HUMAN HEALTH RISK ASSESSMENT—
LOTT CLEAN WATER ALLIANCE RECLAIMED WATER INFILTRATION STUDY

Prepared for:

LOTT CLEAN WATER ALLIANCE
500 Adams Street NE
Olympia, WA

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INTERTOX, INC.
600 Stewart St.
Suite 1101
Seattle, WA 98101

206.443.2115 phone
206.443.2117 facsimile

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ADD	Average Daily Dose
ADI	Acceptable Daily Intake
AF	Attenuation Factor
ARAR	Applicable or Relevant and Appropriate Requirements
AT	Averaging Time
ATSDR	Agency for Toxic Substances and Disease Registry
BCF	Bioconcentration Factor
BIRWP	Budd Inlet Reclaimed Water Plant
BMDS	Benchmark Dose Software
BW	Body Weight
CCL	Contaminant Candidate List
CCRIS	Chemical Carcinogenesis Research Information System
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CF	Conversion Factor
CHO	Chinese Hamster Ovary
COI	Chemical of Interest
DA	Dermally Absorbed Dose (per event)
DWEL	Drinking Water Equivalent Level
EC	European Commission
ED	Exposure Duration
EF	Exposure Frequency
EFSA	European Food Safety Authority
EPC	Exposure Point Concentration
EV	Event Frequency
F	Female
FI	Fraction Ingested (from a contaminated source)
GAF	Gastrointestinal Absorption Factor
GD	Gestation Day
HA	Health Advisory
HBV	Health Based Value
HDPE	High-Density Polyethylene
HED	Human Equivalent Dose
HHRA	Human Health Risk Assessment
HI	Hazard Index

HQ	Hazard Quotient
HRL	Health Reference Level
IARC	International Agency for Research on Cancer
IR	Ingestion Rate
IRIS	Integrated Risk Information System
JEFCA	Joint FAO/WHO Expert Committee on Food Additives
JMPR	Joint FAO/WHO Meeting on Pesticide Residues
LADD	Lifetime Average Daily Dose
LECR	Lifetime Excess Cancer Risk
LOAEL	Lowest Observed Adverse Effect Level
LOTT	LOTT Clean Water Alliance
M	Male
MC	McAllister Creek
MCL	Maximum Contaminant Level
MDH	Minnesota Department of Health
MLE	More Likely Exposure
MRL	Minimal Risk Level (from ATSDR)
MRL	Minimum Reporting Limit
MTCA	Model Toxics Control Act
MW	Molecular Weight
MWRWP	Martin Way Reclaimed Water Plant
NA	Not Analyzed, Not Applicable, or Not Available
NDMA	N-Nitroso dimethylamine
NHANES	National Health and Nutrition Examination Survey
nHRL	Noncancer Human Risk Limit
NL	Notification Level
NLM	National Library of Medicine
NOAEL	No Observed Adverse Effect Level
NSRL	No Significant Risk Level
NTP	National Toxicology Program
O3-BAC-GAC	Ozone-Biological Activated Carbon-Granular Activated Carbon
OEHHA	Office of Environmental Health Hazard Assessment
PBDE	Polybrominated Diphenyl Ether
PCL	Protective Concentration Level
PDF	Probability density function

PFAS	Polyfluoroalkyl substance
PFBA	Perfluoro butanoic acid
PFBuS	Perfluoro-1-butanesulfonate
PFDeA	Perfluoro-n-decanoic acid
PFDoDA	Perfluoro dodecanoic acid
PFHpA	Perfluoro-n-heptanoic acid
PFHxA	Perfluoro-n-hexanoic acid
PFHxS	Perfluoro-1-hexanesulfonate
PFNA	Perfluoro-n-nonanoic acid
PFOA	Perfluoro octanoic acid
PFOS	Perfluoro octanesulfonate
PFOSA	Perfluorooctane sulfonamide
PFPeA	Perfluoropentanoic acid
PFUnA	Perfluoroundecanoic acid
PHG	Public Health Goal
PND	Postnatal Day
PPARα	Peroxisome Proliferator-Activated Receptor alpha
PPCP	Pharmaceutical and Personal Care Product
PPRTV	Provisional Peer Reviewed Toxicity Value
PRA	Probabilistic Risk Assessment
RfC	Reference Concentration
RfD	Reference Dose
PRA	Probabilistic Risk Assessment
RL	Response Level
RM	River Mile
RME	Reasonable Maximum Exposure
RO-AOP	Reverse Osmosis-Advanced Oxidation Process
RSL	Regional Screening Level
RWIS	Reclaimed Water Infiltration Study
SA	Surface Area
SAL	State Action Level
SAT	Soil Aquifer Treatment
SF	Slope Factor
TCEP	Tris(2-carboxyethyl) phosphine
TCEQ	Texas Commission on Environmental Quality

