

**Exposure Assessment: November 2021 Release of JP-5 Jet Fuel into the Joint Base Pearl Harbor Hickam Drinking Water System**

**Hawai'i Department of Health**

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## Foreword

This report presents an *Exposure Assessment* prepared in consideration of the Agency for Toxic Substances and Disease Registry *Public Health Assessment Guidance Manual*. The objective of this report is to fill an information gap that exists due to unknown range of concentrations fuel-related contaminants in the drinking water at the point of use. The report uses the best available information to model and estimate exposure concentrations in a threefold approach: 1) Provide a summary of key contaminants of potential concern (COPCs) associated with contamination of the Joint Base Pearl Harbor Hickam (JBPHH) drinking water system with JP-5 jet fuel in November of 2021; 2) Provide an estimate of Reasonable Maximum Exposure (RME) concentrations associated with the COPCs at and leading up to the peak of contamination within the system, 3) Provide information regarding the estimated duration of exposure and 4) Identify compounds that could have posed potential health risks.

The magnitude and duration of exposure varied both spatially and temporally within the drinking water system during the event. This makes it impossible to know the true exposure experienced by any individual. In addition, individual reactions to similar exposures varied creating additional challenges in understanding how much of the COPCs any individual may have been exposed to. This complicates preparation of a precise Exposure Assessment, however, information provided in the report will assist in setting bounds to exposure concentrations. Understanding the range of possible exposures will aid in preparation of Health Assessments by toxicologists and other medical professionals and help to further the understanding of overall impacts of this event. This exposure assessment focuses on fuel related contaminants and does not include detailed estimates of other COPCs that may have been present in the drinking water including fuel additives other than those discussed, simple green and chlorine disinfection byproducts. This report will be updated periodically as new information is obtained.

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**Disclaimer:** This report is intended to provide additional information to the overall understanding of contamination of the JBPHH drinking water system in November 2021 and aid in future analysis and assessments. Individual exposure and health effects varied significantly. The RMEs presented are applicable to the most impacted areas and are not intended to be reflective of exposure of base occupants as a whole. Refer to Section 8 "Limitations" for additional information.

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## Executive Summary

On November 20, 2021, several thousand gallons of JP-5 jet fuel were released from a ruptured pipeline inside the Navy's underground, Red Hill fuel storage facility in Honolulu, Hawai'i. The release occurred within a few hundred feet of a major water supply well for Joint Base Pearl Harbor Hickam located in the same facility. Residents began reporting fuel odors, sheens, foam and emulsions in tapwater one week later, with the water in some cases emitting flammable vapors. The well was shut down the following day. The volume of contaminated water circulating through the system was at first believed to be minimal, since the majority of water was derived from a separate well located several miles away. In the following days and weeks, however, hundreds of sickened people reported to hospital emergency rooms and clinics, with symptoms ranging from rashes, headaches, vertigo, coughs, diarrhea, nausea, vomiting, bleeding, convulsions and partial paralysis, among others.

Direct correlation of symptoms to exposure has proven problematic due to lack of representative sample data and the absence of comparable studies for reference. Estimates of Reasonable Maximum Exposure (RME) concentrations are instead derived based on the hydrocarbon and additive makeup of the fuel. Four exposure scenarios representing different RMEs are reviewed: 1) Exposure to tapwater with dissolved-phase contaminants only; 2) Exposure to tapwater with dissolved-phase contaminants plus a sheen of free JP-5 product; 3) Exposure to tapwater with an additional, concentrated emulsions of the Fuel System Icing Inhibitor (FSII) additive diethylene glycol monomethyl ether (DiEGME) and 4) Exposure to JP-5 vapors in indoor and outdoor air.

The resulting RME concentrations support the presence of acute to subchronic toxicity levels of contaminants in the tapwater and indoor air at the peak of contamination. This includes:

- Ingestion-related exposure to dissolved-phase >C8 aromatics and potentially DiEGME in tapwater initially entering the drinking water system;
- Additional exposure to >C8-C18 aliphatics in sheens on more heavily contaminated tapwater subsequently drawn into the system;
- Concurrent exposure in some cases to DiEGME-enriched emulsions in the tapwater; and
- Inhalation-related exposure to C5-C8 aliphatic compounds and to a larger degree to >C8-C18 aliphatic compounds emitted to outdoor air during venting of the Red Hill tunnel immediately following the November 20, 2021, release, initial discharges of untreated, JP-5 contaminated water into open areas of base housing and early purging of contaminated water from taps in residences.

Estimates of RME concentrations are based on field observations during the release event and subsequent contamination of the JBPHH drinking water system, sample data from the Red Hill Shaft water well, modeled predictions of maximum contaminant levels based on the chemical makeup of JP-5 jet fuel stored at the facility, and laboratory experiments on the dissolution over time of JP-5 fuel into water, using samples collected from the Red Hill facility. The information provided should assist in the assessment of transient and ongoing health effects experienced by residents exposed to the fuel.

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## 1.0 Setting

### 1.1. Red Hill Fuel Facility History

Constructed in 1941, the Navy's underground Red Hill fuel storage facility in Honolulu, Hawai'i consist of twenty vertical, single-wall, steel tanks 100 feet in diameter and 250 feet tall with each tank capable of storing 12.5 million gallons of fuel (USDN 2022). Fuel is transferred into and out of the facility via an underground network of pipes in tunnels that lead to Joint Base Pearl Harbor Hickam (JBPHH), located approximately three miles away. The tanks were originally constructed to store diesel fuel and Navy Specific Fuel Oil (Bunker B cut with Navy diesel). Since 1970, the tanks have primarily been used to store Jet Propulsion 5 jet fuel (JP-5) and lesser amounts of diesel-related fuels.

On May 6, 2021, rupture of a pipe during transfer of fuel between two tanks lead to a release of an estimated 20,000 gallons of JP-5 onto the floor of the tunnel that connects the bases of the tanks (USDN 2022). The fuel flowed into a sump on the floor of the tunnel. Unknown to facility operators at the time, automated pumps transferred the fuel into an overhead 14" PVC pipe intended to carry Aqueous Fire Fighting Foam (AFFF) wastewater and fuel to an outside storage tank in the event of a release and activation of the facility's fire suppression system.

The fuel remained in the overhead PVC pipe until a drainage valve on the pipe further down the tunnel was inadvertently struck and cracked by a worker on November 20, 2021. Fuel immediately began spraying from the damaged valve, with an estimated 5,000+ gallons released and lost beneath the floor of the tunnel before the flow could be stopped. The fuel migrated approximately 80 feet downward through fracture basalt until reaching the water table and was shortly afterwards drawn into the Red Hill Shaft water supply well, one of two wells that serve JBPHH. Refer to USDN (2022) for additional details.

### 1.2. Contamination of the JBPHH Drinking Water System

The JBPHH drinking water system serves approximately 93,000 military and civilian residents and workers associated with the Navy and other branches of the military. The well is capable of pumping up to five-million gallons of water per day and was fully operational at the time of the November 20th release.

Residents and workers at JBPHH began experiencing burning rashes from showering as early as November 25, 2021 (Vice Media 2022). Photos of water from resident taps are provided in Attachment 1. Navy Facility Flushing Checklist logs that document the presence the jet fuel in home or building tapwater are provided in Attachment 2. Reports of fuel odors, sheens, emulsions and foam in the tapwater became widespread by November 27, 2021, with the water in some cases emitting flammable vapors. Flammable vapors could have been associated with jet fuel hydrocarbons and/or ether-based Fuel System Icing Inhibitor known to be preblended into the JP-5. The Red Hill Shaft well was shut down and disconnected from the drinking water system by the Navy on November 28th. The Hawai'i State Department of Health issued a health

advisory on November 29, 2021, cautioning JBPHH residents against using water from their taps (HIDOH 2021).

Navy divers entered the Red Hill shaft and the connected, 1,100 foot-long water supply tunnel that crosses the top of the water table shortly afterwards (USDN 2022). The divers reported fuel dripping from the basalt bedrock ceiling of the tunnel and a fuel sheen on the groundwater.

The volume of contaminated water that had been drawn into the base drinking water system was initially believed to be very limited, since the majority of groundwater fed into the system was derived from the separate, unimpacted well located several miles away in Wai'awa (USDN 2022). Residents were told by base officials that they could continue using the water unless fuel odors or sheens were noted. Flushing of water from fire hydrants began on November 29<sup>th</sup>. On November 30<sup>th</sup>, residents were asked to purge kitchen and bathroom taps in order to remove any remaining contaminated water from the system. While the water discharged from taps in some homes remained seemingly clean, the indoor air of other homes quickly filled up with petroleum vapors, with residents reporting severe headaches, irritation of eyes, shortness of breath, irritation of the throat and lungs, and vomiting.

Due to the urgency of the situation and the need for immediate data, samples collected from the drinking water system early in the crisis focused on rapid turn-around testing for Total Organic Carbon (TOC) as a surrogate for more comprehensive Total Petroleum Hydrocarbon (TPH) and volatile organic compound data that could be used to directly assess health risks (USDN 2022). Residents in areas where elevated TOC was not reported were told that they could continue to use the water up to a least December 9, 2021. Residents still using the water at least as late as December 9<sup>th</sup> were subsequently sickened, with symptoms ranging from rashes, nausea, burning stomachs and lungs, diarrhea, headaches, convulsions and in at least one case temporary, partial paralysis. Sampling results were later determined to be unreliable, due to the elevated laboratory detection limit for TOC (up to 5 mg/L) and the inability of the data to identify water that was obviously contaminated with fuel in the field.

In the following days and weeks, however, hundreds of sickened people reported to hospital emergency rooms and clinics as contaminated water circulated through the drinking water system to other areas of the base (USDN 2022). Arrangements for offsite housing were made for approximately 10,000 JBPHH residents. Bottled drinking water was provided to residents who opted to remain in their homes. Wide variability in the ability to smell or taste fuel and other contaminants in the water and air were reported. Some residents were able to detect jet fuel odors at likely low concentrations, while others in the same household unable to detect any sign of contamination, even at what were likely very high concentrations. The largest percentage of symptoms reported to doctors were related to the nervous system, gastrointestinal system and respiratory system with effects also reported to the skin, ears (hearing loss), throat and eyes. Residents reported that pets and small children were often the first to show symptoms, with adults expressing symptoms of fuel poisoning shortly afterwards (Troeschel et al. 2022).

The intrusion of fuel-contaminated water into homes and buildings appears to in part have been dependent on the timing of water use. Isolated pockets of contaminated water continued to



circulate through the maze of piping for many weeks after the initial release, trapped between but not mixed with clean water drawn in from the second well. It is hypothesized that residents who happened to open a tap at a time when a pocket of contaminated water was passing through the system in front of their house were quickly affected. Adjacent neighbors who returned home later in the day after the pocket of contaminated water had moved further down the piping system might notice no problems with the water discharging from their taps.

### **1.3. Final Flushing and Clearance of the Drinking Water System**

Flushing of the drinking water system using water from the second supply well was carried out over the next three months (USDN 2022). Flushing of the JBPHH drinking water system through fire hydrants continued through March 2022 (USDN 2022). Treatment of discharged water through granulated activated carbon filters was required by the State Department of Health following initial complaints of sheens and strong fuel odors in outdoor areas.

In January 2022, the Department of Health published a TPH tapwater screening (action) level for JP-5 contamination of 211 µg/L. This was calculated based on the expected, aliphatic and aromatic carbon range makeup and effective solubility of the JP-5 jet fuel and corresponding toxicity factors for individual carbon ranges published by the US Environmental Protection Agency available at that time (USEPA 2009a). The TPH screening level was later revised to 266 µg/L to address an error in the initial calculation (HIDOH 2022).

Verification that all contaminated water had been flushed from a targeted area of the drinking water system was made by comparison of sample data based on USEPA Methods 8015M and 8260 for TPH and individual volatile organic compounds, respectively. The system as a whole was declared “clean” and acceptable for normal, unrestricted in March 2022. Residents housed offsite were required to return to the base, although many subsequently chose to be transferred to bases outside of Hawai'i.

Sample collection and testing by both the Navy and the Hawai'i Department of Health during flushing of the drinking water system focused on testing of water anticipated to be clean. These data cannot be assumed to be representative of contaminant types and exposure conditions during the initial contamination period or other episodes when health effects took place. To the authors' knowledge, no sample data collected within the JBPHH system exist that document actual exposure conditions at the time of acute to subchronic health effects experienced by residents. An exception is limited sample data from the Red Hill Shaft well itself that documents significant contamination of the groundwater with JP-5 jet fuel shortly after the well was shut down.

This necessitated use of alternative, modeling and laboratory experiment approaches described in this report to identify specific compounds of interest and estimate Reasonable Maximum Exposure during the time that base personnel became sickened. It is hoped that this information, in conjunction with estimates of exposure durations, can be used to better understand observed, health effects and further assess ongoing symptoms.

#### 1.4. Pre-November 2021 Contamination of Drinking Water

Earlier, longer-term exposure to lower concentrations of degraded fuel and other potential contaminants in the source groundwater has also been postulated by residents who began to experience various types of health issues soon after the initial May 6<sup>th</sup> release of JP-5 jet fuel at the Red Hill facility. Available water sample data for the Red Hill Shaft inlet to the JBPHH drinking water system are not indicative of contamination with jet fuel during this time period. Beginning in early July 2021, however, unidentified, high retention time (>C24, “Residual Range Organics”) contaminants began appearing in both impacted groundwater monitoring wells beneath the Red Hill fuel tank area (RHMW02 sample series) and in water at Red Hill Shaft inlet to the JBPHH drinking water system (RHSF sample series). Example chromatograms are provided in Attachment 3. The compounds were in some cases re removed by silica gel cleanup, indicating a polar nature, and in other samples not. Similar compounds were not detected in blanks submitted with the samples, suggesting that that some type of contaminant was indeed in the groundwater.

Detailed analysis and determination of the specific compounds present were unfortunately not carried out by the Navy or Department of Defense to our knowledge. The total concentrations of High-Range Organic (HRO) contaminants (aka “Residual Range Organics”) in the water was reported to be in the range of several micrograms per liter (e.g., APPL 2022a, 2022b). Quantification of concentrations was made by comparison to standards for heavy oil, however, and are not reliable. The contaminants persisted throughout the summer but began to fade in late September and were largely absent in chromatograms by early November, just prior to the release of JP-5 jet fuel in the near vicinity of the Red Hill Shaft water supply well (APPL 2021).

Hypotheses regarding the nature and origin of the contaminants include: 1) Surfactants and other agents used to clean the tunnel following the May 6<sup>th</sup> release; 2) Older, heavily weathered petroleum flushed from bedrock beneath the tanks during cleanup; 3) Algae and 4) Contaminants from an unknown or unreported release at the facility shortly after the May 6, 2021, release. Additional research into the specific nature of the contaminants present is ongoing and further speculation of this issue and associated, potential health effects of JBPHH residents is beyond the scope of this report.

## 2.0 Contaminants of Potential Concern

Primary hydrocarbons and additive contaminants of potential concern for the release of JP-5 jet fuel into the JBPHH drinking water system are noted in Table 1 and discussed below. A summary of other potential contaminants in tapwater is also provided.

### 2.1. Fuel Hydrocarbons

Petroleum fuels are assessed in terms of three components (TPHCWG 1997; MADEP 1997, 2003; HODOH 2017; ITRC 2018; CAEPA 2019): 1) Individually targeted compounds such as benzene, toluene, ethylbenzene, xylenes, naphthalene, and 1-and 2-methylnaphthalene (BTEXNM); 2) Non-specific compounds grouped into aliphatic and aromatic carbon ranges; 3) additives used to enhance performance or stabilize the fuel and 4) Fuel-related degradation products. Non-specific aliphatic and aromatic compounds are grouped into separate carbon ranges based on measured or predicted similarities in physiochemical properties and toxicity. The third component includes complex mixtures of degraded hydrocarbons associated with the partial oxidation of BTEXNM and carbon range compounds.

Table 1 summarizes the relative BTEXNM and carbon makeup of JP-5 jet fuel stored at the Red Hill facility. The fuel is dominated by >C8-C18 aliphatic compounds with lesser amounts of >C5-C8 aliphatics and >C8 aromatics. Total BTEXNM makes up less than 2% of the fuel, with little to no benzene present. As noted in the table, the carbon range makeup of the neat fuel differs from the carbon range makeup of dissolved-phase JP-5 in water as well as vapors emitted from fresh fuel. The overall, weighted toxicity of neat versus dissolved- and vapor phase hydrocarbons similarly varies and plays a key role in assessment of health risk.

The combined mixture of carbon ranges minus individually targeted compounds such as BTEXNM is collectively assessed as “Total Petroleum Hydrocarbon (TPH).” Laboratories typically measure three separate groupings of TPH-related compounds based on a specified range of retention times and boiling points: 1) Low retention time/boiling point compounds, referred to as “Low-Range Organics (LRO)” (aka “Gasoline Range Organics”); 2) Mid retention time/boiling point compounds, referred to as “Mid-Range Organics (MRO)” (aka “Diesel Range Organics”) and 3) High retention time/boiling point compounds, referred to as “High-Range Organics (HRO)” (aka “Residual Range Organics”). These terms are introduced in this document to avoid improper, separate association of laboratory data for specific gas chromatograph retention time ranges with a specific type of fuel and associated action/screening levels. Gasolines are typically dominated by LRO range compounds but can include a small proportion of compounds in the MRO range. Middle distillates fuels are typically dominated by MRO range compounds but can include compounds in both the LRO and HRO range. Kerosene-based jet fuels such as JP-5, for example, can contain small amounts of C5-C8 aliphatics that fall within the LRO range. Residual fuels are typically dominated by HRO compounds but can include MRO compounds as well. Degraded LRO compounds that have lost their volatility can elute and be reported as MRO range compounds. This explains the common misinterpretation of “diesel” contamination at heavily degraded, gasoline-only release sites.

This necessitates testing for and reporting concentrations of TPH and other hydrocarbon-related compounds associated with each of the analytical ranges. The total concentration of TPH for a sample is determined by adding concentration data for each of these ranges and excluding the concentration of individually targeted compounds (TPH = LRO + MRO + HRO). The reported concentration of TPH for a sample can then be compared to a single, risk-based screening level that reflects the overall toxicity of the carbon range mixture specific to the type of fuel released. Consideration of TPH data, rather than carbon range data, is particularly important for accurate assessment of fuel-contaminated water, since a large portion of the original hydrocarbons might be partially oxidized and not detectable using standard carbon range analytical methods.

## 2.2. Additives

The JP-5 fuel stored at the Red Hill facility was confirmed by the Navy to include a Fuel System Icing Inhibitor (FSII), antioxidants and corrosion inhibitor/lubricity improver additives (USDOD 1999, 2011, 2016). Trace amounts of additional, proprietary additives in the fuel are also possible but were not disclosed by the Navy or reported by the laboratory. The primary FSII compound is diethylene glycol monomethyl ether (DiEGME; USDOD 1999), also referred to as 2-(2-methoxyethoxy) ethanol or by the trade name Methyl Carbitol. Table 1 notes the required concentration of the additives in JP-5 on based on Department of Defense military fuel specifications (USDOD 1998, 2004; USEPA 2016). Testing of JP-5 samples from the Red Hill facility provided by the Navy confirmed the presence of DiEGME in the fuel at a concentration of 0.050% to 0.055% (Newfields 2023b). This is slightly below the mandated range of 0.08% to 0.11% based on a previous summer of additives in the fuel prepared by the USEPA (2016). The laboratory suggested that the lower concentration detected could be due to incomplete extraction of DiEGME from the fuel during the analysis. The compound DiEGME is of particular concern for potential health risks both because of its relatively higher concentration in the fuel in comparison to other additives and its predicted miscibility in water.

Vapors generated from the JP-5 were dominated by >C8-C18 aliphatics with lesser amounts of C5-C8 aliphatics and minimal BTEXN (see Table 1, Newfields 2023b; see also Harley and Coulter-Burke 2000; Chin and Batterman 2012, HIDOH 2012). An annotated chromatograph of vapors from the fuel is included in Attachment 4. Additives in the fuel are not expected to significantly contribute to vapor emissions due to the limited volatility of the targeted compounds and low concentration of any potentially volatile additives present.

