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Development of Drinking Water Screening Levels for TPHs and Associated Chemicals

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Acronyms and Abbreviations

COPC	chemicals of potential concern
CSF	cancer oral slope factor
DOH	Department of Health
EPA	U.S. Environmental Protection Agency
HI	hazard index
HQ	hazard quotient
LOD	limit of detection
RfD	reference dose, oral
RHSF	Red Hill Bulk Fuel Storage Facility
TPH	total petroleum hydrocarbon

Limitations

The conclusions and recommendations presented herein are based on the work performed as described below. Exponent reserves the right to revise these conclusions and recommendations if and when additional credible information becomes available. We have made every effort to accurately and completely present all areas of concern identified during our analysis. If there are perceived omissions or misstatements in this presentation regarding any aspect of our work, we ask that they be brought to our attention as soon as possible so we have the opportunity to address them fully.

Exponent has relied on the monitoring data provided by Intera, Inc. in this analysis; the accuracy of these data are the responsibility of Intera. These data were used to derive screening drinking water concentrations for Total Petroleum Hydrocarbon (TPH) fractions according to the EPA (2009) recommended approach. This is a risk assessment-based approach and therefore, this analysis is limited by the specific assumptions adopted and the inherent uncertainties in this method.

Executive Summary

At the Red Hill Bulk Fuel Storage Facility (RHSF) on Oahu, Hawaii, 20 underground jet fuel storage tanks have been monitored for over a decade. Monitoring has included the analysis of specific chemicals as well as various types of petroleum hydrocarbon mixtures in groundwater. Exponent was requested to develop acceptable drinking water concentrations for the total petroleum hydrocarbons (TPHs) detected at RHSF. The U.S. Environmental Protection Agency method (EPA 2009) for assessing risks from exposure to complex mixtures of petroleum hydrocarbons was used as the framework to derive site-specific screening concentrations in drinking water.

A total of 64 chemicals have been monitored for at the RHSF. Chemicals have been selected as representative of chemical constituents associated with jet fuel and marine diesel fuel (DON 2016). These include volatile organic chemicals and solvents, polyaromatic hydrocarbons, and lead. In addition, three sub-types of TPHs were analyzed at RHSF: TPH-g (gasoline), TPH-d (diesel), and TPH-o (oil). Categorization of TPHs depends on the purpose and analytical method used. Collectively, they represent a range of compounds from short to long chain aliphatic compounds. TPH-g is total petroleum hydrocarbons as gasoline and includes the more volatile and short chain constituents; some analytical methods describe this sub-type as including chains of 6 to 10 carbons (C6-C10). The TPH-g samples were considered to represent the low carbon aliphatic fraction in this analysis, which EPA (2009) has designated to include aliphatics of C5-C8. TPH-d is total petroleum hydrocarbons as diesel and has been described as the middle distillates of 10 to 28 carbon-chain length. The TPH-d represents the medium carbon fraction of aliphatics in this analysis or C9-C18 as characterized in EPA (2009). TPH-o is total petroleum hydrocarbons as oil and is composed of the heaviest constituents with the longest carbon chains, presumably greater than 28 carbons. TPH-o is considered to represent the high carbon aliphatic fraction in this analysis and are designated by EPA (2009) to include C19-C32. The specific carbon chain length for each of the TPH sub-types analyzed at RHSF are unknown.

Exponent's analysis of the monitoring data and derivation of screening levels was based on the most current six years of groundwater monitoring data (2010 – 2015). Only monitoring well data were included; the monitoring at a drinking water well location was not included. Field

duplicates were excluded from estimates of potential exposure. Chemicals of potential concern (COPCs) were identified as those that had been detected at least once between 2010 and 2015. Daily and lifetime intakes of the COPCs were estimated based on mean groundwater concentrations and assuming that the samples designated as "non-detect" were present at one-half the limit of detection (LOD).

Our approach to deriving screening drinking water concentrations was based on the site-specific monitoring data and the risks associated with the COPCs within the EPA TPH framework. The estimated risks based on the monitoring data provided an understanding of the risk profile at the site. This risk profile and the relative contribution that each chemical added to the total risk was the foundation for developing site-specific screening levels for drinking water.

Non-cancer-based screening concentrations for drinking water were developed under a series of scenarios that reflect the risk profile for one of the six years of monitoring data analyzed in this report. Scenario 1 assumed that the COPC representing the greatest contribution to the risk profile for all six years, TPH-d (diesel fraction), was the only chemical present. Scenario 1 resulted in a screening concentration of 280 µg/L for TPH-d. If TPH-d is present at that concentration, no other chemical can be present in the drinking water without exceeding the target risk, and therefore, is not appropriate for screening the mixture of chemicals present at RHSF. Scenario 2 was developed based on the risk profile from 2011, when TPH-d contributed the least to the overall risk, resulting in a screening concentration of 262 µg/L TPH-d. In this scenario, screening levels were estimated for the other COPCs, although many of these water concentrations were low in comparison to drinking water standards. In Scenario 3, the relative contribution to risk for TPH-d was set arbitrarily at 90% of the overall risk profile, which equates to a screening concentration of 252 µg/L for TPH-d and higher screening water concentrations for the other COPCs. The contribution of TPH-d was set to an even lower proportion of overall risk at 75% in a fourth scenario, which resulted in a screening concentration of 210 µg/L for TPH-d.

Cancer-based screening drinking water concentrations were developed based on a range of acceptable target risks for cancer: 1 in 10,000 to 1 in one million. Cancer-based screening levels are only available for eight of the COPCs, as these were the only chemicals that are considered

by EPA to be carcinogens and have an oral cancer slope factor (CSF) from which to estimate risk. An age-adjustment was also incorporated into the derivation of cancer-based screening levels to account for a potentially greater susceptibility for cancer in younger individuals (EPA 2005a). The cancer assessment results in much lower screening concentrations for drinking water than the non-cancer-based assessment for those eight chemicals.

A number of limitations exist with this analysis that may impact the interpretation of the proposed screening levels. Key concerns that may affect the potential risks include the high LOD of the analytical method for some chemicals and time periods from the monitoring wells. Use of high LODs could result in a failure to detect chemicals that are actually present, but at low levels; therefore, these chemicals would not have been selected as COPCs and underestimate the risk. Alternatively, a high LOD for a COPC will likely result in a higher mean groundwater concentration (represented as half of the LOD for non-detect samples) and overestimate the potential risk.

An additional factor that affects the proposed screening concentrations for drinking water is the presumption of an additive model of risk that does not take into account mode of action and target organ toxicity. Estimates were made using the cautious assumption that non-cancer effects for different chemicals could be added to each other in proportion to their dose, despite the lack of any such evidence. For non-cancer effects, the risk assessment tends to be driven nearly completely by a single category of TPH contaminants, TPH-d. Cancer potency was also added over the different chemicals, for which a CSF existed. There are no data available to support or refute this addition. The risks estimates for cancer are much lower than the cancer screening levels.

The screening levels developed as Scenario 4 in the non-cancer assessment and the age-adjusted values for a 1 in 10,000 risk level were also compared to the Hawaii Department of Health (DOH) exposure action levels (EAL), EPA maximum contaminant levels (MCL), and EPA drinking water equivalent level (DWEL) values. The majority of the proposed screening levels are below these regulatory standards. Given the fact that some of these regulatory standards are based on technology or analytical limitations, the screening levels developed in this report may

not be achievable. Additional consideration will need to be given to the analytical methods for the various constituents being monitored for at RHSF.

