requires handling and processing of liquid waste.
- Vapors may require treatment before discharge.
- Effectiveness is limited to saturated NAPL conditions and requires additional technology (vapor extraction, bioventing, surfactant flush) to complete remediation of residual NAPL.

Conclusion: Not recommended for implementation; evaluation of the method to be included in Work Plan/SOW

Conclusions

1. Evaluate Subsurface Geology
2. Investigate the LNAPL
3. Identify COPCs
4. Expand the Monitoring Network
5. Update the Existing Groundwater Model
6. Update CF&T Model and Evaluate Whether to Perform a Tracer Study
7. Evaluate Remedial Alternatives