## 2.3. Hydrocarbon Oxidation Products

The makeup of a dissolved-phase mixture of petroleum fuel can be further complicated by the presence of polar, hydrocarbon-related degradation compounds. These compounds, collectively referred to as Hydrocarbon Oxidation Products” or “HOPs” (CAEPA 2019), include complex mixtures of partially oxidized hydrocarbons generated by microbial biodegradation of the petroleum (Mohler et al. 2013; Zemo et al. 2013, 2016). Oxidation reduces the volatility of the compounds and can make them more difficult to extract and measure. A portion of the compounds will be reported along with undegraded hydrocarbons that fall within the MRO and

possibly HRO ranges, depending on their retention times and their ability to be extracted from the sample.

The presence of degraded hydrocarbons can be determined by comparison of data for samples tested with and without the use of silica gel cleanup to remove polar compounds. The concentration of TPH determined in the absence of SGC minus the concentration of TPH estimated after silica gel cleanup represents the concentration of HOPs-related compounds in the sample. The fraction of degraded hydrocarbon compounds in JP-5 contaminated water circulating within the JBHH drinking water system is unknown due to the lack of sample data from the early periods after the incident. A comparison of data generated with and without silica gel cleanup for a sample of contaminated groundwater collected from the Red Hill Shaft well two weeks after the well was shut down suggest that significant degradation of dissolved-phase hydrocarbons had occurred by this time, with greater than 80% of compounds removed from the sample following processing with silica gel (NAVFAC 2022).

The separation of true “TPH” versus HOPs-related compounds in a sample is not strictly necessary for assessment of health risk. The toxicity of a mixture of HOPs compounds is assumed by several regulatory agencies to be identical to that of the original TPH plus BTEXNM mixture of hydrocarbons in the impacted media (HIDOH 2017, 2018; CAEPA 2019; see also Zemo et al. 2016). The inclusion of significant, degraded benzene in a HOPs mixture could in theory increase the toxicity of reported TPH associated with contaminated tapwater. The minimal amount of BTEXNM in the JP-5 fuel released from the Red Hill facility negates a significant contribution to overall health risk in comparison to the risk posed by non-specific, aliphatic and/or aromatic carbon range compounds. Separate consideration of HOPs compounds in assessment of the weighted toxicity of the TPH component of contaminated tapwater is therefore excluded from further consideration in this assessment.

Of more concern is the potential for a large fraction of partially oxidized but still potentially toxic degraded compounds to be missed in the analytical data for a sample, due to destruction during processing or an inability to be extracted and included with measurement of the overall “TPH” reported for the sample (Bekins 2016). This could lead to underreporting of the actual concentration of hydrocarbon-related compounds in water contaminated with petroleum and an associated underreporting of risk to human health and the environment.

#### **2.4. Other Potential Contaminants**

Residents reported periodic strong chlorine odors emitted from tapwater in the weeks following release. This was apparently related to intentional, increased chlorination of the water by the Navy to address concerns about potential buildup of bacteria in the system (USDN 2022). Strong chlorine odors in tapwater suggest concentrations well above the odor threshold of 0.31 mg/L (ATSDR 2018). Excessive chlorine in water can cause eye and nose irritation as well as stomach discomfort (USEPA 2009b).

The Navy reportedly used the surfactant Simple Green All Purpose Cleaner to clean the floors and walls of Adit 3 following the November 2021 release of JP-5 jet fuel (Sunshine Makers 2021a). Surfactants such as Simple Green are highly soluble and can enhance the emulsification,

mixing and mobility of petroleum in water. The presence of surfactants in water drawn into the JBPHH drinking water system could in part explain reports of foam-like residue on water from taps in some residential areas of the Navy base (see photos in Attachment 1). The primary compound of interest in the product is the dispersant 1-butoxy-2-propanol (active ingredient). Testing of water mixed with Simple Green in the amount recommended by the manufacturer resulted in dissolved-phase concentrations of 1-butoxy-2-propanol ranging from 35 to 40  $\mu\text{g/L}$  (Newfields 2013b). It is probable that groundwater in the vicinity of the Red Hill Shaft was also contaminated with this compound up to this amount. The lack of published toxicity factors for 1-butoxy-2-propanol negates a more in-depth review of the potential health risks posed by exposure to this compound.

The corrosivity of water from hot water heaters was measured to be high in some cases. The Langelier Saturation Index (LSI), a measure of the balance between pH and calcium carbonate, was in one case reported by a resident to be negative 0.87. While not a direct measurement of corrosivity, an LSI below a value of negative 0.50 can be indicative of potentially corrosive conditions associated with the water (USGS 2016). This was possibly due to corrosion of the water heater sacrificial anode by jet fuel. Residents reported that persistent skin rash problems following flushing of the drinking water system disappeared following replacement of the water heater at the home.

Due to a lack of adequate information, further assessment of contamination of the tapwater with Simple Green, excessive chlorine, chlorine disinfection byproducts and potential skin and other health effects associated with the corrosivity of hot water is excluded from further quantitative consideration in this assessment. Additional review of these conditions should be incorporated in future health assessments of the incident.

### 3.0 Conceptual Site Model

#### 3.1. Contaminant Fate and Transport

Figure 1 presents a Conceptual Site Model (CSM) of the November 20, 2021, release of JP-5 at the Red Hill facility and subsequent exposure of resident at JBPHH (ATSDR 2005a, 2013). Ingestion, inhalation and dermal exposure pathways to contaminants are reviewed in terms of three sources (see Figure 1): 1) Venting of fuel vapors from the Red Hill facility tunnel complex to outdoor air, 2) Use of contaminated tapwater for drinking, cooking, bathing and cleaning and 3) Outdoor discharges of contaminated water onto open areas during initial flushing of the system.

Initial exposure of residents in base communities nearest to the Red Hill facility likely occurred via inhalation of jet fuel vapors in outdoor air impacted by venting of the Red Hill facility tunnel system. Predominant Trade Wind conditions on the day of the release and over the following several weeks carried exhaust from the tunnel southwestward toward JBPHH (Weather Underground 2023). Impacted air was also drawn into home ventilation systems.

In the tunnel itself, jet fuel traveled through gaps, sumps and other structures in the floor and reached underlying groundwater, situated approximately 80 feet below. Free product accumulated at the groundwater surface. More soluble >C8 aromatics and limited BTEXNM were drawn out of the fuel and dissolved into the groundwater, leaving behind sheens of aromatic-depleted aliphatic compounds.

The miscibility of DiEGME suggests that this compound would be completely drawn out of the fuel and dissolved into groundwater (HIDOH 2023). Although detected in a sump that captured fuel and water used for cleanup three weeks after the release, DiEGME was not detected in samples of fuel-contaminated groundwater collected from the Red Hill Shaft itself during the same time period. Degradation of DiEGME, with a reported half-life as short as a few days to several weeks, does not fully explain the absence of DiEGME in samples of groundwater (NIH 2023; USEPA 2023a). It is possible that a dissolved-phase DiEGME at the lead of the groundwater was drawn into the Red Hill shaft ahead of the slower moving, hydrocarbon plume.

It has also been postulated the DiEGME formed a complex emulsion with hydrocarbons, other additives and water soon after the fuel encountered the water table and was present at the top of the water table but not below, where the samples were collected. Use of the surfactant Simple Green to clean the tunnel in the days following the release could have also aided in emulsification of both the fuel and DiEGME. Emulsification of the DiEGME or other factors causing the icing inhibitor to stay with the fuel rather than diffuse into the water is supported by water-fuel studies carried out by HIDOH (Section 3.4.1; Attachment 4).

As discussed in the Section 3.2, testing of samples of water in direct contact with JP-5 fuel indicated minimum dissolution of DiEGME into the water. This supports emulsification of the DiEGME rather than dissolution into the groundwater. Complexation of DiEGME with water in jet fuel is a well-known phenomenon in the aviation industry, referred to as the formation of “apple jelly” (DESC 2002). The resulting gels can be comprised of 30% to 50% or more

DIEGME. The presence of DiEGME-concentrated emulsions is further supported by reports of a gel-like substance floating on the water within the Red Hill Shaft tunnel and foams and gel-like, flakey substances reported by residents in tapwater discharged from sinks and onto the ground (refer to Photos in Attachment 1). Foams on the water suggests the presence of an emulsion and/or the presence of a surfactant like Simple Green in the water.

Contaminated groundwater was drawn into the Red Hill Shaft well as least as early as November 27<sup>th</sup> and likely several days before then, based on earlier complaints of unexplained rashes by residents after showering. The pumping capacity of the well is approximately five-million gallons per day. Pumps were operated until November 28<sup>th</sup>, when the Navy ordered the well to be shut down. Up to 40 million gallons of contaminated groundwater could therefore have been drawn into the JBPPH drinking water system prior to that time.

Water in neighborhoods reporting strong fuel odors and sheens was initially discharged into open, grassy areas untreated, impacting the soil and shallow groundwater and emitting vapors into the ambient air. Discharge of water through large, granulated activated carbon units was later required to minimize additional impacts to the environment and exposure of residents.

Flushing of the JBPHH drinking water system was carried out through March 2022. Flushing began in neighborhoods closest to the Red Hill shaft pumping station and progressed away from these areas as contaminated water was pushed “downgradient” toward open hydrants. The HDOH concurred that water throughout the system was safe for drinking and normal household usage on March 18, 2022, through amendments to the Public Health Advisory (HDOH 2022). Continued, periodic exposure to fuel-contaminated water could have continued during this period for residents in neighborhoods yet to be cleared for tapwater reuse who were unable to leave the base or otherwise elected to stay. The HDOH Public Health Advisory for use of the drinking water system including non-residential areas was formally lifted on October 28<sup>th</sup>, 2022, when all requirements had been satisfied by the Navy. Continued, randomized testing of the entire system for fuel-related contaminants and overall water quality was required for a period of two additional years.

## **3.2. Exposure Pathways**

### *3.2.1. Tunnel Venting to Outdoor Air*

While periodic in nature based on vapor emissions from the tunnel and wind patterns, the exposure pathway to fuel vapors in outdoor air, release is considered to be complete (refer to Figure 1). Outdoor air impacted by vapors emitted from the ventilation system of the Red Hill facility traveled in a westward to southward direction toward JBPHH military housing areas. Concentrations of jet fuel vapors in outdoor air were highest during the first few weeks after the release as cleanup of the tunnel was underway. Inhalation exposure to primarily C5-C8 and >C9-C18 aliphatic compounds could have occurred both outdoors and indoors, as impacted air was drawn into building ventilation systems.

Resident reports indicate that impacts to outdoor air were especially strong in the Red Hill and Aliamanu Military Reservation areas, located adjacent to and directly southwest of the Red Hill fuel storage facility. The Aliamanu Military Reservation is in particular located within an extinct,



bowl-shaped volcanic crater. Persistent poor air circulation within the crater could have led to prolonged periods of exposure to impacted outdoor air.

### *3.2.2. Indoor Tapwater Usage*

Ingestion, inhalation and/or dermal contact exposure pathways to fuel-related contaminants in tapwater are considered to have been complete, depending on the particular circumstances that the water was being used (see Figure 1). Ingestion exposure to dissolved-phase aromatic compounds in tapwater or combined exposure to aromatic, aliphatic and additives in sheens and emulsions occurred both through drinking the water and usage of the water for cooking. Contamination was likely masked in foods prepared with the water, causing residents to unknowingly be exposed to higher concentrations of contaminants than might otherwise have occurred through simple drinking of the water.

Inhalation exposure to C5-C8 and >C9-C18 aliphatic and to a lesser extent more hydrophilic light-end aromatic BTEX and >C8 aromatic compounds emitted from the water was most significant during use for showering and bathing. Additional exposure could have occurred during routine use of tapwater for drinking and cooking and use of dish and clothes washers. The use of hot water during showering would have exacerbated vapor emissions. Significant indoor exposure to JP-5 vapors also occurred in some affected houses when residents were asked to purge water from taps soon after the initial detection of fuel contamination in the system. Several residents reported that strong fuel vapors quickly spread throughout the house and significantly impacted indoor air, leading to significant health effects.

Dermal contact with dissolved-phase aromatics in water and fuel-related contaminants in sheens and emulsion on the water occurred during showering by adults and bathing by young children. Prolonged bathing in warm water would have exacerbated dermal exposure. The primary contaminants of concern during the initial draw of contaminated water into the Red Hill Shaft well were likely dissolved-phase, >C8 aromatics and DiEGME. Any aliphatic compounds dissolved in the tapwater are assumed to be emitted to air during bathing and not available for dermal contact due to their hydrophobic nature volatility. Exposure to these contaminants is instead considered for the inhalation pathway. Later intrusion of more contaminated water into the JBPHH system via the Red Hill Shaft well would have led to increased exposure concentrations of these compounds as well as additional exposure to C8-C18 aliphatics in sheens.

### *3.2.3. Outdoor Water System Discharges*

Exposure to fuel-related contaminants during early discharge of untreated water to open areas was primarily through inhalation of vapors re-emitted to outdoor air in the weeks following initial flushing of the system. Residents reported renewed vapor emissions from impacted soil following periods of heavy rainfall for several months afterwards. Direct ingestion of soil and dermal contact with soil by young children was likely to be minimal due to grass and other landscaping as well as dislocation of families in the most impacted areas to alternative housing.

### 3.3. Exposure Scenarios

Exposure concentrations are estimated for four scenarios: 1) Exposure to dissolved-phase contaminants in tapwater, 2) Exposure to dissolved-phase contaminants and sheens of free product on the tapwater, 3) Exposure to dissolved-phase contaminants, sheens and DiEGME emulsions in tapwater and 4) Exposure to JP-5 vapors in indoor and outdoor air. Sample data directly representative of exposure conditions under the noted scenarios are not available. Exposure point concentrations are instead estimated based on multiple lines of evidence, including: 1) Field observations by based residents, Navy staff and regulatory officials, 2) Estimate of effective solubility of individual components of the jet fuel, 3) Groundwater data for samples collected from Red Hill Shaft and 4) Laboratory experiments that utilized JP-5 from the Red Hill facility to evaluate the dissolution of fuel-related contaminants into water over time.

Observations of strong fuel odors, sheens and foamy emulsions in tapwater indicate the presence of free product. Reasonable Maximum Exposure (RME) concentrations of dissolved-phase contaminants in the water are estimated based on the effective solubility of individually targeted compounds. Estimations of RMEs associated with exposure to JP-5 sheens and DiEGME emulsions are made based on the original makeup of the fuel and available data regarding fuel-additive-water emulsions. Estimates of RME exposure concentrations associated with vapors emitted from tapwater during bathing and other uses are more qualitatively based on data for vapors collected over fresh JP-5 fuel from the facility and published odor thresholds for kerosene-based fuels. Exposure to RME levels of contaminants is likely to have been episodic, with exposure to lesser amounts of contaminants during periods when less contaminated water was moving past in the JBPHH drinking water system at the time that water was drawn from a tap in a residence.

Figure 2 summarizes specific categories of contaminant of concern associated with the different exposure pathways and exposure scenarios. Ingestion of water that contained dissolved-phase contaminants only includes exposure to all dissolved-phase hydrocarbons and additives in the water, dominated by more soluble aromatic compounds. Aromatic compounds are assumed to stay in the water and be taken up via the dermal absorption pathway. More volatile, aliphatic compounds present in the water are assumed to be quickly emitted to indoor air, with exposure occurring via the inhalation pathway.

Ingestion of water containing a sheen results in exposure to both aliphatic and aromatic hydrocarbons as well as additives in the original fuel, plus dissolved-phase hydrocarbons and additives in the water (see Figure 2). The same compounds are considered in the dermal exposure pathway. Indoor and outdoor inhalation exposure focuses on exposure to both volatile aromatics and aliphatic compounds in the fuel.

Exposure to DiEGME emulsions in the tapwater in addition to fuel sheens would have occurred via the ingestion and dermal pathways (see Figure 2). Both pathways include exposure to aliphatic and aromatic hydrocarbons and aromatic hydrocarbons dissolved in the water.

### 3.4. Exposure Concentrations

#### 3.4.1. Dissolve-Phase Contaminants

Estimated RMEs for tapwater contaminated with dissolved-phase hydrocarbons and additives but not exhibiting a sheen are presented in Table 2. The RMEs reflect data from experiments utilizing a JP-5 jet fuel from the Red Hill facility provided to HODOH by the Navy. Photographs and detailed data summary tables are provided in Attachment 4.

The experiments were conducted by carefully placing a 10-milliliter layer of JP-5 jet fuel onto one-liter of sterilized water in funnel flask and allowing the fuel and water to equilibrate over 20 days (after Bobra 1992). Five flasks were prepared and labeled "Day 1," "Day 5," "Day 10," "Day 15" and "Day 20." A water sample collected from a flask on the noted day of the experiment and tested for BTEXMN, carbon ranges and DiEGME. In a separate, second set of experiments, a 1:10 mixture of Extreme Simple Green concentrate (Sunshine Makers 2021b) and water was prepared, with 100 ml of the resulting solution sprayed onto the layer of JP-5 each of the five flasks. These experiments were intended to help assess the potential added dissolution of emulsification of jet fuel during cleaning of the Adit 3 tunnel following the November 20, 2021, release. Samples collected from the experiments were additionally tested for 1-butoxy-2-propanol, a primary component of the cleaning solution.

A summary of the resulting laboratory data is provided in Attachment 4. Measured concentrations of dissolved-phase hydrocarbons in the experiments are supported by predictions of effective solubility of individual compounds, also provided in Attachment 5. The total reported concentration of dissolved-phase hydrocarbons in experiments not amended with Simple Green ranged from 0.599 mg/L on Day 0 to 5.6 mg/L on Day 20, with concentrations approaching the saturation limit by Day 5 (4.7 mg/L). The average measured total hydrocarbons from Day 5 to Day 20 after allowing for equilibration was 5.2 mg/L, with 3.1 mg/L contributed by the carbon ranges and 2.1 mg/L contributed by BTEXNM.

Attachment 5 provides a comparison of water-fuel experiment data to the predicted makeup of dissolved-phase JP-5 based on the effective solubility of the individual components. The average, total concentration of hydrocarbons measured in the experiments closely matches the sum of the predicted, effective solubility of the compounds of 5.4 mg/L, with 3.9 mg/L contributed by the carbon ranges and 1.5 mg/L contributed by BTEXNM. As predicted, dissolved-phase hydrocarbons in water-fuel experiments were dominated by >C8 aromatic compounds (average 60%). No dissolved-phase aliphatic compounds were detected in the water-fuel experiments. Trace amounts (2% of total) of dissolved-phase C5-C18 aliphatics were predicted based on the presence of small amounts of these compounds in the JP-5 fuel and their calculated effective solubilities (refer to Attachment 5).

Dissolved BTEXNM was dominated by xylenes and naphthalene, with both making up 12% each of total dissolved hydrocarbons. With the exception of naphthalene, concentrations of individual compounds in the water were less than the corresponding, predicted effective solubility, indicating less than saturated conditions for the compounds.

The addition of Simple Green to the experiments did not significantly affect the solubility of the hydrocarbons. The total concentration of dissolved-phase hydrocarbons was only slightly higher, at 5.3 mg/L. This primarily reflects the lack of change in the dissolved-phase concentration of C8 aromatics. The total concentration of BTEXNM in Simple Green amended experiment was a marginal 6% higher than in the non-amended experiment.

Only a minimum amount of DiEGME was drawn out of the fuel and into the water over the course of the experiments. The 10 milliliters of JP-5 fuel used in the experiments is estimated to have contained 5 mg to 11 mg of DiEGME, based on based on direct testing of the fuel (0.05%; Newfields 2023b) and the upper limit of DiEGME permitted in JP-5 (0.011%; USDOD 1999). A dissolved phase concentration of DiEGME of just 49 µg/L was reported for the Day 0 water sample in the absence of Simple Green (refer to Attachment 4). The Day 0 water sample in the experiment where Simple Green was added was marginally lower, at 45 µg/L. The difference is within expected laboratory error. The average concentration in the water samples was 51 µg/L for both sets of experiments, suggesting no influence from the addition of Simple Green to the experiments. This indicates that 99% or more of the DiEGME failed to dissolve into the water, in spite of the predicted effective solubility of 1,700 mg/L. The DiEGME appears to have instead been captured in gel-like emulsion that formed on top of the water (refer to photos in Attachment 4). This correlates well with reports of the formation of a water-DiEGME emulsion referred to as “Apple Jelly” associated with fuels pre-blended with FSII (DESC 2002). Implications of the present of a DiEGME-enriched emulsion in contaminated tapwater are further discussed in Section 3.4.3.

