

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

Hawai'i Department of Health

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Updates

June 26, 2023:

Section 3.3.5. Vapors. AEGL values and units in paragraphs 4 & 5 corrected.

Table 6. RME's corrected to match Table 2; subchronic TPH screening level corrected. Predicted Subchronic Health Risks approach revised.

Attachment 3, Figure 1: Sample ID numbers corrected; reported concentrations of Mid-Range and High-Range organics in RHMW02 chromatogram figure corrected; correct laboratory report pdf added.

August 7, 2023:

- Text edited for clarity;
- Final Newfields laboratory reports included in Attachment 4.
- Annotated JP-5 Neat fuel and vapor chromatograms added as Figure 1 in main document.
- Summary figure of primary risk drivers under different exposure scenarios added (Figure 4).
- Significant digits expanded in tables for ease of comparison.

August 14, 2023

- Title and text clarified to note that drinking water systems connected to the JBPHH system proper and Red Hill Shaft well are included in the Exposure Assessment (collectively referred to as "JBPHH" drinking water system in the report).

October 2, 2023

- Edited to consider September 26, 2023, comments from ATSDR (refer to separate October 2, 2023, letter to ATSDR). The ATSDR edits improved the clarity of several topics but did not significantly change the overall content or conclusions of the report.

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 and connected drinking water systems (collectively referred to as “JBPHH”) 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 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.

Identification of primary contaminants of concern and estimates of RME concentrations is based in part on data from laboratory experiments carried out by a research-level laboratory that utilized JP-5 fuel from the Red Hill facility. The experiments were necessary in part due to the lack of representative, tapwater sample data from JBPHH at the height of contamination. Data from the experiments also provides information on the toxicity of the fuel that would have been unavailable from actual sample data generated by a commercial laboratory. This includes data for the carbon range makeup of both the neat fuel and dissolved-phase hydrocarbons. These data allow estimation of the weighted toxicity of the overall TPH mixture of hydrocarbons in the fuel and water, allowing for a more detailed assessment of potential health risks. Data from the experiments also provides information on the weighted toxicity of mixtures of degraded hydrocarbons likely present in the drinking water system. This information would again have been unavailable using standard laboratory methods.

The magnitude and duration of exposure varied both spatially and temporally within the drinking water system during the event. This makes it difficult 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, cleaning agents such as Simple Green and chlorine disinfection byproducts. This report will be updated periodically as new information is obtained.

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and funded through grants provided to the Hawai'i Department of Health by the US Environmental Protection Agency.

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 and connected drinking water systems (collectively referred to as "JBPHH") located in the same facility. Residents began reporting fuel odors, sheens, foam and emulsions in tapwater less than 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 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.

Estimated Reasonable Maximum Exposure (RME) concentrations of COPCs in tapwater are based on multiple lines of evidence, including: 1) The hydrocarbon and additive makeup of the JP-5 fuel based on testing of samples collected at the Red Hill facility, 2) Modeled predictions of maximum dissolved-phase concentrations of COPCs based on the measured chemical makeup of the fuel, 3) Laboratory experiments of the dissolution JP-5 fuel into water over time of using samples from the Red Hill facility, 4) Sample data from the Red Hill Shaft water well and 5) Field observations during the release event and subsequent contamination of the JBPHH drinking water system.

Estimated RME concentrations of COPCs in tapwater 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.

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 2022a](#)). 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 and Aliamanu Military Reservation (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 led 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 2022a](#)). 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 and connected drinking water systems (collectively referred to as "JBPHH"). Refer to USDN (2022) for additional details.

Contaminated groundwater was drawn into the Red Hill Shaft well as least as early as November 27th 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 28th, 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 over the eight days that the well operated following the initial release.

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 of 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 exposes the top of the water table shortly afterwards ([USDN 2022a](#)). 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 is derived from the separate, unimpacted well located several miles away in Wai'awa ([USDN 2022a](#)). 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 29th. On November 30th, 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.

Data for initial water samples collected from the JBPHH drinking water system between November 29th and December 26th did not identify contaminants clearly related to fresh JP-5 jet fuel, with only trace levels of non-specific, Residual Range Organics (RRO) reported (USDN 2021). The data cannot be considered to be representative of initially impacted areas of the base, given the noted presence of jet fuel product and strong vapors emitted from taps in many areas of the base. Such observations indicate significant contamination of the water well in excess of 2017 HIDOH TPH action levels still being referenced by the Navy at that time. The cause of the discrepancy is uncertain but could denote the presence of overlooked, isolated slugs of contaminated water moving through the system and/or testing problems at the laboratory.

Due to the urgency of the situation and the need for immediate data, subsequent samples collected by the Navy from the drinking water system ~~early in the crisis~~ focused on rapid turn-around testing for Total Organic Carbon (TOC). This was intended to serve as a surrogate for more comprehensive Total Petroleum Hydrocarbon (TPH) and volatile organic compound data that could be used to directly assess health risks but could take up to two weeks to report ([USDN 2022a](#)). Laboratory data for TOC were later determined to be unreliable due to the elevated laboratory detection limit in tapwater (up to 5,000 µg/L) and the inability of the data to identify water that was obviously contaminated with fuel in the field.

Residents in areas where elevated TOC was not reported were told up to a least December 9, 2021, that they could continue to use the water. 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 2022a](#)). Residents told that they could continue to use the tapwater at least as late as December 9th 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. 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).

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 intrusion of fuel-contaminated water into homes and buildings appears to have been in part dependent on the timing of water use. [Contaminant levels within the drinking water system varied both spatially and temporally](#). Isolated pockets of contaminated water that continued to circulate through the maze of piping for many weeks after the initial release, could have been trapped between but not mixed with clean water drawn in from the Wai'awa well. [In other cases, water from both wells might have become mixed to varying degrees in aboveground storage tanks located within the bases](#). Under such circumstances, 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 would have been quickly exposed. Adjacent neighbors who returned home later in the day after the pocket of contaminated water had moved further down the piping system, however, 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 JBPHH drinking water system through fire hydrants was initiated in late November, 2021, soon after the initial release ([USDN 2022a](#)). Heavily contaminated water was initially flushed to open areas, causing impacts to air quality, sheens in runoff water and contamination of soil. Treatment of discharged water through granulated activated carbon filters was subsequently required by the State Department of Health.

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. 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 action level applies to the total sum of low-, mid- and high-range organics (“gasoline,” “diesel” and “residual”) reported for TPH-related compounds in a sample. The TPH screening level was later revised to 266 µg/L to address an error in the initial calculation (HIDOH 2022). This became one of the main tools to verify when adequate flushing of specific areas of the base had been accomplished.

Verification testing of water samples collected within the JBPHH drinking water system began in early January 2022 (USDN 2022b; interactive data results maps for drinking water zones). This included detailed testing for TPH as well as BTEXNM for comparison to HIDOH EALs. 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. 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. Sample data collected from taps during this period were in general predictably low and below HIDOH EALs, in that samples were only collected when the targeted zone of the drinking water system was anticipated to have been cleared of petroleum contamination. The data are not representative of conditions immediately following the November release of jet fuel into the JBPHH drinking water system and cannot be used to assess exposure of residents during this time.

The HIDOH 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 and flushing was discontinued (HIDOH 2022). Residents housed offsite were requested to return to the base, although many subsequently chose to live elsewhere or be transferred to bases outside of Hawai'i. The HIDOH Public Health Advisory for use of the drinking water system including non-residential areas was formally lifted on October 28th, 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.

1.4. Documentation of Conditions at the Height of Exposure

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. The resulting data are not 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 at the time that well was shut down.

This necessitated use of alternative, modeling and laboratory experiment approaches described in subsequent sections of 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.

1.5. 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 6th 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 contaminants above the normal chromatogram signature range of JP-5 fuel 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. Total concentrations of these high boiling point contaminants in the water were reported to be in the range of several hundred micrograms per liter (e.g., APPL 2022). 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 6th 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. Chemical Makeup of JP-5 Jet Fuel

Petroleum fuels are assessed in terms of three components (TPHCWG 1997; MADEP 1997, 2003; HDOH 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.

The overall, weighted toxicity of neat versus dissolved- and vapor phase hydrocarbons similarly varies and plays a key role in assessment of health risk. Table 1 summarizes the relative BTEXNM and carbon makeup of JP-5 jet fuel stored at the Red Hill facility. Chromatograms of the fuel and vapors from the fuel are provided in Figure 1. The fuel is dominated by >C8-C18 aliphatic compounds with lesser amounts of >C5-C8 aliphatics and >C8 aromatics. Vapors generated from the JP-5 were dominated by >C8-C18 aliphatics with lesser amounts of C5-C8 aliphatics and minimal BTEXN (see Newfields 2023b; see also Harley and Coulter-Burke 2000; Chin and Batterman 2012, HDOH 2012).

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 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)” (e.g., C5-C12; aka “Gasoline Range Organics”); 2) Mid retention time/boiling point compounds, referred to as “Mid-Range Organics (MRO)” (e.g., C10 or C12 to C24; aka “Diesel Range Organics”) and 3) High retention time/boiling point compounds, referred to as “High-Range Organics (HRO)” (e.g., >C24; 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.

The potential presence of JP-5 related compounds across the LRO, MRO and HRO laboratory reporting ranges necessitates separate, initial quantification of the concentration of “TPH” for each range. The total concentration of TPH for a sample is then determined by summing the TPH concentration across the ranges (TPH = LRO + MRO + HRO). The reported concentration of TPH for a sample is then be compared to a single, risk-based screening level that reflects the overall toxicity of the petroleum mixture. The concentration of individually targeted compounds such as BTEXNM are excluded from the calculation, since they are assessed separately. 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. This issue is further discussed in Section 2.3.

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 other, proprietary additives in the fuel are also possible but were not disclosed by the Navy or reported by the laboratory. Additives in the fuel are not expected to significantly contribute to vapor emissions. This is due to the low concentration as well as limited volatility of the targeted compounds.

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.

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. Fuel-related degradation 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 both 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 nonpolar, hydrocarbon compounds from HOPs-related degradation products in a sample is not 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 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. This can occur due to destruction of polar compounds during sample processing or an inability of the compound 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 2022a](#)). 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 µg/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 2 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: 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.

Vapors from jet fuel released in the tunnel were vented to outdoor air via the tunnel ventilation system. The vapors were dominated by >C8-C18 aliphatic compounds (chemistry of vapors emitted from JP-5 jet fuel discussed in Section 3.3.5 and Attachment 4). 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).

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. Additional >C8-C18 aliphatic compounds were emitted from the fuel as it migrated downwards. 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 less soluble, aliphatic compounds. Dissolved fuel and ultimately sheens of free product were drawn into the Red Hill shaft and into the JBPHH drinking water system. Partial oxidization and degradation of the fuel by naturally occurring microbes in the groundwater likely began immediately after contact of the fuel with the groundwater. The rate of biological degradation would have at least partially decreased following chlorination of the water as it entered the drinking water system.

