Consolidation and Optimization of the Groundwater Sampling Programs
Red Hill Bulk Fuel Storage Facility

Joint Base Pearl Harbor-Hickam, O'ahu, Hawai'i

Naval Facilities Engineering Systems Command, Hawaii, JBPHH HI

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1. Executive Summary

The Navy is consolidating Notice of Interest (NOI), Groundwater Long-Term Monitoring (GW LTM), delineation and sentinel wells, and per- and polyfluoroalkyl substances (PFAS) groundwater sampling programs into one comprehensive, optimized groundwater sampling program. The new program is based on the following:

- Hawai'i Department of Health (DOH) guidance;
- The Red Hill Administrative Order on Consent (AOC);
- DOH Notice of Interest (NOI) requirements that have expired on November 13, 2022;
- The March 8, 2023 meeting with the U.S. Environmental Protection Agency (EPA) and DOH regarding future sampling requirements;
- The April 13, 2023 Red Hill Remediation Roundtable meeting, and
- Reviews of NOI data collected and analyzed at least weekly since May 2021

The consolidated sampling approach includes the following changes:

- Integrating and coordinating all of the Red Hill groundwater sampling programs into a single program to facilitate better regulatory oversight, and sampling event execution throughout and in the vicinity of the Red Hill Bulk Fuel Storage Facility;
- Revising the NOI analyte list, with a focus on fuel-related analytes;
- Optimizing the NOI sampling frequency from weekly to monthly;
- Incorporation of Data Quality Objectives;
- Optimizing NOI monitoring locations to provide comprehensive assessment of the general area; and
- Standardizing the NOI sample collection method to use low-flow purging and sampling methodology, as recommended in the DOH Technical Guidance Manual for the Implementation of the Hawaii State Contingency Plan (TGM) (DOH 2021)

2. Groundwater Sampling Program Improvements

2.1 SAMPLING PROGRAM INTEGRATION

To optimize the sampling programs for targeted sapling for faster lab turnaround times and more efficient data analyses, the various programs have been integrated into a single, comprehensive groundwater sampling program. The consolidated groundwater monitoring program requirements include the analytical suite, analytical methods, laboratory turnaround times, sampling locations, sample collection methods, and sampling frequency.

In accordance with the *Sampling and Analysis Plan, Investigation and Remediation of Releases and Groundwater Protection and Evaluation, Revision 01* (DON 2017b), the U.S. Navy Environmental Restoration Program, NAVFAC Pacific, Navy Project Procedures Manual (DON 2015), and the TGM, the consolidated groundwater sampling program includes NOI and GW LTM sampling of inside- and outside-tunnel sampling locations using low-flow sampling techniques. Groundwater sampling also includes measuring depth to groundwater and depth to well bottom from the top of casing and assessing the presence or absence of an immiscible phase. A photoionization detector is used to evaluate whether well volatile organic compound levels are above ambient conditions, prior to deploying an oil/water interface probe.

Headspace monitoring is performed at all locations, and fuel product thickness gauging is conducted at wells with screens that bracket the water table. Bailers are used to assess and photo document the presence or absence of floating product on the groundwater surface in wells installed in unconfined conditions.

Field parameters collected during purging include water level measurements, observations (i.e., water clarity and condition, evidence of free product), dissolved oxygen measurements, and groundwater sampling parameters (turbidity, specific conductance, oxidation reduction potential, pH).

During the April 13, 2023 Red Hill Remediation Roundtable meeting, the Regulatory Agencies requested that the Navy include PFAS-specific sampling in the consolidated groundwater sampling program. Consistent with the *PFAS-Specific Sampling and Analysis Plan* (DON 2022), PFAS is sampled from 10 monitoring wells to determine whether the aqueous film-forming foam (AFFF) release near the ground surface impacted the groundwater using low-flow (pump) purging. Two additional samples are collected at piezometers RHMW17S and RHMW17D (shallow and intermediate), which are installed in perched groundwater above the basal aquifer. Samples are analyzed for all PFAS components that are included in the EPA Draft Method 1633 list.