Concentrations of hydrocarbons and additives measured in the water-fuel study are adopted as dissolved-Phase RMEs. The RMEs reflect an assumed constantly replenished, thin layer of JP-5 fuel on groundwater at the Red Hill Shaft. This assumption matches field observations of fresh fuel still dripping into the shaft several weeks at the November 20, 2021, release (USDN 2022).

#### *3.4.2. Dissolved-Phase Contaminants Plus Sheen*

Estimated RMEs for tapwater contaminated with dissolved-phase hydrocarbons and additives and exhibiting a sheen are included in Table 2. The presence of a sheen on petroleum-contaminated water implies near saturation conditions of dissolved-phase hydrocarbons in the water. Concentrations of TPH up to 150 mg/L (0.015%) were reported for groundwater samples collected from the Red Hill shaft three weeks after the initial release of JP-5. This reflects the last water drawn into the JBPHH drinking water system prior to shut down of the well. The reported concentration of TPH far exceeds the predicted or measured solubility of JP-5 jet fuel, indicating the presence of free product in the sample.

For the purposes of this report, a concentration of 0.015% JP-5 product in tapwater was used to estimate of an RME concentration tapwater exhibiting a sheen. The concentration of individual carbon ranges and BTEXNM in the sheen were predicted by conversion of the percent makeup of the individual components to micrograms per liter and multiplication by 0.015%. This generates a TPH RME for exposure to tapwater expressing a sheen of 155 mg/L (see Table 2). All aromatic compounds in the fuel are assumed to have been transferred into the water, leaving

the sheen enriched in lower-solubility, >C8 to C18 aliphatic compounds and slightly increasing the RMEs for dissolved-phase BTEXNM (see Table 2).

A significantly greater exposure to hydrocarbons is predicted when a sheen is present on the tapwater (refer to Table 2). The relative makeup of hydrocarbon exposure mimics the makeup of the fuel, dominated by >C8-C18 aliphatic compounds (121 mg/L) with a lesser amount of >C8 aromatics (39 mg/L) and a small contribution from BTEXMN compounds (4.3 mg/L). The predicted total dissolved- plus neat-phase concentration of DiEGME in the water increases only moderately above the predicted dissolved-phase concentration. This is due to the relatively small amount of fuel assumed to make up the sheen (155 mg per liter of water) and the corresponding small mass of DiEGME in the sheen (0.11% of 155 mg sheen per liter of water).

#### *3.4.3. Dissolved-Phase Contaminants Plus Sheen Plus DiEGME Emulsion*

Estimated RMEs for tapwater contaminated with dissolved-phase hydrocarbons and additives and inclusive of a sheen as well as a DiEGME-enriched emulsion are noted in Table 2. Water sprayed from hoses at a residence exhibited a relatively high proportion of foamy material (refer to photo in Attachment 1). Other photos and videos of the water from resident taps show a flakey, white material on the water very distinct from a sheen and estimated to make up <1% of the water volume as a whole. Photos of a sample of tapwater collected from a JBPHH residence exhibit what appears to be an approximately one-millimeter-thick, yellowish clear layer of what is interpreted to be a DiEGME emulsion on 100 millimeters of water (refer to in Attachment 1). A gel-like emulsion interpreted to consist concentrated DiGME also appeared in the water-fuel experiments discussed in Section 3.4.1 (refer to photos in Attachment 4).

Based on these observations, a 0.1% concentration of 40% DiEGME emulsion is assumed for this exposure scenario. This equates to a predicted, RME concentration of DiEGME in tapwater of 400 mg/L (Table 2). Although somewhat subjective, this is utilized as a conservative REM concentration of DiEGME in tapwater that exhibits a sheen plus emulsion. Unlike the sheen exposure scenario, the predicted dissolved-phase concentration of DiEGME in water is not added to predicted concentration in the emulsion, since the entire mass of DiEGME is assumed to remain entrapped in the emulsion.

#### *3.4.4. Vapors*

Estimates of RME concentrations of JP-5 vapors in outdoor and indoor are noted in Table 2. Direct testing of vapors above JP-5 fuel collected from the Red Hill facility as part of the water-fuel experiments and reports of vapor impacts to indoor air by residents was used in lieu of models. Samples in the experiments were collected from the airspace above the layer of JP-5 product in the funnel flasks.

A summary of the vapor data is included in in Attachment 4. Samples collected from the water-fuel experiments were dominated by >C8-C18 aliphatic compounds (average 77%), with lesser amounts of C5-C8 aliphatics (average 18%) and only trace levels of aromatics (average 4%). This reflects the lower amount of C5-C8 aliphatics and aromatics in JP-5 fuel in comparison to data vapors emitted from lighter end, JP-8 jet fuels (HIDOH 2012; see also Brewer et al. 2013). The total concentration of TPH related carbon ranges of 8,160,000  $\mu\text{g}/\text{m}^3$  reported for the JP-5

vapor on Day 0 of the laboratory experiments is likely well above RME concentrations for exposure of residents to JP-5 vapors in indoor and outdoor air. Significant dilution of vapors can be expected a short distance away from the source.

Strong fuel odors in indoor air and in some cases acute health effects including headaches and vomiting were reported by residents following the requested flushing of taps in homes in late November and early December 2021. Strong odors indicate a concentration of JP-5 vapors well above the published upper odor threshold for kerosene-based jet fuels of 7,700  $\mu\text{g}/\text{m}^3$  (ATSDR 2017). Significant health within minutes to hours after exposure effects suggests vapor concentrations at least above Level 1, Acute Exposure Guideline Level (AEGL-1) for kerosene vapors of 290,000  $\mu\text{g}/\text{m}^3$  (ATSDR 2017). This value is applied to the TPH concentration of vapors in air reported as kerosene.

The AEGLs represent threshold exposure levels above which health effects can be expected within 10 minutes to 8 hours of exposure (NRC 2001; NAS 2016). Exposure above the AEGL-1 level is predicted to cause “notable discomfort, irritation, or certain asymptomatic nonsensory effects.” Health effects are predicted to be transitory, meaning that the effects are reversible once the person leaves the contaminated environment. Given common reports of eye, nose and throat irritation among residents and in cases vomiting, an RME concentration greater than the AEGL-1 of 290 mg/L level is appropriate or a particular sensitivity to jet fuel vapors.

The Level 2 AEGL (AEGL-2) for exposure to kerosene vapors is 1,100 mg/L. Exposure above this level for as little as 10 minutes is predicted to potentially cause irreversible or other long-lasting health effects. Continuing, inhalation-related health effects of residents exposed to JP-5 vapors following the release at Red Hill could indicate an RME in some cases that exceeds the AEGL-2 level or again a particular sensitivity to jet fuel vapors.

## 4.0 Health Effects

A summary of health effects associated with chronic, subchronic and acute exposure to jet fuel and fuel additives is included in Table 3. Noted health effects are presented for general informational purposes only and might not be fully inclusive. Noted effects are inclusive of published information for acute, subchronic and chronic exposure. Effects can also differ between individuals under the same exposure conditions. Refer to Attachment 6 for a listing of health effects specific to each exposure category and related references.

Acute toxicity is defined as the occurrence of health effects within less than one day to 14 days after or during exposure (ATSDR 2018). Chronic toxicity is defined as health effects that only begin to be expressed after a year or more of regular exposure. Subchronic toxicity falls in between these two categories and is defined as health effects experienced within 14 to 365 days of exposure. This is typically associated with exposure to lower but persistent concentrations of a contaminant. Cancer risk is normally associated with chronic rather than acute exposure.

Potential acute health effects posed by short-term exposure to relatively high concentrations of hydrocarbons include eye and skin irritation, dermatitis, defatting of skin, dizziness, headache, anesthesia, coughing, gagging, vomiting, griping, diarrhea, depressed respiration and pulmonary edema (ATSDR 2023; NIH 2023). Acute health effects posed by exposure to high concentration of DiEGME include headache, dizziness, tiredness, nausea, vomiting and eye irritation (NIH 2023, ThermoFisher Scientific 2021). Short-term exposure to high concentrations of 2,6-Di-Tert-Butyl-4-Methylphenol can cause throat irritation, dermatitis, abdominal pain, nausea, confusion and dizziness (NIH 2023).

Long-term, chronic exposure to hydrocarbons can affect multiple organs and lead to numerous health effects (MADEP 2002; USEPA 2022, 2023d; ILEPA 2023; NIH 2023). This include effects on the alimentary tract, kidneys and eyes and impacts to the cardiovascular, developmental, endocrine, hematologic, immune, nervous, reproductive and respiratory systems. Effects caused by long term-exposure to DiEGME includes impacts to the alimentary tract, kidneys and skin and impacts to the developmental and reproductive systems.

Subchronic health effects bridge the gap between health effects associated with acute and chronic exposure. Specific subchronic health effects associated with exposure to hydrocarbons include impacts to the alimentary, developmental, hematologic, kidney, nervous, reproductive and respiratory organs and systems (USEPA 2022, 2023c; refer to Attachment 6).

## 5.0 Toxicity Factors

### 5.1. Individually Targeted Compounds

Table 3 presents chronic and subchronic Reference Doses (RfDs), Reference Concentrations (RfCs), Cancer Slope Factors (CSFs) and Inhalation Unit Risk (IUR) factors for BTEXNM and targeted additives. Reference doses applicable to dermal exposure are assumed to be identical to RfDs for oral toxicity. Subchronic toxicity factors presented in the table are based on information provided in the USEPA *Provisional Peer-Reviewed Toxicity Values* (PPRTV) documents for individual compounds (USEPA 2023b) unless otherwise noted.

Confidence in the toxicity factors as reported in the referenced documents is noted in Table 3. Route-to-route extrapolation of the oral RfD was used to generate an RfC for 1- and 2-methylnaphthalenes. Subchronic RfCs were not available for 1-methylnaphthalene, 2-methylnaphthalene and naphthalene. The chronic RfC was substituted for the purpose of calculating risk-based screening levels. Confidence in extrapolation of these toxicity factors is noted as “Low” in the table. Consideration of the inhalation pathway for these compounds is, however, necessary for assessment of health risk. Acute toxicity factors are not available any of the compounds. Toxicity factors were not identified for linoleic acid dimers. These compounds were excluded from further consideration based on this factor, a low concentration in the parent fuel and an assumed, low toxicity of fatty acids in general (Health Canada 2018).

### 5.2. Carbon Ranges and TPH

#### 5.2.1. Carbon Ranges

Toxicity factors selected for assessment of carbon range compounds associated with JP-5 jet fuel are included in Table 3. Numerous entities have published physiochemical constants and toxicity factors for individual aliphatic and aromatic carbon ranges (e.g., Edwards et al. 1997; ATSDR 1999; MADEP 2003; WADOE 2006; CAEPA 2009, 2019; USEPA 2009a, 2022; see also Brewer et al. 2013; HIDOH 2018). Toxicity factors published by USEPA in 2022 are carried forward for use in this report. Use of the factors allows groupings of multiple compounds in a single carbon range to be quantitatively evaluated in the same manner as done for individual compounds (e.g., MADEP 2002, HIDOH 2017).

The USEPA toxicity factors for carbon ranges noted in Table 3 represent recent updates of toxicity factors published in 2009 (USEPA 2009a) and used to prepare previous HIDOH tapwater action levels for JP-5 (HIDOH 2022). The oral Reference Dose for >C8 aromatics was reduced by a factor of three in comparison to toxicity factors published in 2009 (0.010 mg/kg-day vs original 0.030 mg/kg-day). This effectively reduces TPH screening levels for mixtures dominated by >C8 aromatics by a similar degree. Confidence in the updated toxicity factors was not reviewed as part of the Environment Assessment but should be included in subsequent Health Assessments that incorporate health effects experienced by JBPHH residents.

#### 5.2.2. Total Petroleum Hydrocarbons

Table 4 presents carbon range-weighted, chronic and subchronic TPH toxicity factors for JP-5 jet fuel under each of the four exposure scenarios noted in Figure 1. Direct assessment of health risk



posed by exposure to petroleum fuels could in theory be carried based on data for individual carbon ranges. Accurate quantification of the carbon range makeup of petroleum-related contaminants in a sample is hindered by the limited number of commercial laboratories that can reliably carry out the analyses. Assessment of risk is further complicated by the presence of hydrocarbon-related degradation compounds (HOPs) that are detectable by standard carbon range methods. This is particularly important for assessment of fuel-contaminated water, where significant, partial-oxidation of hydrocarbon compounds is common. These limitations favor the use of less precise but also less biased widely available and more encompassing "TPH" analytical methods to quantify the total concentration of hydrocarbon-related compounds in a sample.

The TPH toxicity factors presented in Table 4 were calculated based on the harmonic mean of the measured carbon range makeup of neat fuel, dissolved-phase JP-5 in water and JP-5 vapors noted in Table 1 and toxicity factors presented in Table 3. The methodology used to calculate the toxicity factors and summary tables of the calculations are provided in Attachment 7.

Carbon range-weighted TPH chronic ingestion and dermal contact toxicity factors for exposure to dissolved-phase JP-5 in tapwater and exposure to JP-5 product in sheens are identical, despite the former being dominated by >C8 aromatics the latter being dominated by >C8-C18 aliphatics. This is due to assignment of the same RfD to each carbon range. Weighted *subchronic* ingestion and dermal toxicity factors differ for dissolved vs sheen exposure scenarios, however, due to an assumed lower (more conservative) subchronic toxicity factor for >C8 aromatic compounds (0.04 mg/kg-day) than that assumed for >C8-C18 aliphatic compounds (0.10 mg/kg-day).

The weighted TPH inhalation toxicity factor calculated for vapors emitted from dissolved-phase JP-5 is more conservative than the toxicity factor calculated for vapors emitted from sheens due to the lower RfC for >C8 aromatics assumed to dominate dissolved-phase hydrocarbons in comparison to the RfC for >C8-C18 aliphatic that dominate vapors from sheens (refer to Table 4). The concentration of TPH in vapors emitted from sheens will be much higher, however, offsetting the marginal difference in toxicity and posing a great inhalation health risk. The carbon range-weighted TPH RfC for vapors emitted to outdoor air from venting of the Red Hill tunnel and discharge of untreated water with sheens from hydrants and impacted soil are assumed to be identical to the RfC for vapors emitted to indoor air from sheens on tapwater.

The toxicity factors for dissolved-phase JP-5 based on the results of the water-fuel experiments compare very well with weighted toxicity factors based on the modeled carbon-range makeup (see Attachment 5). This is due to the measured and predicted dominance of dissolved-phase >C8 aromatic compounds. Trace amounts of dissolved-phase C5-C8 and C8-C18 aliphatics predicted to be in the water based on their presence in the JP-5 fuel and effective solubility results in a slightly but insignificantly different, model-based chronic and subchronic inhalation RfCs for exposure to dissolved-phase carbon range compounds (refer to Attachment 5).

## 6.0 Screening Levels

### 6.1. Tapwater

#### 6.1.1. Individual Compounds

Screening levels for chronic and subchronic exposure to individually targeted chemicals associated with JP-5 contaminated tapwater are presented in Table 5. Screening levels based on noncancer health hazard to young children are provided in the main table. Screening levels for potential cancer risks associated with benzene, ethylbenzene and naphthalene are included in the footnotes to the table. Screening levels for chronic exposure are intended to be protective against adverse health effects following continuous exposure over a period of one year or more. Screening levels for subchronic exposure are slightly higher and intended to be protective against adverse health effects following continuous exposure over a period of two weeks to one year (ATSDR 2018).

The screening levels were generated using the USPA Regional Screening Level (RSL) model for tapwater using the chronic and subchronic toxicity factors presented in Table 3 (USEPA 2023c). The model includes exposure to contaminants via direct ingestion of tapwater, bathing and inhalation of vapors. Ingestion and dermal pathway toxicity factors with or without a sheen are identical due to the application of identical toxicity factors for >C8 aromatics (dominate dissolved TPH) and >C8-C18 aliphatics (dominate sheen). Default parameter values utilized in the tapwater RSLs are presented in the Attachment 8. Screening levels intended to address noncancer health hazard are based on potential exposure of children age 0 to 6 years old. Screening levels intended to be protective of cancer risks assume long-term exposure of both children and adults to contaminants in the water over a combined period of 30 years. Promulgated Maximum Contaminant Levels (MCLs) for benzene, toluene, ethylbenzene and xylenes do not directly reflect risk and are not suitable for quantitative assessment of risk.

#### 6.1.2. Total Petroleum Hydrocarbons

Chronic and subchronic tapwater screening levels specific to dissolved-phase TPH and TPH present as a sheen of free product on tapwater were calculated in the same manner as carried out for individually targeted contaminants (Table 5). Incorporation of the dermal absorption pathway into the USEPA tapwater model for TPH requires respective calculation of carbon range weighted values for several additional parameters. A summary of the calculations of the factors is provided in Attachment 8.

The TPH screening level for chronic exposure to dissolved-phase JP-5 in tapwater was derived based on September 2022 updates to USEPA toxicity factors for individual carbon ranges (USEPA 2022; refer to Table 3). The screening (action) level published by HDOH in April 2022 and based on USEPA toxicity factors for individual carbon ranges published in 2009 is provided for reference (USEPA 2009a). Reduction in the RfD for >C8 aromatics by a factor of three as part of the 2022 update effectively reduces the TPH screening level by a similar degree. Confidence in the updated toxicity factor was not reviewed as part of the Environment Assessment but should be included in subsequent Health Assessments that incorporate health effects experienced by JBPHH residents.

## 6.2. Ambient Air

Chronic and subchronic ambient air screening levels for residential exposure to individual, BTEXNM compounds are included in Table 5. Screening levels for long-term, chronic exposure are taken directly from the USEPA RSL guidance (USEPA 2023c). Screening levels for subchronic exposure were calculated by incorporating subchronic RfCs noted in Table 3 in the same model equation.

Chronic and subchronic, ambient air screening levels for TPH were calculated based on incorporation of the respective, carbon range-weighted RfCs in the USEPA ambient air model. Both screening levels below common background levels of TPH in ambient air of up to and greater than 1,000 µg/L (after NJDOH 2010; see also HIDOH 2017).

## 7.0 Risk Characterization

### 7.1. Exposure Duration

The most significant exposure to JP-5 related contaminants in the JBPHH drinking water system following the November 20, 2021, occurred over a time period of a few days to a few week. Comparison of predicted RME's to subchronic screening levels is therefore appropriate.

Residents reported symptoms including rashes that were likely related to contamination in the drinking water system as early as November 25<sup>th</sup>. Heavily contaminated water was clearly moving through the drinking water system by November 27<sup>th</sup>, when hundreds of residents began reporting strong vapors and sheens in tapwater. Residents in areas of the base who were initially told that their water was safe to use were subsequently sickened by contamination at least as late as December 9<sup>th</sup>. This suggests a range of exposure durations of minutes to as long as two weeks prior to the development of symptoms clearly related to contamination of the water with jet fuel. It is possible, however, that the delay in significant health effects in some areas was due to the delayed intrusion of heavily contaminated water into their neighborhoods as water moved through the base piping system.

The duration of exposure places health effects falls within the timeframe of acute to subchronic toxicity. The duration and periodicity of exposure of individual residents likely varied within the base as isolated pockets of less and more contaminated water migrated through the piping network to more distant area of the base. Early exposure was likely associated with comparatively low concentrations of dissolved-phase fuel in the drinking water, primarily >C8 aromatics. The magnitude of exposure and health effects steadily increased as free product and emulsions of fuel, water and additives began to enter the system and residents were exposed to sheens and emulsions in the water containing high levels of >C8-C18 aliphatics and emulsions containing high concentrations of DiEGME. At this stage, it is likely that health effects occurred within minutes or hours after single exposure event related to use of the water for drinking, cooking or bathing.

### 7.2. Summary of Exposure Assessment

Table 6 presents a comparison of RMEs for the described exposure scenarios to subchronic screening levels for targeted contaminants of concern. The comparison suggests that health risk was highest due to exposure to high concentrations of >C8 aromatics dissolved in the tapwater at the peak of contamination, >C8-C18 aliphatics in sheens on the water and DiEGME suspected to be concentrated in emulsions in the water. Additional health risk could have also been posed by 2-methylnaphthalene and naphthalene in sheens. Inhalation health effects were primarily related to exposure to high levels of >C0-C18 aliphatics in indoor and outdoor air due to venting of the Red Hill fuel storage facility in the days and weeks following the release, initial flushing of the drinking water system to outdoor areas of the base, flushing of taps within residents at the base and use of the water for drinking, cooking, washing and bathing. Exposure under each scenario was at times high enough to cause immediate, acute health effects.