The miscibility of DiEGME initially suggested that this compound would be completely drawn out of the fuel and dissolved into groundwater (HIDOH 2023). DiEGME was detected in a sump that captured fuel and water used for cleanup three weeks after the release. DiEGME was not, however, 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. Images of contaminated water from resident taps suggest, however, that the DiEGME formed a complex emulsion with hydrocarbons and water soon after the fuel encountered the water table (see to Attachment 1). The DiGME was instead likely trapped at the top of the water table and largely absent in the groundwater 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 DiEGME or other factors that caused 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 3.34.1; Attachment 4). 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). Formation of the gel is expected to have taken place relatively quickly after contact of the fuel with groundwater within the Red Hill tunnel. Foams could also reflect the presence of a surfactant cleaning agent in the water.

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.

3.2. Exposure Pathways

3.2.1. Tunnel Venting to Outdoor Air

While variable 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 have been complete (refer to Figure 2). 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 during the day of the November 2021 release and for several weeks following the release (Weather Underground 2023). Vapors were dominated by >C8-C18 aliphatic compounds. 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 could have occurred both outdoors and indoors, as impacted air was drawn into building ventilation systems.

The Deputy Fuels Director reported strong jet fuel odors in outdoor air at the H3 highway while driving to the Red Hill facility on November 20, 2023 (USDN 2022a). Residents reported to the author of this EA report ~~s-indicate~~ that ~~impacts jet fuel odors in to~~ outdoor air were especially strong in the Red Hill and Aliamanu Military Reservation (AMR) areas in the days and weeks following the initial release of jet fuel. These areas are, located adjacent to and directly southwest and downwind of the Red Hill fuel storage facility. The Aliamanu Military Reservation is 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 in the weeks following the November 20, 2021, release at the Red Hill facility. The author of this EA report also identified periodic, strong fuel vapors in outdoor air while traveling in the area between Red Hill and AMR during this time period.

3.2.2. Use of Indoor Tapwater

Ingestion, inhalation and/or dermal contact exposure pathways to fuel-related contaminants in tapwater are considered to have been complete, (see Figure 2). Ingestion exposure to dissolved-

phase aromatic compounds in tapwater and later additional exposure to aliphatic and DiGME 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 >C8-C18 aliphatic and to a lesser extent less volatile, BTEX and >C8 aromatic compounds emitted from the water was most significant during 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 flush water from taps on November 30, 2021, in an attempt to clear contaminated water from the system. Several residents reported that strong fuel vapors quickly spread throughout the house and significantly impacted indoor air, leading to headaches and in some cases vomiting and other health effects (e.g., refer to interviews in Vice Media 2022).

Dermal contact with fuel-contaminated 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 BTEXNM. 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 additional dermal exposure to C8-C18 aliphatics in sheens as well as DiGME in emulsions.

3.2.3. Discharges of Contaminated Water to Outdoor Areas

Exposure to fuel-related contaminants during discharge of untreated water to open areas was primarily through inhalation of vapors emitted to outdoor air during initial flushing of the system in later November and early December. 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 Concentrations

3.3.1. Estimation of Reasonable Maximum Exposure Concentrations

Reasonable Maximum Exposure (RME) concentrations are estimated for four exposure scenarios based on the completed pathways identified: 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.

Reasonable Maximum Exposure concentrations of dissolved-phase contaminants in the water are estimated based on observations of strong fuel odors, sheens and foamy emulsions in the tapwater indicate the presence of free product. Estimations of RMEs associated with exposure to JP-5 sheens and DiEGME emulsions are made based on the chemical makeup of the fuel, groundwater data from the Red Hill Shaft and published studies of DiGME emulsions associated with jet fuel. 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.

Figure 3 summarizes specific contaminants of concern associated with each exposure pathway and scenario. Ingestion of water that contained dissolved-phase contaminants focuses on exposure to soluble, aromatic compounds. Aromatic compounds are also assumed be taken up via the dermal absorption pathway during bathing. Any volatile, aliphatic compounds dissolved in 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 additional exposure to both aliphatic and aromatic hydrocarbons as well as additives in the original fuel (see Figure 3). The same compounds are considered in the dermal exposure pathway. Exposure to DiEGME emulsions in the tapwater in addition to fuel sheens would have occurred via the ingestion and dermal pathways. Indoor and outdoor inhalation exposure focuses on exposure to volatile, aliphatic compounds emitted from sheens.

3.3.2. 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 laboratory-based experiments utilizing a JP-5 jet fuel from the Red Hill facility. The samples were provided to HDOH by the Navy. Photographs of the experiments 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 (1:100 ratio of water to fuel) and allowing the fuel and water to equilibrate over 20 days (refer to figures in Attachment 4; after Bobra 1992). Selection of a 1:100 ratio of fuel to water was based on previous trial experiments. Use of a 1:1,000 ratio of fuel to water as done in the Bobra (1992) experiments resulted in concentrations of dissolved-phase hydrocarbons below laboratory detection limits. Sterilized water was used to prevent degradation of dissolved-phase hydrocarbons during the course of the experiment. This allowed for a more detailed assessment of the weighted toxicity of dissolved-phase compounds to be evaluated, including aliphatic and aromatic carbon ranges. (Separate laboratory experiments to

evaluate degradation of JP-5 in groundwater collected from the Red Hill area have been discussed by University of Hawaii researchers but to date such experiments has not been undertaken to the EA author's knowledge.)

Five flasks were prepared and labeled "Day 0," "Day 5," "Day 10," "Day 15" and "Day 20." A water sample was collected from a flask on the noted day of the experiment and tested for BTEXMN, targeted aliphatic and aromatic carbon ranges and DiEGME. Individual ranges reflect groupings of compounds based on the number of carbon molecules present and the predicted toxicity and physiochemical properties of the compounds.

In a separate, second set of otherwise identical 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 detailed summary of the resulting laboratory data is provided in Attachment 4. 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. Dissolved-phase hydrocarbons in water-fuel experiments were dominated by >C8 aromatic compounds (average 60%). Dissolved BTEXNM was dominated by xylenes and naphthalene, with both making up 12% each of total dissolved hydrocarbons.

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. No dissolved-phase aliphatic compounds were detected in the water-fuel experiments. Trace amounts (2% of total) of dissolved-phase C5-C18 aliphatics in water predicted based on the presence of small amounts of these compounds in the JP-5 fuel were also detected in the water samples. With the exception of naphthalene, concentrations of individual compounds in the water were less than concentrations predicted by their 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 in comparison to the initial experiments. 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.

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). This equates to a dissolved-phase mass of just 49 µg in the sample. The Day 0 water sample in the experiment where Simple Green was added was marginally lower, at 45 µg/L. The average concentration of DiGME in the water samples over the course of the bot sets of experiments was 51 µg/L, 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 (refer to Appendix 5). The DiEGME appears to have instead been incorporated into a gel-like emulsion that formed on top of the water in the experiments (refer to photos in Attachment 4). This correlates with reports of the formation of a water-DiEGME emulsion referred to as “Apple Jelly” in 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. [3.44.3](#).

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 subsequently drawn into the JBPHH drinking water system. This assumption matches field observations of fresh fuel continuing to drip into the shaft several weeks at the November 20, 2021, release ([USDN 2022a](#)).

3.3.3. *Dissolved-Phase Contaminants Plus Sheen*

Estimated RMEs for tapwater contaminated with dissolved-phase hydrocarbons and additives and that additionally exhibit a sheen are included in Table 2. The presence of a sheen on the water implies saturation conditions of dissolved-phase hydrocarbons in the water, especially low-solubility aliphatic compounds. Concentrations of TPH up to ~~142150~~ [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 ([Sample ERH2226; refer to January 19, 2023, Energy Laboratory report included in Attachment 9](#)). This [reasonably](#) 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. [Significant migration of contamination into the portion of the Red Hill Shaft where the pump is located and where samples were collected after the pump was turned off is unlikely. The rate of natural groundwater flow in the area is very low. Fuel was also not observed to be directly leaking into the shafter area by Navy inspectors \(USDN 2022a\).](#)

For the purposes of this report, a concentration of 0.015% JP-5 product in tapwater ([150 mg/L; conservatively rounded upwards from 142 mg/L](#)) was used to estimate of an RME concentration tapwater exhibiting a sheen. Concentrations 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. The final concentration of each compound is based on the estimated mass of the compound in the 10ml of fuel originally placed on the water in the experiments. This leaves 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 targeted compounds 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).

Dissolved-phase concentrations of BTEXNM in the experiments were significantly higher than reported for the above-noted groundwater sample from the Red Hill Shaft. Benzene, toluene, naphthalene and methylnaphthalenes were not detected in the groundwater sample (respective BT detection limit = 0.25 µg/L, NM detection limit = 0.097 µg/L). Ethylbenzene and xylene were reported at concentrations of only 0.063 µg/L and 7.2 µg/L, respectively. This is interpreted to be due at least in part to rapid, partial oxidation of dissolved-phase BTEXNM in the groundwater and subsequent inclusion of the degradation products in quantification of the diesel-range organics fraction of TPH. This also highlights the difficulty in estimating the weighted toxicity and risk posed by petroleum-contaminated water in absence of detailed knowledge of the initial chemistry of the released fuel.

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).

3.3.4. 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. 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 B and F in Attachment 1). Other photos and videos display a foamy material in cups and in water sprayed from hoses (Photo C in Attachment 1).

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 (Photo D 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 RME

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.

3.3.5. Outdoor and Indoor Air

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 (refer to photos in Attachment 4).

A summary of the vapor data is included in in Attachment 4. An annotated chromatogram for a sample of JP-5 vapors is included. Samples collected from the water-fuel experiments were dominated by >C8-C12 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). Health effects associated with inhalation of JP-5 vapors are concluded to have been caused primarily by C9-C12 aliphatic compounds, given both their dominance in the vapors and their higher toxicity in comparison to C5-C8 compounds. 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. This is likely well above RME concentrations for exposure of residents to JP-5 vapors in indoor and outdoor air, since 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 (e.g., refer to interviews in Vice Media 2022; [see also Troeschel et al. 2022](#)). 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).

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 290,000 $\mu\text{g}/\text{m}^3$ level is appropriate or a particular sensitivity to jet fuel vapors.

The Level 2 AEGL (AEGL-2) for exposure to kerosene vapors is 1,100,000 $\mu\text{g}/\text{m}^3$ (ATSDR 2017). 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 collective summary of health effects associated with chronic, subchronic and acute exposure to jet fuel and fuel additives is included in Table 3. Refer to Attachment 6 for a more detailed overview. Noted health effects are presented for general informational purposes only and is not intended to be comprehensive. Effects can also differ between individuals under the same exposure conditions.

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

Potential acute health affects 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 icing inhibitor include headache, dizziness, tiredness, nausea, vomiting and eye irritation (NIH 2023, ThermoFisher Scientific 2021). Note that most of the health effects associated with DiEGME described in the referenced reports are based on animal studies. Short-term exposure to high concentrations of 2,6-Di-Tert-Butyl-4-Methylphenol, a compound in Simple Green, 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).