TDCPP	Tris(1,3-dichloroisopropyl) phosphate
TDI	Tolerable Daily Intake
TRRP	Texas Risk Reduction Program
U.S. EPA	United States Environmental Protection Agency
UCMR	Unregulated Contaminant Monitoring Rule
UCL	Upper Confidence Limit
UDS	Unscheduled DNA Synthesis
UF	Uncertainty Factor
UR	Unit Risk
WC	Woodland Creek
WHO	World Health Organization

EXECUTIVE SUMMARY

As part of the Reclaimed Water Infiltration Study (RWIS) undertaken by the LOTT Clean Water Alliance (LOTT), a human health risk assessment (HHRA) was conducted to characterize the potential human health significance of residual chemicals detected in reclaimed water produced by LOTT and used to recharge groundwater. Residual chemicals screened included pharmaceutical and personal care product ingredients (PPCPs), hormones, pesticides, organobromine compounds, polyfluoroalkyl substances (PFAS), and other industrial chemicals.

Specific objectives of the HHRA are to derive estimates of average daily doses of each chemical of interest examined in the HHRA for hypothetical potentially exposed populations representing a range of exposure scenarios, who could be exposed to the residual chemicals in well or tap water from residential or public supply wells that access groundwater aquifers downgradient of the recharge basins, or in surface water impacted by these aquifers (Woodland Creek and McAllister Creek). Based on these dose estimates, quantitative estimates of the potential for adverse health effects to exposed populations were derived. Potential adverse effects considered in the HHRA include noncancer hazards and lifetime excess cancer risks.

In an initial screening-level evaluation, concentrations of 84 residual chemicals detected in at least one water sample during Tasks 1 and 2 of the RWIS (including 27 reclaimed water and 24 porewater samples) were "screened" to identify those that might present health risks that exceed U.S. EPA's allowable risk range to people who contact the water. These included a broad range of chemicals found in household products, PPCPs, and industrial chemicals. In the screening-level evaluation, maximum-detected concentrations of the chemicals in reclaimed water or porewater were compared to toxicity benchmark concentrations, termed Drinking Water Equivalent Levels (DWELs). DWELs were set equal to existing federal or state water quality standards or toxicity criteria, or derived from published toxicological data or therapeutic doses (for pharmaceuticals).

The screening-level evaluation showed that 15 chemicals were detected at least once in reclaimed water or porewater at a concentration in excess of their DWEL. Because this list included four hormones and two PFAS, all other hormones and PFAS analyzed in the RWIS were also selected for further evaluation in the HHRA, as were 14 additional chemicals that were detected at a maximum concentration of 10% or more (i.e., within one order of magnitude) of their DWEL. Overall, a total of 44 chemicals were selected for further evaluation in the HHRA.

People living downgradient of LOTT's infiltration basins do not have direct contact with reclaimed water or porewater and will not have direct contact in the future. Further, chemicals dissolved in the reclaimed water that undergo subsurface transport through groundwater will be subject to several processes, including advection, dispersion, diffusion, sorption, and decay, that affect the concentration and location of each constituent, resulting in attenuation of downgradient concentrations prior to points where exposure could occur. To account for the impact of these processes on potential exposure point concentrations (EPCs) of chemicals in downgradient well water or surface water, the list of chemicals considered was further refined by comparing estimated EPCs of each chemical, based on monitoring for these chemicals in downgradient domestic, municipal, or monitoring wells or on fate and transport modeling, to the DWELs. If the maximum-estimated EPC of a chemical was equal to or greater than 10% of the chemical's DWEL, the chemical was retained for more detailed evaluation in the HHRA. If the chemical was never detected in monitoring, it was not included in the HHRA.