Limitations in these conclusions includes inherent uncertainty in toxicity factor referenced for contaminants and corresponding screening levels and the lack of correlative, published health studies for comparison, particularly for the gap between acute and subchronic toxicity. Additive and synergistic effects related to simultaneous exposure to hydrocarbons and DiEGME as well as disinfection products and surfactants in the water complicate a full understanding exposure conditions and related health effects.

Health effects differed both within individuals in single households and within affected neighborhoods. Factors affecting effects on health likely included: 1) The physical state of contaminants that the individual was exposed to at a given time (e.g., dissolved, sheen, emulsion), 2) The concentration of the contaminant in the water at that time, 3) The duration of exposure and 4) Variability between the physiological susceptibility of individuals (age, weight, pre-existing conditions, etc.). A better understanding of observed and reported health effects both within the effected community as a whole and between affected individuals requires a thorough public health assessment of affected base residents. It is hoped that the information provided in this report will assist in this endeavor.

## 8.0 Limitations

Reliable testing for C8 to C24 hydrocarbon compounds and associated degradation products or “Mid-Range Organics (MRO) (aka “Diesel Range Organics”) in water is constrained by at typical laboratory Method Reporting Limit (MRL) for of approximately 200 µg/L. Sample data below this concentration are typically qualified with a “J” flag. Below this concentration, the laboratory is both unable to verify that the detected compound is associated with petroleum and that the estimated concentration of the compound is accurate. Identified compounds could also be related to algae or other naturally occurring organic compounds in the tapwater, as well as trace levels of contaminants introduced from piping, pumps, gaskets and other material in the drinking water system. A potential loss of 30% or more of hydrocarbon-related compounds during sample processing and testing using standard USEPA laboratory methods (e.g., Method 8105) further complicates interpretation of sample data at concentrations that approach a risk-based screening level.

TPH tapwater screening levels for JP-5 based on 2022 USEPA updates to carbon range toxicity factors are well below the Method Reporting Level for mid-range organics (MRO; see Table 5). This complicates the interpretation of J-flagged sample data from the JBPHH drinking water system as well as groundwater data for the Red Hill facility. HDOH guidance recommends the use of the laboratory Method Reporting Level as the screening (action) level when the risk-based screening level is lower unless a more detailed analysis of the sample can be carried out (HDOH 2017). The presence of well-defined spikes on the chromatograph can assist in a more detailed comparison to standards for specific compounds. Other lines of evidence should be considered for interpretation of the data, including:

- Comparison to chromatograms for previous samples collected from the same location, including obviously contaminated samples;
- Degree of flushing that has been carried out within the specific area of the drinking water system;
- Field observations of sheens, odors or petroleum tastes in tapwater; and
- Comparisons to MRO data for unimpacted areas of the drinking water system or similar drinking water systems in other areas of Hawai'i.

These factors and limitations in the utility of the TPH tapwater screening levels based on the updated USEPA toxicity factors for carbon ranges should be taken into consideration for future monitoring of the JBPHH drinking water system and impacted groundwater beneath the Navy's Red Hill fuel storage facility.

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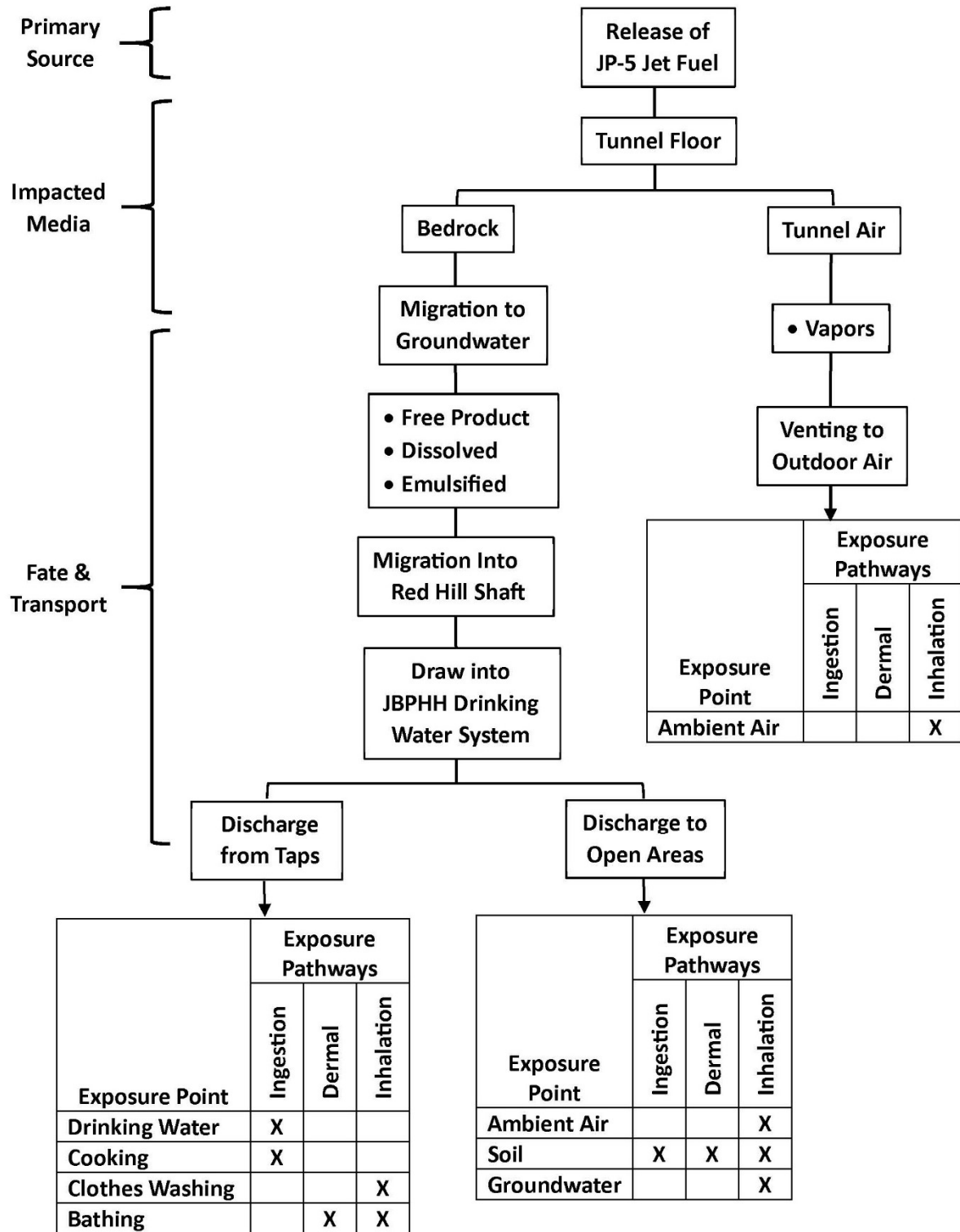
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Figure 1. Conceptual Site Model of exposure of JBPHH residents to JP-5 jet fuel.



**Figure 2. Primary contaminants of concern for specific exposure pathways.**

<b>Exposure Pathway</b>	<b>Dissolved-Phase Contaminants Only</b>			<b>Dissolved-Phase Contaminants Plus Sheen +/-DiEGME Emulsion</b>		
	<b>Aliphatics</b>	<b>Aromatics</b>	<b>DiEGME</b>	<b>Aliphatics</b>	<b>Aromatics</b>	<b>DiEGME</b>
<b>Ingestion</b>		<b>X</b>	<b>X</b>	<b>X</b>	<b>X</b>	<b>X</b>
<b>Dermal Absorption</b>		<b>X</b>	<b>X</b>	<b>X</b>	<b>X</b>	<b>X</b>
<b>Inhalation</b>		<b>X</b>		<b>X</b>		

Table 1. Relative BTEXNM and Carbon Range makeup of neat-, dissolved- and vapor-phase JP-5 jet fuel.

Utility	Chemical Group	Chemical/ Carbon Range	<sup>1</sup> Relative Makeup of Neat-Phase JP-5 Jet Fuel	<sup>2</sup> Relative Makeup of Dissolved-Phase JP-5 Jet Fuel	<sup>3</sup> Relative Makeup of Vapor Phase JP-5 Jet Fuel
<sup>4</sup> Jet Fuel Hydrocarbons	Individually Targeted Hydrocarbons	Benzene	0.004%	0.28%	0.03%
		Toluene	0.025%	3.1%	0.26%
		Ethylbenzene	0.049%	1.6%	0.18%
		Xylenes	0.25%	12%	0.91%
		Naphthalene	0.35%	12%	0.05%
		1-Methylnaphthalene	0.49%	6.3%	0.03%
		2-Methylnaphthalene	0.69%	4.6%	0.02%
	Carbon Range Groupings	C5-C8 Aliphatics	0.42%	0.10%	19%
		>C8-C18 Aliphatics	79%	0.0%	77%
		>C18-C32 Aliphatics	0.0%	0.0%	0.0%
>C8 Aromatics		19%	60%	3.1%	
Additives	<sup>4</sup> Fuel System Icing Inhibitor (FSII)	Diethylene glycol monomethyl ether (DiEGME)	0.08% to 0.11% (800 mg/L to 1,100 mg/L)	-	-
	<sup>5</sup> Antioxidants	2,6-Di-tert-butyl-4- methylphenol	0.0024% (24 mg/L)	-	-
	<sup>5</sup> Corrosion Inhibitor/ Lubricity Improver	Linoleic acid dimers	0.0054% (54 mg/L)	-	-

**Table 1 (cont.). Relative BTEXNM and Carbon Range makeup of neat-, dissolved- and vapor-phase JP-5 jet fuel.**

1. Relative makeup of neat JP-5 fuel based on testing of samples collected from the Navy Red Hill fuel storage facility (Newfields 2023a).
2. Relative makeup of dissolved-phase, JP-5 hydrocarbons based on average of Days 5, 10, 15 and 20 in water-fuel experiment (Newfields 2023a).
3. Relative hydrocarbon makeup of vapors collected directly above JP-5 fuel in the water-fuel experiments (Newfields 2023a).
4. Upper limit of required DiEGME in JP-5 jet fuel (USDOD 1999).
5. Relative concentration of antioxidants and Corrosion Inhibitor/Lubricity Improver additives based on review of Department of Defense military fuel specification requirements and related documents (USDOD 1999, 2011, 2016; Flake et al. 2014). 2,4-dimethyl-6-tert-butylphenol and mixed methyl and dimethyl tert-butylphenols also used in some antioxidant formulations.

**Table 2. Estimated Reasonable Maximum Exposure (RME) concentrations of contaminated water drawn into the JBPHH drinking water system.**

		RME Concentration		
Compound		<sup>1</sup> Dissolved-Phase Contaminants Only (µg/L)	<sup>2</sup> Dissolved Contaminants +JP-5 Sheen (µg/L)	<sup>3</sup> Dissolved Contaminants +JP-5 Sheen +FSII Emulsion (µg/L)
<b>Total BTEXNM:</b>		<b>2,116</b>	<b>4,291</b>	<b>4,291</b>
<b>Total Carbon Ranges:</b>		<b>3,088</b>	<b>150,913</b>	<b>150,913</b>
<b>JP-5 Fuel</b>	<b>Benzene</b>	13	16	16
	<b>Toluene</b>	154	182	182
	<b>Ethylbenzene</b>	81	123	123
	<b>Xylenes</b>	630	943	943
	<b>Naphthalene</b>	649	1,083	1,083
	<b>1-Methylnaphthalene</b>	339	1,155	1,155
	<b>2-Methylnaphthalene</b>	250	789	789
	<b>C5-C8 Aliphatics</b>	6.6	250	250
<b>&gt;C8-C18 Aliphatics</b>	0	120,962	120,962	
<b>&gt;C18-C32 Aliphatics</b>	0	0	0	
<b>&gt;C8 Aromatics</b>	3,082	29,702	29,702	
<b>Total Hydrocarbons (ug/L):</b>		<b>5,204</b>	<b>155,204</b>	<b>155,204</b>
<b>JP-5 Additives</b>	<b>Diethylene Glycol Monomethyl Ether</b>	50	215	400,000
	<b>2,6-Di-Tert-Butyl-4-Methylphenol</b>	1.2	25	25
	<b>Linoleic acid dimers</b>	0.005	54	54

1. Measured dissolved-phase concentration of hydrocarbons and DiEGME in water-fuel experiments using JP-5 fuel collected from the Navy's Red Hill fuel storage facility. Concentration of other additives estimated based on percent composition in fuel and effective solubility.

2. Estimated concentrations based on assumed 0.015% JP-5 free product in tapwater plus noted dissolved-phase concentrations. DiEGME only present in original concentration in fuel.

3. Includes dissolved-phase contaminants plus sheens and an assumed 0.1% concentration of 40% DiEGME emulsion. Other additives assumed to remain dissolved in water and/or in product sheen.



**Table 3. Toxicity factors for individually targeted contaminants and carbon ranges.**

Chemical/ Carbon Range	<sup>1,3</sup> Chronic		<sup>2,3</sup> Subchronic		<sup>1</sup> CSF <sub>0oral</sub> (mg/kg-d) <sup>-1</sup>	<sup>1</sup> IUR (µg/m <sup>3</sup> ) <sup>-1</sup>	<sup>4</sup> Example Health Effects	
	RfD <sub>0oral/dermal</sub> (mg/kg-day)	RfC <sub>inh</sub> (µg/m <sup>3</sup> )	RfD <sub>0oral/dermal</sub> (mg/kg-day)	RfC <sub>inh</sub> (µg/m <sup>3</sup> )				
<b>Benzene</b>	0.004 (M)	30 (M)	0.01 (M)	80 (M)	0.055	7.8 x 10 <sup>-6</sup>	CARC, ALM, CARD, DEV, EYE, HEM, IMM, NERV, RESP, SKN	
<b>Toluene</b>	0.08 (L)	5,000 (H)	0.8 (M)	5,000 (H)	-	-	ALM, CARD, DEV, EYE, IMM, HEP, KID, NERV, REP, RESP, SKN	
<b>Ethylbenzene</b>	0.05 (L/M)	1,000	0.05 (M)	9,000 (M)	0.011	2.5 x 10 <sup>-6</sup>	CARC, ALM, DEV, END, EYE, HEM, KID, NERV, RESP, SKN	
<b>Xylenes (total)</b>	0.2 (L/M)	100	0.4 (L/M)	400 (M)	-	-	ALM, CARD, DEV, EYE, KID, NERV, REP, RESP, SKN	
<b>Naphthalene</b>	0.02 (L)	3 (L)	0.6 (H)	3 (L)	0.12	1.1 x 10 <sup>-4</sup>	CARC, ALM, EYE, HEM, IMM, NERV, RESP, SKN	
<b>1-Methylnaphthalene</b>	0.07 (L)	280 (L)	0.07 (L)	280 (L)	0.029	-	CARC, ALM, EYE, HEM, IMM, KID, NERV, RESP, SKN	
<b>2-Methylnaphthalene</b>	0.004 (L/M)	16 (L)	0.004 (L)	16 (L)	-	-	ALM, DEV, EYE, HEM, IMM, NERC, REP, RESP, SKN	
<b><sup>4</sup>Volatile Carbon Ranges</b>	<b>C5-C8 Aliphatics</b>	0.005 (L)	400 (M)	0.05 (M)	2,000 (M)	-	-	ALM, EYE, HEM, KIDN, NERV, RESP, SKN
	<b>C9-C12 Aliphatics</b>	0.01 (L)	100 (M)	0.1 (L)	100 (M)	-	-	ALM, EYE, HEM, KIDN, NERV, RESP, SKN
	<b>C9-C10 Aromatics</b>	0.01 (M)	60 (M)	0.04 (M)	200 (M)	-	-	NERV
	<b>C9-C18 Aliphatics</b>	0.01 (L)	100 (M)	0.1 (L)	-	-	-	ALM, EYE, HEM, KIDN, NERV, RESP, SKN
<b><sup>4</sup>Nonvolatile Carbon Ranges</b>	<b>C19-C36 Aliphatics</b>	3.0 (M)	-	30 (M)	-	-	-	ALM, EYE, HEM, KIDN, NERV, RESP, SKN
	<b>C11-C32 Aromatics</b>	0.01 (M)	-	0.04 (M)	-	-	-	NERV
<b><sup>5</sup>Additives</b>								
<b>Diethylene Glycol Monomethyl Ether</b>	0.04	-	0.04	-	-	-	ALM, EYE, DEV, KID, NERV, REP, SKN	
<b>2,6-Di-Tert-Butyl-4- Methylphenol</b>	0.3	-	-	-	0.0036	-	ALM, DEV, END, KID, REP, RESP	

**Table 3 (cont.). Toxicity factors for individually targeted contaminants and carbon ranges.**

1. Chronic Reference Doses (RfDs), Reference Concentrations (RfCs), Cancer Slope Factors (CSFs) and Inhalation Unit Risk (IUR) factors for BTEXNM and additives from USEPA (2023b). Carbon range RfDs and RfCs from USEPA (2022). Chronic RfD for 1-methylnaphthalene from ATSDR (2005b).
2. Subchronic toxicity factors from USEPA PPRTV documents for individual compounds (USEPA 2023b) and for carbon ranges (USEPA 2022). Chronic and subchronic RfC for 1- & 2-methylnaphthalene extrapolated from the RfD. Acute Minimum Risk Level substituted as subchronic RfD for naphthalene (ATSDR 2005b).
3. Confidence in subchronic RfD and RfC toxicity factor noted in parenthesis (USEPA 2022, 2023c): L = Low, M = Medium, H = High, NA = Not Available (chronic toxicity factors substituted). Confidence in carbon ranges noted as (L) specifically stated in USEPA (2022) PPRTV document. Confidence in carbon ranges noted as (M) not specifically stated but assumed to be medium.
4. USEPA toxicity factors for carbon ranges updated in 2022 noted (USEPA 2022). The applicability and adequacy of the toxicity factors to the release of JP-5 should be reviewed as part of a Health Assessment conducted for the JP-5 release.
5. For example only. Sum of acute, subchronic and chronic exposure health effects. Refer to Attachment 6 for detailed listing of health effects and related references. CARC: Carcinogen, ALM: Alimentary, CARD: Cardiovascular, DEV: Developmental, END: Endocrine, EYE, HEM: Hematologic, IMM: Immune, HEP: Hepatic, NERV: Central Nervous System, : REP: Reproductive, RESP: Respiratory, SKN: Skin.

**Table 4. <sup>1</sup>Estimated carbon range-weighted TPH chronic and subchronic toxicity factors for tapwater exposure scenarios based on fuel-water study.**

<sup>3</sup> Exposure Pathway	<sup>2,3</sup> JP-5 TPH Chronic/Subchronic Toxicity Factor	
	Dissolved-Phase	<sup>4</sup> Dissolved-Phase Plus Sheen
Ingestion (RfD)	0.010/0.040 mg/kg-day	0.010/0.079 mg/kg-day
Dermal (RfD)	0.010/0.040 mg/kg-day	0.010/0.079 mg/kg-day
<sup>5</sup> Inhalation (RfC)	60/200 µg/m <sup>3</sup>	115/126 µg/m <sup>3</sup>

1. Based on measured carbon range makeup of neat- and dissolved-phase JP-5 jet fuel from the Navy's Red Hill fuel storage facility (Newfields 2023a).

2. Oral and dermal Reference Doses (RfDs) and inhalation Reference Concentration (RfC) weighted with respect to measured carbon range makeup of neat (sheens) and dissolved-phase JP-5 fuel (excludes BTEXNM).

3. Ingestion and dermal pathway chronic TPH toxicity factors for dissolved-phase-only versus sheen scenarios are identical due to identical toxicity factors used for >C8 aromatics (dominate dissolved phase) and >C8-C18 aliphatics (dominate sheen phase). Subchronic TPH factors are different for the dissolved-only scenario due to differences in subchronic toxicity factors for >C8-C18 aliphatics vs >C8 aromatics.

4. Dermal exposure pathway only considers aromatic compounds for dissolved-phase only contamination. Aliphatic compounds assumed emitted to indoor air during water use included under inhalation exposure pathway.

5. Inhalation pathway considers only aromatics in dissolved-phase scenario based on carbon range of water samples in water-fuel study. Inhalation toxicity factors for sheen based on measured carbon range makeup of vapors emitted from JP-5 fuel (dominated by >C8-C18 aliphatics).

