RED HILL
WATER ALLIANCE INITIATIVE
(WAI)
REPORT

November 2023

Governor Josh Green, M.D.
Rep. Scott K. Saiki, Speaker, State House of Representatives
Sen. Ronald D. Kouchi, President, State Senate
Dawn N.S. Chang, Chair, Board of Land and Natural Resources, and Commission on Water Resource Management
Dr. David Lassner, President, University of Hawaiʻi
Mayor Rick Blangiardi, City and County of Honolulu
Councilmember Tommy Waters, Chair, Honolulu City Council
Ernest Y.W. Lau, P.E.**,** Manager & Chief Engineer, Honolulu Board of Water Supply

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May 9, 2023

Unified Statement on Red Hill

If we mālama the water, the water will mālama us. This is a relationship that requires active stewardship. The contamination of the land above the aquifer and of the aquifer itself are unprecedented threats. Our unified efforts are required.

Our goal is to have clean and pure water now and for future generations. Closure of the Red Hill tanks and facilities and remediation of the lands upon which they sit must meet this goal. Corrective actions and restoration of the aquifer may be required in addition to remediation in order to meet the goal of clean and pure water now and for future generations.

Aquifer remediation should be undertaken guided by a policy document that describes our goals, the implementation process, roles, guidelines, and regulatory framework as an agreement between the State of Hawai'i and the federal government. Development of the policy and the remediation effort itself will benefit from constructive and timely public engagement.

We seek a proactive approach, plan, and operational integration rather than one that defensively regulates a cleanup to the extent that current laws allow. We understand that this will require new ways of thinking and acting, locally and nationally. This is in the interest of all of the people of Hawaiʻi and, we believe, in the interest of this country.

Supported by:

Governor Josh Green, M.D.
State of Hawaiʻi

Senator Ronald D. Kouchi
President, State Senate

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Chair, Board of Land and Natural Resources
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RED HILL WATER ALLIANCE INITIATIVE REPORT

November 2023

A. Red Hill Water Alliance Initiative (WAI): Origin and Mandate, Goals, Focus, and Stance

On May 9, 2023, State and City and County of Honolulu officials signed a Unified Statement on Red Hill, recognizing the stewardship responsibility to ensure that there is clean water for future generations. "We seek a proactive approach, plan, and operational integration…. We understand that this will require new ways of thinking and acting, locally and nationally."

Towards this goal, the Red Hill Water Alliance Initiative (WAI), a working group, met regularly since the signing of the Unified Statement. We posed questions, conducted research, listened to subject matter experts, and formulated recommended policies. Our approach of total stewardship responsibility required a stance of extending beyond statutory roles, specific responsibilities, tenure in those roles, and even lifetimes. Our inquiry included the pursuit of critical questions for which there may currently be no answers. The pursuit of those answers is part of the ongoing work.

The focus of the Red Hill WAI's inquiry is the remediation needs after the defueling of the tanks and removal of residual fuel and contaminants from the facility. In particular, the group is concerned with the unknowns posed by fuel contaminants already in the ground, as well as the residuals of the fuel plume in the aquifer as a result of the spill of November 2021. In alignment with a proactive approach, the Red Hill WAI seeks to describe the remediation it believes necessary for the future well-being of the aquifer in which there is a negligible risk to water sources (including Hālawa Shaft, Hālawa wells, and ʻAiea wells), both current and future, to the water distribution system, and to the ecosystem including springs, streams, and nearshore waters, from mauka to makai.

Signatories to the Unified Statement include: Governor Josh Green, Honolulu Mayor Rick Blangiardi, Senate President Ronald Kouchi, Speaker of the House of Representatives Scott Saiki, Honolulu City Council Chair Tommy Waters, Chair Dawn Chang of the Board of Land and Natural Resources and Commission on Water Resource Management, Director Dr. Kenneth Fink of the Department of Health, Chief Engineer Ernest Lau of the Honolulu Board of Water Supply, and President Dr. David Lassner of the University of Hawaiʻi.

Red Hill WAI working group members include: Luke Meyers (Governor's Office), Mike Formby and Sam Moku (Mayor Blangiardi's Office), Sen. Jarrett Keohokalole, House Speaker Scott K. Saiki, Rep. Linda Ichiyama and Rep. Nicole Lowen (Co-chairs of the House Special Committee on Red Hill), Duncan Osorio (for Honolulu City Council Chair Tommy Waters), Dawn Chang (Board of Land and Natural Resources and Commission on Water Resource

Management), Ernest Lau, Erwin Kawata and Nāʻālehu Anthony (Honolulu Board of Water Supply), Don Thomas and Vassilis Syrmos (University of Hawaiʻi), and Norma Wong (facilitator and advisor to Speaker Saiki). As a regulatory agency, the Department of Health is not a member of the Red Hill WAI, but attended meetings as an observer.

B. Hawaiʻi's Constitutional Mandates and Public Trust Duties

In addition to its regulatory functions under federal and state environmental laws, the State of Hawaiʻi has unique public trust responsibilities as set forth in the Hawaiʻi State Constitution that establishes an affirmative duty on the part of the State to preserve and protect public trust resources, in particular, water resources. Article XI, Section 1 of the Hawaiʻi State Constitution mandates the State to "conserve and protect Hawaiʻi's natural beauty and all natural resources . . . and shall promote the development and utilization of these resources in a manner consistent with their conservation and in furtherance of the self-sufficiency of the State." Further, Article XI, Section 7 provides that the State "has an obligation to protect, control and regulate the use of Hawaiʻi's resources for the benefit of its people." Article XII, Section 7 proclaims that the "The State reaffirms and shall protect all rights, customarily and traditionally exercised for subsistence, cultural and religious purposes and possessed by ahupuaʻa tenants who are descendants of native Hawaiians who inhabited the Hawaiian Islands prior to 1778, subject to the right of the State to regulate such rights."

C. History of the Red Hill Bulk Fuel Storage Facility

The construction of the Red Hill Bulk Fuel Storage Facility began while World War II was already underway in Europe and threatening in the Pacific theater, and it continued during a period of martial law in Hawaiʻi. As designed, the facility was and continues to be the largest in the U.S. and one of the largest in the world, and unique in its design and geological location. Work on the facility occurred without the knowledge of most residents or the government of the Territory of Hawaiʻi, to whom the Navy was not accountable. The public and local officials were largely unaware of the grave dangers posed by the siting of the massive fuel tanks just 100 feet above a principal source of drinking water on Oʻahu and were therefore deprived of any opportunity to make their official views or concerns known. The facility was not declassified until 1995. Consequently, the Navy's primary mission of logistical readiness for national security appears to have taken precedence over their responsibility for environmental and public health.

Additional details in Attachment A.

D. Assumption of Risk

Most of the attention of the public and public decision-makers has been on removing the fuel from the facility. The Red Hill WAI focused its inquiries on fuel constituents in the ground. If the Navy successfully defueled without incident, there would still be the continuing environmental risk of previous spills that may have been left in the ground.

Many hazardous waste sites in the U.S. are assessed, contained, and capped without active remediation. These sites were deemed to be of limited risk at the time of determination. However, conditions can and have changed. An estimated 5,000 previously closed sites in Northern California are being urgently reassessed. As the sea rises, previously unaccounted for surface and subterranean flooding can cause movement of contaminants into other areas, including aquifers. This is a cautionary example of what can happen when sites are not remediated, and a direct forewarning for our situation at Red Hill which is in a coastal area likely to be impacted by sea level rise.

One of the scientific theories upon which remediation plans are frequently based can be roughly summarized as follows: if fuel spilled into the ground has not yet been found in the water table, then it is not likely to reach the aquifer. The subject matter experts who made presentations to the Red Hill WAI did not present any data to support this theory at Red Hill; in fact, they challenged the unsupported assumption.