2.2 REVISED ANALYTE LIST

NOI, GW LTM, delineation well, and sentinel well sampling has generated a substantial dataset characterizing the nature and extent of the fuel releases. The NOI sampling included analyses of chemicals of potential concern (COPCs) and additional analytes including chemicals that are not associated with fuels. Therefore, this document presents the notification of changes to the ongoing NOI sampling program and integration of the various groundwater monitoring programs into one overall program informed by the substantial body of laboratory results, DOH guidance, and the composition of the fuels. This process mimics the process employed under the AOC. Table 1 and Table 2 provide a summary of the analytical list for the consolidated groundwater monitoring program, which includes monthly analytes, analytical methods, and screening criteria.

The following ten primary COPCs were established in February 2016 (EPA Region 9 and DOH 2016) for the AOC investigations and the GW LTM program and shall remain the same for the consolidated sampling program:

- Total petroleum hydrocarbons (TPH)-gasoline range organics (TPH-g), TPH-diesel range organics (TPH-d), and TPH-oil range organics (TPH-o)
- Naphthalene, 1-methylnaphthalene, and 2-methylnaphthalene
- Benzene, toluene, ethylbenzene, and total xylenes (BTEX)

During the March 8, 2023 Navy, EPA, and DOH collaboration meeting, the Navy presented a list of reduced analytes for NOI sampling. Inclusion of the non-fuel related, full suite analytes increased processing time for commercial laboratories, data validators, and sampling and shipping, without adding valuable information to identify and characterize potential fuel release impacts. This contributed to delays in validation, reporting, and timely analyses of results, and impeded rapid assessment of impacts to groundwater and the ability to quickly respond to changes in groundwater conditions.

Although it was valuable during emergency response activities in late 2021 and early 2022, continued inclusion of additional analytes runs counter to TGM guidance of "Do not simply list chemicals associated with specific laboratory methods that will be utilized to test samples collected at the site"[1] and will no longer be implemented. Based on the laboratory results from all groundwater monitoring events, the infrequent detection of low concentrations of analytes that are not associated with fuel confirms that the analytes used as the AOC and GW LTM COPCs are appropriate. Out of an abundance of caution, additional Polycyclic Aromatic Hydrocarbons (PAHs) analyzed for NOI sampling will also continue as part of the consolidated sampling program, because some

[1] https://health.hawaii.gov/heer/tgm/section-06/, last accessed March 15, 2023.

PAHs are potentially associated with jet fuels at low concentrations. The Navy also agreed to add non-volatile dissolved organic carbon and it has been added to the natural attenuation parameter (NAP) list for monthly sampling.

Table 1. Consolidated Groundwater Monitoring Program (Fuel).