5.0 Toxicity Factors

5.1. Individually Targeted Compounds

Table 3 presents published 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 RfDs were not available for 1-methylnaphthalene, 2-methylnaphthalene and naphthalene. Chronic RfDs and RfCs 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 pertinent to potential expression of adverse health effects within an exposure duration up to 14 days are only available for BTEX and naphthalene (“Minimal Risk Levels;” ATSDR 2023). The lack of acute toxicity factors for aromatic and aliphatic carbon range compounds precludes the development of a comprehensive set of correlative screening levels and detailed assessment of acute toxicity risk in this report.

Toxicity factors were not identified for linoleic acid dimers, a potential additive in the fuel. 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; HODOH 2018). 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, HODOH 2017).

Carbon range toxicity factors published by the USEPA in 2009 (USEPA 2009a) were used to prepare previous HODOH tapwater action levels for JP-5 (HODOH 2022). Recently updated toxicity factors published by USEPA (2022) are preliminarily utilized in calculation of screening levels for TPH in this report. The oral Reference Dose for >C8 aromatics was reduced by a factor of three in comparison to the toxicity factor 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 magnitude. Confidence in the updated toxicity factors was not reviewed as part of the Exposure Assessment. The reliability of the updated toxicity factors will be reviewed by ATSDR as part of that agency's Health Assessment report for the JBPHH incident. HDOH will incorporate final carbon range toxicity factors recommended by ATSDR in future updates to TPH action levels as appropriate.

5.2.2. Total Petroleum Hydrocarbons

Direct assessment of health risk posed by exposure to petroleum fuels could in theory be carried out 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.

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 2. 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 by USEPA of the same RfD to each carbon range (refer to Table 3). 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. As noted in Section 5.2.1, the adequacy of the updated toxicity factors will be

reviewed by ATSDR as part of that agency's Health Assessment. It is possible that the agency might also recommend alternative toxicity factors.

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 to these compounds 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 are 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, release occurred over a period of several weeks. Rashes after bathing reported by residents as early as November 25th (e.g., see HNN 2021a,b,c and Vice Media 2022) were likely related to lower-level, dissolved-phase contaminants in the drinking water system. Heavily contaminated water was clearly moving through the drinking water system by November 27th, 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 9th. This could suggest an exposure duration up to several weeks prior to the development of symptoms 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 instead 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. Comparison of predicted RME's to subchronic rather than chronic screening levels is therefore appropriate. 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. 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 RMEs are intended to collectively address ingestion, dermal absorption and inhalation exposure routes. A summary of the relative risk posed by specific contaminants under each of the four exposure scenarios is provided in Figure 4.

Initial ingestion- and dermal-related health effects were likely associated with exposure to dissolved-phase, >C8 aromatics and possibly naphthalene and methylnaphthalenes in the tapwater. Risk significantly increased as more heavily contaminated water reached residences. Health effects were primarily caused by >C8-C18 aliphatics concentrated in sheens of free product in the water and DiEGME suspected to be concentrated in emulsions. Additional risk could have also been posed by naphthalene and 2-methylnaphthalene still present in the sheens.

Inhalation health effects were primarily related to exposure to high levels of >C8-C12 aliphatics in outdoor and indoor 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.

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. (Note that ATSDR will not be collecting additional health outcome data; refer to comments in Attachment 5).

8.0 Limitations

Limitations in these conclusions include 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 other additives in the fuel, surfactants associated with cleaning agents and disinfection products limit a comprehensive understanding exposure conditions and associated health effects.

Reliable identification of 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) 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. More precise and reliable laboratory methods have reportedly been developed by some laboratories but were not reviewed as part of this report.

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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Figure 1. Chromatograms of JP-5 vapor vs JP-5 neat fuel.

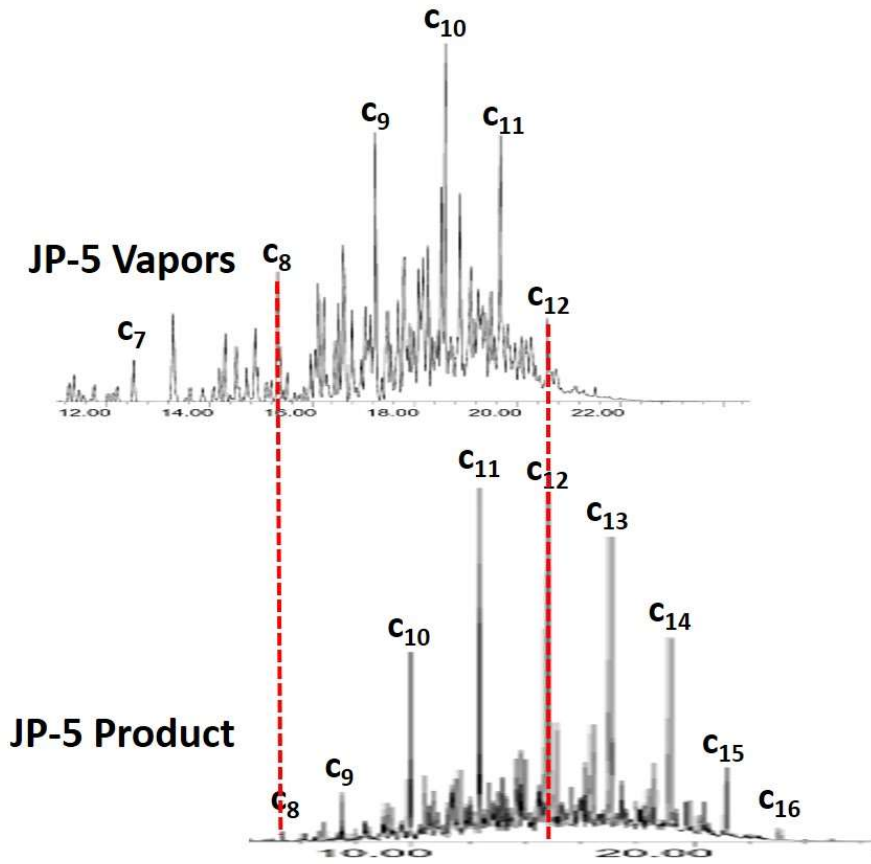


Figure 2. Conceptual Site Model of exposure of JBPHH residents to JP-5 jet fuel.

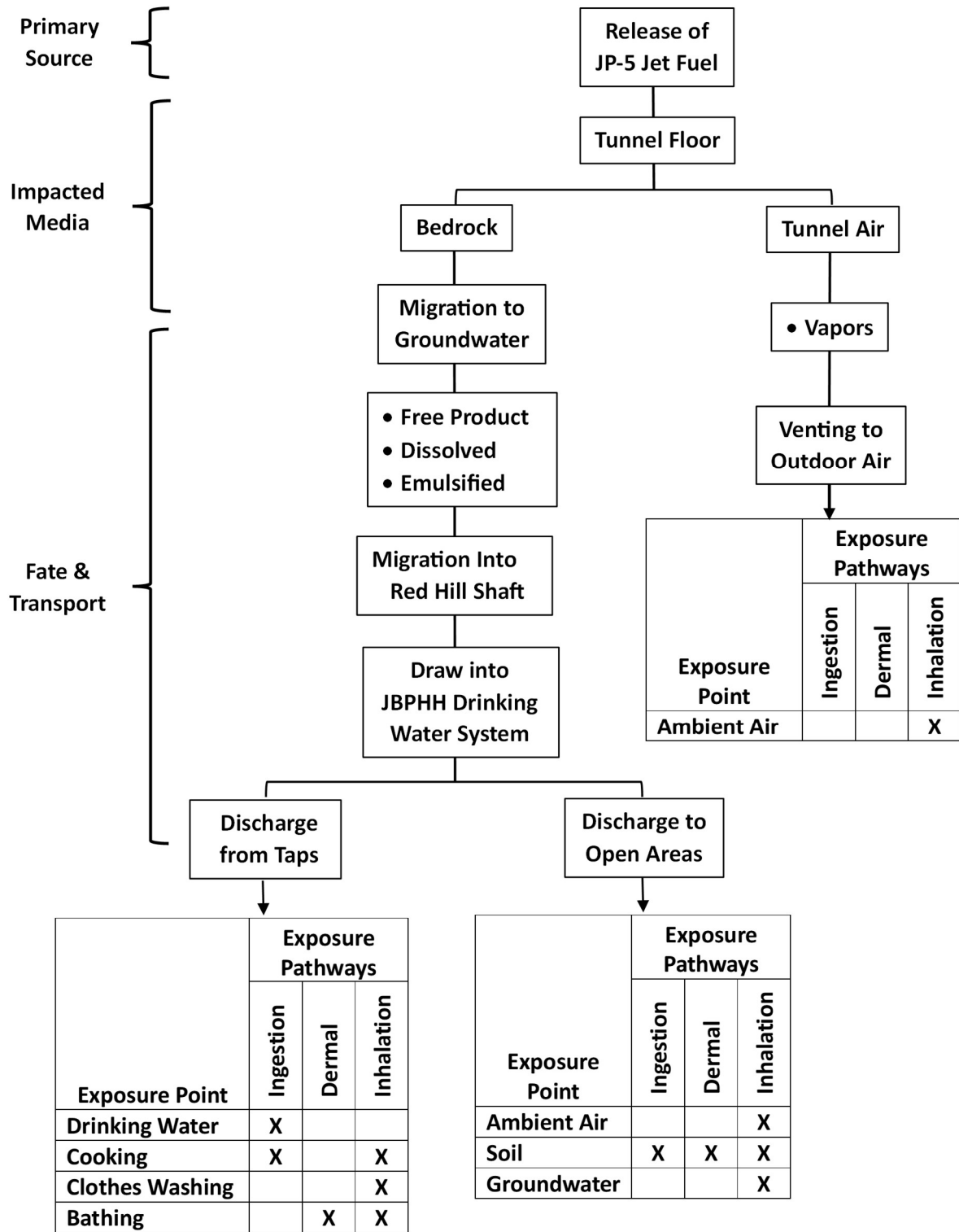


Figure 3. Primary contaminants of concern for specific exposure pathways and exposure scenarios.

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

Figure 4. Risk drivers for contaminated air and tapwater under different exposure scenarios.

Exposure Route	Dissolved Only	Dissolved + Sheen	Dissolved + Sheen + Emulsion
	¹ Inhalation	>C8 Aromatics	>C8-18 Aliphatics
		>C8 Aromatics	>C8 Aromatics
² Ingestion & Dermal	>C8 Aromatics	>C8-18 Aliphatics	>C8-18 Aliphatics
	Naphthalene	>C8 Aromatics	DiEGME
	2-Methylnaph.	Naphthalene	>C8 Aromatics
		2-Methylnaph.	Naphthalene
		1-Methylnaph.	2-Methylnaph.
			1-Methylnaph.