Another scientific theory is that fuel constituents will naturally degrade through the interaction of microbes found in the soil. While that is so as a matter of science, there is insufficient research to show how efficient degradation occurs in the specific environment beneath the tanks, more than 500 feet below the surface and 100 feet above the aquifer, and whether degradation to the level of neutralizing harm and becoming suitable for human consumption will occur prior to the fuel reaching the saturated portion of ground.

How long does it take for natural degradation? Has the fuel spilled in the early years—the 1940s and 1950s—been neutralized? Evidence from other parts of the Pacific says otherwise. Although we cannot draw a one-to-one conclusion because the sub-surface geologies differ, volatile (meaning still able to be set on fire) bunker fuel and other Total Petroleum Hydrocarbons have been found in American Sāmoa, the Northern Mariana Islands, and Palau dating back to military activity in the 1930s and 1940s.

How much ground contamination should we be concerned about? The documented amount of fuel constituents in the ground is an estimated 180,000 gallons, spilled over 80 years in 70 incidences. This information has been known for several years.

However, after listening to subject matter experts, it is the conclusion of the Red Hill WAI that a number significantly higher than 180,000 gallons must be assumed for the purposes of risk assessment and formulating remediation strategies, since this aquifer provides water to the majority of residents on O‘ahu, including Navy personnel.

The calculation is as follows:

- 180,000 gallons documented, plus
- About 5,800 gallons/year in "incidental leaks", as estimated by the Navy, over 80 years = an additional 464,000 gallons, plus
- A former Red Hill Bulk Fuel Storage Facility employee reported to a contractor about a bunker fuel oil spill in the 1940s, equaling as much as 1.3 million gallons
- Total: At least 180,000 + 464,000 = 644,000 gallons and as much as 644,000 + 1,300,000 = 1.94 million gallons

Under any circumstances, between 644,000 and 1.94 million gallons of fuel spilled upon the land would be a significant hazard to the environment. For this to occur over a period of 80 years just 100 feet above an aquifer on an island that cannot replace its water source presents an existential challenge.

Additional details in Attachment B.

E. Monitoring and Testing

Monitoring plays a key role under any remediation theory and plan. More information than currently available is needed to assess both immediate and future risks, and to inform trend and directional analyses necessary for remediation planning.

Toward this end, the Red Hill WAI has four priorities:

(1) The Red Hill WAI needs access to all of the Navy's monitoring wells.

(2) If direct access is not possible or difficult to achieve, then the Red Hill WAI requires the Navy to conduct tests in accordance with the Red Hill WAI's separate schedules and specifications.

(3) To provide sufficient data points to assess aquifer quality, inform identified need for remediation, and guide the location of future production wells, the Red Hill WAI believes there is a need to establish a "sentinel" monitoring grid in addition to the existing monitoring wells identified by the Navy between the Red Hill facility and the Hālawa Shaft, Hālawa wells, and ‘Aiea wells. A comprehensive grid may consist of up to 122 monitoring wells at 61 sites, but terrain, access, and contamination issues will likely change the array or numbers of wells within the array. A fuller site-level assessment will

establish priorities and numbers of wells. The locations, specifications including depths, and testing from this grid should be determined by the Red Hill WAI in compliance with applicable law.

(4) Establish a testing/monitoring program to ensure the health of our ecosystems and watershed protection, specifically for springs, streams, and estuaries, including presence of fuel constituents in aquatic, terrestrial, and avian biota and species; monitoring and management actions in forest reserves; and monitoring of impacts to the recharge for the Pearl Harbor and adjacent aquifers (understanding that nearshore waters are subject to pollutants from multiple sources).

Additional details in Attachment C.

F. Remediation

The Red Hill WAI heard presentations by subject matter experts on remediation strategies, and formulated policy views based on known science as it meets the existential goal of protecting the future health of the island's water source.

In other environments where the water table is shallow or contained in a confined geologic formation, remediation can be done by excavation and treatment, or injection of heat or steam to mobilize the fuel to recover some of the product. Neither of these conditions exists at Red Hill, and the consensus of the subject matter experts' team is that these and similar currently available methods are unlikely to recover enough fuel to have a significant effect on the recovery and restoration of the aquifer. Such palliative actions can be costly distractions. Moreover, since the geological conditions work against the efficacy of these remediation strategies, deploying them may lead to the faulty conclusion that there is very little fuel to be removed from the ground or aquifer.

Of the known and currently available remediation strategies, Monitored Natural Attenuation (monitoring and allowing the biodegradation of the fuel to proceed naturally with little or no intervention to accelerate the process) is typically the default strategy. A limitation to this strategy may be that the so-called "free product"—fuel products that are in the ground or in the water table—could remain present for a century or more. New production wells or the reopening of wells would be at risk of encountering free product or contaminated groundwater. Monitored Natural Attenuation would also require the most conservative development posture on the part of the Board of Water Supply. Accordingly, the Red Hill WAI considers Monitored Natural Attenuation to be an unacceptable policy.

The Red Hill WAI prioritizes a remediation strategy in two parts:

(1) There should be a systematic and periodic review by a panel of subject matter experts of new remediation technologies and methods for applicability at Red Hill.

(2) Accelerating the natural process of biodegradation is the most promising remediation strategy for the scale of desired restoration.

   (a) In order to pursue this strategy, research work is needed to understand the distribution, movement, and characterization of fuel constituents below and in the vicinity of the fuel facility structures that are in the ground and not yet in the water table. Securing data on where the deposits are, the direction and rate of movement, and the state of the fuel supports a more accurate risk assessment as well as the development of a plan to accelerate biodegradation.

   (b) For the same reasons as described in paragraph (a), further research is needed to understand the distribution of the fuel plume at the water table.

   (c) An independently generated Contaminant Fate and Transport Model is needed. The Navy's model was not approved and has specific errors in its assumptions that were identified by subject matter experts, who have little confidence that a re-do by the Navy's contractor will be satisfactory. A model that has the confidence of experts and regulators is needed to inform remediation efforts and for there to be more confidence in risk assessments.

   (d) Concurrent to the work described above, biodegradation research, modeling, and field tests are needed to provide information on the efficacy, risks, and choices that accelerate the natural process of biodegradation in the unsaturated ground as well as at/in the water table.

The Red Hill WAI recommends these applied research efforts be coordinated out of the University of Hawaiʻi in conjunction with the WAI policy coordinator.

Additional details in Attachment D.

G. Future Use of the Red Hill Bulk Fuel Storage Facility

There have been reports of potential reuses of the facility. From the perspective of the Red Hill WAI:

(1) The facility cannot be used for any purpose that will store or use substances harmful to the water, air, or natural environment, or accelerate the level of contamination of the

subsurface or water table. This prohibition includes any use that introduces substantial amounts of water intentionally or accidentally as this would accelerate the migration of fuel contaminants.

(2) Any use of the facility may not interfere with or delay remediation, restoration, or monitoring, or research related to remediation and restoration efforts.

(3) Federal legislation should be enacted to prohibit reactivation of the Red Hill Bulk Fuel Storage Facility for any fuel storage following its closure ordered by the Department of Health.

H. Public Health

The best safeguards for public health and the health of the ecosystem are to prevent fuels and other contaminants from reaching the water table by accelerating biodegradation and other methods that may become known in the future, and to neutralize as much of the contaminants that are already in the aquifer.

The impacts to health by acute exposure through breathing, drinking contaminated water, living in areas near spills, or touching contaminated soil are significantly documented. The impacts for long-term low-level exposures are not well known. To date, the Environmental Protection Agency has not established standards for Total Petroleum Hydrocarbons (TPH) in drinking water.

There is not enough science or current research to indicate what the health impacts are for the long-term consumption of low levels of fuels diluted in many parts of water, or the consumption of plants or animals that have been propagated with low levels of fuels in water.