The proposed screening level of 210 µg/L for TPH-d in drinking water (Scenario 4) is protective of public health because it is based ingestion the water over the course of a lifetime (70 years) without any appreciable risk to human health. The Hawaii EAL for drinking water based on toxicity (190 µg/L) is similar to the proposed screening level. However, an alternative EAL has been established for gross contamination based on the taste and odor threshold for TPHs at 100 µg/L. Given the potential for public concerns regarding the palatability of the drinking water, it is recommended that the Hawaii EAL of 100 µg/L be relied on as the clean-up level for TPHs.

Background and Recommended Approach

The RHSF is a US federal government site located in Halawa Heights on the Island of Oahu which contains 18 active and two inactive underground jet fuel storage tanks. The site is operated by the Naval Supply Systems Command Fleet Logistics Center (NAVSUP FLC Pearl Harbor), and compliance of groundwater monitoring well testing is overseen by the Hawaii Department of Health (DOH).

Monitoring is performed quarterly to assess the potential leaching of chemical constituents associated with jet fuel and marine diesel fuel into the local groundwater. A total of 64 COPCs, including TPH components, have been historically monitored from a number of water sampling points. Five monitoring wells are located outside of the RHSF tunnel system (OWDFMW01, HDMW2253-03, RHMW04, RHMW06, and RHMW07) and four are located within the lower access tunnel (RHMW01, RHMW02, RHMW03, and RHMW05). One sampling point is within the nearest drinking water supply well in the Red Hill Shaft Well RHMW2254-01.

Exponent was requested to develop site-specific screening drinking water concentrations for TPHs. Our approach to developing the screening drinking water concentrations is described below. In brief, site-specific risks were estimated to determine the risk profile or the relative contribution of each COPC to overall risk. Screening levels were then derived based on the risk profile for the COPCs detected at RHSF and an acceptable target risk level.

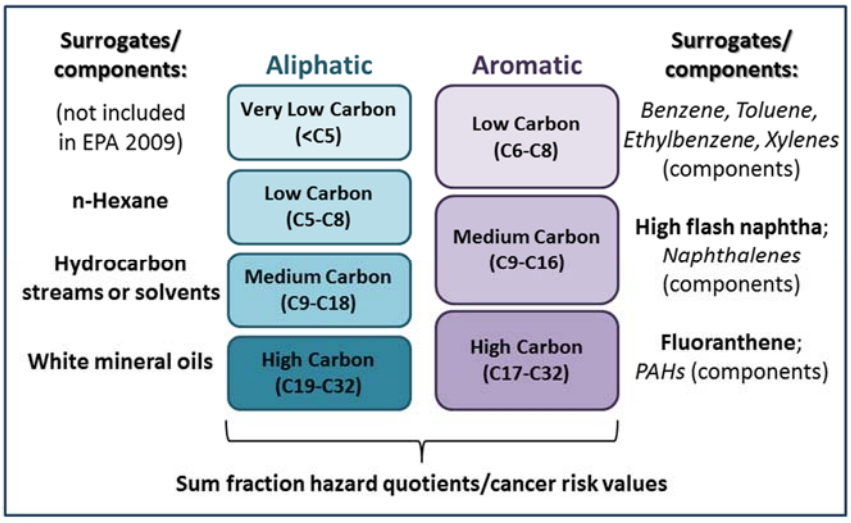
Our Approach

TPHs represent a complex mixture of chemicals derived from fuels and each constituent has its own health risks. Several different approaches exist to assess risks due to exposure from complex mixtures of hydrocarbons, including those developed by the Massachusetts Department of Environmental Protection (MADEP), the Total Petroleum Hydrocarbon Criteria Working Group (TPHCWG), and the US Environmental Protection Agency (EPA). The EPA guideline on “Provisional Peer-Reviewed Toxicity Values for Complex Mixtures of Aliphatic and Aromatic Hydrocarbons” (EPA 2009) builds on previous approaches (including MADEP and TPHCWG), incorporates EPA standard risk assessment methodology, and utilizes a hybrid

approach that combines the use of individual chemicals or a surrogate chemical to assess the toxicity of each fraction of the mixture. The EPA method was used for the derivation of site-specific screening levels in drinking water based on the chemicals detected in the monitoring wells of RHSF.

EPA's approach is a fraction-based risk assessment framework for complex mixtures of aliphatic and aromatic hydrocarbons. Fractions are based on the expected transport in the environment and analytical methods employed to identify and quantify petroleum hydrocarbon environmental contamination. Risks for non-cancer and cancer effects are determined separately. Toxicity values are assigned for each fraction, based on individual chemicals (components) or representatives of each fraction as a whole (surrogates). Dose-addition (for non-cancer) or response-addition (for cancer) is assumed across and within fractions to develop the risk assessment for the whole mixture. This additive risk approach is very conservative and does not take into account the potential differences in target organ toxicity or mode of action for individual chemicals. Figure 1 presents the TPH fractions with the respective surrogates or components for each fraction.[1]

Figure 1: TPH Fractions[2]



[1] This diagram includes a fraction for very low carbon (<C5) aliphatics that are not typically included in the EPA framework for assessing petroleum hydrocarbon mixtures, but were added to the analysis to incorporate the potential risks posed by these chemicals detected at the site.

[2] Surrogates (bold) and components (italicized) for each fraction are listed next to that fraction.

To assess total non-cancer health risks for TPHs, the hazard quotient (HQ) for each detected chemical is estimated based on the site-specific water concentration at the monitoring wells and proposed/established[3] "safe" daily oral concentrations for each component or surrogate. A hazard index (HI) for each of the fractions (e.g., aromatic low carbon) is calculated by summing the HQ for each component or surrogate in that fraction. In some cases, such as the aliphatic high carbon fraction which is represented by the detection of a single COPC, TPH-o, the HQ is equal to the HI. The calculated HIs for each fraction are then summed to derive a total risk estimate. A similar method is used for cancer risk estimations, where overall risk is determined by summing the cancer risks calculated for each fraction.

Screening levels for TPH chemicals in drinking water were based on the risk profile of COPCs detected in the monitoring wells at RHSF, the relative contribution of each compound to the overall risk, and an acceptable target risk level. Target risk levels were set as the HI=1 for non-cancer and 1 in 10,000 or 1 in one million for cancer. The drinking water concentrations are characterized as screening levels, because they are conservative and assume that the potential risks associated with the chemicals are additive. This approach does not take into account the differences in mode-of-action or target organ toxicity.

The individual steps in our approach to deriving site-specific drinking water concentrations are outlined below:

Step 1: Identification of COPCs and data analysis:

- Organized the cumulative monitoring data from wells at RHSF
- Identified COPCs
- Determined the mean water concentration for each COPC on an annual basis
- Categorized the COPCs into the appropriate fractions

[3] In most cases, an oral reference dose (RfD) exists for the COPCs. However, in some cases the regulatory threshold concentration is a proposed value as provided in EPA's PPRTV documentation.