Very High Risk
High Risk
Moderate Risk
Lower Risk

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

Utility	Chemical Group	Chemical/ Carbon Range	¹ Relative Makeup of Neat-Phase JP-5 Jet Fuel	² Relative Makeup of Dissolved-Phase JP-5 Jet Fuel	³ Relative Makeup of Vapor Phase JP-5 Jet Fuel
⁴ Jet Fuel Hydrocarbons	Individually Targeted Hydrocarbons	Benzene	0.002%	0.25%	0.03%
		Toluene	0.019%	3.0%	0.26%
		Ethylbenzene	0.028%	1.6%	0.18%
		Xylenes	0.21%	12%	0.91%
		Naphthalene	0.29%	13%	0.05%
		1-Methylnaphthalene	0.54%	6.5%	0.03%
		2-Methylnaphthalene	0.36%	4.8%	0.02%
Carbon Range Groupings	C5-C8 Aliphatics	0.16%	0.13%	19%	
	>C8-C18 Aliphatics	81%	0.0%	77%	
	>C18-C32 Aliphatics	0.0%	0.0%	0.0%	
	>C8 Aromatics	18%	59%	3.1%	
Additives	⁴ Fuel System Icing Inhibitor (FSII)	Diethylene glycol monomethyl ether (DiEGME)	0.08% to 0.11% (800 mg/L to 1,100 mg/L)	-	-
	⁵ Antioxidants	2,6-Di-tert-butyl-4- methylphenol	0.0024% (24 mg/L)	-	-
	⁵ 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		¹ Dissolved-Phase Contaminants Only (µg/L)	² Dissolved Contaminants +JP-5 Sheen (µg/L)	³ Dissolved Contaminants +JP-5 Sheen +FSII Emulsion (µg/L)
Total BTEXNM:		2,116	4,291	4,291
Total Carbon Ranges:		3,088	150,913	150,913
JP-5 Fuel	Benzene	13	16	16
	Toluene	154	182	182
	Ethylbenzene	81	123	123
	Xylenes	630	943	943
	Naphthalene	649	1,083	1,083
	1-Methylnaphthalene	339	1,155	1,155
	2-Methylnaphthalene	250	789	789
	C5-C8 Aliphatics	6.6	250	250
>C8-C18 Aliphatics	0	120,962	120,962	
>C18-C32 Aliphatics	0	0	0	
>C8 Aromatics	3,082	29,702	29,702	
Total Hydrocarbons (ug/L):		5,204	155,204	155,204
JP-5 Additives	Diethylene Glycol Monomethyl Ether	50	215	400,000
	2,6-Di-Tert-Butyl-4-Methylphenol	1.2	25	25
	Linoleic acid dimers	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	^{1,3} Chronic		^{2,3} Subchronic		¹ CSF _{0oral} (mg/kg-d) ⁻¹	¹ IUR (µg/m ³) ⁻¹	⁴ Example Health Effects	
	RfD _{Oral/dermal} (mg/kg-day)	RfC _{Inh} (µg/m ³)	RfD _{Oral/dermal} (mg/kg-day)	RfC _{Inh} (µg/m ³)				
Benzene	0.004 (M)	30 (M)	0.01 (M)	80 (M)	0.055	7.8 x 10 ⁻⁶	CARC, ALM, CARD, DEV, EYE, HEM, IMM, NERV, RESP, SKN	
Toluene	0.08 (L)	5,000 (H)	0.8 (M)	5,000 (H)	-	-	ALM, CARD, DEV, EYE, IMM, HEP, KID, NERV, REP, RESP, SKN	
Ethylbenzene	0.05 (L/M)	1,000	0.05 (M)	9,000 (M)	0.011	2.5 x 10 ⁻⁶	CARC, ALM, DEV, END, EYE, HEM, KID, NERV, RESP, SKN	
Xylenes (total)	0.2 (L/M)	100	0.4 (L/M)	400 (M)	-	-	ALM, CARD, DEV, EYE, KID, NERV, REP, RESP, SKN	
Naphthalene	0.02 (L)	3 (L)	0.6 (H)	3 (L)	0.12	1.1 x 10 ⁻⁴	CARC, ALM, EYE, HEM, IMM, NERV, RESP, SKN	
1-Methylnaphthalene	0.07 (L)	280 (L)	0.07 (L)	280 (L)	0.029	-	CARC, ALM, EYE, HEM, IMM, KID, NERV, RESP, SKN	
2-Methylnaphthalene	0.004 (L/M)	16 (L)	0.004 (L)	16 (L)	-	-	ALM, DEV, EYE, HEM, IMM, NERC, REP, RESP, SKN	
⁵Volatile Carbon Ranges	C5-C8 Aliphatics	0.005 (L)	400 (M)	0.05 (M)	2,000 (M)	-	-	ALM, EYE, HEM, KIDN, NERV, RESP, SKN
	C9-C12 Aliphatics	0.01 (L)	100 (M)	0.1 (L)	100 (M)	-	-	ALM, EYE, HEM, KIDN, NERV, RESP, SKN
	C9-C10 Aromatics	0.01 (M)	60 (M)	0.04 (M)	200 (M)	-	-	NERV
	C9-C18 Aliphatics	0.01 (L)	100 (M)	0.1 (L)	-	-	-	ALM, EYE, HEM, KIDN, NERV, RESP, SKN
Nonvolatile Carbon Ranges	C19-C36 Aliphatics	3.0 (M)	-	30 (M)	-	-	-	ALM, EYE, HEM, KIDN, NERV, RESP, SKN
	C11-C32 Aromatics	0.01 (M)	-	0.04 (M)	-	-	-	NERV
Additives								
Diethylene Glycol Monomethyl Ether	0.04	-	0.04	-	-	-	ALM, EYE, DEV, KID, NERV, REP, SKN	
2,6-Di-Tert-Butyl-4- Methylphenol	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 Minimal 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. For example only. Includes 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.
5. USEPA toxicity factors for carbon ranges updated in 2022 noted (USEPA 2022). The applicability and adequacy of the toxicity factors in comparison to other published carbon range toxicity factors should be reviewed as part of a Health Assessment conducted for the JP-5 release.

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

³ Exposure Pathway	^{2,3} JP-5 TPH Chronic/Subchronic Toxicity Factor	
	Dissolved-Phase	⁴ 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
⁵ Inhalation (RfC)	60/200 µg/m ³	115/126 µg/m ³

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	
	¹ Chronic Exposure (µg/L)	² Subchronic Exposure (µg/L)	¹ Chronic Exposure (µg/m ³)	² Subchronic Exposure (µg/m ³)
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	3.1
1-Methylnaphthalene	530	530	58	58
2-Methylnaphthalene	30	30	3.3	3.3
³ TPH JP-5	⁴ Dissolved Only	266	-	-
	^{5,6} Dissolved Only	91	350	63
	^{5,6} 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/m³ E = 1.1 µg/m³, N = 0.08 µg/m³.

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	¹ Tapwater Subchronic Screening Level (µg/L)	² Reasonable Maximum Exposure Concentration			³ 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	Benzene	150	13	16	16	Insignificant Health Risk
	Toluene	1,200	154	182	182	Insignificant Health Risk
	Ethylbenzene	650	81	123	123	Insignificant Health Risk
	Xylenes	2,500	630	943	943	Insignificant Health Risk
	Naphthalene	36	649	1,083	1,083	High Health Risk
	1-Methylnaphthalene	530	339	1,155	1,155	No to Low Health Risk
	2-Methylnaphthalene	30	250	789	789	Moderate to High Health Risk
	⁴ TPH (JP-5)	350 (520)	5,204	155,204	155,204	High to Very High Health Risk
DiEGME	800	50	215	400,000	Low to Very High Health Risk	

1. Refer to Table 5.

2. Refer to Table 2.

3. Subjective: Insignificant Risk = < Screening Level; Low = >1X to 3X Screening Level; Moderate Risk = >3X to 10X Screening Level; High Risk = >10X to 30X Screening Level; Very High Risk = >30X 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 9: Additional Referenced Laboratory Reports

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 Media 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 DURRING 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

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Date

Attachment 3. Red Hill Shaft Faucet Chromatograms

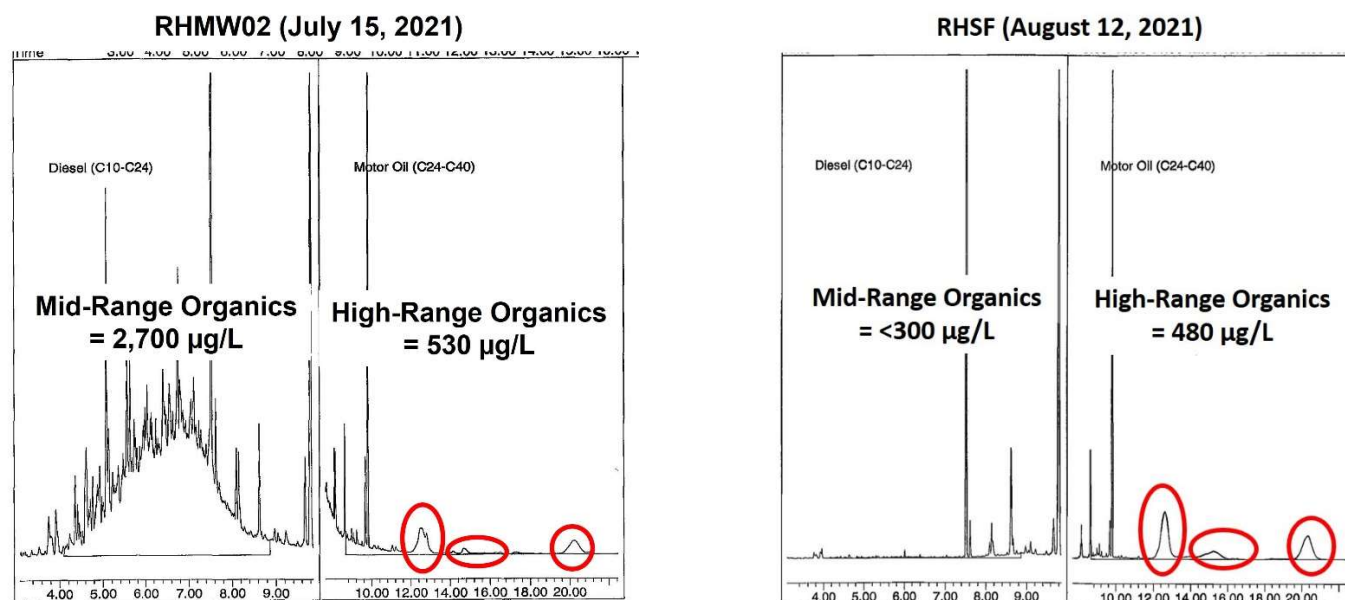


Figure 1. Chromatograms documenting the appearance in July of 2021 of unknown, high retention time and boiling point “High-Range Organic (HRO)” compounds (circled in red; aka “Residual Range Organics”) in groundwater immediately beneath the Red Hill Fuel Storage Facility (Monitoring Well RHMW02, Sample ERH1535; APPL 2022) 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 ERH1539; APPL 2022). 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, 2022 Data Validatable Report : APPL Labs, March 31, 2022.