The Red Hill WAI recommends:

(1) Creation of a long-term health registry to monitor and study effects of acute exposure to TPH in drinking water.

(2) Periodic and regular review of the state of science of chronic long-term exposure to low levels of TPH in drinking water.

The Red Hill WAI recommends these efforts be coordinated by the WAI policy coordinator with the University of Hawaiʻi and other state and federal agencies.

I. Policy Coordination and Public Education

The Red Hill WAI recognizes that the overall strategy includes substantial elements that go beyond the roles and responsibilities of any given agency. It is a proactive approach requiring leadership and coordination.

(1) The proposal is for the Department of Land and Natural Resources to be the State's policy lead through a WAI policy coordinator, which would be located in the office of the Chair, to work with the State and county governments and other groups to ensure implementation and monitoring and interface with federal entities on Red Hill WAI initiatives.

  (a) In implementation of proactive protection and rehabilitation, the WAI policy coordinator will work with appropriate agencies and groups to periodically and regularly review the health status of the ecosystem, and to periodically and regularly review the state of science and opportunities for remediation and rehabilitation.

(2) A significant aspect of mutual stewardship is the inclusion of the people who are beneficiaries of the resource which, in this case, are the residents of the island of Oʻahu. Toward this end, the WAI policy coordinator will work with others to:

  (a) Ensure the development and maintenance of a public-facing test results dashboard describing the significance of results (State/County), as part of a broader public education program; and

  (b) Coordinate the implementation of a 36-month public information/education program to describe, inform, and educate the general public and institutions on the post-defueling remediation phases for Red Hill to restore public trust, secure public support, and inform health and environmental concerns.

J. Indemnification and Liability

Under federal and state laws, the Navy, Department of Defense, and U.S. government are the responsible parties for the contamination and the impacts of the contamination. The Red Hill WAI asserts that:

(1) The Department of Defense should be required to indemnify the State, all of its political subdivisions and agencies, and nearby landowners against all claims, demands, losses, damages, liens, liabilities, injuries, deaths, penalties, fines, lawsuits, and other proceedings arising out of or in any manner predicated upon the presence, release, or

threatened release of hazardous materials associated with the previous, ongoing, or subsequent operation of the Red Hill Bulk Fuel Storage Facility during the Department of Defense's use or control, or following its subsequent transfer;

(2) The United States should remain liable for and retain responsibility for any environmental restoration, remediation, or corrective action for the release or threatened release of hazardous materials associated with the previous, ongoing, or subsequent operation of the Red Hill Bulk Fuel Storage Facility within and beyond the footprint of the facility; and

(3) The United States bears responsibility for the loss of access to water from a portion of Oʻahu's EPA-designated Sole Source Aquifer (Southern Oʻahu Basal Aquifer) that is clean and safe for the residents and environment of the island of Oʻahu.

K. Conclusion

We the undersigned reaffirm our commitment to the health of our water source for future generations of Hawai`i. As its current stewards, we understand the work will require the determination of several generations and will do our part to reverse the course of threats. These proactive efforts are in the interest of all the people of Hawai`i and, we believe, will set an example for what is needed in this country as we face the challenges of climate change. As we mālama the water, the water will mālama us.

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Attachment A: History

The first part of this history focuses on the early period in which decisions were made on why, how, where, and what would be constructed into the Red Hill Bulk Fuel Storage Facility.

Strategic location within the Pacific leads to development of Pearl Harbor for Navy use

Well before Hawaiʻi was annexed by the United States, the United States Navy recognized the strategic importance of controlling a harbor in the Pacific for docking, fueling, repairing, and maintaining its fleet. In fact, under the 1887 extension of the 1875 Reciprocity Treaty between the United States and the Hawaiian Kingdom, the United States had already secured sole rights to Pearl Harbor as a coaling and repair station for the use of American vessels.[1] Japan's 1905 victory in the Russo-Japanese War stressed America's need for a strategy to check the rising power of Japan in the Pacific and a location from which to defend the Hawaiian islands against any attack.[2] Thereafter, the Pearl Harbor Naval Station was established in 1908 but remained largely unused as a Navy harbor as it was too shallow to accommodate larger ships, lacked a dry dock for vessel repairs and maintenance, and had not received funding to make the requisite changes to accommodate these uses.[3]

To bolster a military presence in Hawaiʻi, Prince Jonah Kūhiō Kalanianaʻole engaged in lobbying efforts to persuade Congress to fund the dredging and construction of a dry dock at Pearl Harbor, which was completed in 1919.[4] Subsequent work in the 1920s to widen and deepen the channel allowed the harbor to then be navigable for any United States Navy battleship.[5]

More Navy ships required the transport and storage of fuel

Discussions to establish a coaling station in the Pacific had occurred in the 1800s and centered around potential sites in the Hawaiian Islands or Midway Atoll. The United States had been reluctant to pay to construct stations in other countries unless it had exclusive control and use, so the 1887 extension of the 1875 Reciprocity Treaty paved the way for the United States to more heavily invest its resources into Pearl Harbor.

Plans to develop Pearl Harbor for the Navy's ships also necessitated plans for fueling those ships. Coal engines became common among Navy ships during the Civil War, displacing wind-

[1] hi0642data.pdf (loc.gov)
[2] The Key to the Pacific: The Construction of the Pearl Harbor Naval Base | The National WWII Museum | New Orleans (nationalww2museum.org)
[3] The Key to the Pacific: The Construction of the Pearl Harbor Naval Base | The National WWII Museum | New Orleans (nationalww2museum.org)
[4] The Key to the Pacific: The Construction of the Pearl Harbor Naval Base | The National WWII Museum | New Orleans (nationalww2museum.org)
[5] Pearl Harbor | Proceedings - May 1930 Vol. 56/5/327 (usni.org)

powered ships, but there was a dearth of coal fueling sites for ships traversing the Pacific Ocean. The completion of the Panama Canal in 1914 changed routes for many ships by allowing easier access from the Atlantic Ocean to the Pacific Ocean and consequently increased the importance of Hawaiʻi as a mid-Pacific fueling station for ships.[6]

The United States had been storing 1,500 to 2,000 tons of coal in a leased lot in Honolulu for its Navy ships. A coaling depot at Pearl Harbor had been recommended in the early 1900s and was finally authorized in 1912; coaling stations were then transferred from Honolulu facilities to Pearl Harbor in 1913. Heavy fuel oil was already becoming a more popular fuel source for ships by then, and the Navy largely converted its ships from coal to oil in the early 1910s, but coal remained a fuel source for ships through World War II.[7] From 1913 to 1915, seven metal fuel oil tanks were built adjacent to the coal facilities at Pearl Harbor, and through the build up to World War II in the 1930s, additional facilities were added, nearly all above ground.[8]

Impending war and threats to naval fuel supply leads to plans for an unprecedented, secret facility

In 1938, the Navy Shore Development Board expressed grave concern over the "adequacy and security of fuel oil storage at Pearl Harbor." The entire fuel supply for the Pacific fleet was contained in above-ground fuel tanks located throughout the Pearl Harbor Naval Station, making them highly visible and vulnerable to an attack. Aside from their vulnerability, the tanks also had inadequate storage capacity. Therefore, on June 25, 1940, the Fuel Storage Board recommended to the Secretary of the Navy "that the present tank farms be removed as rapidly as appropriations can be obtained to place the oil underground at least to the point of concealment."[9]

The Fuel Storage Board's recommendation resulted in a plan that called for the construction of four 300,000-barrel-capacity horizontal storage tanks, each 1,123 feet long, 20 feet wide, and 42 feet high, to be set deep into the earth to guard against attacks by enemy aircraft. Furthermore, the tanks were to be situated away from Pearl Harbor to avoid interference with future expansion plans for the naval base and to reduce the potential for a single attack to destroy the entire fuel supply along with the fleet.