Based on these comparisons, eight chemicals of interest (COIs) were retained for further evaluation in the HHRA. These COIs are:

- 1,4-Dioxane (an industrial chemical with widespread use as a stabilizer in certain chlorinated solvents, paint strippers, greases, and waxes)
- Carbamazepine (a pharmaceutical used to treat certain types of seizures such as epilepsy, and typically classified as an anticonvulsant)
- N-Nitroso dimethylamine (NDMA) (a chemical that was formerly used in the production of rocket fuel, antioxidants, and softeners for copolymers and that is currently used for research purposes, but is also produced as a byproduct of water chlorination disinfection processes undertaken at some water treatment facilities; it is also occurs in some cosmetics and other products and is produced in the human body from nitrosamines and nitrates present in foods such as smoked or cured meats and fish, dried milk and formula, and vegetables, and in beverages such as beer and whiskey)
- Perfluoro octanoic acid (PFOA), perfluoro-n-hexanoic acid (PFHxA), and perfluoropentanoic acid (PFPeA) (three members of a class of human-made compounds known as polyfluoroalkyl substances (PFAS) that have been used in surface coating and protectant formulations because of their unique surfactant properties, including in paper and cardboard packaging products, carpets, leather products, textiles, firefighting foams, and nonstick coatings)
- Primidone (a pharmaceutical used to treat seizure disorders and typically classified as an anticonvulsant)
- Quinoline (an industrial chemical used mainly as an intermediate in the manufacture of other products, and also as a catalyst, corrosion inhibitor, preservative for anatomical specimens, and solvent for resins and terpenes, as well as in metallurgical processes, dye manufacture, and production of polymers and agricultural chemicals)

In the HHRA, potential exposures to hypothetical future populations that could be exposed to COIs in tap or well water or in surface water in Woodland Creek or McAllister Creek were quantified using U.S. EPA recommended risk assessment methodologies. Several scenarios and populations were selected to represent a range of potential exposures. The scenarios and populations evaluated in the HHRA are:

- Residents (child and adult) exposed directly to potable water from domestic water supply wells via ingestion and dermal contact, and that could be exposed via inhalation of volatiles from the water into the domestic living space. For these populations, both a reasonable maximum exposure (RME) (defined as an upper bound estimate of exposure to a resident that could reasonably be expected to occur via a given exposure pathway) and a more likely exposure (MLE) (defined as an estimate of an "average" level of exposure to a resident that could reasonably be expected to occur via a given exposure pathway) are evaluated.
- Maintenance/landscape workers (adult) exposed to tap or well water via direct ingestion and dermal contact (e.g., while irrigating at a park or golf course).
- Recreators (child) exposed to tap or well water at a recreational water feature through dermal contact and incidental ingestion as well as through direct ingestion of tap water while engaging in play (e.g., at a playground or ball field).
- Recreators (child and adult) exposed to surface water in Woodland Creek or McAllister Creek through dermal contact and incidental ingestion during playing, fishing, wading, or swimming.
- Fish consumers (child and adult) who eat fish caught in Woodland Creek or McAllister Creek that took up residual chemicals that are assumed to have migrated through the shallow or deep aquifers to creek water.

Exposures to these populations were estimated using EPCs determined in fate and transport modeling conducted by HDR (2021) and exposure parameters that describe behavioral characteristics and physiological characteristics representative of the populations of interest. For most exposure parameters, characteristics descriptive of U.S. populations or U.S. EPA standardized default exposure parameters for characterizing reasonable maximum exposures were used. As appropriate, locally relevant information and/or professional judgment was also applied.

Potential EPCs of COIs in tap or well water were based on the maximum-estimated concentrations in the shallow and deep aquifers which, for all COIs, were estimated to occur at a location 200 feet downgradient of the discharge basins (the closest location for which concentrations were modeled). While no domestic or municipal water supply wells are currently located this close to the recharge basins, it is assumed that 200 feet represents the minimum buffer that would be required in future permitting to install a new groundwater supply well in proximity to an infiltration basin. Use of EPCs estimated at 200 feet downgradient is assumed to provide a conservative (health-protective) estimate of potential exposures to future downgradient populations.

For those chemicals estimated to infiltrate from the aquifers to points of entry into each creek, EPCs were estimated assuming concentrations in the aquifers at points of entry are reduced by mixing with flow within each creek.

For the exposure populations and scenarios, doses in units of milligrams per kilogram body weight per day (mg/kg-d) were estimated for each pathway and COI using assumed exposure parameters and EPCs. For evaluation of noncarcinogenic effects, doses were averaged over one year and presented as annual average daily doses (ADDs). For evaluation of cancer risk, doses were averaged over a lifetime (assumed to be 70 years) and presented as lifetime average daily doses (LADDs). These dose estimates were then combined with chemical- and pathway-specific noncancer or cancer toxicity criteria to derive estimates of noncancer hazard and cancer risk associated with the exposures.