**Table 5. Risk-based screening levels for JP-5 jet fuel-related contaminants in tapwater and ambient air.**

Compound	Tapwater		Residential Ambient Air	
	<sup>1</sup> Chronic Exposure (µg/L)	<sup>2</sup> Subchronic Exposure (µg/L)	<sup>1</sup> Chronic Exposure (µg/m <sup>3</sup> )	<sup>2</sup> Subchronic Exposure (µg/m <sup>3</sup> )
Benzene	59	150	31	83
Toluene	1,200	12,000	1,000	1,000
Ethylbenzene	620	650	1,000	9,400
Xylenes	820	2,500	100	420
Naphthalene	6.1	36	3.1	0.63
1-Methylnaphthalene	530	530	58	58
2-Methylnaphthalene	30	30	3.3	3.3
<sup>3</sup> TPH JP-5	<sup>4</sup> Dissolved Only	266	-	-
	<sup>5,6</sup> Dissolved Only	91	350	63
	<sup>5,6</sup> Dissolved +Sheen	97	520	120
DiEGME	800	800	(not volatile)	(not volatile)
2,6-Di-Tert-Butyl-4-Methylphenol	3.4	(not available)	(not volatile)	(not volatile)

1. Chronic Exposure: Potential noncancer health effects if average exposure exceeds the noted screening level for a period of one year or more. Tapwater cancer-based screening levels ( $10^{-6}$  excess cancer risk): B = 0.46 µg/L E = 1.5 µg/L N = 0.12 µg/L. Ambient air cancer-based screening levels ( $10^{-6}$  excess cancer risk): B = 0.36 µg/m<sup>3</sup> E = 1.1 µg/m<sup>3</sup>, N = 0.08 µg/m<sup>3</sup>.

2. Subchronic Exposure: Potential noncancer health effects if average exposure exceeds the noted screening level for a period of more than two weeks to one year. Subchronic toxicity factors not available for methylnaphthalenes. Chronic screening levels substituted.

3. Separate tapwater screening level for TPH associated with dissolved-phase only JP-5 vs dissolved-phase plus a sheen noted. Levels differ for exposure to dissolved-phase TPH versus exposure to tapwater with a sheen due to different carbon range makeup different phases (refer to Table 1). Vapors emitted from dissolved JP-5 assumed to be dominated by >C8 aromatics. Vapors emitted from sheen assumed to be dominated by slightly less toxic >C8-C18 aliphatics.

4. HDOH April 2022 JP-5 TPH tapwater screening level noted – based on 2009 USEPA toxicity factors for aliphatic an aromatic carbon ranges (HDOH 2022).

5. TPH screening levels based on 2022 USEPA update of carbon range toxicity factors. (USEPA 2022; see Table 3). Confidence in the updated toxicity factors and applicability to the release of JP-5 into the JBPHH drinking water system should be reviewed as part of a Health Assessment.

6. Calculated tapwater screening levels fall below normal laboratory Method Reporting Limit (MRL) for >C8-C24 fuel compounds of approximately 200 µg/L (“Mid-Range Organics (MRO)” aka “Diesel Range Organics”). Sample data below this concentration are typically qualified with a “J” flag. In these cases, the laboratory is both unable to verify that the detected compound is associated with petroleum and that the estimated concentration of the compound is accurate.

**Table 6. Summary of assessment of exposure of JBPHH residents to contaminants in tapwater immediately following the November 20, 2021, release of JP-5 jet fuel into the base drinking water system.**

Exposure Pathway	Compound	<sup>1</sup> Tapwater Subchronic Screening (µg/L)	<sup>2</sup> Reasonable Maximum Exposure Concentration			<sup>3</sup> Predicted Subchronic Health Risk
			Dissolved-Phase Contaminants Only (µg/L)	Dissolved Contaminants +JP-5 Sheen (µg/L)	Dissolved Contaminants +JP-5 Sheen +FSII Emulsion (µg/L)	
Tapwater Ingestion	<b>Benzene</b>	150	168	174	174	Minimal Health Risk
	<b>Toluene</b>	1,200	267	304	304	Insignificant Health Risk
	<b>Ethylbenzene</b>	650	145	219	219	Insignificant Health Risk
	<b>Xylenes</b>	2,500	775	1,149	1,149	Insignificant Health Risk
	<b>Naphthalene</b>	36	156	680	680	Potential Min to Mod Health Risk
	<b>1-Methylnaphthalene</b>	530	162	883	883	Minimal Health Risk
	<b>2-Methylnaphthalene</b>	30	221	1,256	1,256	Potential Min to Mod Health Risk
	<b><sup>4</sup>TPH (JP-5)</b>	350 (270)	6,101	156,101	156,101	Potential High to Very High Health Risk
<b>DiEGME</b>	800	1,695,833	1,696,933	4,000,000	Potential High to Very High Health Risk	

1. Refer to Table 5.

2. Refer to Table 2.

3. Insignificant Risk = < Screening Level; Minimal Risk = ≤10X Screening Level; Moderate Risk = 10X to ≤100X Screening Level; High Risk = 100X to ≤1,000X Screening Level; Very High Risk = >1,000X Screening Level.

4. Risk posed by dissolved-phase TPH driven by >C8 aromatics; risk posed by TPH in sheen on water driven by >C8-C18 aliphatics, with a less contribution from >C8 aromatics.

## **10.0 ATTACHMENTS**

Attachment 1. Photographs

Attachment 2. Navy Facility Flushing Checklist Field Logs

Attachment 3. Red Hill Shaft Faucet Chromatograms

Attachment 4. Water-Fuel Experiment Laboratory Reports

Attachment 5: Calculation of Reasonable Maximum Exposure Levels

Attachment 6. COPC Health Effects

Attachment 7. Calculation of Weighted TPH Toxicity Factors

Attachment 8. Tapwater Screening Level Model

**Attachment 1. Images of Contaminated Tapwater**



Figure 1. Sheens and gel-like emulsions and foams in tapwater from residences following release of JP-5 jet fuel into JBPHH drinking water system (Hawaii News Now 2021a). A) Fuel sheen on tapwater from JBPHH resident home (Hawaii News Now 2021a,b); B) Foamy residue on tapwater from JBPHH resident home (Hawaii News Now 2021b) C) Emulsion-like material on tapwater from JBPHH resident (HNN 2021c); D) Approximately one-millimeter thick layer of gel-like emulsion on sample of fuel-contaminated; tapwater collected by JBPHH resident (used with permission from resident); E) Flammable vapors from fuel-contaminated tapwater at a JBPHH residence (Vice News 2022); F) Foamy residue from garden hose of JBPHH resident home (used with permission from resident).



## Figure 1 (cont.)

## References:

HNN, 2021a, *Navy water system users should avoid consuming water after 'fuel-like' odor reported*: Hawaii News Now, Published November 29, 2021.

<https://www.hawaiinewsnow.com/2021/11/29/navy-investigating-reports-chemical-smell-water-homes-joint-base-pearl-harbor-hickam-area>

HNN, 2021b, *A military family invited us in to see (and smell) their water firsthand. Here's what we saw*: Hawaii News Now, Published November 30, 2021.

<https://www.hawaiinewsnow.com/2021/12/01/military-families-show-oily-smelly-sheen-water-hnn-sends-samples-independent-lab/>

HNN, 2021c, *Hawaii News Now, HNN sent water from the Navy's lines to a private lab. Here's what they found*: Hawaii News Now, Published December 2, 2021.

<https://www.hawaiinewsnow.com/2021/12/03/hnn-sent-navys-tainted-water-private-lab-testing-heres-what-they-found/>

Vice Media, 2022, *How Military Jet Fuel Leaked Into Hawaii's Drinking Water*: Vice News, April 27, 2022, <https://www.youtube.com/watch?v=AuDsana5wvQ>

**Attachment 2. Navy Facility Flushing Checklist Field Logs**

# FACILITY FLUSHING CHECKLIST

**ZONE:** Flushing Zone A1

**NEIGHBORHOOD:** \_\_\_\_\_

**ADDRESS:** 1608 Aloha Avenue (A1-ALOH1608)

## FLUSHING CHECKLIST COMPLETION STATUS

- STEP 1: FOLLOW STANDARD SITE SAFETY AND COVID-19 PROTOCOL
- STEP 2: PREPARE FACILITY FOR FLUSHING
- STEP 3: PERFORM SERVICE LINE FLUSH AND COLD WATER PLUMBING FLUSH
- STEP 4: WATER HEATERS AND EXPANSION TANKS
- STEP 5: PERFORM HOT WATER SYSTEM FLUSH
- STEP 6: FLUSH ALL SPIGOTS
- STEP 7: ADDRESS MAJOR APPLIANCES AND WATER CONSUMING EQUIPMENT
- STEP 8: CLEAN UP
- STEP 9: RECORD WATER USE OR FLUSHING TIME, OBSERVATIONS AND NOTES

- FUEL ODOR PRESENT DURING OR AFTER FLUSHING?

Notes: JP4 in toilets before flushing.

- Residents are COVID-19 Risk
- UNABLE TO GAIN SAFE ACCESS TO THIS ADDRESS
  - Unsecure Pet
  - Unsupervised Child
  - Tenant denied entry
  - Locked Door (no key available)
  - Maintenance Issues
  - Other: reason can't access address

## General Notes:

General notes test 1.

## Confirmation of Flushing of Facility

Flusher  
\_\_\_\_\_  
**Name of Facility Flusher**

Org  
\_\_\_\_\_  
**Organization**

Digitally signed/certified by Facility Flusher

1/8/2022 3:15:12 PM  
\_\_\_\_\_  
**Date**

# FACILITY FLUSHING CHECKLIST

**ZONE:** Flushing Zone B1

**NEIGHBORHOOD:** \_\_\_\_\_

**ADDRESS:** Building 1, RECREATION FACILITY-RICHARDS (B1-BLDG0001)

## FLUSHING CHECKLIST COMPLETION STATUS

- STEP 1: FOLLOW STANDARD SITE SAFETY AND COVID-19 PROTOCOL
- STEP 2: PREPARE FACILITY FOR FLUSHING
- STEP 3: PERFORM SERVICE LINE FLUSH AND COLD WATER PLUMBING FLUSH
- STEP 4: WATER HEATERS AND EXPANSION TANKS
- STEP 5: PERFORM HOT WATER SYSTEM FLUSH
- STEP 6: FLUSH ALL SPIGOTS
- STEP 7: ADDRESS MAJOR APPLIANCES AND WATER CONSUMING EQUIPMENT
- STEP 8: CLEAN UP
- STEP 9: RECORD WATER USE OR FLUSHING TIME, OBSERVATIONS AND NOTES

- FUEL ODOR PRESENT DURING OR AFTER FLUSHING?

Notes:

- Residents are COVID-19 Risk
- UNABLE TO GAIN SAFE ACCESS TO THIS ADDRESS
  - Unsecure Pet
  - Unsupervised Child
  - Tenant denied entry
  - Locked Door (no key available)
  - Maintenance Issues
  - Other: substation no water

## General Notes:

## Confirmation of Flushing of Facility

jules  
**Name of Facility Flusher**

mwr  
**Organization**

Digitally signed/certified by Facility Flusher

1/28/2022 4:42:39 PM  
**Date**

## FACILITY FLUSHING CHECKLIST

**ZONE:** Flushing Zone D2

**NEIGHBORHOOD:** \_\_\_\_\_

**ADDRESS:** Building 1055H,SHOP-ACFT GEN PURP HGR 34&35 (D2-BLDG1055H)

### FLUSHING CHECKLIST COMPLETION STATUS

- STEP 1: FOLLOW STANDARD SITE SAFETY AND COVID-19 PROTOCOL
- STEP 2: PREPARE FACILITY FOR FLUSHING
- STEP 3: PERFORM SERVICE LINE FLUSH AND COLD WATER PLUMBING FLUSH
- STEP 4: WATER HEATERS AND EXPANSION TANKS
- STEP 5: PERFORM HOT WATER SYSTEM FLUSH
- STEP 6: FLUSH ALL SPIGOTS
- STEP 7: ADDRESS MAJOR APPLIANCES AND WATER CONSUMING EQUIPMENT
- STEP 8: CLEAN UP
- STEP 9: RECORD WATER USE OR FLUSHING TIME, OBSERVATIONS AND NOTES

- FUEL ODOR PRESENT DURING OR AFTER FLUSHING?

Notes:

- Residents are COVID-19 Risk
- UNABLE TO GAIN SAFE ACCESS TO THIS ADDRESS
  - Unsecure Pet
  - Unsupervised Child
  - Tenant denied entry
  - Locked Door (no key available)
  - Maintenance Issues
  - Other:

### General Notes:

### Confirmation of Flushing of Facility

TSgt BETANCOURT, A  
\_\_\_\_\_  
**Name of Facility Flusher**

15 MXG  
\_\_\_\_\_  
**Organization**

Digitally signed/certified by Facility Flusher

1/26/2022 2:32:38 PM  
\_\_\_\_\_  
**Date**

## FACILITY FLUSHING CHECKLIST

**ZONE:** Flushing Zone C2

**NEIGHBORHOOD:** \_\_\_\_\_

**ADDRESS:** Building 1746,REGION LEGAL SERVICE OFFICE (C2-BLDG1746)

### FLUSHING CHECKLIST COMPLETION STATUS

- STEP 1: FOLLOW STANDARD SITE SAFETY AND COVID-19 PROTOCOL
- STEP 2: PREPARE FACILITY FOR FLUSHING
- STEP 3: PERFORM SERVICE LINE FLUSH AND COLD WATER PLUMBING FLUSH
- STEP 4: WATER HEATERS AND EXPANSION TANKS
- STEP 5: PERFORM HOT WATER SYSTEM FLUSH
- STEP 6: FLUSH ALL SPIGOTS
- STEP 7: ADDRESS MAJOR APPLIANCES AND WATER CONSUMING EQUIPMENT
- STEP 8: CLEAN UP
- STEP 9: RECORD WATER USE OR FLUSHING TIME, OBSERVATIONS AND NOTES

FUEL ODOR PRESENT DURING OR AFTER FLUSHING?

Notes:

- Residents are COVID-19 Risk
- UNABLE TO GAIN SAFE ACCESS TO THIS ADDRESS
  - Unsecure Pet
  - Unsupervised Child
  - Tenant denied entry
  - Locked Door (no key available)
  - Maintenance Issues
  - Other:

**General Notes:**

### Confirmation of Flushing of Facility

LTJG CAIN ALEXIA  
**Name of Facility Flusher**

RLSONW DET HI  
**Organization**

Digitally signed/certified by Facility Flusher

1/25/2022 1:12:33 PM  
**Date**

## FACILITY FLUSHING CHECKLIST

**ZONE:** Flushing Zone D3

**NEIGHBORHOOD:** \_\_\_\_\_

**ADDRESS:** Building 1856H,DORM AIRMAN PERMANENT PARTY (D3-BLDG1856H)

### FLUSHING CHECKLIST COMPLETION STATUS

- STEP 1: FOLLOW STANDARD SITE SAFETY AND COVID-19 PROTOCOL
- STEP 2: PREPARE FACILITY FOR FLUSHING
- STEP 3: PERFORM SERVICE LINE FLUSH AND COLD WATER PLUMBING FLUSH
- STEP 4: WATER HEATERS AND EXPANSION TANKS
- STEP 5: PERFORM HOT WATER SYSTEM FLUSH
- STEP 6: FLUSH ALL SPIGOTS
- STEP 7: ADDRESS MAJOR APPLIANCES AND WATER CONSUMING EQUIPMENT
- STEP 8: CLEAN UP
- STEP 9: RECORD WATER USE OR FLUSHING TIME, OBSERVATIONS AND NOTES

- FUEL ODOR PRESENT DURING OR AFTER FLUSHING?

Notes:

- Residents are COVID-19 Risk
- UNABLE TO GAIN SAFE ACCESS TO THIS ADDRESS
  - Unsecure Pet
  - Unsupervised Child
  - Tenant denied entry
  - Locked Door (no key available)
  - Maintenance Issues
  - Other:

### General Notes:

### Confirmation of Flushing of Facility

msgt dueltgen  
**Name of Facility Flusher**

jbphh  
**Organization**

Digitally signed/certified by Facility Flusher

1/27/2022 2:55:02 PM  
**Date**

# FACILITY FLUSHING CHECKLIST

**ZONE:** Flushing Zone D1

**NEIGHBORHOOD:** \_\_\_\_\_

**ADDRESS:** Building 3455,JBPHH PASS & ID OFFICE (D1-BLDG3455)

## FLUSHING CHECKLIST COMPLETION STATUS

- STEP 1: FOLLOW STANDARD SITE SAFETY AND COVID-19 PROTOCOL
- STEP 2: PREPARE FACILITY FOR FLUSHING
- STEP 3: PERFORM SERVICE LINE FLUSH AND COLD WATER PLUMBING FLUSH
- STEP 4: WATER HEATERS AND EXPANSION TANKS
- STEP 5: PERFORM HOT WATER SYSTEM FLUSH
- STEP 6: FLUSH ALL SPIGOTS
- STEP 7: ADDRESS MAJOR APPLIANCES AND WATER CONSUMING EQUIPMENT
- STEP 8: CLEAN UP
- STEP 9: RECORD WATER USE OR FLUSHING TIME, OBSERVATIONS AND NOTES
  
- FUEL ODOR PRESENT DURING OR AFTER FLUSHING?  
Notes: NOTICED FUEL SHEEN ON THE DRINKING FOUTIAN DURING FLUSHING (15 SECONDS)
  
- Residents are COVID-19 Risk
  
- UNABLE TO GAIN SAFE ACCESS TO THIS ADDRESS
  - Unsecure Pet
  - Unsupervised Child
  - Tenant denied entry
  - Locked Door (no key available)
  - Maintenance Issues
  - Other:

## General Notes:

## Confirmation of Flushing of Facility

TRAVIS SONNEBORN  
\_\_\_\_\_  
**Name of Facility Flusher**

JBPHH SECURITY  
\_\_\_\_\_  
**Organization**

Digitally signed/certified by Facility Flusher

1/22/2022 2:19:06 PM  
\_\_\_\_\_  
**Date**



## FACILITY FLUSHING CHECKLIST

**ZONE:** Flushing Zone D4

**NEIGHBORHOOD:** \_\_\_\_\_

**ADDRESS:** Building 3566H, SECURITY POLICE KENNEL K9 (D4-BLDG3566H)

### FLUSHING CHECKLIST COMPLETION STATUS

- STEP 1: FOLLOW STANDARD SITE SAFETY AND COVID-19 PROTOCOL
- STEP 2: PREPARE FACILITY FOR FLUSHING
- STEP 3: PERFORM SERVICE LINE FLUSH AND COLD WATER PLUMBING FLUSH
- STEP 4: WATER HEATERS AND EXPANSION TANKS
- STEP 5: PERFORM HOT WATER SYSTEM FLUSH
- STEP 6: FLUSH ALL SPIGOTS
- STEP 7: ADDRESS MAJOR APPLIANCES AND WATER CONSUMING EQUIPMENT
- STEP 8: CLEAN UP
- STEP 9: RECORD WATER USE OR FLUSHING TIME, OBSERVATIONS AND NOTES
  
- FUEL ODOR PRESENT DURING OR AFTER FLUSHING?

Notes:

- Residents are COVID-19 Risk
  
- UNABLE TO GAIN SAFE ACCESS TO THIS ADDRESS
  - Unsecure Pet
  - Unsupervised Child
  - Tenant denied entry
  - Locked Door (no key available)
  - Maintenance Issues
  - Other:

### General Notes:

facility with no water to flush

### Confirmation of Flushing of Facility

Austin Kelly  
\_\_\_\_\_  
**Name of Facility Flusher**

NAVFAC  
\_\_\_\_\_  
**Organization**

Digitally signed/certified by Facility Flusher

1/31/2022 2:46:08 PM  
\_\_\_\_\_  
**Date**

# FACILITY FLUSHING CHECKLIST

**ZONE:** Flushing Zone F2

**NEIGHBORHOOD:** \_\_\_\_\_

**ADDRESS:** Building G-2944-AND, DETACHED GARAGE (2944-AND) (F2-BLDGG-2944-A)

## FLUSHING CHECKLIST COMPLETION STATUS

- STEP 1: FOLLOW STANDARD SITE SAFETY AND COVID-19 PROTOCOL
- STEP 2: PREPARE FACILITY FOR FLUSHING
- STEP 3: PERFORM SERVICE LINE FLUSH AND COLD WATER PLUMBING FLUSH
- STEP 4: WATER HEATERS AND EXPANSION TANKS
- STEP 5: PERFORM HOT WATER SYSTEM FLUSH
- STEP 6: FLUSH ALL SPIGOTS
- STEP 7: ADDRESS MAJOR APPLIANCES AND WATER CONSUMING EQUIPMENT
- STEP 8: CLEAN UP
- STEP 9: RECORD WATER USE OR FLUSHING TIME, OBSERVATIONS AND NOTES

FUEL ODOR PRESENT DURING OR AFTER FLUSHING?