Just days after the Fuel Storage Board released its report citing the inadequacies of Pearl Harbor's fuel-storage facilities, the project received $4 million for initial design and construction, then an additional $2.25 million in appropriations in September 1940. The Navy believed the project to be primarily a mining job and selected a tunneling specialist as the prime contractor, along with other contractors. The contractors performed studies to identify a suitable site for the

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[6] hi0642data.pdf (loc.gov)
[7] hi0642data.pdf (loc.gov)
[8] hi0642data.pdf (loc.gov)
[9] hi1016data.pdf (loc.gov), p. 4.

project, developed specifications, studied maps, conducted ground studies, and took core samples at various sites. However, after a mere month of searching, the contractors decided on a long ridge of volcanic rock that stretched from the Koʻolau Mountains to the near shores of Pearl Harbor: Kapūkakī, commonly known as Red Hill.

The property now known as the Red Hill Bulk Fuel Storage Facility is situated on lands condemned and purchased by the U.S. government. Lands of M. Kekūanaoʻa and Kamaʻikuʻi succeeded to the estates of Bernice Pauahi Bishop and Emma Kaleleonālani (a.k.a. Queen Emma), and subsequently to Emma Kaleleonālani in entirety.[10] Of those lands, 24.75 acres were condemned in 1916, and 211.1 and 123.92 acres in February 1941. Lands of Lot Kamehameha (a.k.a. Prince Lot) succeeded to the estate of Samuel Damon. Of those lands, 86.52 acres were condemned in February 1941, and 33.747 acres in June 1944. The total compensation for these lands, with the exception of the earliest condemnation in 1916 for which there is no listed amount, was $78,612.53.

Given the speed with which the site was selected, it is unlikely that either the Navy or its contractors had a thorough understanding of the hydrology and geology of the potential sites and how they would impact the environment or affect the movement of substances released from the fuel tanks. Additionally, it appears that little thought or care was given to the ultimate siting of the project just 100 feet above[11] the underground aquifer that supplied a principal source of drinking water for the nearly 260,000 residents of Oʻahu [12] at the time. The project's engineers knew of the existence of fresh drinking water beneath the fuel tanks but proceeded nevertheless,[13] and the Navy has not produced any information indicating whether or why Red Hill was determined to be the best site environmentally for the underground fuel storage facility. To the contractors, the Red Hill site afforded ample coverage for the facility and the necessary elevation to allow gravity to move fuel from the tanks to Pearl Harbor. Moreover, the length of the hill allowed the Navy to greatly expand the project by ultimately requesting 16 more fuel tanks than it had originally sought. Altogether, 20 tanks were ordered by and delivered to the Navy.[14]

The Navy insisted that the fuel be stored underground, but engineers were given wide flexibility in other design aspects of the facility. The fundamental design of the tank lining was to reinforce the tanks with concrete walls and quarter-inch steel-plate lining and envelop them in the surrounding rock. At some point during the planning process, a consultant on the project convinced the project manager to change the original design of the facility to orient the tanks

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[10] A title search was conducted by Title Guaranty and the Land Division of the Department of Land and Natural Resources for this report.
[11] https://sierraclubhawaii.org/redhill
[12] https://www.census.gov/history/pdf/1940hawaiipop-12-2016.pdf
[13] https://www.civilbeat.org/2022/03/how-hawaii-activists-helped-force-the-militarys-hand-on-red-hill/
[14] hi1016data.pdf (loc.gov)

vertically, rather than horizontally. They expected that novel design would require less investment in construction equipment, require fewer workers, ensure oil-tight storage, significantly shorten construction time, and greatly reduce the ultimate cost of the project. Orienting the tanks vertically would make the removal of excavated material more efficient by allowing gravity to assist in moving the loosened rock down and out of the excavations and onto a conveyor belt to the disposal area.[15] The consultant and project manager presented the novel design to the Officer in Charge of the project the next day, and the proposal was considered by others in Pearl Harbor and Washington, D.C. Ultimately, the Chief of the Bureau of Yards and Docks, who "firmly believed that contractors should be permitted to draw on their own experience and ingenuity in devising innovative ways of accomplishing tasks as long as 'integrity of intent' was not sacrificed",[16] enthusiastically approved the design.

The vertical tank design has been touted as an innovative engineering feat. However, with such emphasis on speed and cost-efficiency and perhaps an eagerness to achieve proof of concept with the novel design, neither the Navy nor its contractors seem to have seriously considered or planned for the potential failure of the tanks after construction; the risk of contamination to the environment and aquifer; options to accurately monitor, recover, or remediate any released fuel in the surrounding environment; and options and mechanisms for the maintenance and eventual decommissioning, removal, or future use of the facility. It seems even more unlikely that after the design was drastically amended and as the Navy requested more tanks, additional time and funds would have been expended to carefully study these potential impacts, even if the depth at which the tanks would sit and their total footprint may have changed drastically.

As the threat of war increased, the massive undertaking at Red Hill became one of the nation's most closely guarded secrets. All workers were required to sign affidavits stating that they would not reveal the project to anyone. Civilian guards hired by the contractor patrolled the hillside surrounding the site. Because of the great secrecy surrounding the project, the public was largely unaware of the excavation and construction of the Red Hill Bulk Fuel Storage Facility, and the community certainly lacked any opportunity to make its views known. Hence, the Navy was not accountable to the public.[17]

Actual construction work on the project began on December 26, 1940. On December 7, 1941, nearly one year after the project commenced and before the fuel stored above ground at Pearl Harbor could be moved elsewhere, Pearl Harbor was attacked about three miles from the project site. Fortunately, the Japanese did not destroy the above-ground fuel tanks and other critical infrastructure at Pearl Harbor. War historians believe that the destruction of Pearl Harbor's fuel tanks would have deterred the Allies' advance across the Pacific far more than the damage

[15] hi1016data.pdf (loc.gov)
[16] hi1016data.pdf (loc.gov)
[17] hi1016data.pdf (loc.gov)

inflicted on the fleet during the Pearl Harbor attack. While the attack itself had little direct impact on the Red Hill project site, it did have cascading effects through the declaration of martial law, reduction of skilled laborers and equipment available for the project, and perhaps increased urgency to complete the project so that the fuel supply could be moved underground.

Some viewed the novel vertical tank design selected by the Navy and its contractors as preposterous and inconceivable, and even the builders' peers doubted the project as late as May of 1941, calling for a return to the horizontal tank design.[18] The Navy was apparently undeterred and ignored such exhortations that, if heeded, would have jeopardized the rapid completion of the project. The first fuel tank was completed and received its first oil in September of 1942. In total, it took 3,900 workers laboring around the clock for nearly three years to complete and deliver the project on September 30, 1943, nine months ahead of schedule.

Construction of the Red Hill fuel storage tanks involved numerous features for which no prior example was found in design or construction. Although numerous tunnels had been built in the lava of surrounding mountains, no construction project had ever been attempted, in Hawaiʻi or elsewhere, that required the 100-foot rock span necessary in the building of these 20 immense tanks, each of which is large enough to engulf Aloha Tower[19]. When completed, the tanks—each 250 feet high and 100 feet in diameter, and buried more than 100 feet in a mountain ridge—stored and protected 252 million gallons (the equivalent of approximately 382 Olympic-sized swimming pools) of fuel.