Parameter	Analytical Method	Analyte(s)	GW Screening Criterion (DOH EALs) (µg/L)	Quarterly LTM	Monthly NOI
TPH	EPA 8260	TPH-g	300	x	x
	EPA 8015	TPH-d	400	x	x
		TPH-o	500	x	x
Total TPH	—	Reported as a non-overlapping sum of TPH-g/d/o with BTEXMN subtracted	—		x
TPH with SGC	EPA 3630/8015	TPH-d	—	x	x
		TPH-o	—	x	x
VOCs	EPA 8260	Benzene	5	x	x
		Ethyl Benzene	30	x	x
		Toluene	40	x	x
		Total Xylenes	20	x	x
AOC / LTM PAHs	EPA 8270 SIM	1-Methylnaphthalene	10	x	x
		2-Methylnaphthalene	10	x	x
		Naphthalene	17	x	x
PAHs	EPA 8270 SIM	Acenaphthene	20	x	x
		Acenaphthylene	240	x	x
		Anthracene	0.18	x	x
		Benzo(a)anthracene	0.029	x	x
		Benzo(a)pyrene	0.2	x	x
		Benzo(b)fluoranthene	0.22	x	x
		Benzo(g,h,i)perylene	0.13	x	x
		Benzo(k)fluoranthene	0.4	x	x
		Chrysene	1	x	x
		Dibenzo(a,h)anthracene	0.022	x	x
		Fluoranthene	13	x	x
		Fluorene	240	x	x
		Indeno(1,2,3-cd)pyrene	0.095	x	x
		Phenanthrene	210	x	x
		Pyrene	68	x	x
Fuel Additives	EPA 8270	Phenol	300	x	x
	EPA 8270	2-(2-Methoxyethoxy) Ethanol	800	x	
Lead Scavengers[a]	EPA 8011	1,2-Dibromoethane	0.04	x	x
	EPA 8260	1,2-Dichloroethane	5	x	x
NAPs	SM 3500-Fe	Ferrous Iron	—	x	
	RSK 175M	Methane	—	x	x
	EPA 300.0	Nitrate, Sulfate, Chloride	—	x	
	EPA 353.2	Nitrate-Nitrite as Nitrogen	—	x	
	EPA 2320	Carbonate, Bicarbonate, and Total Alkalinity	—	x	
	EPA 9060A	TOC	—	x	x
	EPA 9060A	Dissolved Organic Carbon[a]	—	x	
	EPA 9060A	NVDOC	—		x
General Chemistry[b]	EPA 300.0	Bromide, Chloride, Fluoride, Nitrate, Sulfate	—	x	
	EPA 6010C	Calcium, Iron, Dissolved Lead, Total Lead, Magnesium, Manganese, Potassium, Sodium	—	x	
	SMWW4500-Si-D / SIO2-C	Dissolved Silica, Total Silica	—	x	

Notes:

x	Compound is included in the respective groundwater sampling program	MN	1- and 2-methylnaphthalenes
—	not applicable	NAP	natural attenuation parameters
a	Discontinued if one year's worth of sampling show levels are below DOH EALs	PAH	polycyclic aromatic hydrocarbons
b	Monitored on the first GW LTM event of a new well	SGC	silica gel clean-up
ug/L	microgram per liter	TPH-g	total petroleum hydrocarbons - gasoline range organics
BTEX	benzene, toluene, ethylbenzene, xylene	TPH-d	total petroleum hydrocarbons - diesel range organics
DOH EAL	Hawaii Department of Health Environmental Action Level	TPH-o	total petroleum hydrocarbons - residual range organics
GW	groundwater	VOC	volatile organic compounds

Table 2. Consolidated Groundwater Monitoring (PFAS).