Step 2: Risk estimate calculations:

- Calculated average daily or lifetime intakes for each COPC
- Calculated HQs and HIs (non-cancer)
- Calculated cancer risks

Step 3: Calculation of screening drinking water concentrations:

- Determined the relative contribution to the HI and total cancer risk for each COPC/fraction based on the annual/lifetime risk profile
- Based on the relative proportion to the total risk that each COPC contributed and the target risk level, screening drinking water concentrations were calculated for each COPC

Identification of COPCs and Data Analysis

As a first step, the monitoring data from wells at RHSF were organized by year and whether or not the chemical had been detected. Samples other than "water" were excluded, along with samples prior to 2010. The Red Hill Shaft Department of Navy (DON) drinking water well, RHMW2254-01, was excluded from the analysis as well. Field duplicates were also excluded from further analysis. COPCs were any chemical that had been detected at least once in a RHSF monitoring well between 2010 and 2015.

Sampling data were available for nine monitoring wells, although not all wells were active for the entire period of 2010 through 2015. Out of 64 chemicals monitored for at RHSF, 27 chemicals were selected as COPCs. All COPCs were analyzed each quarter, with the exception of TPH-o (residual fuels) which was not analyzed in 2010 and 2013.

Annual average groundwater concentrations were calculated for each COPC (these data are provided in Appendix A, Table A-1). Samples designated as "undetected" were assumed to be equal to half of the LOD in the calculation of the annual average groundwater concentrations. The LOD for each chemical was highly variable, with up to a 250-fold difference between the highest and lowest LOD. For those COPCs with limited detection (i.e., detected only once or twice and reported at levels less than LODs), this variability may have affected the annual groundwater averages. For the years without sampling data for TPH-o, the mean concentration based on data from the other four years of monitoring data was substituted as the groundwater concentration for 2010 and 2013.

COPCs were assigned to the fractions specified in the EPA guidance (EPA 2009). However, nine of the monitored chemicals selected as a COPC are not specifically included in EPA's approach for assessing a complex mixture of TPHs and cannot be classified into any of the six fraction categories. These include volatile organic chemicals (VOCs) such as 1,1,2,2-tetrachloroethane and acetone. Therefore, a seventh fraction category (very low carbon aliphatic) was added to accommodate these COPCs monitored at RHSF. Table 1 presents the 27 COPCs in their respective fractions.

Table 1: Fraction Assignment of COPCs

Category	Fraction	Chemical	# Carbons
Aliphatics	Very Low Carbon (<C5)	1,1,2,2-Tetrachloroethane	2
		1,2,3-Trichloropropane	3
		1,2-Dichloroethane	2
		Acetone	3
		Bromodichloromethane	1
		Chloroform	1
		Chloromethane (Methyl Chloride)	1
		Methylene Chloride (Dichloromethane)	1
		Methyl ethyl ketone	4
	Low Carbon Range (C5-C8)	TPH-g (gasoline)	?
	Medium Carbon Range (C9-C18)	TPH-d (middle distillates)	?
	High Carbon Range (C19-32)	TPH-o (residual fuels)	?
Aromatics	Low Carbon Range (C6-C8)	Benzene	6
		Toluene	7
		Ethylbenzene	8
		Xylenes	8
	Medium Carbon Range (C9-C16)	Acenaphthene	12
		Acenaphthylene	12
		Anthracene	14
		Fluorene	13
		Phenanthrene	14
		Pyrene	16
		1-Methylnaphthalene	11
		2-Methylnaphthalene	11
		Naphthalene	10
	High Carbon Range (C17-C32)	Fluoranthene	16
		Benz(a)anthracene	18

The chain lengths for the TPH sub-types at RHSF may not correspond directly with the EPA (2009) designated fractions; the exact number of carbons for each of the sub-types of TPHs in the RHSF samples are unknown. The EPA method 8015 is specified as the analytical method used to evaluate groundwater samples at RHSF. However, it is not clear which aliphatics and their respective chain length are included in each TPH-sub-type based on a general description of this method. Modifications to the method may also have been incorporated to analyze TPH-o, in particular. Further, it is not clear if any overlap exists in the analytical method for these sub-types (ATSDR 1999).

Finally, although fluoranthene has only 16 carbons, EPA recommends that this chemical is included in the high carbon range aromatics fraction (C17-C32). The inclusion of fluoranthene in this fraction is due to a lack of non-cancer toxicity reference values for the other compounds in this fraction and the availability of an RfD for fluoranthene (EPA 2009). Thus, fluoranthene serves as the surrogate for all of the chemicals included in this fraction.

Risk Estimates for Chemical Fractions

In order to derive site-specific screening concentrations for drinking water, the relative contribution of each COPC to the overall risk needed to be determined. Therefore, risk estimates were calculated for both non-cancer and cancer at the RHSF site in order to understand the site-specific risk profile based on the COPCs detected in the monitoring wells.

Non-cancer Risk

Non-cancer risk estimates are based on the ratio of a daily intake to a regulatory threshold dose. For oral exposures, the regulatory threshold dose typically relied on is an oral reference dose (i.e., RfD). The RfD is defined as "an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily oral exposure to the human population (including sensitive groups, such as asthmatics, or life stages, such as children or the elderly) that is likely to be without an appreciable risk of deleterious effects during a lifetime" (EPA 2002). The resulting ratio of the daily intake and the RfD is called the HQ (i.e., hazard quotient).

The mean daily intake was calculated for each COPC, based on the annual mean water concentrations as described above using standard EPA risk assessment methods (EPA 1989, 2014). The details and assumptions used in the intake equation are provided in Appendix B. An EPA recommended reference dose (RfD) or alternative oral intake value was available for all COPCs and were used in the calculation of HQs. This was calculated for each COPC or fraction by dividing the calculated daily intake by the oral reference value:

$$Hazard\ Quotient\ (HQ)_{chemical} = \frac{Daily\ Intake\ (mg/kg/day)}{RfD\ (mg/kg/day)}$$

HQ values were summed for each fraction to determine the HI for each of the six years (Table 2):

$$Hazard\ Index\ (HI) = \sum HQ_{chemical\ or\ fraction}$$

Table 2: Hazard Indices (HI) by TPH-Fraction and Year

Chemical	Hazard Index					
	2010	2011	2012	2013	2014	2015
1,1,2,2-Tetrachloroethane	0.041	0.041	0.049	0.073	0.068	0.026
1,2,3-Trichloropropane						
1,2-Dichloroethane						
Acetone						
Bromodichloromethane						
Chloroform						
Chloromethane (Methyl Chloride)						
Methylene Chloride (Dichloromethane)						
Methyl ethyl ketone						
TPH-g (gasoline)	0.004	0.001	0.003	0.006	0.003	0.002
TPH-d (middle distillates)	4.784	0.824	1.569	2.136	2.042	2.152
TPH-o (residual fuels)	0.001	0.001	0.001	0.001	0.0005	0.001
Benzene	0.001	0.002	0.003	0.003	0.002	0.001
Toluene						
Ethylbenzene						
Xylenes						
Acenaphthene	0.026	0.013	0.018	0.061	0.048	0.065
Acenaphthylene						
Anthracene						
Fluorene						
Phenanthrene						
Pyrene						
1-Methylnaphthalene						
2-Methylnaphthalene						
Naphthalene						
Fluoranthene	0.00006	0.0001	0.0001	0.00005	0.00004	0.00002
Benz(a)anthracene						

As described above, sampling data are lacking for TPH-o (residual fuels) in 2010 and 2013. The mean groundwater concentration for the years with monitoring data (i.e., 2011, 2012, 2014, and 2015) was used to derive a mean HQ for 2010 and 2013.