The Red Hill Bulk Fuel Storage Facility was constructed without federal or state safeguards for environmental and public health

Since construction and completion of the Red Hill Bulk Fuel Storage Facility occurred largely during a period of martial law in Hawaiʻi, the only entity that could have provided any modicum of scrutiny or oversight for the project would have been the military, which had little, if any incentive, to do so. Furthermore, due to the extreme secrecy shrouding the project, it is difficult to imagine an outside institution, including the civil government of the Territory of Hawaiʻi, even being aware of the project. The Navy viewed the facility as critical in its war efforts. In fact, at the height of World War II, Admiral Chester Nimitz referred to the Pearl Harbor Naval Supply Depot, which controlled the tanks, as "the secret weapon of the Pacific." For the Navy, speed and secrecy in the construction and completion of the project were of paramount importance. There were a few newspaper articles in the late 1940s emphasizing the national security importance of the facility. The Red Hill Bulk Fuel Storage Facility was not declassified until 1995,[20] so for over fifty years, the fuel tanks and their concomitant dangers remained out of

[18] hi1016data.pdf (loc.gov)
[19] https://sierraclubhawaii.org/redhill
[20] https://www.govinfo.gov/content/pkg/BILLS-115s437is/html/BILLS-115s437is.htm

sight to the people and government of Hawaiʻi. As a result, any environmental or public health considerations about the project lay squarely on the shoulders of the Navy.

None of today's major regulatory protections for environmental or public health existed at the time of the project's construction, such as the Clean Water Act, the Safe Drinking Water Act, the Comprehensive Environmental Response, Compensation, and Liability Act, and the Leaking Underground Storage Tank Trust Fund. Even if modern regulatory safeguards had been in place at the time of construction, the urgency of the project during wartime conditions may have enabled construction to be exempt from any regulations that might have existed.

The history of the Red Hill Bulk Fuel Storage Facility is a history of spills and leaks in a secret underground facility

Since it was built in the 1940s, there have been 70 documented leaks and spills for an estimated 180,000 gallons of various types of fuel. This information was not widely available. During the course of briefings by subject matter experts, it became clear to the Red Hill WAI that a much larger number must be considered for the purposes of risk assessment and remediation planning. The additional gallonage includes the Navy's own estimate of 5,800 gallons per year in "incidental leaks" from the tanks that are too small to be accurately measured by available instruments. There was also an account by a former Red Hill employee of the release of 1.3 million gallons of bunker fuel in the 1940s, which principally but not in its entirety flowed into Hālawa Stream. For the purposes of risk assessment and formulating remediation strategies, the Red Hill WAI places the number between 644,000 gallons and 1.94 million gallons—a substantially larger number than previously reported.

The first report of a fuel spill at Red Hill by the Navy to the Department of Health occurred on November 10, 1998, when petroleum-stained basalt cores were discovered beneath tanks, indicating that there were leaks from the tanks into the ground. In the early 2000s, transverse cores were performed beneath each tank, revealing evidence of petroleum staining beneath 19 of the 20 tanks.

On December 9, 2013, the Navy placed Tank #5 back into service and refilled the tank with petroleum after routine scheduled maintenance, including cleaning, inspecting, and repairing multiple areas within the tank. It is believed that a release of approximately 27,000 gallons occurred from Tank #5 between December 12, 2013, and January 6, 2014, and was verbally reported to the Department of Health on January 13, 2014.

Following the 2014 fuel release, the Environmental Protection Agency and Department of Health entered into the Red Hill Administrative Order on Consent[21] with the Navy and Defense Logistics Agency.

On May 6, 2021, there was a pressure surge event resulting in the release of approximately 20,000 gallons of jet fuel from supply piping in the lower access tunnel during the refilling of Tank #20. Reported estimates of the fuel released on May 6, 2021, was only 1,600 gallons, and the Navy did not discover that more fuel had been released until the November 2021 incident.

The November 2021 spill directly entered the Red Hill Shaft and the water system serving military dependents, residents, businesses, schools, and child development centers, becoming the precipitous event leading to the defueling and closure of the fuel storage facility

On November 20, 2021, there was a release of approximately 14,000 gallons of a mixture of water and JP-5 jet fuel from a crack in a fire suppression drain line, contaminating Red Hill Shaft and the Navy's Joint Base Pearl Harbor-Hickam drinking water system. Eight days later, customers—many of them military dependents—began complaining of a fuel odor coming from their water and/or an oily sheen. These complaints were followed by reports of family members and pets experiencing health issues such as rashes, mouth sores, stomach aches, vomiting, burning eyes, sore throats, headaches, and nausea.

On November 29, 2021, one day following the complaints, the Department of Health issued an advisory to all users on the Navy's water system to avoid using tap water for drinking, cooking, or oral hygiene, and those who detected a fuel odor to also avoid using tap water for bathing, dishwashing, and laundry.

Over 3,000 residents were required to move out of their homes, with most temporarily relocated for several months to hotels. Several businesses were shut down or were forced to limit their operations by not using tap water. Several public schools and child development centers on the system were also impacted, forced to close off sinks and water fountains, and use only bottled water for handwashing, drinking, and dishwashing.

Across the valley from the Red Hill Bulk Fuel Storage Facility is the Board of Water Supply Hālawa Shaft that supplies 20 percent of the water to metropolitan Honolulu. Immediately after Red Hill Shaft was shut down, the Board of Water Supply shut down Hālawa Shaft and its Hālawa and ʻAiea wells in order to protect the aquifer and the drinking water system from the

[21] https://www.epa.gov/red-hill/2015-administrative-order-consent

risk of "pulling" the jet fuel plume further into the aquifer toward Hālawa Shaft, and/or drawing contamination directly into the Board of Water Supply's water distribution system.

By December 3, 2021, the Department of Health received nearly 500 complaints of fuel or chemical odors from the drinking water. There were daily headlines and strong calls from the public and public officials for investigations, defueling, and closure of the facility.

On December 6, 2021, the Department of Health issued an emergency order[22] requiring the Navy to immediately suspend operations, deeming the facility to be "an imminent peril to human health and safety or the environment", and to take measures to treat contaminated water and remove all fuel. The emergency order clearly states that the Navy has not demonstrated and cannot ensure that immediate and appropriate response actions are available or will be available should another fuel release occur in the future.

The Navy and Department of Defense contemplated challenging the emergency order in federal court. Ultimately, they withdrew their challenge and on March 7, 2022, the Secretary of Defense issued a memorandum[23] directing all steps necessary be taken to defuel and permanently close the facility.

On August 31, 2022, a class action lawsuit was brought on behalf of military families in U.S. District Court.

Joint Task Force-Red Hill was established to oversee the defueling process. Defueling began on October 16, 2023, and is estimated to be completed in April 2024. Removal of residual fuel and other contaminants is expected to take an additional three to five years.

[22] https://health.hawaii.gov/news/newsroom/new-red-hill-emergency-order-sets-expectations-for-safe-defueling-and-closure-of-red-hill/
[23] https://www.defense.gov/News/Releases/Release/Article/2957825/statement-by-secretary-of-defense-lloyd-j-austin-iii-on-the-closure-of-the-red/

Attachment B: Assumption of Risk

The focus of the Red Hill WAI's inquiry is the remediation needs after the defueling of the tanks and removal of residual fuel and contaminants from the facility. To do so, the group needed a better understanding of what is known and unknown about the fuel contaminants already in the ground. Toward this end, the group heard technical presentations from several subject matter experts for the Department of Health, Environmental Protection Agency, Honolulu Board of Water Supply, and University of Hawaiʻi. Dr. Donald Thomas, PhD, Director of the Center for the Study of Active Volcanoes, UH Hilo, and Senior Researcher for the Hawaiʻi Groundwater & Geothermal Resources Center, UH Manoa, also served as a regular participant from the University of Hawaiʻi on the Red Hill WAI.