The results of the HHRA predicted the following with regard to noncancer hazards under the baseline (current) reclaimed water treatment scenario:

- Estimated upper bound noncancer hazard indices (HIs) exceed the minimum threshold level of concern of 1.0 for only one chemical and scenario—perfluoropentanoic acid (PFPeA) for the RME child resident scenario, with an estimated HI of 1.3 (or 1 if rounded to one significant figure). The RME scenario is intended to reflect a high end estimate of potential exposures. It is defined as the highest exposure that is reasonably expected to occur at a site, and is intended to estimate a conservative exposure case (i.e., well above the average case) that is still within the range of possible exposures, e.g., within approximately the 90^{th} to 99.9^{th} percentiles of the risk distribution for an exposure scenario.
- An HI >1 does not mean that adverse health effects are expected or will occur. In fact, if the noncancer HI is close to 1 (as is the case for the upper bound noncancer hazard estimate for the RME child resident scenario for PFPeA), adverse health effects are unlikely even if a person's exposure is at this estimated upper bound level. This is because multiple uncertainty factors are incorporated into the derived toxicity criterion (i.e., allowable daily dose) that is used to calculate the noncancer hazard for this chemical, to ensure it is at a level at which health effects are not expected.
- Estimated upper bound noncancer HIs for PFPeA for the shallow and deep aquifers are nearly the same because the estimated EPCs for these aquifers are nearly the same (with the EPCs for the deep aquifer slightly lower).

- For the RME resident scenarios, estimated noncancer HIs for a child are approximately two times those for an adult. This is because HIs are determined based on an estimated annualized average daily dose and typically, the average intake of a child on a per kilogram of body weight basis is greater than that of an average adult. The estimated upper bound noncancer HI for the RME adult resident scenario is below 1.0.
- Greater than 99% of the estimated noncancer HIs for the RME child or adult resident scenarios for PFPeA are contributed by the water ingestion pathway. This pathway assumes a child drinks approximately 1 liter of water per day or an adult drinks approximately 2.6 liters of water per day, nearly every day (350 days per year) in the home. The contribution of dermal contact with water to total daily dose is <1%.
- Estimated noncancer HIs for all other chemicals and all other scenarios, including the MLE resident scenario, are below 1.0. Under the MLE resident scenarios, the rate of ingestion of tap water in the home is assumed to be approximately one-half liter per day for a child and 1.3 liters per day for an adult for 234 days per year (approximately two-thirds of a year).
- People can also be exposed to PFPeA in the diet. Estimated daily exposures for the RME resident from tap water are estimated to be comparable to exposures from the diet unrelated to potential reclaimed water sources.

With regard to predicted cancer risks under the baseline (current) treatment scenario, the following was found:

- Estimated upper bound lifetime excess cancer risks (LECRs) exceed the *de minimis* cancer benchmark of 1 in 1,000,000, or 10^{-6} for only one chemical and scenario—NMDA for the RME resident scenario, which has an estimated LECR of 2.9×10^{-6} (3×10^{-6} if rounded to one significant figure).
- This LECR can be interpreted as a probability that, at the upper bound of the risk estimates, 2.9 persons in one million (10^6) people could develop cancer if they are exposed to this chemical at this rate over their lifetime.
- While the upper bound LECR estimate for the RME resident scenario slightly exceeds a *de minimis* one-in-a-million LECR, it falls within the range of risks considered to be allowable by U.S. EPA and others at different sites depending on specific site characteristics (1×10^{-4} to 1×10^{-6}, or 1 in 10,000 to 1 in 1,000,000).
- Estimated upper bound LECRs for NDMA for the shallow and deep aquifers are nearly the same because the estimated EPCs for these aquifers are nearly the same (with the EPCs for the deep aquifer slightly lower). More than 99% of this estimated risk is contributed by the water ingestion pathway.
- Estimated LECRs for all other chemicals of interest and exposure scenarios, including the MLE resident scenario, are below 1×10^{-6}.
- Other sources of exposure to NDMA, other than water, include food or beverages that contain nitrosamines, such as smoked or cured meats and fish, vegetables, dried milk or formula, and malt beverages (“exogenous” NDMA) and food that contains nitrates, such as cured meats or fish and vegetables, that can be converted to NDMA in the stomach (“endogenous” NDMA). Estimated upper bound daily exposures for the RME resident from tap water are estimated be about 1 to 3% of exposures to exogenous or endogenous NDMA from sources unrelated to potential reclaimed water sources.