Parameter	Analytical Method	Analyte(s)	GW Screening Criterion (DOH EALs) (µg/L)	Monthly PFAS
PFAS	EPA 8015	2(2-Butoxyethoxy) ethanol	—	x
	EPA Draft Method 1633	Perfluorobutanoic acid	15	x
		Perfluoropentanoic acid	1.5	x
		Perfluorohexanoic acid	1.9	x
		Perfluoroheptanoic acid	0.077	x
		Perfluorooctanoic acid	0.012	x
		Perfluorononanoic acid	0.012	x
		Perfluorodecanoic acid	0.0077	x
		Perfluoroundecanoic acid	0.019	x
		Perfluorododecanoic acid	0.026	x
		Perfluorotridecanoic acid	0.026	x
		Perfluorotetradecanoic acid	0.26	x
		Perfluorobutanesulfonic acid	1.7	x
		Perfluoropentansulfonic acid	—	x
		Perfluorohexanesulfonic acid	0.077	x
		Perfluoroheptanesulfonic acid	0.038	x
		Perfluorooctanesulfonic acid	0.0077	x
		Perfluorononanesulfonic acid	—	x
		Perfluorodecanesulfonic acid	0.038	x
		Perfluorododecanesulfonic acid	—	x
		1*H*,1*H*, 2*H*, 2*H*-Perfluorohexane sulfonic acid	—	x
		1*H*,1*H*, 2*H*, 2*H*-Perfluorooctane sulfonic acid	1.5	x
		1*H*,1*H*, 2*H*, 2*H*-Perfluorodecane sulfonic acid	—	x
		N-methyl perfluorooctanesulfonamide	—	x
		N-ethyl perfluorooctanesulfonamide	—	x
		Perfluorooctanesulfonamide	0.046	x
		N-methyl perfluorooctanesulfonamidoacetic acid	—	x
		N-ethyl perfluorooctanesulfonamidoacetic acid	—	x
		N-methyl perfluorooctanesulfonamidoethanol	—	x
		N-ethyl perfluorooctanesulfonamidoethanol	—	x
		Hexafluoropropylene oxide dimer acid	0.012	x
		4,8-Dioxa-3*H*-perfluorononanoic acid	1.2	x
		9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid	—	x
		11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid	—	x
		3-Perfluoropropyl propanoic acid	—	x
		2*H*,2*H*,3*H*,3*H*-Perfluorooctanoic acid	—	x
		3-Perfluoroheptyl propanoic acid	—	x
		Perfluoro(2-ethoxyethane) sulfonic acid	—	x
		Perfluoro-4-methoxybutanoic acid	—	x
		Perfluoro-3-methoxypropanoic acid	—	x
		Nonafluoro-3,6-dioxaheptanoic acid	—	x

Notes:

x	Compound is included in the respective groundwater sampling program
—	not applicable
µg/L	microgram per liter
DOH EAL	Hawaii Department of Health Environmental Action Level
GW	groundwater
PFAS	per- and polyfluorinated substances

2.3 OPTIMIZE SAMPLING FREQUENCY

As discussed during the March 8, 2023 collaboration meeting, weekly NOI sampling conducted after the 2021 release events effectively captured the increase and subsequent decrease of COPC concentrations in the monitoring wells following the releases, which provided an understanding of the impacts of those releases. The data showed that concentrations have significantly decreased and stabilized, in most cases, returning to non-detectable or within historical ranges. As a result, the current weekly sampling frequency no longer provides added information that is not captured by monthly (or quarterly) sampling. Reducing the sampling frequency to monthly allows for groundwater characterization and trend analyses without sacrificing accuracy, and reduces processing time for the commercial laboratories, the data validators, and sampling and shipping. The monthly sampling frequency is in accordance with the DOH TGM, which states: "Long-term monitoring of groundwater should be carried out at a frequency adequate to assess trends in potential environmental concerns and guide and monitor the effectiveness of remedial actions" (DOH TGM Section 6.6.8.5[2]).

Tables 3 and 4, below, summarize the frequency for each sampling location monitored monthly and quarterly under the consolidated sampling program.

Table 3. Sampling Matrix (Fuel).

Sampling Matrix (Fuel)	HDMW2253-03	RHMW2254-01	RHP01	RHP02	RHP03	RHP04A	RHP04B	RHP04C	RHP05	RHP06	RHP07	RHP08	RHMW01R	RHMW02	RHMW03	RHMW04	RHMW05	RHMW06	RHMW08	RHMW09	RHMW10	RHMW11	RHMW12A	RHMW13	RHMW14	RHMW15	RHMW16	RHMW17	RHMW18 (JJ)	RHMW19	RHMW20 (BB)	RHMW21 (II)	NMW22 (MM)	NMW23 (XA)	NMW24 (ZZ)	NMW25 (TT)	NMW26 (KK)	NMW27 (QQ)	NMW28 (PP)	NMW29 (MW1)	NMW30 (MW3)
2015 AOC LTM	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q
2021 NOI Sampling (Fuel)	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M

Notes
Q - Quarterly
M - Monthly
Gray shading are monitoring wells planned for installation.

Table 4. Sampling Matrix (PFAS).