The HQs were summed for all fractions by year to determine the HI for each year as depicted in Figure 1. An HI of less than 1 would not trigger further evaluation because the non-cancer risks

for lifetime exposures resulting in HIs less than 1 are considered acceptable. The risk profile for COPCs presented in Table 2 demonstrate that TPH-d (diesel or middle distillates) is, by far, the greatest contributor to the overall non-cancer risk every year, with the largest HQ/HI, 4.784, in 2010. This was also the year with the highest mean groundwater concentration for TPH-d based on the monitoring data (Appendix A, Table A-1).

Cancer Risk

Cancer risk is estimated from a lifetime average daily intake and a cancer slope factor (CSF). The CSF is an upper-bound estimate of the average risk in a population or for a randomly selected individual (EPA 2005b). Cancer risks are typically presented as the risk of developing cancer on a population basis, such as a 1 in one million risk of developing cancer.

Only eight of the 27 COPCs had oral CSF values; these were used to estimate cancer risks. In contrast to the non-cancer risk estimation which evaluates daily exposure, a lifetime average daily intake was estimated assuming the average of six years of monitoring data are reflective of typical chemical concentrations over a lifetime of exposure (see Appendix B). The cancer risk was calculated for each of the COPCs with a CSF by multiplying the daily intake by the CSF:

$$Cancer\ Risk = Daily\ intake\ (mg/kg/day) \times CSF\ (per\ mg/kg/day)$$

EPA (2009) recommends using the well-established chemical mixture method of employing relative potency factors (RPFs) for polyaromatic hydrocarbons (PAHs), with benzo[a]pyrene used as the surrogate to represent the carcinogenicity of other PAHs. In the case of benz(a)anthracene, the RPF of 0.1 was multiplied by the CSF for benzo[a]pyrene to determine cancer risk. No other PAH identified as a COPC has been assigned a RPF, and therefore, has not been included in the estimation of cancer risk.

Table 3 presents the cancer risk profile for the eight COPCs, which were subsequently summed to determine the total cancer risk. The blank cells in the table are COPCs that are not considered carcinogenic and lack a CSF to estimate potential cancer risk.

Table 3: Lifetime Cancer Risk

Chemical	Lifetime Cancer Risk
1,1,2,2-Tetrachloroethane	4.31E-07
1,2,3-Trichloropropane	1.69E-04
1,2-Dichloroethane	2.06E-07
Acetone	—
Bromodichloromethane	1.29E-07
Chloroform	2.35E-08
Chloromethane (Methyl Chloride)	—
Methylene Chloride (Dichloromethane)	1.29E-08
Methyl ethyl ketone	—
TPH-g (gasoline)	—
TPH-d (middle distillates)	—
TPH-o (residual fuels)	—
Benzene	4.19E-08
Toluene	—
Ethylbenzene	—
Xylenes	—
Acenaphthene	—
Acenaphthylene	—
Anthracene	—
Fluorene	—
Phenanthrene	—
Pyrene	—
1-Methylnaphthalene	—
2-Methylnaphthalene	—
Naphthalene	—
Fluoranthene	—
Benz(a)anthracene	3.50E-07

The COPC with the greatest contribution towards the cancer risk profile is 1,2,3-trichloropropane. This is not due to particularly high concentrations of the chemical, but due to a large CSF value of 30. In fact, 1,2,3-trichloropropane was detected only once from 2010 – 2015 and at a concentration that was roughly half of the LOD for that sample. The cancer risk estimates for each of the other substances were less than one in a million (10^{-6}).

The cancer-based screening levels presented above are based on a risk profile developed using adult drinking water intake only. EPA has published supplementary guidance for assessing the

susceptibility to cancer in children (EPA 2005a). In the case of mutagens, it is recommended that CSFs be adjusted to account for a potential increase in susceptibility when individuals are exposed at an early age. In the case of drinking water, an additional adjustment is required to account for the differences in intake for an infant (≤2 years of age), child (>2 to 16 years old), and adults (≥16 years old). Of the eight COPCs for which cancer-based screening levels have been developed, only six are considered to be mutagens. Inclusion of an age-adjustment factor for the CSF and incorporating differences in intake, results in a 4.8-fold greater risk for all mutagenic COPCs (Table 4).

Table 4: Age-adjustment of Cancer Risk for Mutagenic Chemicals

Mutagenic Chemicals	Age-Adjusted Cancer Risk[1]	Mean Lifetime Cancer Risk	Fold-Difference
1,2,3-Trichloropropane	8.05E-04	1.69E-04	4.8
1,2-Dichloroethane	9.81E-07	2.06E-07	4.8
Bromodichloromethane	6.14E-07	1.29E-07	4.8
Methylene Chloride (Dichloromethane)	6.12E-08	1.29E-08	4.8
Benzene	1.99E-07	4.19E-08	4.8
Benz(a)anthracene	1.67E-06	3.50E-07	4.8

[1] Mean concentration multiplied by CSF is multiplied by the age-adjusted cancer risk factor (0.063)

Development of Groundwater Screening Concentrations

Screening concentrations for drinking water were derived from the site-specific risk profiles developed in the previous section of this report. Allowable concentrations in drinking water were estimated based on the chemicals being present in the same proportions as the risk profile, assuming an acceptable target risk level. For predicting drinking water concentrations based on non-cancer risks, the acceptable target risk was a HI of 1.0. The target cancer risk was selected to bracket the range of acceptable risk levels and was set at 1 in 10,000 or 1 in one million. Therefore, the water concentrations reflect the relative contributions of COPCs to risk at the RHSF site. For example, if TPH-d contributed 90% of the risk, then a screening drinking water concentration was calculated based on 90% of the acceptable risk being allocated to the TPH-d concentration. Separate assessments were conducted to estimate screening water concentrations based on non-cancer risks and cancer risks.

Non-cancer-based Screening Drinking Water Concentrations

Non-cancer-based screening drinking water concentrations were based on the relative contribution or percent of the total HI for each fraction or COPC, reflecting the annual risk profile (Table 5). As shown in Table 4, TPH-d (middle distillates) contributed the majority of the total risk, >93% for any given year (range of 93.4 – 98.5%).

Table 5: Percentage of Total Hazard Index (%HI) by TPH-Fraction and Year

Chemical	% Hazard Index					
	2010	2011	2012	2013	2014	2015
1,1,2,2-Tetrachloroethane	0.853	4.627	2.955	3.191	3.165	1.169
1,2,3-Trichloropropane						
1,2-Dichloroethane						
Acetone						
Bromodichloromethane						
Chloroform						
Chloromethane (Methyl Chloride)						
Methylene Chloride (Dichloromethane)						
Methyl ethyl ketone						
TPH-g (gasoline)	0.077	0.098	0.154	0.245	0.123	0.088
TPH-d (middle distillates)	98.486	93.420	95.520	93.698	94.341	95.741
TPH-o (residual fuels)	0.021	0.143	0.077	0.045	0.023	0.048
Benzene	0.030	0.244	0.168	0.125	0.114	0.049
Toluene						
Ethylbenzene						
Xylenes						
Acenaphthene	0.530	1.453	1.120	2.694	2.232	2.903
Acenaphthylene						
Anthracene						
Fluorene						
Phenanthrene						
Pyrene						
1-Methylnaphthalene						
2-Methylnaphthalene						
Naphthalene						
Fluoranthene	0.001	0.015	0.007	0.002	0.002	0.001
Benz(a)anthracene						
% HI Sum	100	100	100	100	100	100

Assuming an overall HI of 1 (100% of total HI) and the relative contribution of risk for a specific COPC, the non-cancer-based screening water concentrations were calculated based on a re-arrangement of the standard risk equation used to calculate mean daily intake (see Appendix C). As Table 5 demonstrates, there was variability in the distribution of risk among the 6 years of monitoring data. To capture a range of potential screening concentrations for drinking water and account for yearly variation in the proportions of total risk, four scenarios were developed.