Notes:

Residents are COVID-19 Risk

UNABLE TO GAIN SAFE ACCESS TO THIS ADDRESS

- Unsecure Pet
- Unsupervised Child
- Tenant denied entry
- Locked Door (no key available)
- Maintenance Issues
- Other:

**General Notes:**

## Confirmation of Flushing of Facility

SEABEE  
\_\_\_\_\_  
**Name of Facility Flusher**

NAVFAC  
\_\_\_\_\_  
**Organization**

Digitally signed/certified by Facility Flusher

2/3/2022 1:59:20 PM  
\_\_\_\_\_  
**Date**

## FACILITY FLUSHING CHECKLIST

**ZONE:** Flushing Zone F2

**NEIGHBORHOOD:** \_\_\_\_\_

**ADDRESS:** Building G-3062-AND, DETACHED GARAGE (3062-AND) (F2-BLDGG-3062-A)

### FLUSHING CHECKLIST COMPLETION STATUS

- STEP 1: FOLLOW STANDARD SITE SAFETY AND COVID-19 PROTOCOL
- STEP 2: PREPARE FACILITY FOR FLUSHING
- STEP 3: PERFORM SERVICE LINE FLUSH AND COLD WATER PLUMBING FLUSH
- STEP 4: WATER HEATERS AND EXPANSION TANKS
- STEP 5: PERFORM HOT WATER SYSTEM FLUSH
- STEP 6: FLUSH ALL SPIGOTS
- STEP 7: ADDRESS MAJOR APPLIANCES AND WATER CONSUMING EQUIPMENT
- STEP 8: CLEAN UP
- STEP 9: RECORD WATER USE OR FLUSHING TIME, OBSERVATIONS AND NOTES

- FUEL ODOR PRESENT DURING OR AFTER FLUSHING?

Notes:

- Residents are COVID-19 Risk
- UNABLE TO GAIN SAFE ACCESS TO THIS ADDRESS
  - Unsecure Pet
  - Unsupervised Child
  - Tenant denied entry
  - Locked Door (no key available)
  - Maintenance Issues
  - Other:

### General Notes:

### Confirmation of Flushing of Facility

SEABEE  
\_\_\_\_\_  
**Name of Facility Flusher**

NAVFAC  
\_\_\_\_\_  
**Organization**

Digitally signed/certified by Facility Flusher

2/3/2022 2:07:53 PM  
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**Date**

**Attachment 3. Red Hill Shaft Faucet Chromatograms**

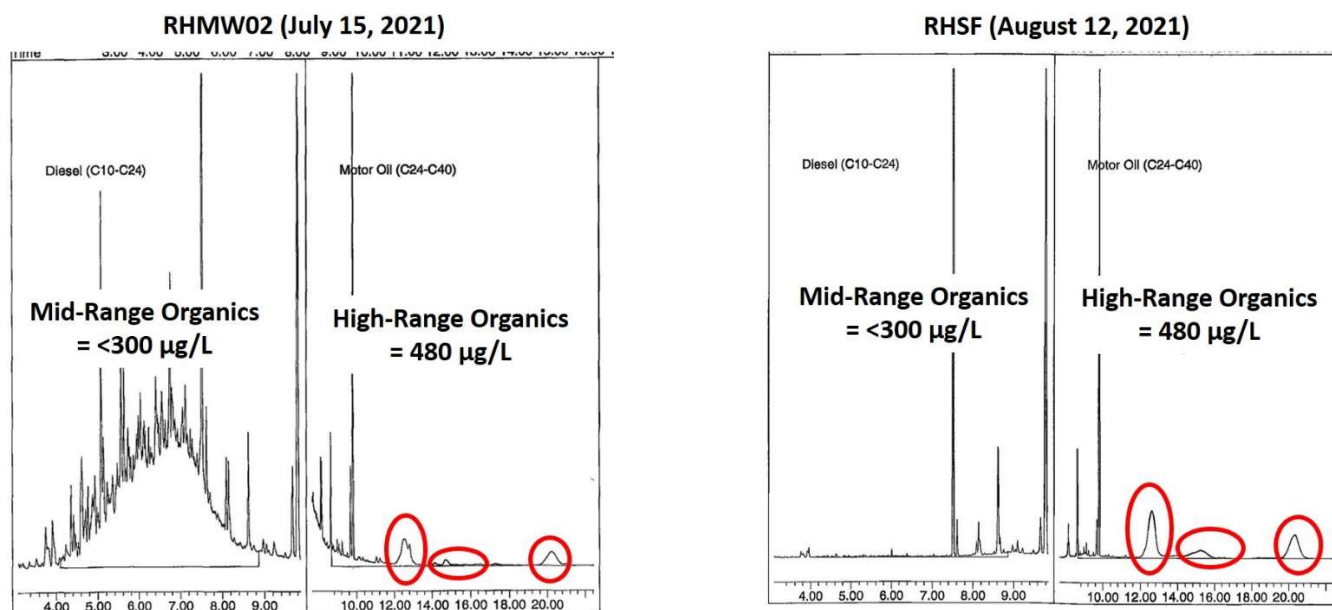


Figure 1. Chromatograms documenting the appearance in July of 2021 of unknown, high retention time and boiling point “High-Range Organic (HRO)” compounds (circled in red; aka “Residual Range Organics”) in groundwater immediately beneath the Red Hill Fuel Storage Facility (Monitoring Well RHMW02, Sample ERH1539; APPL 2022a ) and several thousand feet downgradient in water samples collected from the intake point into the Joint Base Pearl Harbor Hickam (JBPHH) drinking water system adjacent to the Red Hill Shaft water supply well (sampling point RHSF, Sample ERH1590; APPL 2022b). Groundwater in the vicinity of the monitoring well has been known to be contaminated with middle distillate fuels from past releases for many years, noted in the figure as “Mid-Range Organics (MRO)” (aka “Diesel Range Organics”). The specific types and concentrations of the HRO compounds were not determined by the Navy. Based on discussions with laboratory chemists, the compounds do not appear to be directly related to hydrocarbons associated with fresh jet fuel. The HRO range compounds were no longer detectable in water samples from either location by November 2021. Absence of the compounds in field blanks collected at the same time and tested by the laboratory confirm the presence of the compounds in the groundwater.

APPL, 2022a, Data Validatable Report : APPL Labs, March 31, 2022.

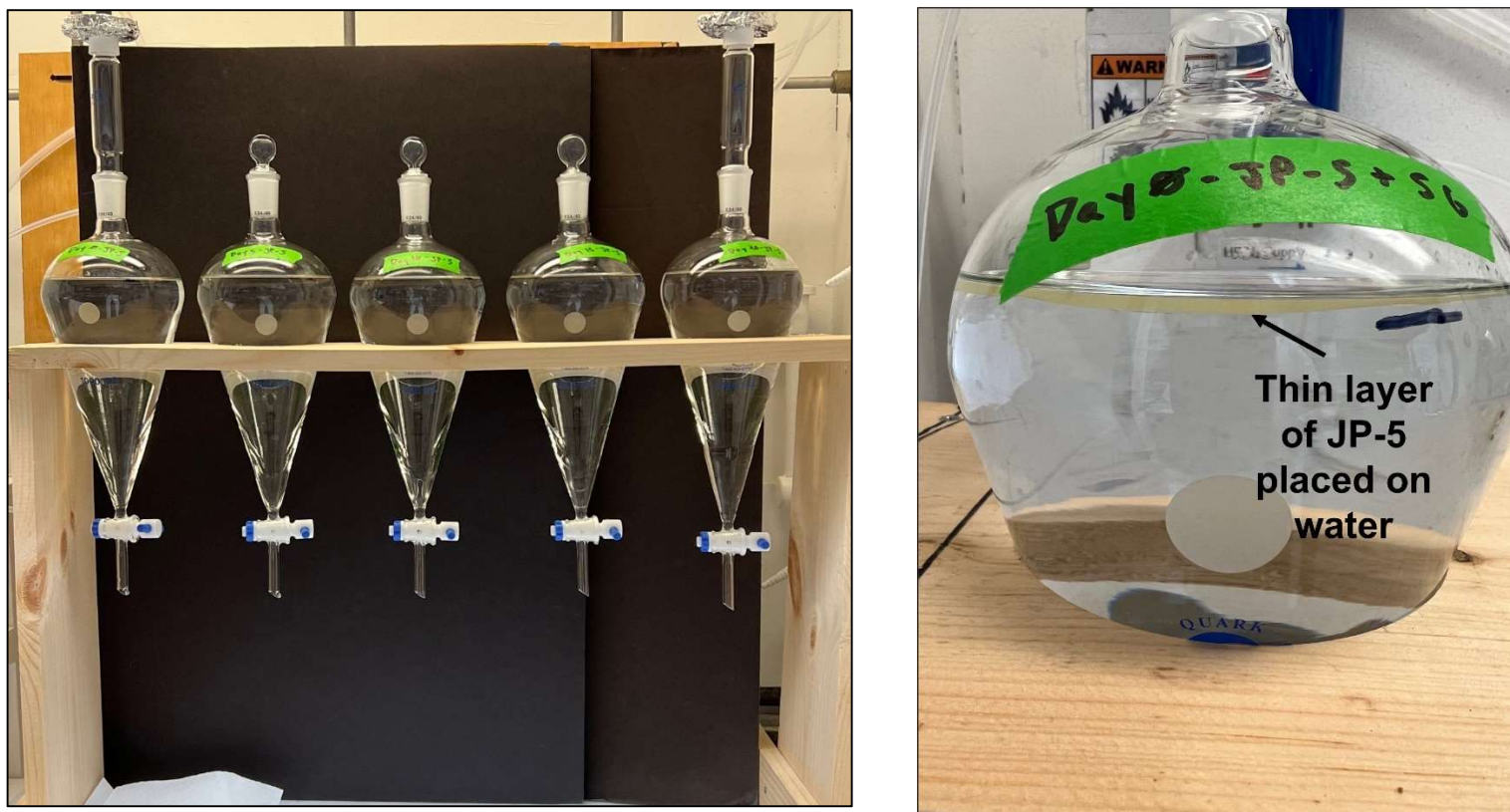
APPL, 2022b, Data Validatable Report : APPL Labs, August 12, 2022

**APPL Laboratory Reports (provided in separate pdf files)**

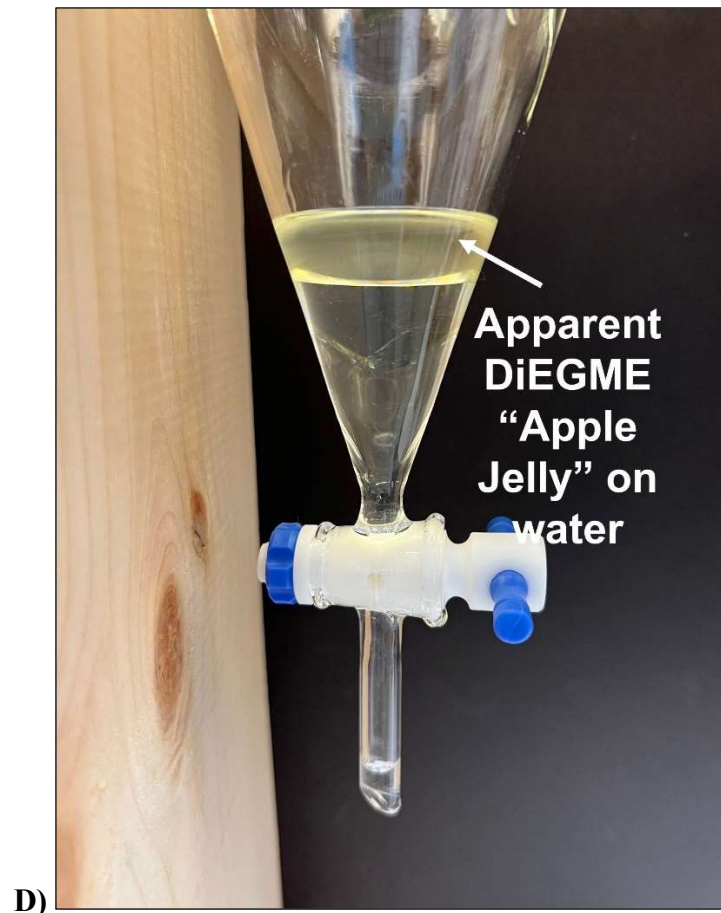


**Attachment 4. Water-Fuel Experiment Laboratory Data**





**Figure 1. Photographs of water-fuel experiments: A) Experiment setup using one-liter funnel flasks (L-R: Day 0, Day 5, Day 10, Day 15, Day 20); B) Closeup of 10 ml layer of JP-5 fuel placed on top of one liter of water.**



**Figure 1 (cont.). Photographs of water-fuel experiments: C) Collection of headspace vapor samples; D) Formation of apparent “apple jelly” emulsion of water and DiEGME on water.**

**Table 1. Summary of water-fuel laboratory experiment JP-5 neat fuel sample data.**

<b>Analytes</b>	<b>Units</b>	<b>Unadjusted</b>	<b><sup>1</sup>Adjusted</b>
Benzene	mg/kg	23	23
Toluene	mg/kg	187	187
Ethylbenzene	mg/kg	279	279
Xylenes	mg/kg	2,089	2,089
Naphthalene	mg/kg	2,890	2,890
1-Methylnaphthalene	mg/kg	5,440	5,440
2-Methylnaphthalene	mg/kg	3,590	3,590
C5-C8 Aliphatics	mg/kg	1,237	1,621
>C8-C18 Aliphatics	mg/kg	615,190	806,414
>C18-C32 Aliphatics	mg/kg		
>C8 Aromatics	mg/kg	135,385	177,467
DiEGME	mg/kg	500-550	500-550
	<b>Total:</b>	<b>766,309</b>	<b>1,000,000</b>
	<b>Total BTEXNM:</b>	<b>14,498</b>	<b>14,498</b>
	<b>Total Carbon Ranges:</b>	<b>751,811</b>	<b>985,502</b>

1. Carbon range data adjusted at recommendation of Newfields to generate a total concentration of compounds in the JP-5 fuel of 1,000,000 mg/kg (100%).

Table 2. Summary of water-fuel laboratory experiment data for dissolved-phase JP-5 in water.

Analyte	1Experiment Day										SG% Increase
	Day 0 (µg/L)	Day 0 (SG) (µg/L)	Day 5 (µg/L)	Day 5 (SG) (µg/L)	Day 10 (µg/L)	Day 10 (SG) (µg/L)	Day 15 (µg/L)	Day 15 (SG) (µg/L)	Day 20 (µg/L)	Day 20 (SG) (µg/L)	
Benzene	2.4	2.4	13	12	13	13	14	13	11	13	19%
Toluene	19	20	158	159	162	166	154	162	143	160	12%
Ethylbenzene	7.8	8.9	84	87	82	87	79	85	78	85	8%
Xylenes	60	68	628	641	635	678	624	681	633	675	7%
Naphthalene	61	65	612	602	616	660	706	725	662	693	5%
1-Methylnaphthalene	29	31	318	308	322	343	371	381	345	360	4%
2-Methylnaphthalene	21	22	233	228	236	254	275	286	257	269	5%
C5-C8 Aliphatics	0.0	0.0	7.8	7.9	6.9	6.7	6.2	5.8	5.4	5.9	9%
>C8-C18 Aliphatics	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
>C18-C32 Aliphatics	-	-	-	-	-	-	-	-	-	-	
>C8 Aromatics	400	357	2,682	2,655	3,323	2,748	2,855	3,417	3,466	3,417	-1%
DiEGME	49	45	49	53	52	59	53	47	-	53	
1-butoxy-2-propanol	0.0	35	0.0	39	0.0	36	0.0	39	-	41	
<b>Total:</b>	<b>648</b>	<b>619</b>	<b>4,784</b>	<b>4,753</b>	<b>5,448</b>	<b>5,015</b>	<b>5,138</b>	<b>5,803</b>	<b>5,600</b>	<b>5,730</b>	<b>2%</b>
<b>Total BTEXNM:</b>	<b>199</b>	<b>217</b>	<b>2,046</b>	<b>2,038</b>	<b>2,067</b>	<b>2,201</b>	<b>2,223</b>	<b>2,334</b>	<b>2,129</b>	<b>2,255</b>	<b>6%</b>
<b>Total Carbon Ranges:</b>	<b>400</b>	<b>357</b>	<b>2,690</b>	<b>2,663</b>	<b>3,330</b>	<b>2,755</b>	<b>2,862</b>	<b>3,422</b>	<b>3,471</b>	<b>3,423</b>	<b>-1%</b>

1. SG: Simple Green solution added to experiment.

**Table 3. <sup>1</sup>Summary of water-fuel laboratory experiment vapor data.**

Analytes	Units	Experiment Day (replicate samples)				
		Neat Fuel	Day 0	Day 0	Day 20	Day 20
Benzene	µg/m <sup>3</sup>	3,180	403	326	1,610	2,190
Toluene	µg/m <sup>3</sup>	30,600	8,710	6,520	22,600	29,700
Ethylbenzene	µg/m <sup>3</sup>	21,300	11,400	8,080	16,700	21,200
Xylenes	µg/m <sup>3</sup>	108,300	66,500	47,600	91,600	115,700
Naphthalene	µg/m <sup>3</sup>	6,080	3,700	3,170	3,850	5,560
1-Methylnaphthalene	µg/m <sup>3</sup>	3,649	2,124	2,172	0	0
2-Methylnaphthalene	µg/m <sup>3</sup>	2,743	1,927	1,995	0	0
C5-C8 Aliphatics	µg/m <sup>3</sup>	2,211,128	1,177,402	944,202	1,887,957	2,194,998
C9-C12+ Aliphatics	µg/m <sup>3</sup>	9,165,198	6,601,820	4,571,074	6,679,692	8,041,379
C9-C12+ Aromatics	µg/m <sup>3</sup>	373,769	282,125	195,255	347,868	456,854
	<b>Total:</b>	<b>11,925,947</b>	<b>8,156,110</b>	<b>5,780,394</b>	<b>9,051,877</b>	<b>10,867,580</b>
	<b>Total BTEXNM:</b>	175,852	94,763	69,864	136,360	174,350
	<b>Total Carbon Ranges:</b>	11,750,095	8,061,347	5,710,531	8,915,517	10,693,230

1. Vapor sample collected from HIDOH water-fuel experiments (Newfields 2022a).

**Table 4. <sup>1</sup>Relative carbon range makeup of vapors emitted from JP-5 fuel.**

Analytes	Neat Fuel	Experiment Day (replicate samples)						Average Day 0 & 20 % Makeup
		Day 0 #1 % Makeup	Day 0 #2 % Makeup	Day 0 Ave % Makeup	Day 0 #1 % Makeup	Day 0 #2 % Makeup	Day 20 Ave % Makeup	
Benzene	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Toluene	0.3%	0.1%	0.1%	0.1%	0.2%	0.3%	0.3%	0.2%
Ethylbenzene	0.2%	0.1%	0.1%	0.1%	0.2%	0.2%	0.2%	0.2%
Xylenes	0.9%	0.8%	0.8%	0.8%	1.0%	1.1%	1.0%	0.9%
Naphthalene	0.1%	0.0%	0.1%	0.1%	0.0%	0.1%	0.0%	0.0%
1-Methylnaphthalene	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2-Methylnaphthalene	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
C5-C8 Aliphatics	18.5%	14%	16%	15%	21%	20%	21%	18%
C9-C12+ Aliphatics	76.9%	81%	79%	80%	74%	74%	74%	77%
C9-C12+ Aromatics	3.1%	3.5%	3.4%	3.4%	3.8%	4.2%	4.0%	3.7%
<b>Total BTEXNM:</b>	<b>1.5%</b>	<b>1.2%</b>	<b>1.2%</b>	<b>1.2%</b>	<b>1.5%</b>	<b>1.6%</b>	<b>1.6%</b>	<b>1.4%</b>
<b>Total Carbon Ranges:</b>	<b>98.5%</b>	<b>98.8%</b>	<b>98.8%</b>	<b>98.8%</b>	<b>98.5%</b>	<b>98.4%</b>	<b>98.4%</b>	<b>98.6%</b>