With regard to potential noncancer hazards and cancer risks associated with consumption of fish from either McAllister Creek or Woodland Creek, the HHRA predicts that even at a high end fish consumption rate of 330.5 g/d (corresponding to the 95th percentile estimate of "total fish" consumption from the Puget Sound and elsewhere by Squaxin Tribe consumer only adults, as presented by U.S. EPA and supported by the Squaxin Tribe, or approximately 609 servings per year assuming an average 7-ounce serving size), estimated noncancer hazards and cancer risks for these scenarios are below threshold levels of concern.

Evaluation of hazards and risks assuming implementation of two possible treatment options (Option 1: RO-AOP or Option 2: O3-BAC-GAC) indicates that these options would reduce all estimated noncancer HIs and LECRs to below threshold levels of concern.

Results of a PRA conducted for the two chemicals with upper bound hazard or risk estimates that slightly exceed allowable thresholds based on the deterministic risk assessment—PFPeA and NDMA, for the resident scenario—indicate that estimated HIs for PFPeA and LECRs for NDMA meet the human health protection goals set by the Florida Department of Environmental Protection and the Oregon Department of Environmental Quality (the only two regulatory agencies with PRA-based water quality goals corresponding to specific distribution percentiles for HIs and LECRs), and that even at the 99th percentile, the LECRs for NDMA are within U.S. EPA's allowable risk range (1×10^{-6} to 1×10^{-4}).

Two key sources of uncertainty in the PRA noncancer hazard and cancer risk estimates for PFPeA and NDMA are the assumed water concentrations and the applied toxicity criteria. Water concentrations applied in the PRA are point estimate values and are the same as values used in the deterministic HHRA. They are based on the 95 percent upper confidence limit (UCL) of the arithmetic mean concentrations of these chemicals in reclaimed water applied to the infiltration basins, modeled to locations in the shallow or deep aquifers 200 feet downgradient of the basins. For these chemicals, no biodegradation or sorption downgradient of the source was assumed to occur. Overall, these assumptions are assumed to result in conservative (health protective) estimates of potential EPCs for these chemicals. The toxicity criteria used to estimate noncancer hazards or cancer risk for these chemicals are the same as applied in the deterministic HHRA and are assumed to provide a conservative (health protective) estimate of potential hazards or risks at a given dose. Thus, even if exposures consistent with the upper bounds of the PRA output distributions were to occur, it does not mean that adverse health effects are expected or will occur.

1.0 INTRODUCTION

The LOTT Clean Water Alliance (LOTT) provides services to treat and manage wastewater for the urban areas of Lacey, Olympia, and Tumwater in Thurston County, Washington (at the southern end of Puget Sound). Since 2006, LOTT has produced reclaimed water that is used for irrigation and other non-drinking purposes. LOTT has undertaken a Reclaimed Water Infiltration Study (RWIS) to improve understanding of which chemicals may exist in LOTT's reclaimed water after treatment and what may happen to them over time, assess the potential effects of these chemicals on human health and the environment, and provide local scientific data and community perspectives to help policymakers make informed decisions about future reclaimed water treatment.

In Tasks 1 and 2 of the RWIS, samples of reclaimed water, porewater, effluent water, groundwater, and surface water were collected from 2013 to 2018 and analyzed for residual chemicals and other water quality indicators. To understand the potential significance of detected chemicals with regard to human health risks, a human health risk assessment (HHRA; Task 3.1) was initiated. Prior to a detailed HHRA, an initial screening-level evaluation was conducted to identify residual chemicals detected in reclaimed water that warrant further evaluation of potential exposures and health risks in the HHRA (Intertox, 2021). The screening-level evaluation applied conservative (i.e., health protective) assumptions intended to overestimate potential exposures and human health risks, in order to "screen out" those chemicals that are highly unlikely to be of concern with regard to human health under more realistic exposure conditions. The HHRA further evaluates the remaining chemicals of interest (COIs) to assess whether exposure to residual chemicals that occur in off-site groundwater or surface water could present human health risks at levels that exceed U.S. EPA's allowable risk range.