The first scenario assumes that the fraction of TPH-d represents 100% of the overall non-cancer risk (Table 6). This scenario reflects the risk profile from 2010 where the TPH-d is 98.5% of the risk. Scenario 1 results in a screening water concentration of 280 µg/L TPH-d. In this case, if

TPH-d is present at the screening level of 280 µg/L, no other COPCs can be present in the groundwater samples without exceeding the target risk, and therefore, it is not appropriate for screening the mixture of chemicals present at RHSF.

Scenario 2 is based on the year in which TPH-d contributed the lowest proportion of total risk. This occurred in 2011, when TPH-d contributed 93.42% of the total non-cancer risk. The drinking water screening concentrations for the remaining COPCs were calculated assuming the same risk profile and associated contributions to total non-cancer risk. Consequently, the screening water concentrations for TPH-d was lower than in Scenario 1 or 261.57 µg/L TPH-d (Table 6). The screening levels for other COPCs were estimated to range from 120.19 µg/L for TPH-o to 0.06 µg/L for anthracene. In Scenario 2, several of the individual COPCs have extremely low screening levels. In fact, some of these levels are impractical based on the typical detection limits used to analyze these compounds. For example, the LOD range for acetone was 1.9 – 10 µg/L from 2010 to 2015 and in Scenario 2, the screening concentration is 1.08 µg/L. Thus, the analytical methods used over the last six years would not be sufficient to detect acetone at this concentration. In fact, the LOD became less precise and increased to 10 µg/L for all acetone measurements beginning in 2013. TPH-g is another example of a chemical whose proposed screening concentration would not be detectable with the historical analytical methods, as the screening concentration from Scenario 2 of 8.24 µg/L for TPH-g is less than the lowest LOD (12.12 µg/L). The minimum LOD and screening concentrations for each COPC in Scenario 2 are presented in Table D-1 in Appendix D.

In Scenario 3, TPH-d was arbitrarily set at 90% of the HI and percentages for the other 26 chemicals were based on the same risk profile from 2011, as in Scenario 2. Scenario 3 results in a screening concentration of 252 µg/L TPH-d and higher allowable concentrations of TPH-o (182.64 µg/L) and anthracene (0.09 µg/L) (Table 6).

In Scenario 4, TPH-d was arbitrarily set at 75% of the HI in order to allow for the allocation of potential risk resulting from a broader range of the chemicals detected in the groundwater. Additionally, this allocation of risk results in an acceptable drinking water concentrations for other chemicals that under Scenarios 1-3 could not be present in the water due to the allowable concentration estimated to be below the LOD. With an even lower contribution to the overall

risk, the screening concentration for TPH-d is further reduced to 210 µg/L. Again, this allows for higher concentrations of other chemicals such as TPH-o (456.61 µg/L) and anthracene (0.22 µg/L) (Table 6). Scenarios 3 and 4 provide examples of the impact of balancing the relative contributions to overall risk across all COPCs on site.

Table 6: Non-cancer Water Screening Levels

Chemical	Screening Concentration (µg/L)			
	Scenario 1 TPH-d = 100%	Scenario 2 TPH-d = 93%	Scenario 3: TPH-d = 90%	Scenario 4: TPH-d = 75%
1,1,2,2-Tetrachloroethane	0	0.11	0.17	0.43
1,2,3-Trichloropropane	0	0.44	0.67	1.68
1,2-Dichloroethane	0	0.16	0.24	0.60
Acetone	0	1.08	1.64	4.09
Bromodichloromethane	0	0.16	0.24	0.60
Chloroform	0	0.08	0.12	0.31
Chloromethane (Methyl Chloride)	0	0.38	0.58	1.45
Methylene Chloride (Dichloromethane)	0	0.40	0.60	1.51
Methyl ethyl ketone	0	0.68	1.03	2.58
TPH-g (gasoline)	0	8.24	12.52	31.29
TPH-d (middle distillates)	280	261.57	252.00	210.00
TPH-o (residual fuels)	0	120.19	182.64	456.61
Benzene	0	0.25	0.38	0.94
Toluene	0	0.19	0.30	0.74
Ethylbenzene	0	0.26	0.40	1.00
Xylenes	0	0.25	0.38	0.95
Acenaphthene	0	0.10	0.15	0.39
Acenaphthylene	0	0.07	0.11	0.27
Anthracene	0	0.06	0.09	0.22
Fluorene	0	0.08	0.12	0.29
Phenanthrene	0	0.08	0.12	0.30
Pyrene	0	0.09	0.14	0.34
1-Methylnaphthalene	0	1.26	1.92	4.79
2-Methylnaphthalene	0	0.23	0.36	0.89
Naphthalene	0	3.05	4.64	11.59
Fluoranthene	0	0.09	0.14	0.34
Benz(a)anthracene	0	0.08	0.12	0.30

Cancer-based Screening Drinking Water Concentrations

Cancer-based screening drinking water concentrations were derived based on the relative contribution or percent of the total cancer risk (either 1 in 10,000 or 1 in one million) for each

fraction or COPC (Table 7). However, in contrast to non-cancer risks which are based on daily exposure, cancer risk is estimated from a lifetime of exposure. Therefore, the cancer-based screening concentrations are calculated from the lifetime risk profile that reflects the average exposures to COPCs from the six years of monitoring data. Only eight of the COPCs have been identified by EPA as carcinogenic and have CSF values to estimate potential cancer risks. As shown in Table 7, 1,2,3-tricholoropropane contributed, by far, the largest proportion of risk (>99%) and consequently will be allotted the largest proportion of allowable risk in the derivation of a screening water concentration. As noted above, 1,2,3-trichloropropane was detected only once in the six years evaluated and for other sampling dates was assumed to be present at one-half the LOD. Therefore, this is a high theoretical risk based on very limited evidence.

Table 7: Proportion of Lifetime Cancer Risk and Screening Concentrations

Chemical	% Total Lifetime Cancer Risk	Screening Concentration for Drinking Water (µg/L)		
		Lifetime Average (10^{-6})	Lifetime Average (10^{-4})	Infant Age-adjusted (10^{-4})
1,1,2,2-Tetrachloroethane	0.253	0.00095	0.095	—
1,2,3-Trichloropropane	99.299	0.00250	0.250	0.096
1,2-Dichloroethane	0.121	0.00100	0.100	0.039
Acetone	—	—	—	—
Bromodichloromethane	0.076	0.00092	0.092	0.035
Chloroform	0.014	0.00104	0.104	—
Chloromethane (Methyl Chloride)	—	—	—	—
Methylene Chloride (Dichloromethane)	0.008	0.00285	0.285	0.110
Methyl ethyl ketone	—	—	—	—
TPH-g (gasoline)	—	—	—	—
TPH-d (middle distillates)	—	—	—	—
TPH-o (residual fuels)	—	—	—	—
Benzene	0.025	0.00124	0.124	0.048
Toluene	—	—	—	—
Ethylbenzene	—	—	—	—
Xylenes	—	—	—	—
Acenaphthene	—	—	—	—
Acenaphthylene	—	—	—	—
Anthracene	—	—	—	—
Fluorene	—	—	—	—
Phenanthrene	—	—	—	—
Pyrene	—	—	—	—
1-Methylnaphthalene	—	—	—	—
2-Methylnaphthalene	—	—	—	—
Naphthalene	—	—	—	—
Fluoranthene	—	—	—	—
Benz(a)anthracene	0.206	0.00021	0.021	0.008