Each of these experts had particular areas of knowledge to offer. On a policy basis, there were a few common themes, such as:

- The amount of fuel in the ground is greater than previously reported; most historical releases at the Red Hill Bulk Fuel Facility did not report release volumes.
- The geology beneath and in the area surrounding the Red Hill Bulk Fuel Storage Facility is one of the most complex systems encountered by the subject matter experts who have investigated various national and international remediation sites.
- Large rainfall events have mobilized residual fuels, indicating that there are fuels held up in the vadose zone rocks above the water table for some unknown period of time.
- There is insufficient data to know the extent of lateral and vertical contaminant migration.

Context for Bioremediation Investigation
Background Notes from Dr. Donald Thomas

The questions identified for the bioremediation/biodegradation investigations are, to a degree, based on some known facts, some assumptions, and a few basic principles. We know that a substantial volume of fuel has been released from the facility and associated support infrastructure. Initial testing has indicated that the majority of the "lighter" released fuels (gasoline, diesel, JP-5, JP-8) are likely to have migrated through the unsaturated zone to the water table; however, some fraction of these fuels is retained within the unsaturated zone for some period of time until they are evaporated, biologically degraded, or flushed out by rainfall recharge passing through the unsaturated zone. Once the fuel reaches the water table, it spreads across the surface of the water through cracks and interconnected pore space until it reaches a stable free-product thickness after which it resists further mechanical movement by pumping (or more accurately, induced motion of the water in the underlying water table as a result of pumping). In other environments: where the water table is shallow, remediation/restoration of a release can be done by excavation of the fuel-saturated soil with treatment of the soil to remove the fuel free product; or where the fuel is contained in a confined geologic formation, injection of heat/steam can mobilize the fuel in both the vapor and liquid phase and modest fractions of the fuel can be recovered. Neither of these conditions exist at Red Hill and hence the consensus of opinion of the regulatory agency SME team is that these and similar methods would not be able to recover enough of the released fuel to have a significant effect on recovery/restoration of the aquifer.

At other release sites where recovery/removal of released fuel is not possible, a frequent strategy applied to the free product plume is Monitored Natural Attenuation, which consists of monitoring of the dissolved contaminant plume generated from the free product and allowing biodegradation of the fuel to proceed naturally with little or no intervention to accelerate the process. This is an option for Red Hill as well, but would mean that free product <u>could</u> remain present for a century or more and development of new production wells in this region would be at risk of encountering free product or contaminated groundwater. ("could" is underlined above because we are not certain where the free product is, other than some that is likely present near RHMW02, and most of the water samples being collected currently show very low levels of dissolved contaminants.)

The alternative to Monitored Natural Attenuation is to take measures to accelerate the natural process of biodegradation using strategies that would: increase the population of microbial fuel degraders in the groundwater; increase the access of the microbial degraders to the fuel; or increase the availability of other required nutrients of the microbial fuel degraders to increase their populations. Each of these actions can have side effects that, under some sets of conditions, could increase the risks to the drinking water supply and, hence, any proactive effort to apply these methods will require detailed investigation to ensure that those risks are known and can be managed in a way to minimize or eliminate any likely impacts to surrounding drinking water sources. For example, the different organic compounds making up a given fuel have varying levels of toxicity; as the fuel biodegrades, new chemical compounds are created—referred to as intermediary compounds—that are progressively broken down until the final breakdown products are carbon dioxide and water. The intermediary compounds add further complexity and uncertainty in terms of human health risks, and some of the intermediates may even have higher toxicities than the original compounds making up the fuel. By accelerating the breakdown of the fuel, we would be (temporarily) increasing the concentration of those compounds in the water column until they too are broken down further. Hence, if we undertake an action to accelerate the biodegradation, we will need to be certain that water flow rates and directions from that treatment site are either not toward a drinking water source, or the rate of transport is slow enough that both the original fuel constituents and the intermediary compounds are either fully broken down or at concentration levels low enough so as to pose no threat to the consumers of that water.

This, in part, is the motivation behind development of the groundwater flow model: once we know the locations of the free product and the rate and direction of water flow, we can determine whether treatment of the free product plume would likely allow contaminants to flow toward any of the production wells in the area; and, as will be discussed below, that flow model, once validated, will also form the foundation of a Fate and Transport model. The Fate and Transport model will incorporate the reactivity and biodegradation rates of the fuel constituents (and the intermediary byproduct compounds of biodegradation) to determine how fast and how far those constituents can travel in the water column.

While fuel naturally biodegrades over time, the presence of fuel from 80+ years in the Pacific offers a cautionary tale

A memorandum from Dr. Peter Peshut provides a brief description of "legacy" petroleum contamination in soils and geologic substrates in the Pacific, which has been widely observed and documented though poorly remediated.

Dr. Peshut describes three sites of which he has personal knowledge based on over 30 years working among the government agencies: Aūa Tank Farm on Tutuila Island in American Sāmoa, Isley Well Field in Saipan in the Commonwealth of the Northern Mariana Islands, and the Blue Bay Bulk Fuel Storage Facility on Malakal of the Republic of Palau. In Sāmoa, under conditions of high rainfall and steep terrain, the legacy petroleum has remained as free product for 75 years. In Saipan, fuel remains volatile after 50 years in the ground sitting atop the water table. In Palau, the Malakal plume may be nearly 100 years old.

Attachment C: Monitoring and Testing

Monitoring and testing play key roles in risk assessment and remediation

More information than currently available is needed to assess immediate and future risks, and to inform remediation planning and actions

In the past few years, subject matter experts advocated for the installation of many more monitoring wells beyond the surface footprint of the fuel facility. In 2023, the Navy attempted the siting and drilling of 23 wells.

Recognizing the faster moving development of the monitoring infrastructure, the Red Hill WAI, the Governor's Office, and the state Office of Planning and Sustainable Development produced a map showing current and planned wells, as of October 2023. A digital version is available for viewing at:

https://www.capitol.hawaii.gov/CommitteeFiles/Special/HSCRH/Document/RedHillWelldata.pdf

There is a need to establish a "sentinel" monitoring grid between the fuel facility and water production wells

The proposed "sentinel" grid is designed to heavily supplement existing testing sites and provide expanded coverage of the most likely directions of contaminant movement within the basal aquifer. Actual siting will be dependent on terrain, access, compatibility with surface activities, and other factors. Coordination with the applied research efforts for remediation will be key, especially as the knowledge develops of geological and hydrogeological formations as well as particle flow projections.

The proposed grid would consist of shallow and deep wells installed at each location. Shallow wells will screen above and below contact with the basal aquifer. Deep wells are intended to screen approximately 50 feet below the surface of the basal aquifer. These will be 4-inch diameter wells.

Estimated project period is 5 years.

Beyond measuring and monitoring what is in the ground, we have a responsibility to the health of the ecosystem

From mauka to makai, an ecosystem approach addresses surface and underground land, water, and species.

The goal of monitoring is to determine and quantify how the ecology of Hālawa Stream and the lower estuary area is being impacted by the Red Hill recovery, and to understand what mitigation measures may be necessary. This would include establishing testing and monitoring for the entirety of the Hālawa stream ecosystem, including terrestrial biota, aquatic biota, and stream flow monitoring.

In the mauka areas, the Department of Land and Natural Resources proposes monitoring in the forest reserves, including continued support of U.S. Geological Survey research and data collection that quantify impacts of forest species on water availability and recharge. The goal is to determine the impacts to the recharge for Pearl Harbor and adjacent aquifers.

In the makai shoreline areas, the challenge is to measure and analyze the confluence of contaminants from multiple sources. The goal is to determine impacts to marine resources we consume, the health of the resources, and impacts on cultural practices. The monitoring area would include the makai end of Hālawa Stream, Pearl Harbor and Māmala Bay, and the marine environment along the south shore.

Attachment D: Remediation

There appear to be relatively few options available for remediation of prior fuel releases and many unknowns. In stewardship of the aquifer, the pursuit of the unknowns is a responsibility. Where are the residual fuels in the vadose zone and at the water table? What are the methods to identify fuel-contaminated rocks and soils? What are the methods, effectiveness, and risks of enhanced biodegradation in the conditions specific to Red Hill? And what, therefore, is the remediation plan based on the findings?