Sampling Matrix (PFAS)	HDMW2253-03	RHMW2254-01	RHMW02	RHMW03	RHMW04	RHMW06	RHMW10	RHMW12A	RHMW16	RHMW17
2022 NOI Sampling (PFAS)	M	M	M	M	M	M	M	M	M	M

Notes
M - Monthly
PFAS - Per and Polyfluorinated Substances

[2] https://health.hawaii.gov/heer/tgm/section-06/, last accessed March 15, 2023.

2.4 OPTIMIZE MONITORING LOCATIONS

Sampling locations in each program were evaluated and locations were retained or excluded in an effort to optimize future sampling. Locations were removed based on their representativeness of groundwater conditions, duplication of (e.g., close proximity to) other sampling locations, anomalous water levels (elevated) and response to pumping conditions or other factors that differ from surrounding wells, or inclusion in another groundwater sampling program. Figure 1 shows the groundwater monitoring well sampling locations. Appendix A provides the justification for each well that was retained or excluded from the consolidated groundwater sampling program.

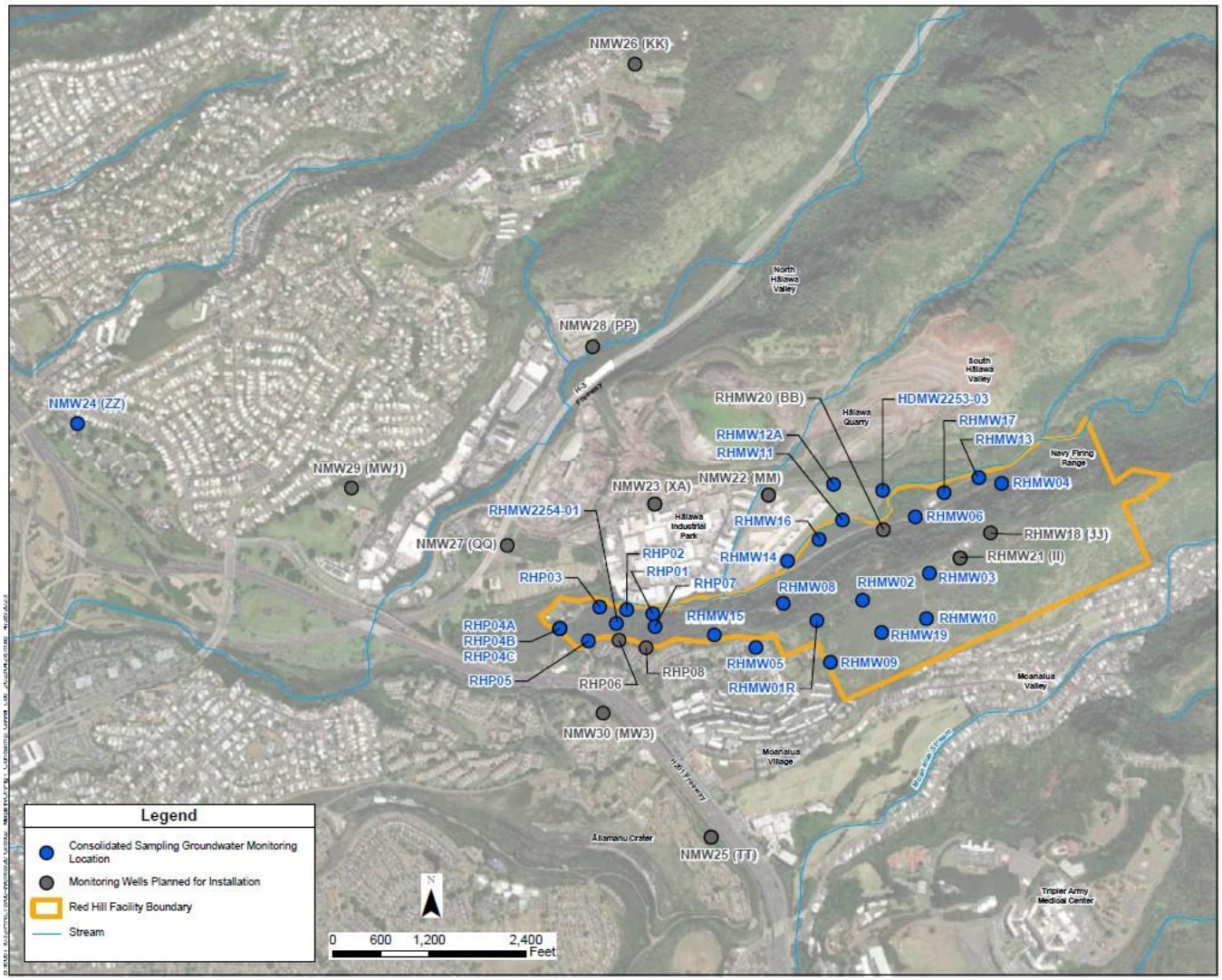

Figure 1. Groundwater Monitoring Well Sampling Locations.

2.5 STANDARDIZE SAMPLE COLLECTION METHOD

NOI sampling was conducted using both unpurged bailer and low-flow (pump) purging. No fuel product has been observed at monitoring locations to date with the exception of Red Hill Shaft shortly after the November 2021 release event. The use of different sampling methods have resulted in notable differences in analyte concentrations between the NOI and GW LTM programs. The low-flow sampling method is widely accepted to produce results that are more representative of surrounding aquifer conditions, as indicated in the DOH TGM, and as discussed in the following[3]. The inconsistency in sampling methods can impede long-term trend analysis of aquifer conditions.

The DOH TGM cautions against sampling with bailers, because "Bailers [are] prone to agitate the water column and result in loss of VOCs or inclusion of suspended sediment in sample if not used properly." In addition, the TGM states that "Caution should also be taken in the use of a bailer to collect samples that are to be tested for highly sorptive, semi-volatile and non-volatile organic compounds and metals due to the possible suspension of sediment in the bottom of the well and bias of data intended to be compared to action levels for dissolved-phase contaminants" (DOH TGM Section 6.6.7.4[4]). For these and other reasons, according to the TGM:

> "The HEER Office recommends that low-flow purging and sampling approaches be utilized whenever feasible in order to improve the representativeness of the sample data." (DOH TGM Section 6.6.5.3[5])

Therefore, the Navy will return to collecting samples via DOH and EPA's recommended low-flow methodology, which is used during the GW LTM, to ensure sample integrity, representativeness of aquifer conditions, and compatibility with environmental action levels.

The use of bailers will continue for field observations in wells installed in unconfined aquifer conditions, including photo-documentation, which consists of collecting bailer samples at the water surface in wells installed in unconfined conditions prior to purging or sampling and taking pictures of a clear bailer held against a white background to make observations of whether there are any signs of product or sheen.

3. Summary of Changes

Overall, the extensive groundwater data sets provided useful data confirming that the COPC list (EPA Region 9 and DOH 2016) remains appropriate for groundwater monitoring at the Red Hill Bulk Fuel Storage Facility and should continue to be used in the consolidated groundwater sampling program, with additional fuel-related analytes.

The Navy has revised and consolidated the current groundwater sampling program to the following:

(1) **Wells**. Figure 1 summarizes the monitoring locations included in the consolidated groundwater sampling program. Appendix A explains the rationale for the well locations included in the consolidated program.

(2) **Analytes**. Table 1 and Table 2 summarize the parameters that will be analyzed in the consolidated groundwater sampling program.

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[3] EPA also cautions against collecting unpurged bailer samples because "Stagnant water is subject to physiochemical changes and may contain foreign material, which can be introduced from the surface or during well construction, resulting in non-representative sample data. To safeguard against collecting a sample biased by stagnant water, specific well-purging guidelines and techniques should be followed." One of the appropriate sampling methods discussed in this EPA guidance is sampling via a low-flow sampling pump. *Ground-Water Sampling Guidelines for Superfund and RCRA Project Managers,* https://health.hawaii.gov/heer/files/2021/07/USEPA2002b.pdf

[4] https://health.hawaii.gov/heer/tgm/section-06/, last accessed March 15, 2023.