Similar to the calculation of non-cancer-based screening water concentration, the risk equation was re-arranged to derive the cancer-based water concentration screening levels for each fraction or COPC (Appendix C). The additional factors used to estimate cancer-based screening concentrations include the percentage of lifetime cancer risk, the chemical-specific CSF, and the target cancer risk level. Two target cancer risk levels were used to derive the water concentrations to bracket the range of acceptable cancer risk from an upper bound of 1 in one million (10^{-6}) to a lower-bound of 1 in 10,000 (10^{-4}). The cancer-based screening water concentrations are very low, particularly at the 1 in one million risk level. At this risk level, screening concentrations range from 0.00021 µg/L benz(a)anthracene to 0.00285 µg/L

methylene chloride. Obviously, at the 1 in 10,000 risk level, the screening levels for these compounds are 100-fold higher: 0.021 µg/L benz(a)anthracene to 0.285 µg/L methylene chloride.

Age-adjusted cancer-based screening concentrations were also calculated for the six COPCs for which there is some evidence that they may induce cancer by a mutagenic mode of action. Screening drinking water concentrations were estimated at the 1 in 10,000 risk level using the same calculations as for the lifetime average concentrations presented in Appendix C. The screening concentrations developed for an infant were lower than those calculated based on a child's (2-16 years of age) or adult's age-adjusted exposure (Appendix E, Table E-1). The lowest concentrations are expected for an infant based on the greatest adjustment to the CSF (10-fold) and the relatively greater intake of water on a body weight basis. The infant screening water concentrations for the relevant COPCs are presented in Table 7 and the assumptions used are provided in Appendix C.

Comparison with Established Exposure Levels

Non-cancer-based (Scenario 4) and cancer-based (1 in 10,000 risk) screening concentrations for drinking water are summarized in Table 8 together with the Hawaii DOH exposure action levels (EAL), EPA maximum contaminant levels (MCL), and EPA drinking water equivalent level (DWEL) values. Historically, the chemical EALs have been used for comparison with monitoring well sampling data by the U.S. Department of the Navy. The shaded cells in the tables indicate where the screening levels exceed the EALs.

As seen in Table 8, many of the proposed screening levels are lower than the various regulatory standards. Some of these standards are not strictly health-based and have been established based on technology or analytical limitations. Consequently, some of the screening levels developed in this report may not be achievable. The minimum LOD used for groundwater monitoring samples from RHSF and screening concentrations for each COPC in Scenarios 2 and 4 are presented in Table D-1 in Appendix D and demonstrate which levels may not be achievable given current LODs. Additional consideration will need to be given to the analytical methods for the various constituents being monitored for at RHSF.

Table 8: Summary of Non-cancer and Cancer Screening Concentrations

Chemical	Hawaii DOH EAL (µg/L)	MCL (µg/L)	DWEL (µg/L)	Screening Concentration for Drinking Water (µg/L)		
				Non-cancer Scenario 4	Lifetime Average Cancer (10^{-4})	Infant Age-adjusted Cancer (10^{-4})
1,1,2,2-Tetrachloroethane	0.067	5	400	0.43	0.095	—
1,2,3-Trichloropropane	0.6	—	100	1.68	0.250	0.096
1,2-Dichloroethane	0.15	5	—	0.60	0.100	0.039
Acetone	1,500	—	—	4.09	—	—
Bromodichloromethane	0.12	80	100	0.60	0.092	0.035
Chloroform	70	80	350	0.31	0.104	—
Chloromethane (Methyl Chloride)	1.8	—	—	1.45	—	—
Methylene Chloride (Dichloromethane)	4.8	5	2000	1.51	0.285	0.110
Methyl ethyl ketone	7,100	—	20000	2.58	—	—
TPH-g (gasoline)	100	—	—	31.29	—	—
TPH-d (middle distillates)	100	—	—	210.00	—	—
TPH-o (residual fuels)	100	—	—	456.61	—	—
Benzene	5	5	100	0.94	0.124	0.048
Toluene	40	1000	3000	0.74	—	—
Ethylbenzene	30	700	3000	1.00	—	—
Xylenes	20	10000	7000	0.95	—	—
Acenaphthene	20	—	2000	0.39	—	—
Acenaphthylene	240	—	—	0.27	—	—
Anthracene	22	—	10000	0.22	—	—
Fluorene	240	—	1000	0.29	—	—
Phenanthrene	240	—	—	0.30	—	—
Pyrene	68	—	—	0.34	—	—
1-Methylnaphthalene	4.7	—	—	4.79	—	—
2-Methylnaphthalene	10	—	—	0.89	—	—
Naphthalene	17	—	700	11.59	—	—
Fluoranthene	130	—	—	0.34	—	—
Benz(a)anthracene	0.092	—	—	0.30	0.021	0.008

Gray shaded cells: screening concentration is greater than Hawaii DOH EAL (most conservative regulatory standard)

Limitations/Additional Considerations

A number of limitations exist in the data analysis leading to uncertainty in the drinking water screening concentrations derived in this report. These limitations, their consequences, and some further considerations are outlined below:

- The historical groundwater monitoring data are variable. Prior to 2010, several other sampling wells or sites existed, and monitoring wells RHMW06 and RHMW07 were only added in 2014. In the future, if new wells are added or if older wells are included again in the monitoring analysis, the detected levels of certain chemicals would likely change. These changes could result in an altered chemical risk profile that would consequently require modification of the COPC screening concentrations.
- Exponent's analysis included 27 COPCs, but there were an additional 34 chemicals historically analyzed from RHSF monitoring wells. These chemicals were not detected in any of the nine monitoring wells between 2010 and 2015, and therefore, were not included in the analysis of risk estimates or screening concentrations. In the future, if these chemicals are detected in monitoring wells, they would contribute towards overall health risks and may need to be considered for inclusion in the non-cancer and cancer risk profiles for derivation of drinking water screening concentrations.
- There is a potential overlap among the TPH fraction measurements based on the analytical methods. As a consequence, TPH-g, -d, and –o measurements may inaccurately estimate concentrations in the monitoring wells. If the analytical methods overestimate the levels of TPHs, this would increase their contribution to overall risk. Given that TPH-d contributed the greatest proportion of non-cancer risk in the entire time period of interest (2010-2015), the accuracy of quantitation method for this fraction is crucial.
- TPH-o was not analyzed in 2010 and 2013. Therefore, the four available years of sampling data were used to determine an annual mean concentration and adopted as a representative concentration for 2010 and 2013. This fraction was missing one-third of the groundwater monitoring data compared to the other COPCs, and therefore, may be inaccurately represented in the risk profiles of this report. It is unknown whether TPH-o

contributed more or less towards non-cancer risks during 2010 and 2013, and therefore, causes some uncertainty in the proposed screening concentrations for drinking water.