APPL Laboratory Reports (provided in separate pdf file)

Attachment 4. Water-Fuel Experiment Laboratory Data

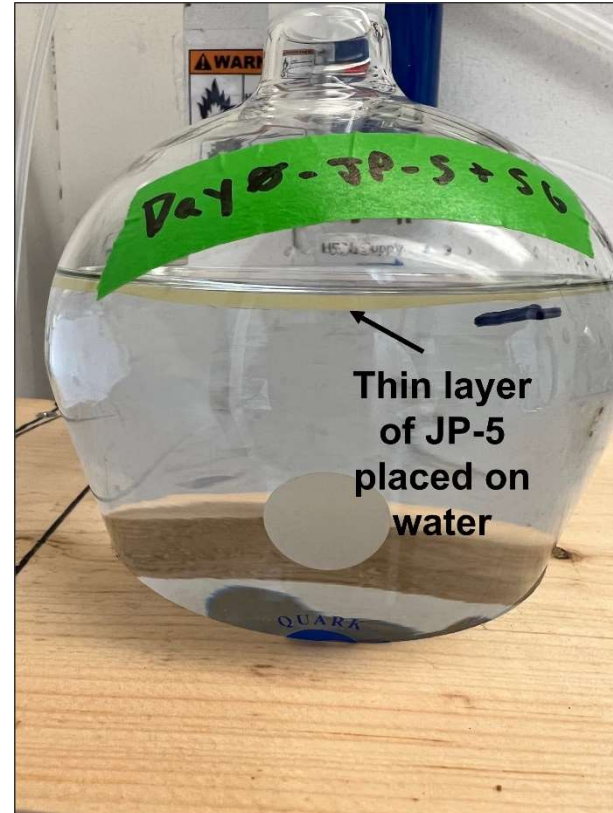


Figure 1. Photographs of water-fuel experiments: A) Experiment setup using one-liter funnel flasks (L-R: Day 0, Day 5, Day 10, Day 15, Day 20); B) Closeup of 10 ml layer of JP-5 fuel placed on top of one liter of water.

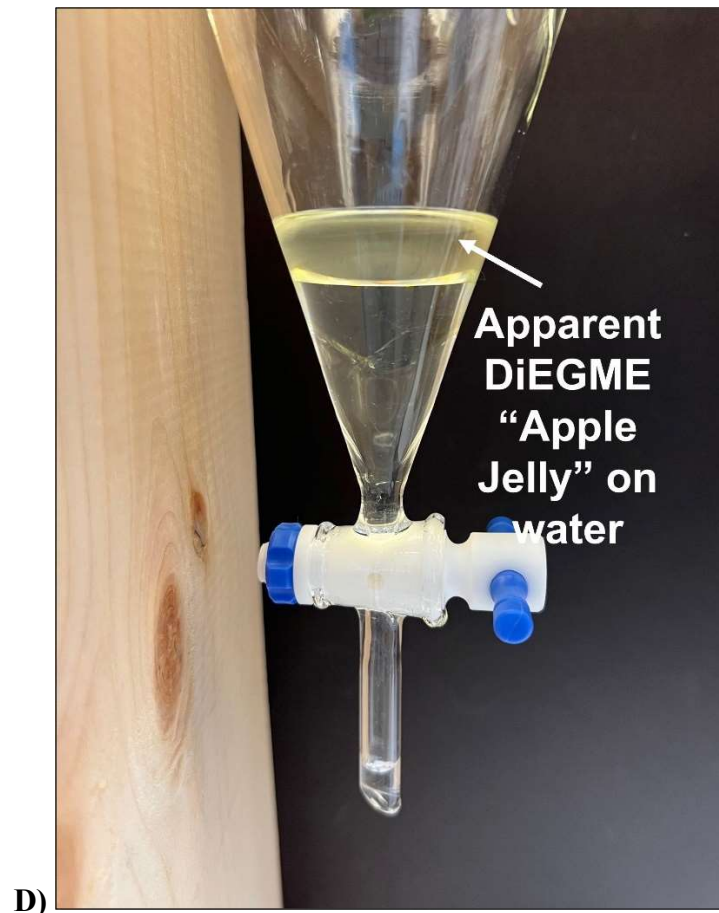


Figure 1 (cont.). Photographs of water-fuel experiments: C) Collection of headspace vapor samples; D) Formation of apparent “apple jelly” emulsion of water and DiEGME on water.

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

Analytes	Units	Unadjusted	¹Adjusted
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
	Total:	766,309	1,000,000
	Total BTEXNM:	14,498	14,498
	Total Carbon Ranges:	751,811	985,502

1. Carbon range data normalized at recommendation of Newfields to generate a total concentration (mass) of compounds in the JP-5 fuel of 1,000,000 mg/kg (100%). Sum of BTEXNM and carbon ranges and DiEGME must necessarily add up to 1,000,000 mg/kg, since these are the primary components of the fuel. Newfields indicated that BTEXNM and DiEGME data are anticipated to be accurate and that error in the measurements was likely restricted to the carbon ranges.

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	
Total:	648	619	4,784	4,753	5,448	5,015	5,138	5,803	5,600	5,730	2%
Total BTEXNM:	199	217	2,046	2,038	2,067	2,201	2,223	2,334	2,129	2,255	6%
Total Carbon Ranges:	400	357	2,690	2,663	3,330	2,755	2,862	3,422	3,471	3,423	-1%

1. SG: Simple Green solution added to experiment.

Table 3. ¹Summary 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 ³	3,180	403	326	1,610	2,190
Toluene	µg/m ³	30,600	8,710	6,520	22,600	29,700
Ethylbenzene	µg/m ³	21,300	11,400	8,080	16,700	21,200
Xylenes	µg/m ³	108,300	66,500	47,600	91,600	115,700
Naphthalene	µg/m ³	6,080	3,700	3,170	3,850	5,560
1-Methylnaphthalene	µg/m ³	3,649	2,124	2,172	0	0
2-Methylnaphthalene	µg/m ³	2,743	1,927	1,995	0	0
C5-C8 Aliphatics	µg/m ³	2,211,128	1,177,402	944,202	1,887,957	2,194,998
C9-C12+ Aliphatics	µg/m ³	9,165,198	6,601,820	4,571,074	6,679,692	8,041,379
C9-C12+ Aromatics	µg/m ³	373,769	282,125	195,255	347,868	456,854
	Total:	11,925,947	8,156,110	5,780,394	9,051,877	10,867,580
	Total BTEXNM:	175,852	94,763	69,864	136,360	174,350
	Total Carbon Ranges:	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. ¹Relative 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%
Total BTEXNM:	1.5%	1.2%	1.2%	1.2%	1.5%	1.6%	1.6%	1.4%
Total Carbon Ranges:	98.5%	98.8%	98.8%	98.8%	98.5%	98.4%	98.4%	98.6%

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
(values presented in tables reflect rounding in Excel)

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

Chemical/ Carbon Range	¹ Relative Weight Percent Makeup of Neat Fuel	² Makeup of Dissolved-Phase Hydrocarbons (mg/L)	² Relative Makeup of Dissolved- Phase Hydrocarbons
Total BTEXMN:	1.4%	2.1	41%
Total Carbon Ranges:	98.6%	3.1	59%
Benzene	0.002%	0.01	0.25%
Toluene	0.02%	0.15	3.0%
Ethylbenzene	0.03%	0.08	1.6%
Xylenes	0.21%	0.63	12%
Naphthalene	0.29%	0.65	13%
1-Methylnaphthalene	0.54%	0.34	6.5%
2-Methylnaphthalene	0.36%	0.25	4.8%
C5-C8 Aliphatics	0.16%	0.01	0.13%
>C8-C18 Aliphatics	81%	0.00	-
>C18-C32 Aliphatics	0.00%	0.00	-
>C8 Aromatics	18%	3.1	59%
Sum:	100%	5.2	100%

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)
DiEGME	51
2,6-Di-tert-butyl-4-Methylphenol	38
Linoleic Acid	-

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

Chemical/ Carbon Range	²Relative Carbon Range Makeup of Dissolved-Phase Hydrocarbons (ingestion)	²Relative Carbon Range Makeup of Dissolved-Phase Hydrocarbons (aromatics dermal)	³Relative BTEXNM Makeup of Dissolved-Phase Hydrocarbons	⁴Relative Volatile Carbon Range Makeup of Dissolved-Phase Hydrocarbons	⁵Relative CR+BTEXNM Makeup of Dissolved-Phase Hydrocarbons (ingestion)	⁵Relative CR+BTEXNM Makeup of Dissolved-Phase Hydrocarbons (dermal)
Total BTEXN					41%	
Total Aliphatic Carbon Ranges					0.13%	
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%				0.00%	
>C6-C8 Aliphatics	0.22%				0.13%	
>C8-C10 Aliphatics	0.00%				0.00%	
>C10-C12 Aliphatics	0.00%				0.00%	
>C12-C16 Aliphatics	0.00%				0.00%	
>C16-C21 Aliphatics	0.00%				0.00%	
>C21-C32 Aliphatics	0.00%				0.00%	
>C8-C10 Aromatics	23%	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%
Sum:	100%	100%	100%	100%	100%	100%

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. ¹Water-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	² Relative Carbon Range Makeup of JP-5 Neat Fuel	³ Relative Carbon Range Makeup of JP-5 Neat Fuel Hydrocarbons	³ Relative Carbon Range Makeup of Dissolved-Phase Hydrocarbons (Total)	⁴ Relative Carbon Range Makeup of Dissolved-Phase Hydrocarbons (Dermal Consideration)	⁵ Relative BTEXMN Makeup of Dissolved-Phase Hydrocarbons	⁶ Relative Volatile Carbon Range Makeup of Dissolved-Phase Hydrocarbons	⁷ Relative CR+BTEXMN Makeup of Dissolved-Phase Hydrocarbons (ingestion)
Total BTEXMN:	1.4%						41%
Total Carbon Ranges:	98.6%						59%
Benzene	0.002%				0.60%		0.25%
Toluene	0.02%				7.3%		3.0%
Ethylbenzene	0.03%				3.8%		1.6%
Xylenes	0.21%				30%		12%
Naphthalene	0.29%				31%		13%
1-Methylnaphthalene	0.54%				16%		6.5%
2-Methylnaphthalene	0.36%				12%		4.8%
C5-C8 Aliphatics	0.16%	0.16%	0.22%	-		0.00%	0.13%
>C8-C18 Aliphatics	81%	82%	0.00%	-		0.00%	0.00%
>C18-C32 Aliphatics	0.00%	0.00%	0.00%	-		0.00%	0.00%
>C8 Aromatics	18%	18%	100%	100%		100%	59%
Sum:	100%	100%	100%	100%	100%	100%	100%

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

(values presented in tables reflect rounding in Excel)

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

Chemical/ Carbon Range	¹ Relative Weight Percent Makeup of Neat Fuel	² Predicted Makeup of Dissolved-Phase Hydrocarbons (mg/L)	² Predicted Relative Makeup of Dissolved- Phase Hydrocarbons
Total BTEXMN:	1.4%	1.5	27%
Total Carbon Ranges:	98.6%	3.9	73%
Benzene	0.002%	0.10	1.8%
Toluene	0.02%	0.20	3.7%
Ethylbenzene	0.03%	0.08	1.5%
Xylenes	0.21%	0.65	12%
Naphthalene	0.29%	0.13	2.4%
1-Methylnaphthalene	0.54%	0.18	3.4%
2-Methylnaphthalene	0.36%	0.12	2.1%
C5-C8 Aliphatics	0.16%	0.03	0.59%
>C8-C18 Aliphatics	81%	0.05	0.85%
>C18-C32 Aliphatics	0.00%	0.00	0.00%
>C8 Aromatics	18%	3.9	72%
Sum:	100%	5.4	100%

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

2. Based on effective solubilities noted in Table 6 of main document and assumed saturated solution in water.

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

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

2. JP-5 average molecular weight assumed to be 185.

Table C. ¹Modeled relative carbon range makeup of dissolved-phase fuel arranged for use in assessment of different exposure pathways.