[5] https://health.hawaii.gov/heer/tgm/section-06/, last accessed March 15, 2023.

(3) **Frequency**. Table 3 and Table 4 summarize the revised sampling frequencies for the groundwater monitoring programs.

(4) **Sampling Methods**. Sampling of the monitoring wells and Red Hill Shaft will use the low-flow sampling methods recommended in the DOH TGM, consistent with the quarterly GW LTM program. Bailers will continue to be used prior to purging and sampling to conduct field observations (including photo-documentation) in monitoring wells installed in unconfined conditions.

No other changes are being made to the sampling program at this time. Based on data obtained and additional work to identify the nature and extent of the fuel releases in the environment, the scope and frequency of data collection may change. When conditions allow, the Navy expects to eventually transition the consolidated sampling program to normal quarterly sampling, consistent with the GW LTM program.

4. References

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Appendix A

Justification for Monitoring Location Changes

Locations	Description of Change	Reason For Change
Adit 3 Sump	Removal of monitoring location from NOI program	Not a basal groundwater location. Location was appropriate initially during the emergency response phase of the NOI for source investigation, but not appropriate for assessing risk since the NOI has transitioned to groundwater monitoring. The sump water is sourced by drainage from the tunnel and vadose zone and water samples from the sump are not representative of groundwater. Contribution to detects at Adit 3 Sump are not necessarily attributed to fuel and instead are from external sources un-related to the fuel stored at the Facility. Sump sampling may occur intermittently during site characterization and remediation activities, as necessary.
RHMW01	Removal of monitoring well from GW LTM program; replaced with RHMW01R	Duplicate well with better alternative available. RHMW01 is submerged while 01R is screened across water table. RHMW01R was installed to replace RHMW01 and provide a well that can also be utilized to measure for the presence/absence of light non-aqueous phase liquid.
RHMW07	Removal of monitoring well from GW LTM program; replaced with RHMW16	Not representative; better alternative at RHMW16. Well is screened in a zone lacking strong hydraulic connection with surrounding basal aquifer, as evidenced by elevated water levels and muted response to pumping and barometric pressure changes. RHMW16, located very close to RHMW07, will be included in the sampling program and is installed in a deeper zone with a strong connection to the basal aquifer.
RHMW10	Add monitoring well in NOI program	RHMW10 fills in a potential gap to the southeast from the center of the tank farm; GW LTM and PFAS programs already sample this well.
RHMW16A	Removal of monitoring well from GW LTM program	Duplicate well - RHMW16 is screened in a deeper zone with a strong hydraulic connection to the basal aquifer while 16A is above water table.
Halawa Deep HDMW 2253-03	Add monitoring well to NOI program	There is interest in sampling wells in the vicinity of the quarry to assess whether there is any potential COPC migration to the northwest towards Halawa Shaft; GW LTM and PFAS programs already sample at this well.
Oily Waste Disposal Facility Wells	Removal of monitoring wells; replaced with RHP wells	Prior to Plume Delineation well installations, OWDF wells were sampled because they were the only wells in that area. There are currently eight P-wells installed, and two more that will be completed, that are better suited for condition assessments from the release due to their proximity to the Red Hill Shaft and the 2021 fuel release.
RHP Wells	Add RHP wells in NOI and GW LTM program	Red Hill Plume Delineation wells have been installed both on and off the Red Hill facility to expand the groundwater monitoring network and evaluate the horizontal extent of fuel impacts that were observed following the November 2021 release.
Sentinel Wells	Add Sentinel Wells in NOI and GW LTM program	Similar to RHP wells, Sentinel wells have been installed on and off the Red Hill facility to characterize potential contaminant migration following the November 2021 release, and understand the surrounding geology.