At the request of the Red Hill WAI, Dr. Donald M. Thomas, Geochemist, and his colleague Dr. Tao Yan, whose specialty is in environmental microbiology and biotechnology, at the University of Hawaiʻi prepared a description of work.

There are three phases: (1) information gathering; (2) field testing and process refinement; and (3) full implementation of remediation and restoration of the vadose zone and water table.

Phase I: Information Gathering

Task I.1: Fuel volume and distribution

One of the earliest Phase I tasks will be an audit of prior Navy and regulatory agencies' records to compile and analyze the distribution of known and suspected releases that have occurred in and around the facility. This would include not only the fuel tanks, but also pumping stations, oily waste disposal facilities, "slop" tanks, pipelines, valving banks, and other associated equipment. Recent findings have shown that the data that has been made available to the regulatory agencies is by no means complete. Better documentation will provide us with a starting point for more active methods of determining the likely extent of contaminated soils and rock within the vadose zone and the underlying water table.

Task I.2: Controlled source geophysical surveys over suspected fuel release sites

There are relatively few methods of detecting fuel at the interface between the unsaturated and saturated zones at the water table. With the substantial depth to the water table, direct measurement by drilling is not considered to be reliable or cost-effective due to the number of boreholes that would need to be drilled and the hit-or-miss nature of the measurements. There are geophysical methods that have been successfully applied to the detection and mapping of contaminated ground; however, the most successful of those attempts have been able to detect fuels at significantly shallower depths than occur at Red Hill. This site will be even more challenging due to the existing infrastructure (e.g., electrical power lines, buried pipelines, tanks, etc.) that can produce interfering signals or electrical anomalies in the geophysical measurements. The most likely geophysical method that could detect the impacts of fuel at the water table are likely to be controlled-source electro-magnetic surveys over the areas of interest. These surveys would need to take advantage of what is learned from the ongoing geophysical investigations at Red Hill as well as the dye tracer investigation and the groundwater flow modeling work. (It is most likely that spread of the released fuel plumes will be elongated in the direction of groundwater flow.)

Task I.3: Groundwater forensic analysis of fuel degradation byproducts

Assessment of the distribution of the fuel plume can be derived from further analysis of the total organic carbon (TOC) in water samples from the Navy's monitoring well network. Elevated levels of TOC above those naturally present imply that an upgradient source of hydrocarbons is present. We can also analyze for specific fuel biodegradation products generated by the breakdown of the fuel. (Where we find biodegradation products, we can reasonably infer that fuel is present in the rocks up the flow gradient from the sampling point.)

Microbiological forensics: Analysis of water samples for biological evidence for the presence of microbial fuel degraders: whether by detection and quantification of specific microbial fuel degraders directly or through comparative analysis of microbial communities present in fuel-exposed waters and non-fuel-exposed waters. A potentially more sensitive method for detecting evidence of fuel degraders is through the use of genetic amplification methods that will be able to detect much lower concentrations of genetic fragments of fuel degraders that will persist in groundwater for extended periods after the water has passed through a degrading fuel plume.

Drilling: Full characterization of the extent of the fuel contamination may also require drilling additional monitoring holes where none currently exist. If the dye tracer testing and the groundwater flow model indicate flow trajectories that are significantly different from those that have been considered up to the present time, it may be necessary to drill and sample additional test holes to ensure that we have fully characterized the extent of the free product fuel remaining in the formation.

Task I.4: Determination of fuel volumes contained within the vadose zone

Laboratory testing of rock samples, model development of flow through the vadose zone, and field monitoring of fuel vapor concentrations will support the determination of fuel volumes in the vadose zone

Petro-physics: Two types of laboratory testing need to be performed to better constrain the amounts of fuel remaining within the vadose zone beneath release sites:

(1) Laboratory testing of samples of the different types of rocks (e.g., massive basalt, ‘a‘ā clinker and welded ‘a‘ā clinker, pāhoehoe basalts, saprolite [heavily weathered

basalts], alluvium, and marine and terrestrial sedimentary deposits) to determine their ability to absorb and retain liquid fuels as well as their ability to release retained fuels when exposed to infiltrating rainfall; and

(2) Laboratory testing of rock cores where the rock layers are known to have been exposed to fuels at some point in the past. The Navy has collected, and continues to collect, core samples from monitoring wells being installed around the Red Hill Bulk Fuel Storage Facility; some of those cores show evidence of having been exposed to petroleum products at some point in the past. Laboratory extraction of the petroleum products from those cores will enable us to determine what quantities of fuel can be retained for extended periods of time within the rocks; how their compositions change with time; and what degree of risk the residual compounds pose for long-term contamination of water supplies below the vadose zone.

Model development: As fuel moves downward through the geologic formations of the vadose zone, there will be both vertical and lateral (down-slope) flow and spread of the fuel and progressively increasing volumes of rock exposed to the fuel until it reaches the water table. Although the Navy contractor attempted to model this process, the resultant model did not take into account the structural complexity of the geologic formations present below the facility and was rejected. This effort will have to be repeated and substantially improved in order to better approximate the volumes of rock in the vadose zone that have been exposed to prior documented fuel releases. This model will also be an extremely valuable component of the remediation program. When treatment agents are injected into the vadose zone to enhance degradation there, these models will allow us to better assess the distribution of the treatment agents as they migrate toward the water table.

Field Monitoring: Fuel vapor concentrations below the tanks have been used for more than fifteen years to identify new fuel releases which produce significant, localized increases in hydrocarbon vapors in the vicinity of the leaking tank. Although this is an indirect method of quantifying the amount of residual fuel in the vadose zone, continued monitoring of fuel vapors will enable us to assess natural attenuation/degradation of residual fuel prior to treatment and to assess the efficacy of one or more enhanced biodegradation strategies after they are applied to areas in which residual fuel is present.

Task I.5: Determination of fuel distribution at the surface of the water table

Investigation of prior work of fuel interactions in water-saturated rock, and laboratory work to test the intermixing of fuel and water in the effects of adding emulsifiers and surfactants will support the determination of fuel distribution at the water table.

A **literature search** will be performed to compile prior work of fuel interactions with water-saturated rock from prior fuel releases in similar geologic environments to Hawai‘i as well as in (rare) oil reservoirs that occur in basalts. These investigations will be evaluated for insights into how fuel and water distribute themselves in a saturated environment as well as an active environment where the water table is rising and falling (the so-called smear zone).

Laboratory investigations and testing of fuel, water, and fractured crystalline rock will be performed to determine the degree of intermixing between the fuel and water; degrees of infiltration of the fuel into the water saturated rocks; and the effects of adding emulsifiers or surfactants to the water column on the distribution and mobility of the fuel within this system. Ultimately, the goal of this effort will be to determine the thickness of a stable fuel+water plume at the water table below Red Hill, the estimated overall area of that plume given the known volume of fuels released, and the effects of modifying the surface tension of the water with surfactants on mobility of the oil plume.

Task I.6: Development of a Contaminant Fate and Transport model

In order to safely undertake an enhanced bioremediation program for the contaminated vadose zone and aquifers, we will need to develop a Contaminant Fate and Transport (CF&T) model that will consider the rate and direction of water flow within and around any prospective areas of treatment along with the half-lives/decay rates of the primary compounds in the fuels as well as the intermediary compounds that are produced during the biodegradation process. This model will enable us to perform risk assessments for the likelihood of impacting drinking water sources in the aquifers surrounding the facility. This model will be tested and validated in the Phase II Field Testing and Validation of enhanced bioremediation approaches that will be applied.