Chemical/Carbon Range	²Relative Carbon Range Makeup of Dissolved-Phase Hydrocarbons (ingestion)	²Relative Carbon Range Makeup of Dissolved-Phase Hydrocarbons (dermal)	³Relative BTEXNM Makeup of Dissolved-Phase Hydrocarbons	⁴Relative Volatile Carbon Range Makeup of Dissolved-Phase Hydrocarbons	⁵Relative CR+BTEXN Makeup of Dissolved-Phase Hydrocarbons (ingestion)	⁵Relative CR+BTEXN Makeup of Dissolved-Phase Hydrocarbons (dermal)
Total BTEXN					27%	
Total Aliphatic Ranges					1.4%	
Total Aromatic Ranges					72%	
Benzene			6.6%		1.8%	1.8%
Toluene			14%		3.7%	3.7%
Ethylbenzene			5.7%		1.5%	1.5%
Xylenes			45%		12%	12%
Naphthalene			8.9%		2.4%	2.4%
1-Methylnaphthalene			13%		3.4%	3.4%
2-Methylnaphthalene			7.9%		2.1%	2.2%
C5-C6 Aliphatics	0.45%			0.55%	0.33%	
>C6-C8 Aliphatics	0.36%			0.44%	0.26%	
>C8-C10 Aliphatics	0.83%			1.0%	0.61%	
>C10-C12 Aliphatics	0.32%			0.40%	0.24%	
>C12-C16 Aliphatics	0.01%				0.01%	
>C16-C21 Aliphatics	0.00%				0.00%	
>C21-C32 Aliphatics	0.00%				0.00%	
>C8-C10 Aromatics	26%	26%		32%	19%	19%
>C10-C12 Aromatics	53%	54%		66%	39%	39%
>C12-C16 Aromatics	19%	20%			14%	14%
>C16-C21 Aromatics	0.04%	0.04%			0.03%	0.03%
>C21-C32 Aromatics	0.00%	0.00%			0.00%	0.00%
Sum:	100%	100%	100%	100%	100%	100%

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 of main document 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. ¹Modeled 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	² Relative Carbon Range Makeup of Neat Fuel	³ Relative Carbon Range Makeup of Neat Fuel Hydrocarbons	³ Relative Carbon Range Makeup of Dissolved-Phase Hydrocarbons (Total)	⁴ Relative Carbon Range Makeup of Dissolved-Phase Hydrocarbons (Dermal Consideration)	⁵ Relative BTEXMN Makeup of Dissolved-Phase Hydrocarbons	⁶ Relative Volatile Carbon Range Makeup of Dissolved-Phase Hydrocarbons	⁷ Relative CR+BTEXMN Makeup of Dissolved-Phase Hydrocarbons
Total BTEXMN:	1.4%						27%
Total Carbon Ranges:	98.6%						73%
Benzene	0.002%				6.6%		1.8%
Toluene	0.02%				14%		3.7%
Ethylbenzene	0.03%				5.7%		1.5%
Xylenes	0.21%				45%		12%
Naphthalene	0.29%				8.9%		2.4%
1-Methylnaphthalene	0.54%				13%		3.4%
2-Methylnaphthalene	0.36%				7.9%		2.1%
C5-C8 Aliphatics	0.16%	0.16%	0.80%	-		1.0%	0.59%
>C8-C18 Aliphatics	81%	82%	1.2%	-		1.4%	0.85%
>C18-C32 Aliphatics	0.00%	0.00%	0.00%	-		0.00%	0.00%
>C8 Aromatics	18%	18%	98%	99%		98%	72%
Sum:	100%	100%	100%	100%	100.00%	100%	100%

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 of main document 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 ^{a,e}Acute Health Effects.

Chemical	Target Organs for ^{a,e} Acute Health Effects													
	^b Carcinogen	^c Mutagen	^d Alimentary Tract	Cardiovascular	Developmental	Endocrine	Eye	Hematologic	Immune	Kidney	Nervous	Reproductive	Respiratory	Skin
Hydrocarbons														
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			
Additives														
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 ^aSubchronic Health Effects.

*Chemical	Target Organs for ^{a,e} Subchronic Health Effects													
	^b Carcinogen	^c Mutagen	^d Alimentary Tract	Cardiovascular	Developmental	Endocrine	Eye	Hematologic	Immune	Kidney	Nervous	Reproductive	Respiratory	Skin
Hydrocarbons														
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			
Additives														
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 ^aChronic Health Effects.

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

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 2023):

- B: Dimensionless ratio of the permeability coefficient of a compound through the stratum corneum relative to its permeability coefficient across the viable epidermis;
- τ_{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.

¹ 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)	² 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 2023).
 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.

² Exposure Pathway	¹ 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
³ Dermal	0.010/0.040 mg/kg-day	0.010/0.079 mg/kg-day
⁴ Inhalation	60/200 µg/m ³	115/126 µg/m ³

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.

² Exposure Pathway	¹ 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
³ Dermal Contact	0.010/0.040 mg/kg-day	0.010/0.079 mg/kg-day
⁴ Inhalation	61/199 µg/m ³	115/126 µg/m ³

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. A copy of the equations used in the model is provided below. 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 2023) and additional use of a dishwasher and laundry washing machine for one hour each per day.

USEPA, 2023, *User's Guide - 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	¹Value
Skin Area - child	SAres-c	cm ²	6,365
Volatilization Factor	K	L/m ³	0.5
Water ingestion rate - children	IRWc	L/d	0.78
² 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.

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

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Regional Screening Levels (RSLs) - User's Guide

May 2023

To download the most recent Regional Screening Level tables, please go to the Generic Tables <https://epa.gov/risk/regional-screening-levels-rsls-generic-tables> page. For assistance/questions please use the Regional Screening Levels (RSLs) contact us <https://epa.gov/risk/forms/contact-us-about-regional-screening-levels-rsls> page.

Disclaimer

This guidance sets forth a recommended, but not mandatory, approach based upon currently available information with respect to risk assessment for response actions at CERCLA sites. This document does not establish binding rules. Alternative approaches for risk assessment may be found to be more appropriate at specific sites (e.g., where site circumstances do not match the underlying assumptions, conditions and models of the guidance). The decision whether to use an alternative approach and a description of any such approach should be documented for such sites.

Accordingly, when comments are received at individual CERCLA sites questioning the use of the approaches recommended in this guidance, the comments should be considered and an explanation provided for the selected approach.

It should also be noted that the screening levels (SLs) in these tables are based upon human health risk and do not address potential ecological risk. Some sites in sensitive ecological settings may also need to be evaluated for potential ecological risk. EPA's guidance "Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessment" <https://epa.gov/risk/ecological-risk-assessment-guidance-superfund-process-designing-and-conducting-ecological-risk> contains an eight step process for using benchmarks for ecological effects in the remedy selection process.

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Regional Screening Levels (RSLs)

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- RSL Calculator http://epa-prgs.ornl.gov/cgi-bin/chemicals/csl_search
- Generic Tables <https://epa.gov/risk/regional-screening-levels-rsls-generic-tables>
- Contact Us <https://epa.gov/risk/forms/contact-us-about-regional-screening-levels-rsls>

4.1.2 Resident Tapwater

This receptor is exposed to chemicals in water that are delivered into a residence from sources such as groundwater or surface water. Ingestion of drinking water is an appropriate pathway for all chemicals. The inhalation exposure route is only calculated for volatile compounds. Activities such as showering, laundering, and dish washing contribute to contaminants in the air for inhalation. Dermal contact with tapwater is also considered for analytes determined to be within the effective predictive domain as described in Section 4.9.8.

This land use is for developing residential default screening levels that are presented in the RSL Generic Tables.

4.1.2.1 Noncarcinogenic-child

The tapwater land use equation, presented here, contains the following exposure routes:

- ingestion of water

$$SL_{\text{res-wat-ingnc}} \left(\frac{\mu\text{g}}{\text{L}} \right) = \frac{\text{THQ} \times \text{AT}_{\text{res-c}} \left(\frac{365 \text{ days}}{\text{yr}} \times \text{ED}_{\text{res-c}} (6 \text{ yr}) \right) \times \text{BW}_{\text{res-c}} (15 \text{ kg})}{\left(\frac{1}{\text{RfDo}} \left(\frac{\text{mg}}{\text{kg-day}} \right) \right) \times \left(\frac{\text{mg}}{1000 \mu\text{g}} \right) \times \text{EF}_{\text{res-c}} \left(\frac{350 \text{ days}}{\text{yr}} \right) \times \text{ED}_{\text{res-c}} (6 \text{ yr}) \times \text{IRW}_{\text{res-c}} \left(\frac{0.78 \text{ L}}{\text{day}} \right)}$$

- dermal

For Inorganics:

$$SL_{\text{res-wat-dernc}} \left(\frac{\mu\text{g}}{\text{L}} \right) = \frac{\text{DA}_{\text{event}} \left(\frac{\mu\text{g}}{\text{cm}^2 \text{-event}} \right) \times \left(\frac{1000 \text{ cm}^3}{\text{L}} \right)}{K_p \left(\frac{\text{cm}}{\text{hr}} \right) \times \text{ET}_{\text{event-res-c}} \left(\frac{0.54 \text{ hrs}}{\text{event}} \right)}$$

For Organics:

IF $\text{ET}_{\text{event-res-c}} \left(\frac{0.54 \text{ hrs}}{\text{event}} \right) \leq t^*$ (hrs), then:

$$SL_{\text{res-wat-dernc}} \left(\frac{\mu\text{g}}{\text{L}} \right) = \frac{\text{DA}_{\text{event}} \left(\frac{\mu\text{g}}{\text{cm}^2 \text{-event}} \right) \times \left(\frac{1000 \text{ cm}^3}{\text{L}} \right)}{2 \times \text{FA} \times K_p \left(\frac{\text{cm}}{\text{hr}} \right) \times \sqrt{\frac{6 \times \tau_{\text{event}} \left(\frac{\text{hrs}}{\text{event}} \right) \times \text{ET}_{\text{event-res-c}} \left(\frac{0.54 \text{ hrs}}{\text{event}} \right)}{\pi}}}$$

or:

IF $\text{ET}_{\text{event-res-c}} \left(\frac{0.54 \text{ hrs}}{\text{event}} \right) > t^*$ (hrs), then:

$$SL_{\text{res-wat-dernc}} \left(\frac{\mu\text{g}}{\text{L}} \right) = \frac{\text{DA}_{\text{event}} \left(\frac{\mu\text{g}}{\text{cm}^2 \text{-event}} \right) \times \left(\frac{1000 \text{ cm}^3}{\text{L}} \right)}{\text{FA} \times K_p \left(\frac{\text{cm}}{\text{hr}} \right) \times \left[\frac{\text{ET}_{\text{event-res-c}} \left(\frac{0.54 \text{ hrs}}{\text{event}} \right)}{1 + B} + 2 \times \tau_{\text{event}} \left(\frac{\text{hrs}}{\text{event}} \right) \times \left(\frac{1 + 3B + 3B^2}{(1 + B)^2} \right) \right]}$$

where:

$$\text{DA}_{\text{event}} \left(\frac{\mu\text{g}}{\text{cm}^2 \text{-event}} \right) = \frac{\text{THQ} \times \text{AT}_{\text{res-c}} \left(\frac{365 \text{ days}}{\text{yr}} \times \text{ED}_{\text{res-c}} (6 \text{ yr}) \right) \times \text{BW}_{\text{res-c}} (15 \text{ kg})}{\left(\frac{1}{\text{RfDo}} \left(\frac{\text{mg}}{\text{kg-day}} \right) \right) \times \text{GIABS}} \times \left(\frac{\text{mg}}{1000 \mu\text{g}} \right) \times \text{EF}_{\text{res-c}} \left(\frac{350 \text{ days}}{\text{yr}} \right) \times \text{ED}_{\text{res-c}} (6 \text{ yr}) \times \text{EV}_{\text{res-c}} \left(\frac{1 \text{ event}}{\text{day}} \right) \times \text{SA}_{\text{res-c}} (6,365 \text{ cm}^2)$$

- inhalation of volatiles

$$SL_{\text{res-wat-inhnc}} \left(\frac{\mu\text{g}}{\text{L}} \right) = \frac{\text{THQ} \times \text{AT}_{\text{res-c}} \left(\frac{365 \text{ days}}{\text{yr}} \times \text{ED}_{\text{res-c}} (6 \text{ yr}) \right)}{\left(\frac{1}{\text{RfC}} \left(\frac{\text{mg}}{\text{m}^3} \right) \right) \times \left(\frac{\text{mg}}{1000 \mu\text{g}} \right) \times \text{EF}_{\text{res-c}} \left(\frac{350 \text{ days}}{\text{yr}} \right) \times \text{ED}_{\text{res-c}} (6 \text{ yr}) \times \text{ET}_{\text{res-c}} \left(\frac{24 \text{ hrs}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hrs}} \right) \times K \left(\frac{0.5 \text{ L}}{\text{m}^3} \right)}$$

- Total

$$SL_{\text{res-wat-totnc}} \left(\frac{\mu\text{g}}{\text{L}} \right) = \frac{1}{\frac{1}{SL_{\text{res-wat-ingnc}}} + \frac{1}{SL_{\text{res-wat-inhnc}}} + \frac{1}{SL_{\text{res-wat-dernc}}}}$$

4.1.2.2 Noncarcinogenic-adult

The tapwater land use equation, presented here, contains the following exposure routes:

- ingestion of water

$$SL_{\text{res-wat-ingna}} \left(\frac{\mu\text{g}}{\text{L}} \right) = \frac{\text{THQ} \times \text{AT}_{\text{res-a}} \left(\frac{365 \text{ days}}{\text{yr}} \times \text{ED}_{\text{res}} (26 \text{ yr}) \right) \times \text{BW}_{\text{res-a}} (80 \text{ kg})}{\left(\frac{1}{\text{RfDo}} \left(\frac{\text{mg}}{\text{kg-day}} \right) \right) \times \left(\frac{\text{mg}}{1000 \mu\text{g}} \right) \times \text{EF}_{\text{res-a}} \left(\frac{350 \text{ days}}{\text{yr}} \right) \times \text{ED}_{\text{res}} (26 \text{ yr}) \times \text{IRW}_{\text{res-a}} \left(\frac{2.5 \text{ L}}{\text{day}} \right)}$$

- dermal

For Inorganics:

$$SL_{\text{res-wat-derna}} \left(\frac{\mu\text{g}}{\text{L}} \right) = \frac{\text{DA}_{\text{event}} \left(\frac{\mu\text{g}}{\text{cm}^2\text{-event}} \right) \times \left(\frac{1000 \text{ cm}^3}{\text{L}} \right)}{K_p \left(\frac{\text{cm}}{\text{hr}} \right) \times \text{ET}_{\text{event-res-a}} \left(\frac{0.71 \text{ hrs}}{\text{event}} \right)}$$

For Organics:

IF $\text{ET}_{\text{event-res-a}} \left(\frac{0.71 \text{ hrs}}{\text{event}} \right) \leq t^*$ (hrs), then:

$$SL_{\text{res-wat-derna}} \left(\frac{\mu\text{g}}{\text{L}} \right) = \frac{\text{DA}_{\text{event}} \left(\frac{\mu\text{g}}{\text{cm}^2\text{-event}} \right) \times \left(\frac{1000 \text{ cm}^3}{\text{L}} \right)}{2 \times \text{FA} \times K_p \left(\frac{\text{cm}}{\text{hr}} \right) \times \sqrt{\frac{6 \times \tau_{\text{event}} \left(\frac{\text{hrs}}{\text{event}} \right) \times \text{ET}_{\text{event-res-a}} \left(\frac{0.71 \text{ hrs}}{\text{event}} \right)}{\pi}}}$$

or:

IF $\text{ET}_{\text{event-res-a}} \left(\frac{0.71 \text{ hrs}}{\text{event}} \right) > t^*$ (hrs), then:

$$SL_{\text{res-wat-derna}} \left(\frac{\mu\text{g}}{\text{L}} \right) = \frac{\text{DA}_{\text{event}} \left(\frac{\mu\text{g}}{\text{cm}^2\text{-event}} \right) \times \left(\frac{1000 \text{ cm}^3}{\text{L}} \right)}{\text{FA} \times K_p \left(\frac{\text{cm}}{\text{hr}} \right) \times \left[\frac{\text{ET}_{\text{event-res-a}} \left(\frac{0.71 \text{ hrs}}{\text{event}} \right)}{1 + B} + 2 \times \tau_{\text{event}} \left(\frac{\text{hrs}}{\text{event}} \right) \times \left(\frac{1 + 3B + 3B^2}{(1 + B)^2} \right) \right]}$$

where:

$$\text{DA}_{\text{event}} \left(\frac{\mu\text{g}}{\text{cm}^2\text{-event}} \right) = \frac{\text{THQ} \times \text{AT}_{\text{res-a}} \left(\frac{365 \text{ days}}{\text{yr}} \times \text{ED}_{\text{res}} (26 \text{ yr}) \right) \times \text{BW}_{\text{res-a}} (80 \text{ kg})}{\left(\frac{1}{\text{RfDo}} \left(\frac{\text{mg}}{\text{kg-day}} \right) \times \text{GIABS} \right) \times \left(\frac{\text{mg}}{1000 \mu\text{g}} \right) \times \text{EF}_{\text{res-a}} \left(\frac{350 \text{ days}}{\text{yr}} \right) \times \text{ED}_{\text{res}} (26 \text{ yr}) \times \text{EV}_{\text{res-a}} \left(\frac{1 \text{ event}}{\text{day}} \right) \times \text{SA}_{\text{res-a}} (19,652 \text{ cm}^2)}$$

- inhalation of volatiles

$$SL_{\text{res-wat-inhna}} \left(\frac{\mu\text{g}}{\text{L}} \right) = \frac{\text{THQ} \times \text{AT}_{\text{res-a}} \left(\frac{365 \text{ days}}{\text{yr}} \times \text{ED}_{\text{res}} (26 \text{ yr}) \right)}{\left(\frac{1}{\text{RfC}} \left(\frac{\text{mg}}{\text{m}^3} \right) \right) \times \left(\frac{\text{mg}}{1000 \mu\text{g}} \right) \times \text{EF}_{\text{res-a}} \left(\frac{350 \text{ days}}{\text{yr}} \right) \times \text{ED}_{\text{res}} (26 \text{ yr}) \times \text{ET}_{\text{res-a}} \left(\frac{24 \text{ hrs}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hrs}} \right) \times K \left(\frac{0.5 \text{ L}}{\text{m}^3} \right)}$$

- Total

$$SL_{\text{res-wat-totna}} \left(\frac{\mu\text{g}}{\text{L}} \right) = \frac{1}{\frac{1}{SL_{\text{res-wat-ingna}}} + \frac{1}{SL_{\text{res-wat-inhna}}} + \frac{1}{SL_{\text{res-wat-derna}}}}$$

4.1.2.3 Carcinogenic

The tapwater land use equation, presented here, contains the following exposure routes:

- ingestion of water

$$SL_{\text{res-wat-ingc}} \left(\frac{\mu\text{g}}{\text{L}} \right) = \frac{\text{TR} \times \text{AT}_{\text{res}} \left(\frac{365 \text{ days}}{\text{yr}} \times \text{LT} (70 \text{ yrs}) \right)}{\text{CSF}_o \left(\frac{\text{mg}}{\text{kg-day}} \right)^{-1} \times \left(\frac{\text{mg}}{1000 \mu\text{g}} \right) \times \text{IFW}_{\text{res-adj}} \left(\frac{327.95 \text{ L}}{\text{kg}} \right)}$$

where:

$$\text{IFW}_{\text{res-adj}} \left(\frac{327.95 \text{ L}}{\text{kg}} \right) = \left[\frac{\text{EF}_{\text{res-c}} \left(\frac{350 \text{ days}}{\text{yr}} \right) \times \text{ED}_{\text{res-c}} (6 \text{ yr}) \times \text{IRW}_{\text{res-c}} \left(\frac{0.78 \text{ L}}{\text{day}} \right)}{\text{BW}_{\text{res-c}} (15 \text{ kg})} + \frac{\text{EF}_{\text{res-a}} \left(\frac{350 \text{ days}}{\text{yr}} \right) \times \text{ED}_{\text{res-a}} (20 \text{ yr}) \times \text{IRW}_{\text{res-a}} \left(\frac{2.5 \text{ L}}{\text{day}} \right)}{\text{BW}_{\text{res-a}} (80 \text{ kg})} \right]$$

Preliminary remediation goals are the starting points in the development of final cleanup levels at sites. As at all sites addressed under the NCP, these goals may be modified, depending on physical characteristics of a site, State laws and guidance, and other site specific factors, such as additional exposure routes.

The tapwater screening level of 14 µg/L is based on EPA's RfD and using standard RSL equations.

5.27 Styrene-acrylonitrile trimer (SAN Trimer)

Styrene-acrylonitrile trimer (SAN Trimer) is a by-product of specific manufacturing processes for polymers of styrene and acrylonitrile and a mixture of isomers formed by the condensation of two moles of acrylonitrile and one mole of styrene and has a molecular weight of 210. The mixture is composed of two structural forms: 4-cyano-1,2,3,4-tetrahydro-a-methyl-1-naphthaleneacetonitrile (THNA, CASRN 57964-39-3) and 4-cyano-1,2,3,4-tetrahydro-1-naphthalenepropionitrile (THNP, CASRN 57964-40-6). The THNA form consists of four stereoisomers: cis-R-THNA (CASRN 142759-38-4), cis-S-THNA (CASRN 142759-39-5), trans-R-THNA (CASRN 142759-37-3), and trans-S-THNA (CASRN 142759-40-8). The THNP form consists of two stereoisomers: cis-THNP (CASRN 142681-91-2) and trans-THNP (CASRN 142681-92-3). The NTP report [\[1\]](#) provides details regarding the structure and toxicity study for the mixture.