1. Vapor sample collected from HDOH water-fuel experiments (Newfields 2022a).

**Alpha-Newfields Laboratory Reports (provided in separate pdf files)**





**Attachment 5: Calculation of Reasonable Maximum Exposure Levels**

- **Water-Fuel Experiment Based Summary Tables**
- **Model-Based Summary Tables**

## **Laboratory Water-Fuel Experiments**

**Table A. Water-Fuel Experiment measured relative makeup of neat- and dissolve-phase JP-5 fuel.**

Chemical/ Carbon Range	<sup>1</sup> Relative Weight Percent Makeup of Neat Fuel	<sup>2</sup> Makeup of Dissolved-Phase Hydrocarbons (mg/L)	<sup>2</sup> Relative Makeup of Dissolved- Phase Hydrocarbons
<b>Total BTEXMN:</b>	1.4%	2.1	41%
<b>Total Carbon Ranges:</b>	98.6%	3.1	59%
<b>Benzene</b>	0.00%	0.01	0.2%
<b>Toluene</b>	0.02%	0.15	3.0%
<b>Ethylbenzene</b>	0.03%	0.08	1.6%
<b>Xylenes</b>	0.21%	0.63	12.2%
<b>Naphthalene</b>	0.29%	0.65	12.5%
<b>1-Methylnaphthalene</b>	0.54%	0.34	6.5%
<b>2-Methylnaphthalene</b>	0.36%	0.25	4.8%
<b>C5-C8 Aliphatics</b>	0.16%	0.01	-
<b>&gt;C8-C18 Aliphatics</b>	81%	0.00	-
<b>&gt;C18-C32 Aliphatics</b>	0.00%	0.00	-
<b>&gt;C8 Aromatics</b>	18%	3.1	59%
<b>Sum:</b>	<b>100%</b>	<b>5.2</b>	<b>100%</b>

1. Data for sample of JP-5 collected from the Navy's Red Hill fuel storage facility (Newfields 2023).

2. Average of data for Days 5, 10, 15 and 20 of WAF study (Newfields 2023).

**Table B. Water-Fuel experiment measured relative makeup of dissolved-phase additives in water that is in contact with fresh JP-5 jet fuel.**

Additive	Average Days 5-20 (µg/L)
<b>DiEGME</b>	51
<b>2,6-Di-tert-butyl-4-Methylphenol</b>	38
<b>Linoleic Acid</b>	-

**Table C. <sup>1</sup>Water-Fuel experiment measured relative carbon range makeup of dissolved-phase fuel arranged for use in assessment of different exposure pathways.**

Chemical/ Carbon Range	<sup>2</sup> Relative Carbon Range Makeup of Dissolved-Phase Hydrocarbons (ingestion)	<sup>2</sup> Relative Carbon Range Makeup of Dissolved-Phase Hydrocarbons (aromatics dermal)	<sup>3</sup> Relative BTEXNM Makeup of Dissolved-Phase Hydrocarbons	<sup>4</sup> Relative Volatile Carbon Range Makeup of Dissolved-Phase Hydrocarbons	<sup>5</sup> Relative CR+BTEXN Makeup of Dissolved-Phase Hydrocarbons (ingestion)	<sup>5</sup> Relative CR+BTEXN Makeup of Dissolved-Phase Hydrocarbons (dermal)
Total BTEXN					41%	
Total Aliphatic Carbon Ranges					0.0%	
Total Aromatic Carbon Ranges					59%	
Benzene			0.60%		0.25%	0.25%
Toluene			7.3%		3.0%	3.0%
Ethylbenzene			3.8%		1.6%	1.6%
Xylenes			30%		12%	12%
Naphthalene			31%		13%	13%
1-Methylnaphthalene			16%		6.5%	6.5%
2-Methylnaphthalene			12%		4.8%	4.8%
C5-C6 Aliphatics	0.00%				0.0%	
>C6-C8 Aliphatics	0.00%				0.0%	
>C8-C10 Aliphatics	0.00%				0.0%	
>C10-C12 Aliphatics	0.00%				0.0%	
>C12-C16 Aliphatics	0.00%				0.0%	
>C16-C21 Aliphatics	0.00%				0.0%	
>C21-C32 Aliphatics	0.00%				0.0%	
>C8-C10 Aromatics	24%	24%		34%	14%	14%
>C10-C12 Aromatics	46%	46%		66%	27%	27%
>C12-C16 Aromatics	30%	30%			18%	18%
>C16-C21 Aromatics	0.00%				0.0%	0.0%
>C21-C32 Aromatics	0.00%				0.0%	0.0%
<b>Sum:</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>

**Table C (cont.). Water-Fuel experiment measured relative carbon range makeup of dissolved-phase fuel arranged for use in assessment of different exposure pathways.**

1. Measured makeup of dissolved-phase hydrocarbons in contact with fresh JP-5 jet fuel (water-fuel experiments; see Table 1).
2. Based on consideration only of carbon range components.
3. Based on consideration of BTEXNM component only.
4. Relative makeup of dissolved-phase volatile, VPH-equivalent carbon range components (C5-C8 aliphatics, >C8-C12 aliphatics, >C8-C12 aromatics).
5. Based on consideration of combined carbon range plus BTEXNM components.

**Table D. Water-Fuel experiment measured relative carbon range makeup of dissolved-phase fuel arranged for use in assessment of different exposure pathways (arranged to reflect toxicity-based groupings of carbon ranges).**

Chemical/ Carbon Range	<sup>2</sup> Relative Carbon Range Makeup of JP-5 Neat Fuel	<sup>3</sup> Relative Carbon Range Makeup of JP-5 Neat Fuel Hydrocarbons	<sup>3</sup> Relative Carbon Range Makeup of Dissolved-Phase Hydrocarbons (Total)	<sup>4</sup> Relative Carbon Range Makeup of Dissolved-Phase Hydrocarbons (Dermal Consideration)	<sup>5</sup> Relative BTEXMN Makeup of Dissolved-Phase Hydrocarbons	<sup>6</sup> Relative Volatile Carbon Range Makeup of Dissolved-Phase Hydrocarbons	<sup>7</sup> Relative CR+BTEXMN Makeup of Dissolved-Phase Hydrocarbons (ingestion)
<b>Total BTEXMN:</b>	1.4%						41%
<b>Total Carbon Ranges:</b>	98.6%						59%
<b>Benzene</b>	0.00%				0.60%		0.25%
<b>Toluene</b>	0.02%				7.3%		3.0%
<b>Ethylbenzene</b>	0.03%				3.8%		1.6%
<b>Xylenes</b>	0.21%				30%		12%
<b>Naphthalene</b>	0.29%				31%		13%
<b>1-Methylnaphthalene</b>	0.54%				16%		6.5%
<b>2-Methylnaphthalene</b>	0.36%				12%		4.8%
<b>C5-C8 Aliphatics</b>	0.16%	0.16%	0%	-		0.00%	0.0%
<b>&gt;C8-C18 Aliphatics</b>	81%	82%	0%	-		0%	0.00%
<b>&gt;C18-C32 Aliphatics</b>	0.00%	0.00%	0%	-		0.0%	0.0%
<b>&gt;C8 Aromatics</b>	18%	18%	100%	100%		100%	59%
<b>Sum:</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>

1. Measured makeup of dissolved-phase hydrocarbons in contact with fresh JP-5 jet fuel (water-fuel experiments; see Table 1).
2. Based on combined BTEXNM and carbon range data.
3. Based on consideration only of carbon range components.
4. Only dissolved-phase aromatic fraction for dermal update considers; aliphatics assumed emitted to indoor air.
5. Based on consideration of BTEXNM component only.
6. Relative makeup of dissolved-phase volatile, VPH-equivalent carbon range components (C5-C8 aliphatics, >C8-C12 aliphatics, >C8-C12 aromatics).
7. Based on consideration of combined carbon range plus BTEXNM components.

## **Modeled Effective Solubilities**

**Table A. Modeled relative makeup of neat- and dissolve-phase JP-5 fuel..**

Chemical/ Carbon Range	<sup>1</sup> Relative Weight Percent Makeup of Neat Fuel	<sup>1</sup> Predicted Makeup of Dissolved-Phase Hydrocarbons (mg/L)	<sup>1</sup> Predicted Relative Makeup of Dissolved- Phase Hydrocarbons
<b>Total BTEXMN:</b>	1.4%	1.5	27%
<b>Total Carbon Ranges:</b>	99%	3.9	73%
<b>Benzene</b>	0.00%	0.10	1.8%
<b>Toluene</b>	0.02%	0.20	3.7%
<b>Ethylbenzene</b>	0.03%	0.08	1.5%
<b>Xylenes</b>	0.21%	0.65	12%
<b>Naphthalene</b>	0.29%	0.13	2.4%
<b>1-Methylnaphthalene</b>	0.54%	0.18	3.4%
<b>2-Methylnaphthalene</b>	0.36%	0.12	2.13%
<b>C5-C8 Aliphatics</b>	0.16%	0.03	0.59%
<b>&gt;C8-C18 Aliphatics</b>	81%	0.05	0.85%
<b>&gt;C18-C32 Aliphatics</b>	0.0%	0.00	0.00%
<b>&gt;C8 Aromatics</b>	18%	3.9	72%
<b>Sum:</b>	<b>100%</b>	<b>5.4</b>	<b>100%</b>

**Table B. Modeled effective solubilities and relative makeup of dissolved-phase additives in water that is in contact with fresh JP-5 jet fuel.**

Additive	<sup>1</sup> Molecular Weight	Pure Component Solubility (mg/L)	<sup>1</sup> JP-5	<sup>2</sup> Effective Solubility (mg/L)
<b>Diethylene Glycol Monomethyl Ether (DiEGME)</b>	120	1.0E+06	0.11%	1,696
<b>2,6-Di-tert-butyl-4-Methylphenol</b>	220	60	0.0024%	0.0012
<b>Linoleic Acid</b>	280	1.39E-01	0.0054%	5.0E-06



**Table C. Modeled relative carbon range makeup of dissolved-phase fuel arranged for use in assessment of different exposure pathways.**

Chemical/Carbon Range	<sup>2</sup> Relative Carbon Range Makeup of Dissolved-Phase Hydrocarbons (ingestion)	<sup>2</sup> Relative Carbon Range Makeup of Dissolved-Phase Hydrocarbons (dermal)	<sup>3</sup> Relative BTEXNM Makeup of Dissolved-Phase Hydrocarbons	<sup>4</sup> Relative Volatile Carbon Range Makeup of Dissolved-Phase Hydrocarbons	<sup>5</sup> Relative CR+BTEXN Makeup of Dissolved-Phase Hydrocarbons (ingestion)	<sup>5</sup> Relative CR+BTEXN Makeup of Dissolved-Phase Hydrocarbons (dermal)
<b>Total BTEXN</b>					27%	
<b>Total Aliphatic Ranges</b>					1.4%	
<b>Total Aromatic Ranges</b>					72%	
<b>Benzene</b>			7%		1.8%	1.8%
<b>Toluene</b>			14%		3.7%	3.7%
<b>Ethylbenzene</b>			6%		1.5%	1.5%
<b>Xylenes</b>			45%		12%	12.2%
<b>Naphthalene</b>			8.92%		2.4%	2.4%
<b>1-Methylnaphthalene</b>			13%		3.4%	3.4%
<b>2-Methylnaphthalene</b>			8%		2.1%	2.2%
<b>C5-C6 Aliphatics</b>	0.45%			0.55%	0.3%	
<b>&gt;C6-C8 Aliphatics</b>	0.36%			0.44%	0.26%	
<b>&gt;C8-C10 Aliphatics</b>	0.83%			1.0%	0.61%	
<b>&gt;C10-C12 Aliphatics</b>	0.32%			0.40%	0.24%	
<b>&gt;C12-C16 Aliphatics</b>	0.01%				0.01%	
<b>&gt;C16-C21 Aliphatics</b>	0.00%				0.00%	
<b>&gt;C21-C32 Aliphatics</b>	0.00%				0.00%	
<b>&gt;C8-C10 Aromatics</b>	26%	26%		32%	19%	19%
<b>&gt;C10-C12 Aromatics</b>	53%	54%		66%	39%	39%
<b>&gt;C12-C16 Aromatics</b>	19%	20%			14%	14%
<b>&gt;C16-C21 Aromatics</b>	0.04%	0.04%			0.03%	0.03%
<b>&gt;C21-C32 Aromatics</b>	0.00%	0.00%			0.00%	0.00%
<b>Sum:</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>

**Table C (cont.). Modeled relative carbon range makeup of dissolved-phase fuel arranged for use in assessment of different exposure pathways.**

1. Theoretical makeup of dissolved-phase hydrocarbons assuming fresh spill in direct contact with LNAPL and individual components present in water at maximum effective solubility. Based on effective solubilities noted in Table 6 and assumed saturated solution in water.
2. Based on consideration only of carbon range components.
3. Based on consideration of BTEXNM component only.
4. Relative makeup of dissolved-phase volatile, VPH-equivalent carbon range components (C5-C8 aliphatics, >C8-C12 aliphatics, >C8-C12 aromatics).
5. Based on consideration of combined carbon range plus BTEXNM components.

**Table D. <sup>1</sup>Modeled relative carbon range makeup of dissolved-phase fuel arranged for use in assessment of different exposure pathways (arranged to reflect toxicity-based groupings of carbon ranges).**

Chemical/ Carbon Range	<sup>2</sup> Relative Carbon Range Makeup of Neat Fuel	<sup>3</sup> Relative Carbon Range Makeup of Neat Fuel Hydrocarbons	<sup>3</sup> Relative Carbon Range Makeup of Dissolved-Phase Hydrocarbons (Total)	<sup>4</sup> Relative Carbon Range Makeup of Dissolved-Phase Hydrocarbons (Dermal Consideration)	<sup>5</sup> Relative BTEXMN Makeup of Dissolved-Phase Hydrocarbons	<sup>6</sup> Relative Volatile Carbon Range Makeup of Dissolved-Phase Hydrocarbons	<sup>7</sup> Relative CR+BTEXMN Makeup of Dissolved-Phase Hydrocarbons
<b>Total BTEXMN:</b>	1%						27%
<b>Total Carbon Ranges:</b>	99%						73%
<b>Benzene</b>	0.00%				6.6%		1.8%
<b>Toluene</b>	0.02%				13.6%		3.7%
<b>Ethylbenzene</b>	0.03%				5.7%		1.5%
<b>Xylenes</b>	0.21%				45%		12%
<b>Naphthalene</b>	0.29%				8.9%		2.4%
<b>1-Methylnaphthalene</b>	0.54%				12.6%		3.4%
<b>2-Methylnaphthalene</b>	0.36%				7.9%		2.1%
<b>C5-C8 Aliphatics</b>	0.16%	0%	1%	-		1%	0.6%
<b>&gt;C8-C18 Aliphatics</b>	81%	82%	1.2%	-		1.4%	0.85%
<b>&gt;C18-C32 Aliphatics</b>	0.00%	0.00%	0.0%	-		0.0%	0.0%
<b>&gt;C8 Aromatics</b>	17.7%	18%	98%	99%		98%	72%
<b>Sum:</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100.00%</b>	<b>100%</b>	<b>100%</b>

1. Theoretical makeup of dissolved-phase hydrocarbons assuming fresh spill in direct contact with LNAPL and individual components present in water at maximum effective solubility. Based on effective solubilities noted in Table 6 and assumed saturated solution in water.
2. Based on combined BTEXNM and carbon range data.
3. Based on consideration only of carbon range components.
4. Only dissolved-phase aromatic fraction for dermal update considers; aliphatics assumed emitted to indoor air.
5. Based on consideration of BTEXNM component only.
6. Relative makeup of dissolved-phase volatile, VPH-equivalent carbon range components (C5-C8 aliphatics, >C8-C12 aliphatics, >C8-C12 aromatics).
7. Based on consideration of combined carbon range plus BTEXNM components.

## **Attachment 6. COPC Health Effects**

**Table 2a. Example Target Organ and <sup>a,e</sup>Acute Health Effects.**

Chemical	Target Organs for <sup>a,e</sup> Acute Health Effects													
	<sup>b</sup> Carcinogen	<sup>c</sup> Mutagen	<sup>d</sup> Alimentary Tract	Cardiovascular	Developmental	Endocrine	Eye	Hematologic	Immune	Kidney	Nervous	Reproductive	Respiratory	Skin
<b>Hydrocarbons</b>														
Benzene			8	3			8				8		8	3,8
Toluene			8	3			3,8				3,8		3,8	3,8
Ethylbenzene			3,8				3,8				3,8		3,8	3,8
Xylenes			3,8				3,8				3,8		3,8	3,8
1-Methylnaphthalene			8				8				8		8	3,8
2-Methylnaphthalene			8				8				8		8	3,8
Naphthalene			3,8				3,8				3,8		3,8	3,8
Aliphatic Carbon Ranges			3,7				3,7				3,7		3,7	3,7
Aromatic Carbon Ranges											3,7			
<b>Additives</b>														
Diethylene Glycol Monomethyl Ether			9				8,9				8,9	8		8
2,6-Di-Tert-Butyl-4-Methylphenol			8										8	

**Table 2b. Example Target Organ and <sup>a</sup>Subchronic Health Effects.**

*Chemical	Target Organs for <sup>a,e</sup> Subchronic Health Effects													
	<sup>b</sup> Carcinogen	<sup>c</sup> Mutagen	<sup>d</sup> Alimentary Tract	Cardiovascular	Developmental	Endocrine	Eye	Hematologic	Immune	Kidney	Nervous	Reproductive	Respiratory	Skin
<b>Hydrocarbons</b>														
Benzene								6						
Toluene										6				
Ethylbenzene			6											
Xylenes					6									
1-Methylnaphthalene														
2-Methylnaphthalene												6		
Naphthalene														
Aliphatic Carbon Ranges			7					7		7			7	
Aromatic Carbon Ranges											7			
<b>Additives</b>														
Diethylene Glycol Monomethyl Ether			9				8,9				8,9	8		8
2,6-Di-Tert-Butyl-4-Methylphenol			8										8	

\*Subchronic toxicity factors not available for 1-Methylnaphthalene and Naphthalene.

**Table 2c. Example Target Organ and <sup>a</sup>Chronic Health Effects.**

Chemical	Target Organs for <sup>a</sup> Chronic Health Effects													
	<sup>b</sup> Carcinogen	<sup>c</sup> Mutagen	<sup>d</sup> Alimentary Tract	Cardiovascular	Developmental	Endocrine	Eye	Hematologic	Immune	Kidney	Nervous	Reproductive	Respiratory	Skin
<b>Hydrocarbons</b>														
Benzene	A	2	2	4	1,3			1,2,3,8	1,2,3		2	8		
Toluene	D		4,5,8		2,3,8		1,3		3	4,5	1,2,5	2	1,5	
Ethylbenzene	C		1,2,4,5,8		1,3,5	1		8		1,2,3,5,8	2			
Xylenes	D			8	2		1			8	1,2,3,4,5,8	2	1,8	
1-Methylnaphthalene	C		8				8	3,4,5,8	3	8			2	
2-Methylnaphthalene	D				4			3,5	3				2	
Naphthalene	C						2,8	2,3	3		4		1,5	
Aliphatic Carbon Ranges	D		7					7		7	7		7	
Aromatic Carbon Ranges	D										7			
<b>Additives</b>														
Diethylene Glycol Monomethyl Ether	D		8		6,8					8	8	8		8
2,6-Di-Tert-Butyl-4-Methylphenol	D		8		6	8				8		8		8

**Table 2 Series Notes. Summary of Example Target Organ and Chronic Health Effects.****Health Effects:**

- a. Acute: Health effects within >1 day to 14 days (normally associated to exposure to high concentrations of chemical); Subchronic: health effects >14 days to 365 days; Chronic: Health affects after >365 days of exposure (ATSDR 2018).
- b. Carcinogen type from USEPA 2023c (chronic exposure for individually targeted aromatic compounds only).
- c. Chemicals classified as mutagenic (M) in USEPA 2023c (chronic exposure only).
- d. Gastro-intestinal tract, liver, spleen, gall bladder, etc.
- e. Acute health effects from exposure to hydrocarbons can include eye and skin irritation, dermatitis, defatting of skin, dizziness, headache, anesthesia, coughing, gagging, vomiting, griping, diarrhea, blood in the urine, depressed respiration, pulmonary edema, etc. Acute health effects posed by DiEGME include headache, dizziness, tiredness, nausea and vomiting and eye irritation.

ATSDR, 2018, Minimal Risk Levels (MRLs) – For Professionals: U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry, June 21, 2018.