- The LOD for each chemical was highly variable, with up to a 250-fold difference between the highest and lowest LOD over the timeframe from 2010-2015. Several chemicals (11 of 27) had limited detection, in which they were detected in only one or two samples and at levels that are less than LODs. Given that samples designated as "undetected" were assumed to be equal to half of the LOD in the calculation of the average groundwater concentrations, this variability may have increased the groundwater averages. In the future, should the analytical precision/methodology be improved, this would affect the risk profile. A trend in the range of LODs demonstrated higher LODs in more recent years, which indicates that lower detection limits can be achieved. An additional concern is that there may be chemicals (of all those tested from RHSF monitoring wells) missing from the risk profile because some LODs may have been too high to detect low levels of those chemicals. This could include some of the 34 chemicals excluded from the analysis in this report, because they were not detected in the last six years.
- The EPA fraction approach assumes additive risk, which is very conservative. It does not take into account the independence of target organ toxicity or mode of action for individual chemicals. The screening concentrations are based on an acceptable level of risk assuming that all COPCs together are below the target risk level. The addition of the "very low carbon" aliphatics fraction adds an extra nine chemicals to the overall risk profile, thereby further reducing the allowable risk for the chemicals normally considered in the EPA fraction-based approached for complex mixtures of petroleum compounds. This resulted in the low screening concentrations for some of the chemicals.

Conclusions

At the RHSF on Oahu, Hawaii, 20 underground jet fuel storage tanks have been monitored for over a decade. Monitoring has included the analysis of specific chemicals as well as various types of petroleum hydrocarbon mixtures in groundwater. Exponent was requested to develop acceptable drinking water concentrations for the TPHs detected at RHSF. The EPA method (EPA 2009) for assessing risks from exposure to complex mixtures of petroleum hydrocarbons was used as the framework to derive site-specific screening concentrations in drinking water. Monitoring of chemicals in the groundwater were identified as representative of constituents of the fuel stored in the tanks and included VOCs, PAHs, lead, and TPH fractions.

Exponent's analysis of the monitoring data and derivation of screening levels was based on the most current six years of groundwater monitoring data (2010 – 2015). Only monitoring well data were included; the monitoring at a drinking water well location was not included. Field duplicates were excluded from estimates of potential exposure. COPCs were identified as those that had been detected at least once between 2010 and 2015. Daily and lifetime intakes of the COPCs were estimated based mean groundwater concentrations and assuming that the samples designated as "non-detect" were present at one-half the LOD.

Non-cancer-based screening concentrations for drinking water were developed under a series of scenarios that reflect the risk profile for one of the six years of monitoring data analyzed in this report. Scenario 1 assumed that the COPC representing the greatest contribution to the risk profile for all six years, TPH-d, was the only chemical present and resulted in a screening concentration of 280 µg/L for TPH-d. If TPH-d is present at that concentration, no other chemical can be present in the drinking water without exceeding the target risk, and therefore, is not appropriate for screening the mixture of chemicals detected at RHSF. Scenario 2 was developed based on the risk profile from 2011, when TPH-d contributed the least to the overall risk, resulting in a screening concentration of 262 µg/L TPH-d. In this scenario, screening levels were estimated for the other COPCs, although most of these water concentrations were low. In Scenarios 3 and 4, the relative contribution to risk for TPH-d was set arbitrarily at 90% and 75% of the overall risk profile, respectively. This equates to screening concentrations of 252 µg/L and 210 µg/L for TPH-d, respectively, and higher screening water concentrations for the other

COPCs. These scenarios demonstrate how balancing the relative contributions of all COPCs based on the overall risk impacts individual screening concentrations.

Cancer-based screening drinking water concentrations were developed based on a range of acceptable target risks for cancer: 1 in 10,000 to 1 in one million. Cancer-based screening levels are only available for eight of the COPCs as these were the only chemicals that are considered by EPA to be carcinogens and have a CSF from which to estimate risk. Although EPA guidance proposes the incorporation of an age-adjustment to address early life exposures for mutagens, this does not affect the risk profile of the COPCs at RHSF, but it does result in an approximately 3-fold lower screening drinking water concentration based on two years of exposure as an infant. The cancer assessment results in much lower screening concentrations for drinking water than the non-cancer assessment for those eight chemicals.

A number of limitations exist with this analysis that may impact the interpretation of the proposed screening levels. Key concerns that may affect the potential risks include the high analytical method LODs for some chemicals and time periods for groundwater in the monitoring wells. Use of high LODs could result in a failure to detect chemicals that are actually present at low levels; therefore, these chemicals would not have been selected as COPCs and underestimate the risk. Alternatively, a high LOD for a COPC will likely result in a higher mean groundwater concentration and overestimate the potential risk.

An additional factor that affects the proposed screening concentrations for drinking water is the presumption of an additive model of risk that does not take into account mode of action and target organ toxicity. The estimates made the cautious assumption that non-cancer effects for different chemicals could be added to each other in proportion to their dose, despite the lack of any such evidence. For non-cancer effects, the risk assessment tends to be driven nearly completely by a single category of TPH contaminants, TPH-d. Cancer potency was also added over the different chemicals, for which a CSF existed. There are no data available to support or refute this addition. The risks estimates for cancer are much lower than the cancer screening levels.

The screening levels developed as Scenario 4 in the non-cancer assessment and the age-adjusted values for an infant at a 1 in 10,000 risk level were also compared to the Hawaii DOH EALs,

EPA MCLs, and EPA DWEL values. Most of the proposed screening levels are below these regulatory standards. Given the fact that some of these regulatory standards are based on technology or analytical limitations, the screening levels developed in this report may not be achievable. Additional consideration will need to be given to the analytical methods for the various constituents being monitored for at RHSF.

The proposed screening level of 210 µg/L for TPH-d in drinking water (Scenario 4) is protective of public health because it is based on a lifetime of ingesting the water without any appreciable risk to human health. The Hawaii EAL for drinking water based on toxicity is similar to the proposed screening level (190 µg/L). However, an alternative EAL has been established for gross contamination based on the taste and odor threshold for TPHs of 100 µg/L. Given the potential for public concerns regarding the palatability of the drinking water, it is recommended that the Hawaii EAL of 100 µg/L be relied on as the clean-up level for TPHs.