The SAN Trimer mixture is analyzed in environmental media using gas chromatography that yields three peaks. The total concentration corresponds to the total area of the three peaks. The Regional Screening Levels provide RSLs based on the oral Reference Dose for the SAN Trimer derived from the toxicity study described above. The PPRTV RfD used to derive the RSLs is based on the SAN Trimer mixture. The SAN Trimer structural isomers are listed separately in the RSL calculator but are the same values for the individual isomers. To evaluate the non-cancer toxicity of the SAN Trimer, compare the total concentration calculated based on the total of the three peaks to the RSL for either isomer.

5.28 cis- and trans-Chlordane Surrogate

According to an April 7, 2021 memo <https://semsub.epa.gov/src/document/hq/100002784> from the Office of Research and Development,

“..technical chlordane can be considered a suitable surrogate for oral, noncancer screening-level assessments of cis- and trans-chlordane”.

Beginning in May 2021, the RSLs will use the technical chlordane (12789-03-6) Reference Dose as a surrogate for cis-chlordane (5103-71-9, alpha-chlordane) and trans-chlordane (5103-74-2, gamma-chlordane).

6. Recommended Default Exposure Parameters

Table 1 presents the definitions of the most commonly used variables and their default values. All the variables and their default values are available in this spreadsheet file <https://semsub.epa.gov/src/document/hq/403621> or this PDF <https://semsub.epa.gov/src/document/hq/403620>. The calculator follows the recommendations in the OSWER Directive [\[2\]](https://epa-prgs.ornl.gov:8085/radionuclides/efh_changes_table_memo_2014.pdf) concerning use of exposure parameters from the 2011 Exposure Factors Handbook. Any alternative values or assumptions used in remedy evaluation or selection on a CERCLA site should be presented with supporting rationale in Administrative Records.

• **Table 1. Recommended Default Exposure Parameters and Variable Definitions**

Symbol	Definition (units)	Default	Reference
SL	Screening Level (mg/kg, µg/L, or µg/m ³)	Contaminant-specific	Determined in this calculator
TR	Target Risk	1×10^{-6}	Selected by user
THQ	Target Hazard Quotient	0.1	Selected by user
AT	Averaging Time (days)	365 x LT (carcinogenic) 365 x ED (non-carcinogenic)	U.S. EPA 1989 (pg. 6-23)
LT	Lifetime (years)	70	U.S. EPA 1989 (pg. 6-22)
IRW	Ingestion Rate - Water (L/day)	0.78 (child) 2.5 (adult)	OSWER Directive
IRS	Ingestion Rate - Soil (mg/day)	200 (child) 100 (adult)	U.S. EPA 1991a (pg. 15)
IRF	Ingestion Rate - Fish (mg/day)	site-specific	Recommend using site-specific values
SA _{res-c}	Surface Area soil - (cm ² /day)	2373 (child - soil) 6032 (adult - soil) 3527 (worker - soil) 6365 (child - water) 19652 (adult - water)	OSWER Directive
AF	Soil Adherence Factor (mg/cm ²)	0.2 (child) 0.07 (adult) 0.12 (worker) 0.3 (construction worker)	U.S. EPA 2004 (Exhibit 3-5), RAGS Part E
BW	Body Weight (kg)	15 (child) 80 (adult)	U.S. EPA 1991a (pg. 15)
ABS _d	Fraction of contaminant absorbed dermally from soil (unitless)	contaminant-specific Inorganic default = none VOC default = none SVOC default = 0.1	U.S. EPA 2004 (Exhibit 3-4 and section 3.2.2.4)
GIABS	Fraction of contaminant absorbed in gastrointestinal tract (unitless) Note: if the GIABS is >50% then it is set to 100% for the calculation of dermal toxicity values.	contaminant-specific inorganic default = 1.0 VOC default = 1.0 SVOC default = 1.0	U.S. EPA 2004 (Exhibit 4-1 and section 4.2)

EF	Exposure Frequency (days/year)	350 (resident) 250 (indoor worker) 225 (outdoor worker)	U.S. EPA 1991a (pg. 15)
ED	Exposure Duration (years)	26 (resident) 6 (child) 20 (adult) 25 (worker) 1 (construction worker)	OSWER Directive
ET	Exposure Time - Air (hours/day)	24 (resident) 8 (worker)	The whole day The work day
ET _{event}	Exposure Time - Water (hours/event)	0.54 (child) 0.71 (adult)	U.S. EPA 2011, Table 16-28; weighted average of 90th percentile time spent bathing (birth to <6 years)
EV	Events (events/day)	site-specific	Site-specific
DAF	Dilution Attenuation Factor (unitless)	1 (or site-specific)	U.S. EPA. 2002 Equation 4-11
PEF	Particulate Emission Factor (m ³ /kg)	1.36 x 10 ⁹	U.S. EPA 2002 Exhibit D-2
VF	Volatilization Factor (m ³ /kg)	contaminant-specific	U.S. EPA. 2002 Equation 4-8

7. References

U.S. EPA (Environmental Protection Agency). 1987. Processes, Coefficients, and Models for Simulation Toxic Organics and Heavy Metals in Surface Waters. EPA/600/3-87/015. Office of Research and Development, Athens, GA.

U.S. EPA 1989. Risk assessment guidance for Superfund. Volume I: Human health evaluation manual (Part A)(PDF) <<https://semspub.epa.gov/src/document/hq/191>> (289 pp, 6.9 MB). Interim Final. Office of Emergency and Remedial Response. EPA/540/1-89/002.

U.S. EPA 1991a. Human health evaluation manual, supplemental guidance: "Standard default exposure factors (PDF) <<https://semspub.epa.gov/src/document/hq/190591>> (28 pp, 248 K)". OSWER Directive 9285.6-03.

U.S. EPA 1991b. Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (Part B, Development of Risk-Based Preliminary Remediation Goals) (PDF) <<https://semspub.epa.gov/src/document/hq/192>> (68 pp, 721 K). Office of Emergency and Remedial Response. EPA/540/R-92/003. December 1991

U.S. EPA. 1996a. Soil Screening Guidance: User's Guide. Office of Emergency and Remedial Response. Washington, DC. OSWER No. 9355.4-23 <<https://epa.gov/superfund/superfund-soil-screening-guidance>>

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U.S. EPA, 2000b. Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health (PDF) <<https://epa.gov/sites/default/files/2018-10/documents/methodology-wqc-protection-hh-2000.pdf>>(185 pp, 790 K).

U.S. EPA, 2001 (PDF) <<https://semspub.epa.gov/src/document/03/2218724>>(38 pp, 185 K). WATER9. Version 1.0.0. Office of Air Quality Planning and Standards, Research Triangle Park, NC. Web site <<http://www3.epa.gov/ttn/chief/software/water/index.html>>.

U.S. EPA 2002. Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites. OSWER 9355.4-24. December 2002
<<https://epa.gov/superfund/superfund-soil-screening-guidance>>.

U.S. EPA 2004. Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment) Final. OSWER 9285.7-02EP. July 2004. Document (PDF) <<https://semspub.epa.gov/src/document/hq/195>> (186 pp, 4.2 MB) and website <<https://epa.gov/risk/risk-assessment-guidance-superfund-rags-part-e>>.

U.S. EPA 2005. Supplemental Guidance for Assessing Susceptibility from Early-Life Exposure to Carcinogens. March 2005. Document (PDF) <<https://semspub.epa.gov/src/document/hq/190690>> (166 pp, 468 K)

U.S. EPA 2009. Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part F, Supplemental Guidance for Inhalation Risk Assessment) Final. OSWER 9285.7-82. January 2009. Document (PDF) <<https://semspub.epa.gov/src/document/hq/140530>> (68 pp, 724 K), memo (PDF) <<https://semspub.epa.gov/src/document/hq/140529>> (3 pp, 487 K) and website <<https://epa.gov/risk/risk-assessment-guidance-superfund-rags-part-f>>.

U.S. EPA 2011. Exposure Factors Handbook 2011 Edition (Final). National Center for Environmental Assessment, Office of Research and Development. Washington D.C. Currently available online at the EFH webpage or download here (PDF)

<<https://semspub.epa.gov/src/document/hq/190592>> (1436 pp, 21.3 MB).

U.S. EPA 2012. OSWER Directive 9200.1-113: Compilation and Review of Data on Relative Bioavailability of Arsenic in Soil

<<https://semspub.epa.gov/src/document/hq/175339.pdf>>. Washington, DC.

U.S. EPA 2014. OSWER Directive 9200.1-120 (PDF) <<https://semspub.epa.gov/src/document/hq/190670>> (7 pp, 1.1 MB). Washington, DC.

U.S. EPA 2019. Exposure Factors Handbook Chapter 3 Updates <<https://epa.gov/expobox/exposure-factors-handbook-chapter-3>> Office of Research and Development,, Washington, DC.

For assistance/questions please use the Regional Screening Levels (RSLs) contact us <<https://epa.gov/risk/forms/contact-us-about-regional-screening-levels-rsls>> page. For general risk assessment questions, separate from the RSLs, please use the link below.

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[Risk Recent Additions <https://epa.gov/risk/recent-additions-risk-assessment>](https://epa.gov/risk/recent-additions-risk-assessment)

[Human Health Risk Assessment <https://epa.gov/risk/human-health-risk-assessment>](https://epa.gov/risk/human-health-risk-assessment)

[Ecological Risk Assessment <https://epa.gov/risk/ecological-risk-assessment>](https://epa.gov/risk/ecological-risk-assessment)

[Risk Assessment Guidance <https://epa.gov/risk/risk-assessment-guidance>](https://epa.gov/risk/risk-assessment-guidance)

[Risk Tools and Databases <https://epa.gov/risk/human-health-risk-models-and-tools>](https://epa.gov/risk/human-health-risk-models-and-tools)

[Risk Management <https://epa.gov/risk/risk-messaging-guidance>](https://epa.gov/risk/risk-messaging-guidance)

[Superfund Risk Assessment <https://epa.gov/risk/superfund-risk-assessment>](https://epa.gov/risk/superfund-risk-assessment)

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Attachment 9: Additional Referenced Laboratory Reports
(provided in separate zip file)

- Comparison of TPH data with and without silica gel cleanup (report including Red Hill Shaft Sample ERH2018; Energy Laboratory, January 10, 2022)
- TPH reported at 142 mg/L in Red Hill Shaft following shutdown (report including Red Hill Shaft Sample ERH2226, Energy Laboratory, January 19, 2023)
- DiEGME reported at 32,000 µg/L in water sample collected from Adit 3 sump at Red Hill (concentration reported under “2-(2-Methoxyethoxy) ethanol;” report including Red Hill Shaft Sample ERH2274; APPL March 2022)
- Cumulative summary of “Notice of Interest (NOI)” groundwater data collected from May 2021 to July 2023 at Red Hill facility (Excel file; USDN 2023)