**Health Effects References:**

1. CAEPA, 2023, Consolidated Table of Chronic Reference Exposure Levels: California Environmental Protection Agency, Office of Environmental Health Hazard Assessment, Air Resources Board, May 2023.
2. UNEP, 2023, International Chemical Safety Cards: United Nations Environment Program, International Labour Office and World Health Organization, International Programme on Chemical Safety (accessed May 2023). <https://www.ilo.org/dyn/icsc/showcard.listCards3>
3. ATSDR, 2023, *Toxicological Profiles*: Agency for Toxic Substances and Disease Registry (accessed May 2023), <https://wwwn.cdc.gov/TSP/ToxFAQs/ToxFAQsLanding.aspx>. Toxicological profile for JP-5, JP-8 and Jet A Fuels referenced for TPH (carbon ranges).
4. ILEPA, 2023, Tiered Approach to Corrective Action Objectives (TACO), Toxicity Values for Tier 2 and Tier 3 Calculations: Illinois Environmental Protection Agency, <https://epa.illinois.gov/topics/cleanup-programs/taco.html> (accessed May 2023). Critical effect noted.
5. USEPA, 2023a, Integrated Risk Information System: U.S. Environmental Protection Agency, (accessed May 2023). <https://www.epa.gov/iris>
6. USEPA. 2023b. Provisional Peer-Reviewed Toxicity Values: U.S. Environmental Protection Agency, Center for Public Health and Environmental Assessment Office of Research and Development, Cincinnati, Ohio, USA (accessed May 2023).
7. USEPA. 2022. *Provisional Peer-Reviewed Toxicity Values for Complex Mixtures of Aliphatic and Aromatic Hydrocarbons*: U.S. Environmental Protection Agency, Center for Public Health and Environmental Assessment Office of Research and Development, Cincinnati, Ohio, USA. EPA/690/R-22/003F, September 2022.
8. NIH, 2023, PubChem: National Library of Medicine, National Center for Biotechnology Information, accessed May 21, 2023. <https://pubchem.ncbi.nlm.nih.gov/>
9. ThermoFisher Scientific, 2021, 2-(2-Methoxyethoxy)ethanol Safety Data Sheet, December 24, 2021.



**Table 3a. Modeled effective solubilities and relative makeup of dissolved-phase hydrocarbons in water that is in contact with fresh JP-5 jet fuel.**

Chemical/ Carbon Range	<sup>1</sup> Molecular Weight	Pure Component Solubility (mg/L)	<sup>2</sup> Neat JP-5 (raw data) (mg/kg)	<sup>2</sup> Neat JP-5 (adjusted) (mg/kg)	Measure Makeup of Neat JP-5	Effective Solubility (mg/L)	Predicted Relative Makeup of Dissolved-Phase Hydrocarbons
<b>Benzene</b>	78	1,790	23	23	0.00%	0.10	1.8%
<b>Toluene</b>	92	526	187	187	0.02%	0.20	3.7%
<b>Ethylbenzene</b>	106	169	279	279	0.03%	0.08	1.5%
<b>Xylenes</b>	106	178	2089	2,089	0.21%	0.65	12.0%
<b>Naphthalene</b>	128	31	2890	2,890	0.29%	0.13	2.4%
<b>1-Methylnaphthalene</b>	142	25.8	5440	5,440	0.54%	0.18	3.4%
<b>2-Methylnaphthalene</b>	142	24.6	3590	3,590	0.36%	0.12	2.1%
<b>C5-C6 Aliphatics</b>	81	36	163	214	0.02%	0.02	0.3%
<b>&gt;C6-C8 Aliphatics</b>	100	5.4	1,073	1,407	0.14%	0.01	0.3%
<b>&gt;C8-C10 Aliphatics</b>	130	0.43	41,036	53,791	5.4%	0.03	0.6%
<b>&gt;C10-C12 Aliphatics</b>	160	0.03	246,692	323,373	32%	0.01	0.2%
<b>&gt;C12-C16 Aliphatics</b>	200	7.6E-04	322,432	422,656	42%	3.0E-04	0.0%
<b>&gt;C16-C21 Aliphatics</b>	270	2.5E-06	5,030	6,593	0.66%	1.1E-08	0.0%
<b>&gt;C21-C32 Aliphatics</b>	400	1.5E-11	-			0.00	0.0%
<b>&gt;C8-C10 Aromatics</b>	120	65	7,755	10,166	1.0%	1.02	18.9%
<b>&gt;C10-C12 Aromatics</b>	130	25	44,846	58,785	5.9%	2.1	38.7%
<b>&gt;C12-C16 Aromatics</b>	150	5.8	81,015	106,198	11%	0.76	14.1%
<b>&gt;C16-C21 Aromatics</b>	190	0.65	1,769	2,318	0.23%	1.5E-03	0.0%
<b>&gt;C21-C32 Aromatics</b>	240	6.6E-03	-			0.00	0.0%
<b>Total BTEXNM + CRs:</b>			<b>766,309</b>	<b>1,000,000</b>	<b>100%</b>	<b>5.4</b>	<b>100%</b>
<b>Total BTEXNM:</b>			<b>14,498</b>	<b>14,498</b>	<b>1.4%</b>	<b>1.5</b>	<b>27%</b>
<b>Total Carbon Ranges:</b>			<b>751,811</b>	<b>985,502</b>	<b>99%</b>	<b>3.9</b>	<b>73%</b>

1. JP-5 composition based on analysis of JP-5 collected from Red Hill facility (Newfields 2023a). Carbon range data adjusted to generate a total BTEXNM+Carbon Range concentration of 1,000,000 mg/kg.

2. JP-5 average molecular weight assumed to be 185 (see main text).

## **Attachment 7. Calculation of Weighted TPH Toxicity Factors**

## Calculation of Carbon Range-Weighted TPH Toxicity Factors

### *TPH Toxicity Factors*

The weighted toxicity of TPH is calculated as the harmonic mean weighted to the relative proportion of carbon range mixtures noted in Table 1(after ORDEQ 2003):

$$\text{Weighted RfD}_{\text{oral}} \text{ (mg/kg-day)} = \frac{1}{\left[ \frac{(\% \text{ Fraction A})}{\text{Fraction A RfDoral}} + \frac{(\% \text{ Fraction B})}{\text{Fraction B RfD oral}} + \text{etc.} \right]} \quad \text{Eq 1)}$$

where:

- % Fraction X = Percent makeup of the subject carbon range fraction +/- BTEXN relative to the total concentration of measured carbon ranges;
- Fraction X Toxicity Factor: Toxicity factor assigned to subject carbon range fraction +/- BTEXN.

Use of the harmonic mean rather than arithmetic average biases the results to the more toxic component of the mixture. The full mixture of carbon ranges is utilized for calculation of an oral reference dose.

Weighted toxicity factors for dermal exposure, used to assess risk during bathing, are calculated in a similar manner:

$$\text{Weighted RfD}_{\text{dermal}} \text{ (mg/kg-day)} = \frac{1}{\left[ \frac{(\% \text{ Fraction A})}{\text{Fraction A RfDdermal}} + \frac{(\% \text{ Fraction B})}{\text{Fraction B RfDdermal}} + \text{etc.} \right]} \quad \text{Eq 2).}$$

Dermal toxicity factors for TPH focus on more soluble and less volatile, >C12 aromatic carbon range compounds. More volatile and hydrophobic, aliphatic compounds are assumed to be emitted from the water during bathing and available for inhalation exposure.

Weighted Reference Concentrations (RfCs) are again calculated in a similar manner but with a focus on the relative makeup of volatile, C5-C12 aliphatic and C9-C12 aromatic carbon ranges:

$$\text{Weighted RfC} \text{ (}\mu\text{g/m}^3\text{)} = \frac{1}{\left[ \frac{(\% \text{ Fraction A})}{\text{Fraction A RfC}} + \frac{(\% \text{ Fraction B})}{\text{Fraction B RfC}} + \text{etc.} \right]} \quad \text{Eq 3).}$$

The oral RfD and dermal RfD are set equal to the RfD for >C8 aromatics under the dissolved-phase-only exposure scenario and calculation of a weighted toxicity factor is not required. Calculation of a weighted RfC for inhalation exposure to dissolved JP-5 is required due to the small amount of aliphatic compounds also present in the water. Calculation of a weighted toxicity factor is required for oral, dermal and inhalation exposure to sheens, however, due to the mixture of aliphatic and aromatic compounds under each of these exposure pathways.

### *Weighted Dermal Exposure Parameter Values*

Incorporation of the dermal absorption pathway into the USEPA tapwater model for TPH requires respective calculation of carbon range weighted values for several additional parameters. A detailed overview of the dermal absorption models is presented in USEPA (2004). Four chemical-specific parameters specific to dermal absorption are utilized in the USEPA tapwater model (USEPA 2021):

- B: Dimensionless ratio of the permeability coefficient of a compound through the stratum corneum relative to its permeability coefficient across the viable epidermis;
- $\tau_{\text{event}}$ : Dermal absorption lag time per event (hours/event);
- $t^*$ : Time to reach absorption steady state (hours) =  $2.4 \times \tau_{\text{event}}$ ;
- KP: Dermal permeability constant (centimeters/hour).

A summary of published and calculated dermal parameter values for targeted individual compounds and carbon ranges is provided in Table 5. Parameter values for targeted carbon ranges and BTEXN compounds were taken directly from the USEPA (2021) RSL guidance. Parameter values for both C9-C12 aromatics and C13-C22 aromatics are based on the default values presented for “Aromatics Medium,” defined as C9-C16. These values, rather than less conservative values for “Aromatics High” (C17-C32) category, are applied to the full range of C13-C22 aromatics due to the anticipated predominance of smaller aromatics compounds in dissolved-phase mixtures.

Weighted harmonic mean dermal exposure factors for TPH are calculated in the same manner as done for weighted toxicity factors:

$$\text{Dermal Parameter (units vary)} = \frac{1}{\left[ \frac{(\% \text{ Fraction A})}{\text{Fraction A Parameter Value}} + \frac{(\% \text{ Fraction B})}{\text{Fraction B Parameter Value}} + \text{etc.} \right]} \quad \text{Eq 4)}$$

where:

- % Fraction X = Percent makeup of the subject carbon range fraction +/- BTEXN relative to the total concentration of measured carbon ranges;
- Fraction X Toxicity Factor: Dermal absorption parameter value assigned to subject carbon range fraction +/- BTEXN.

Table 1. Calculation of weighted dermal absorption parameters for TPH associated with dissolved-phase JP-5 fuel.

<sup>1</sup> Dermal Absorption Parameters					
	Stratum Corneum Permeability: Epidermis Permeability	Lag Time Per Event	Time to Reach Steady State	Dermal Permeability Coefficient	
Chemical	B (unitless)	$t_{event}$ (hr/event)	$t^*$ (hr)	KP (cm/hr)	<sup>2</sup> Basis
C6-C8 Aliphatics	0.72	0.32	1.2	0.20	USEPA (2020) default Low (C5-C8) Aliphatics values
C9-C12 Aliphatics	7.4	0.55	2.5	1.70	USEPA (2020) default Medium (C9-C18) Aliphatics values
C13-C18 Aliphatics	7.4	0.55	2.5	1.70	USEPA (2020) default Medium (C9-C18) Aliphatics values
C19+ Aliphatics	9.8	0.95	4.3	1.96	USEPA (2020) default High (C19-C32) Aliphatics values
C9-C12 Aromatics	0.31	0.60	1.4	0.069	USEPA (2020) default Medium (C9-C16) Aromatics values
C13-C22 Aromatics	0.31	0.60	1.4	0.069	USEPA (2020) default Medium (C9-C16) Aromatics values
TPH (JP-5)	0.796	1.541	3.595	0.177	Carbon range makeup of JP-5 from Navy Red Hill facility (Newfields 2022a)

1. BTEXN parameter values originally presented in Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual, Part E, Supplemental Guidance for Dermal Risk Assessment (USEPA 2004) and repeated in USEPA Regional Screening Level User's Guide (USEPA 2021).

2. Based on default BTEXN and carbon range makeup of dissolved-phase fuels from JP-5 water-fuel experiments (Newfields 2023a).

**Table 2. Estimated carbon range-weighted TPH chronic and subchronic toxicity factors for tapwater exposure scenarios based on measured carbon range makeup of fuel and *measured* makeup of JP-5 components in water-fuel experiments.**

<sup>2</sup> Exposure Pathway	<sup>1</sup> JP-5 TPH Chronic/Subchronic Toxicity Factor	
	Dissolved-Phase Only Exposure Scenario	Dissolved-Phase Plus Sheen Exposure Scenario
Ingestion	0.010/0.040 mg/kg-day	0.010/0.079 mg/kg-day
<sup>3</sup> Dermal	0.010/0.040 mg/kg-day	0.010/0.079 mg/kg-day
<sup>4</sup> Inhalation	60/200 µg/m <sup>3</sup>	115/126 µg/m <sup>3</sup>

1. Oral and dermal Reference Doses (RfDs) and inhalation Reference Concentration (RfC) weighted with respect to measured carbon range makeup of neat (sheens) and *dissolved-phase JP-5 obtained from fuel-water experiments using JP-5 obtained from the Navy's Red Hill fuel storage facility (Newfields 2023a)*.

2. Ingestion and dermal pathway chronic TPH toxicity factors for dissolved-phase-only versus sheen scenarios are identical due to identical toxicity factors used for >C8 aromatics (dominate dissolved phase) and >C8-C18 aliphatics (dominate sheen phase). Subchronic TPH factors are different for the dissolved-only scenario due to differences in subchronic toxicity factors for >C8-C18 aliphatics vs >C8 aromatics.

3. Dermal exposure pathway only considers aromatic compounds for dissolved-phase only contamination. Aliphatic compounds assumed emitted to indoor air during water use included under inhalation exposure pathway.

4. Inhalation pathway considers only aromatics in dissolved-phase scenario; exposure to >C8-C18 aliphatics dominates dissolved+sheen scenario. Exposure to vapors from sheens based on vapor data obtained as part of water-fuel experiments (dominated by >C8-C18 aliphatics; Newfields 2022a).

**Table 3. Estimated carbon range-weighted TPH chronic and subchronic toxicity factors for tapwater exposure scenarios based on measured carbon range makeup of fuel and *modeled effective solubility* of JP-5 components in water.**

<sup>2</sup> Exposure Pathway	<sup>1</sup> JP-5 TPH Chronic/Subchronic Toxicity Factor	
	Dissolved-Phase Only Exposure Scenario	Dissolved-Phase Plus Sheen Exposure Scenario
Ingestion	0.010/0.040 mg/kg-day	0.010/0.079 mg/kg-day
<sup>3</sup> Dermal Contact	0.010/0.040 mg/kg-day	0.010/0.079 mg/kg-day
<sup>4</sup> Inhalation	61/199 µg/m <sup>3</sup>	115/126 µg/m <sup>3</sup>

1. Oral and dermal Reference Doses (RfDs) and inhalation Reference Concentration (RfC) weighted with respect to measured carbon range makeup of neat (sheens) and *predicted dissolved-phase makeup of JP-5 based on effective solubility of individual carbon ranges*.

2. Ingestion and dermal pathway chronic TPH toxicity factors for dissolved-phase-only versus sheen scenarios are identical due to identical toxicity factors used for >C8 aromatics (dominate dissolved phase) and >C8-C18 aliphatics (dominate sheen phase). Subchronic TPH factors are different for the dissolved-only scenario due to differences in subchronic toxicity factors for >C8-C18 aliphatics vs >C8 aromatics.

3. Dermal exposure pathway only considers aromatic compounds for dissolved-phase only contamination. Aliphatic compounds assumed emitted to indoor air during water use included under inhalation exposure pathway.

4. Inhalation pathway considers only aromatics in dissolved-phase scenario; exposure to >C8-C18 aliphatics dominates dissolved+sheen scenario. Exposure to vapors from sheens based on vapor data obtained as part of water-fuel experiments (dominated by >C8-C18 aliphatics; Newfields 2022a).

**Attachment 8. Tapwater Screening Level Model Notes**

**USEPA tapwater Screening Level Model (USEPA 2023)**

The default Resident Exposure Time (RET) incorporated into the USEPA tapwater model was modified to better reflect typical household conditions. The inhalation portion of the model assumes exposure of residents to vapors emitted from tapwater during use of showers, dishwashers, washing machines. The default RET used to generate tapwater RSLs assumes that these activities occur continuously throughout the day and night with a single, instantaneous exchange of indoor air at the beginning of each day (Resident Exposure Time = 24 hours/day). This assumption is excessively conservative. A more realistic Resident Exposure Time of 4.5 hours per day was selected for use in this report. This assumes use of a shower by two child residents for 0.54 hours each per day and two adults for 0.71 hours per day (USEPA 2021) and additional use of a dishwasher and laundry washing machine for one hour each per day.

USEPA, 2023, *Regional Screening Levels*: U.S. Environmental Protection Agency, May 2023.



**Table 1. Exposure parameter values and assumptions selected for calculation of TPH tapwater screening levels based on noncancer health hazards posed to young children.**

Parameter	Abbreviation	Unit	<sup>1</sup> Value
Skin Area - child	SAres-c	cm <sup>2</sup>	6,365
Volatilization Factor	K	L/m <sup>3</sup>	0.5
Water ingestion rate - children	IRWc	L/d	0.78
<sup>2</sup> Exposure Time - residents	ET	hr/day	4.5
Exposure frequency - residents	EFr	d/y	350
Exposure duration - residents total	EDr	yrs	26
Exposure duration - children	EDc	yrs	6
Body weight - child	BWc	kg	15
Averaging time (years)	AT	yrs	70
Days/year conversion	-	d/yr	365
Target Hazard Quotient	THQ	-	1.0

Notes:

1. USEPA (2021) default tapwater exposure values except as noted.
2. Based on assumed daily use of showers and dishwashers.
3. Physiochemical constants for additives from USEPA (2023a).

**Table 1. Physiochemical constants for targeted contaminants of potential concern.**

<sup>1</sup> Chemical/ Carbon Range	Molecular Weight	<sup>2</sup> Vapor Pressure (mmHg)	Solubility in Water ( $\mu\text{g/L}$ )	Henry's Constant (unitless)	Partition Coefficient ( $\text{cm}^3/\text{g}$ )	Diffusion Coefficient ( $\text{cm}^2/\text{s}$ )		
						air	water	
Benzene	78	95	1,790	0.23	146	0.09	$1.0 \times 10^{-5}$	
Toluene	92	28	526	0.27	234	0.08	$9.2 \times 10^{-6}$	
Ethylbenzene	106	9.6	169	0.32	446	0.07	$8.5 \times 10^{-6}$	
Xylenes (total)	106	8.0	106	0.27	383	0.07	$8.5 \times 10^{-6}$	
Naphthalene	128	0.085	31	0.018	1,544	0.06	$8.4 \times 10^{-6}$	
Volatile Carbon Ranges	C5-C8 Aliphatics	93	76	11,000	54	2,265	0.08	$1 \times 10^{-5}$
	C9-C12 Aliphatics	120	2.2	51,000	0.33	1,778	0.07	$1 \times 10^{-5}$
	C9-C10 Aromatics	170	0.11	10	4,900	680,000	0.07	$5 \times 10^{-6}$
Nonvolatile Carbon Ranges	C9-C18 Aliphatics	280	0.0008	0.0015	110	$4.0 \times 10^8$	-	-
	C19-C36 Aliphatics	120	2.2	51,000	0.33	1,778	0.07	$1 \times 10^{-5}$
	C11-C22 Aromatics	150	0.024	5,800	0.03	5,000	0.06	$1 \times 10^{-5}$
<sup>3</sup> Additives								
Diethylene Glycol Monomethyl Ether	120	0.25	$1 \times 10^{-9}$	$6.1 \times 10^{-10}$	1.0	0.078	$9.1 \times 10^{-6}$	
2,6-Di-Tert-Butyl-4- Methylphenol	220	0.0052	600	$1.7 \times 10^{-4}$	15,000	0.023	$5.6 \times 10^{-6}$	

1. BTEXN constants from USEPA (2023a). Carbon range constants from Massachusetts Department of Environmental Protection (MADEP 2002) except constants from C19-C36 Aliphatics (Gustafson et al., 1997; based on EC>16-35 aliphatics in Table 7). USEPA (2009) RfD and RfC for "high flash naphtha" referenced for C9+ aromatics.

2. Carbon range vapor pressures converted from atmospheres (1atm = 760 mmHg).