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Appendix A

Table A-1: COPC Mean Concentrations by Year

		Mean Concentration (µg/L)							
Fraction	**Chemical**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**6-yr Mean**	**Toxicity Estimation Method**
Very Low Carbon (<C5)	1,1,2,2-Tetrachloroethane	0.138	0.100	0.138	0.250	0.244	0.104	0.162	(component)
	1,2,3-Trichloropropane	0.328	0.390	0.417	0.583	0.500	0.334	0.425	(component)
	1,2-Dichloroethane	0.148	0.140	0.168	0.250	0.238	0.083	0.171	(component)
	Acetone	2.576	0.950	2.096	13.875	5.818	12.519	6.306	(component)
	Bromodichloromethane	0.025	0.140	0.168	0.250	0.244	0.116	0.157	(component)
	Chloroform	0.245	0.073	0.115	0.250	0.241	0.139	0.177	(component)
	Chloromethane (Methyl Chloride)	0.310	0.337	0.931	1.125	0.955	0.343	0.667	(component)
	Methylene Chloride (Dichloromethane)	0.844	0.350	0.397	0.583	0.500	0.237	0.485	(component)
	Methyl ethyl ketone	2.500	0.600	0.998	2.500	2.409	2.352	1.893	(component)
Low Carbon (C5-C8)	TPH-g (gasoline)	31.536	7.263	21.295	46.958	22.400	16.681	24.356	Hexane (surrogate)
Medium Carbon (C9-C18)	TPH-d (middle distillates)	1339.400	230.700	439.450	598.104	571.690	602.431	630.296	Hydrocarbon streams (surrogate)
High Carbon Range (C19-32)	TPH-o (residual fuels)	#DIV/0!	106.000	106.000	#DIV/0!	41.000	90.897	85.974	White mineral oil (surrogate)
Low Carbon Range (C6-C8)	Benzene	0.130	0.218	0.282	0.287	0.240	0.108	0.211	(component)
	Toluene	0.276	0.172	0.219	0.250	0.383	0.110	0.235	(component)
	Ethylbenzene	0.292	0.233	0.235	0.239	0.235	0.122	0.226	(component)
	Xylenes	0.536	0.220	0.278	0.502	0.443	0.204	0.364	(component)
Medium Carbon (C9-C16)	Acenaphthene	0.075	0.090	0.099	0.113	0.093	0.084	0.092	High-flash naphtha (surrogate)
	Acenaphthylene	0.030	0.063	0.052	0.025	0.024	0.019	0.036	(surrogate)
	Anthracene	0.025	0.050	0.044	0.025	0.024	0.009	0.029	(surrogate)
	Fluorene	0.687	0.067	0.072	0.064	0.049	0.041	0.163	(surrogate)
	Phenanthrene	0.030	0.070	0.059	0.025	0.024	0.011	0.036	(surrogate)
	Pyrene	0.032	0.080	0.066	0.025	0.024	0.010	0.040	(surrogate)
	1-Methylnaphthalene	1.547	1.112	1.275	3.899	3.072	4.831	2.622	(component)
	2-Methylnaphthalene	0.425	0.206	0.584	2.384	1.926	2.196	1.287	(component)
	Naphthalene	7.295	2.690	3.481	11.142	8.487	11.640	7.456	(component)
High Carbon (C17-C32)	Fluoranthene	0.032	0.080	0.066	0.025	0.024	0.014	0.040	Fluoranthene (surrogate)
	Benz(a)anthracene	0.030	0.070	0.059	0.025	0.024	0.010	0.036	(surrogate)

Appendix B

Equation to Calculate Mean Daily Intake (EPA 1989, 2014)

$$Intake\ (mg/kg/day) = \frac{CW \times IR \times EF \times ED}{BW \times AT}$$

Where:	**Value**
CW = chemical concentration in water (mg/L)	To be determined
IR = ingestion rate (L/day water)	2.5
EF = exposure frequency (days/year)	365
ED = exposure duration (years)	
non-cancer (national 90th percentile upper-bound time at one residence, years):	26
cancer (lifetime, years):	26
BW = body weight (kg)	70
AT = averaging time (period over which exposure is averaged - days)	
non-cancer (26 years):	9490
cancer (70 years):	25550

Appendix C

Equation to Calculate Screening Concentrations (EPA 1989, 2014)

Non-cancer values:

$$CW\ (mg/L) = \frac{\%HI \times Intake \times BW \times AT}{IR \times EF \times ED}$$

Where:	**Value**
CW = chemical concentration in water (mg/L)	To be determined
HI = hazard index (%HI is the percentage of total HI sum)	2011 values
Intake = oral reference dose (mg/kg/day)	RfD
IR = ingestion rate (L/day water)	2.5
EF = exposure frequency (days/year)	365
ED = exposure duration (years)	
non-cancer (national 90th percentile upper-bound time at one residence, years):	26
BW = body weight (kg)	70
AT = averaging time (period over which exposure is averaged - days)	
non-cancer (26 years):	9490

Cancer values:

$$CW\ (mg/L) = \frac{\%CR \times CRL \times BW \times AT}{CSF \times IR \times EF \times ED}$$

Where:	**Value**
CW = chemical concentration in water (mg/L)	To be determined
CR = cancer risk (%CR is the fraction of cancer risk sum)	mean values
CRL = target CR level	10^{-6} or 10^{-4}
IR = ingestion rate (L/day water)	2.5 or 0.9*
EF = exposure frequency (days/year)	365
ED = exposure duration (years)	
cancer (lifetime, years):	26 or 2*
BW = body weight (kg)	70 or 7.7*
AT = averaging time (period over which exposure is averaged - days)	
cancer (70 years):	20075 or 730

* Infant (< 2 years) age-adjusted factors

Appendix D

Table D-1: COPC Screening Concentrations and Minimum LOD

Chemical	Screening Concentration for Drinking Water (µg/L)					Min LOD (µg/L)
	Non-Cancer Scenario 2 TPH-d = 93%	Non-Cancer Scenario 4 TPH-d = 75%	Lifetime Average Cancer (10^{-6})	Lifetime Average Cancer (10^{-4})	Infant Age-adjusted Cancer (10^{-4})	
1,1,2,2-Tetrachloroethane	0.11	0.43	0.00095	0.095	—	0.002
1,2,3-Trichloropropane	0.44	1.68	0.00250	0.250	0.096	0.5
1,2-Dichloroethane	0.16	0.60	0.00100	0.100	0.039	0.015
Acetone	1.08	4.09	—	—	—	1.9
Bromodichloromethane	0.16	0.60	0.00092	0.092	0.035	0.01
Chloroform	0.08	0.31	0.00104	0.104	—	0.14
Chloromethane (Methyl Chloride)	0.38	1.45	—	—	—	0.2
Methylene Chloride (Dichloromethane)	0.40	1.51	0.00285	0.285	0.110	0.2
Methyl ethyl ketone	0.68	2.58	—	—	—	0.5
TPH-g (gasoline)	8.24	31.29	—	—	—	12.12
TPH-d (middle distillates)	261.57	210.00	—	—	—	10
TPH-o (residual fuels)	120.19	456.61	—	—	—	50
Benzene	0.25	0.94	0.00124	0.124	0.048	0.1
Toluene	0.19	0.74	—	—	—	0.1
Ethylbenzene	0.26	1.00	—	—	—	0.1
Xylenes	0.25	0.95	—	—	—	0.2
Acenaphthene	0.10	0.39	—	—	—	0.005
Acenaphthylene	0.07	0.27	—	—	—	0.005
Anthracene	0.06	0.22	—	—	—	0.005
Fluorene	0.08	0.29	—	—	—	0.005
Phenanthrene	0.08	0.30	—	—	—	0.005
Pyrene	0.09	0.34	—	—	—	0.0096
1-Methylnaphthalene	1.26	4.79	—	—	—	0.005
2-Methylnaphthalene	0.23	0.89	—	—	—	0.005
Naphthalene	3.05	11.59	—	—	—	0.005
Fluoranthene	0.09	0.34	—	—	—	0.0096
Benz(a)anthracene	0.08	0.30	0.00021	0.021	0.008	0.005

Shaded cells: screening concentration is less than the minimum LOD from 2010-2015.

Appendix E

Table E-1: Mutagenic COPC Age-Adjusted Screening Concentrations

Mutagenic Chemicals	Age-Ajusted Screening Concentrations (µg/L)		
	Adult	Child	Infant
1,2,3-Trichloropropane	0.591	0.145	0.096
1,2-Dichloroethane	0.238	0.058	0.039
Bromodichloromethane	0.218	0.054	0.035
Methylene Chloride (Dichloromethane)	0.675	0.165	0.110
Benzene	0.293	0.072	0.048
Benz(a)anthracene	0.050	0.012	0.008

All values are for a 1 in 10,000 cancer risk.