Task I.7: Characterization of the fuel biodegradation processes and products in the Red Hill aquifers

In order to characterize the existing microbiome that is present in the groundwater below the facility, groundwater samples will need to be collected from all wells showing evidence of the presence of primary fuel compounds and secondary byproducts of degradation. The biodegradation products will be quantified and chemically profiled to characterize the entire suite of intermediary compounds produced during the natural biodegradation process. Biodegradation kinetics models—that can be coupled with the groundwater flow and CF&T models—will be developed to describe the breakdown of the fuel compounds in the water column.

Task I.8: Characterization of the biodegradation microbiome in the Red Hill aquifers

Water samples from wells impacted by prior fuel releases will be subjected to microbiological, molecular, and metagenomic analysis to detect and quantify bacterial species, their genes, and metagenomes that are responsible for, or involved in, the natural biodegradation processes. Having characterized the constituents of the microbiome associated with biodegradation, the genetic "fingerprint" of fuel degradation will be used to compare with water from other monitoring and drinking water wells surrounding the facility to determine which, if any, show evidence of receiving water that has been exposed to fuel-derived contaminants.

Task I.9: Bench-scale feasibility tests of in situ bioremediation: effectiveness and potential risks

Bench-scale tests under natural conditions and enhanced processes will test the efficacy and risks of bioremediation.

The project will construct bench-scale climate-controlled reactors to characterize biodegradation processes and rates under natural conditions as well as under a variety of different enhanced bioremediation strategies.

Bench-scale testing under natural conditions will expose samples of Red Hill basalts to relevant fuels and then immerse them in water samples collected from the monitoring wells below the facility and allow biodegradation processes to proceed while maintaining water chemistry conditions (e.g., pH, dissolved oxygen content) to remain similar to those under the tanks. Similar bench-scale testing will also be performed on fuel-exposed basalts under conditions similar to those occurring in the vadose zone below the fuel tanks, including periodic flushing with water having a composition similar to rainfall recharge and atmospheric conditions of high humidity and typical oxygen contents. For each suite of samples, the water phase will be: chemically analyzed for biodegradation byproducts and rates of biodegradation, and analyzed metagenomically for the baseline microbiome and evolving microbiomes responsible for breakdown of the fuel hydrocarbons.

Bench-scale testing under aquifer and vadose zone conditions will then be conducted under a variety of "enhanced" biodegradation conditions that will include: (1) nutrient (nitrogen/phosphorous) amendment; (2) oxygen amendment; (3) soil/water interface enhancement with surfactant; and (4) others while conducting analytical testing of the biodegradation products and microbiome present in the fluid phase. The effectiveness of these treatment strategies will be demonstrated through long-term experiments (3-4 years) to determine the oil degradation rate, benchmark operational costs, and monitor the impacts of enhanced biodegradation on groundwater quality.

Task I.10: Develop novel DNA markers as groundwater tracers

DNA tracers can be detected with extraordinary sensitivity through modern gene amplification techniques and can be easily multiplexed. This is particularly useful for aquifers with high heterogeneity and where multiple points of entry exist; whereas they are free of the drawbacks of many currently used tracers which can potentially adversely affect water quality and aesthetic acceptability, DNA tracers are not entirely conservative because they can be degraded biologically in situ. The project will test different strategies to make DNA markers recalcitrant yet still detectable, including methylation, supercoiling, chimera formation, and complexation with carriers. Development of these tracers will be particularly valuable when the second phase of the remediation work is undertaken. Field testing of enhanced biodegradation techniques will need to be able to track the trajectories of the treated aquifer waters over substantial distances to ensure that biodegradation products are not impacting, or likely to impact, existing sources of drinking water. Use of conventional dye tracers over these distance ranges would likely require quantities of dye that would pose additional risks to near-field water quality.

Phase II: Field Testing and Process Refinement

Phase II will transition the laboratory investigations to the field in order to: demonstrate the efficacy of the laboratory demonstrated biodegradation enhancement strategies; develop more robust "dose/response" characteristics of the enhancement strategies under real world environmental conditions; better assess the risks to potential downstream receptors of varying levels of enhancement of the biodegradation processes; test one or more risk mitigation/risk reduction strategies under field conditions.

Task II.1: Selection of test sites for enhanced bioremediation/restoration

We anticipate selecting three separate test sites for enhanced bioremediation: one located in alluvium (valley fill) materials; one in saturated basalts; and one in vadose zone basalts. Each geologic type represents locations where fuel contamination is known to have occurred, and each enhancement strategy will need to be developed specific to the hydrogeologic conditions present in those materials. The specific sites will be chosen based on evidence of contamination developed during Phase I: Tasks 1, 2, and 3 as well as results of Groundwater Flow and Fate and Transport modeling that will be used to estimate downstream risks to potential receptors that could be impacted.

Task II.2: Formulate a plan for enhanced bioremediation/restoration strategy for each site; complete engineering design for remediation site; install remediation infrastructure; design and install downstream monitoring network.

The enhanced bioremediation plan will specify what amendments and non-reactive DNA tracers will be added; how they are to be added to provide uniform coverage of the contaminated area; where monitoring wells will be installed to gauge the impact of the amendments; and where downstream monitoring wells will be placed to track the flow of degradation byproducts away from the site. Each plan will need to be designed for the geologic and environmental conditions unique to the material that was contaminated with fuels and according to natural groundwater and recharge conditions specific to that site. As specified by that plan, a network of injection wells will be installed at appropriate spacings and to the appropriate depths. Likewise, the downstream monitoring well network will need to be installed at appropriate spacings down the flow gradient to allow for monitoring the concentrations of degradation byproducts and to act as sentinels for transport toward potential receptors.

Task II.3: Execution of the enhanced bioremediation/restoration test at each site and initiation of downstream monitoring

> Execution of the remediation testing will begin at low to moderate levels of amendment addition to ensure that the impacts on down-gradient water quality do not rise to unmanageable levels or appear in unexpected down-gradient wells. As monitoring indicates that amendment levels can be safely increased, coverage of the test sites will be increased and volume of amendments will be increased to find optimum levels that facilitate an increase in biodegradation while minimizing impacts on down-gradient water quality. Throughout the testing and refinement of the enhanced biodegradation test, close surveillance of water quality within and down-gradient of the treatment area will be maintained for: contaminant levels, biodegradation byproduct concentrations, and other groundwater quality parameters as well as for evolution of the microbiome responsible for the enhanced biodegradation processes. At the conclusion of the testing program, one or more additional test holes will be drilled into the formerly contaminated zones to determine the remaining levels of residual fuel compounds present in the treated zone.
>
> Over the course of the field-testing program, monitoring data will be compiled and integrated into the Contaminant Fate and Transport model that will allow us to better estimate the potential impacts of enhanced bioremediation at the remaining contamination sites during full implementation of a remediation and restoration program. We estimate the duration of the testing program to be approximately five years.

Phase III: Full Implementation of Remediation and Restoration

Based on the results of the Phase II field testing, the remaining sites where fuel contaminants have been identified will be assessed for the feasibility of enhanced bioremediation. A remediation plan will need to be developed for each site based on the area being treated, the type of geology involved, the depth of the residual fuel in the vadose zone or at the water table, assessments of risks associated with enhanced remediation to down-gradient receptors derived from the Contaminant Fate and Transport model, as well as any other relevant factors that will impact design, deployment, and operation of a treatment system. Sites will be prioritized for implementation based on the risks they currently pose to existing drinking water wells in the region surrounding the facility as well as the risks posed by the enhanced biodegradation treatments.

Because key data that has not yet been compiled will be needed to determine the number of sites that will require remediation and restoration, cost estimates were produced for a nominal suite of sites consisting of: five small sites (less than one hectare of footprint); five moderate-sized sites (one to five hectares); and two large sites (up to 20 hectares).