1.1 Document Overview

This document presents the methods and results of the HHRA for the RWIS. Subsequent sections of this document are organized as follows:

- **Data Evaluation and Hazard Characterization (Section 2.0).** This section describes the areas and media of interest considered in the HHRA, identifies the COIs detected in reclaimed water or porewater that were selected for more detailed evaluation in the HHRA based on the screening-level evaluation, and describes further refinements to this list based on concentrations of these chemicals in groundwater or surface water that are estimated to potentially occur at points of exposure (i.e., exposure point concentrations; EPCs), based on groundwater monitoring and fate and transport modeling conducted by HDR (2021).
- **Exposure Assessment (Section 3.0).** This section identifies the potentially exposed populations considered in the HHRA, and describes the scenarios and pathways through which they could be exposed as well as the EPCs and exposure parameters applied to estimate doses.
- **Toxicity Assessment (Section 4.0).** This section identifies toxicity criteria that were used to estimate noncancer hazards and lifetime excess cancer risks (LECRs) for each COI associated with the doses estimated in the Exposure Assessment.
- **Risk Characterization (Section 5.0).** This section combines the results of the Exposure Assessment and the Toxicity Assessment to derive quantitative estimates of the potential for adverse health effects, specifically noncancer effects and lifetime excess cancer risks. It also presents a discussion of risk estimates and information to support risk communication.

- **Probabilistic Risk Assessment for Child and Adult Resident Exposure (Section 6.0).** This section summarizes the methods and results of a probabilistic risk assessment (PRA) for PFPeA and NDMA for the resident scenario—these are the only chemicals and scenario that exceeded risk thresholds in the conventional HHRA. This PRA was conducted to better characterize the range of exposures and risks for these chemicals and this scenario, and to provide additional information to support the cost benefit analysis.
- **Summary and Conclusions (Section 7.0).** This section summarizes the results and overall conclusions of the HHRA, including the PRA.
- **References (Section 8.0).** This section provides the references used to support the HHRA.
- **Appendix A.** This appendix summarizes key chemical properties and uptake parameters for the COIs included in the HHRA.
- **Appendix B.** This appendix summarizes exposure parameters applied to calculate doses for exposure scenarios and populations evaluated in the HHRA.
- **Appendix C.** This appendix summarizes toxicity criteria and other toxicity information for the COIs.
- **Appendix D.** This appendix presents detailed noncancer hazard and cancer risk calculation results for the baseline treatment scenario.
- **Appendix E.** This appendix presents the methods and results of the PRA conducted for PFPeA and NDMA for the resident scenario.

1.2 Objectives of the HHRA

Specific objectives of the HHRA are to:

- Derive estimates of average daily doses of each COI for hypothetical potentially exposed populations representing a range of exposure scenarios, that could be exposed to the residual chemicals in well or tap water from groundwater aquifers downgradient of the recharge basins or in surface water (Woodland Creek and McAllister Creek). Populations and scenarios considered include child and adult residents, adult maintenance/landscape workers, child recreators at a water feature or playfield, and child and adult recreators and fish consumers at the creeks.
- Based on the estimated average daily doses and information on the potential health effects of COIs, derive quantitative estimates of the potential for adverse health effects to exposed populations, specifically noncancer hazards and LECRs.
- Present information on how estimated risks compare to other types of risks, and as well as other information to support risk communication.
- Present the results of a PRA for chemicals and scenarios that exceeded risk thresholds in the HHRA.

The HHRA applies methodologies from current U.S. EPA and other risk assessment guidance and policy as appropriate**,** including the following:

- U.S. EPA. 1989. *Risk Assessment Guidance for Superfund (RAGS), Volume I – Human Health Evaluation Manual, Part A. Interim Final.* Office of Solid Waste and Emergency Response, United States Environmental Protection Agency. Washington, D.C. EPA/540/1-89/002. December.

- U.S. EPA. 1991. *Human Health Evaluation Manual, Supplemental Guidance: Standard Default Exposure Parameters*. Office of Solid Waste and Emergency Response, United States Environmental Protection Agency. Washington, D.C. June.
- U.S. EPA. 2002. *A Review of the Reference Dose and Reference Concentration Processes*. EPA/630/P-02/002F. U.S. Environmental Protection Agency. Washington, D.C.
- U.S. EPA. 2003. *Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health (2000) Technical Support Document Volume 2: Development of National Bioaccumulation Factors*. United States Environmental Protection Agency. Washington, D.C.
- U.S. EPA. 2004. *Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment), Final*. EPA/540/R/99/005. Washington, D.C.: U.S. Environmental Protection Agency, Office of Superfund Remediation and Technology Innovation.
- U.S. EPA. 2005. *Guidelines for Carcinogen Risk Assessment*. Risk Assessment Forum, United States Environmental Protection Agency. Washington, D.C. EPA/630/P-03/001F. March.
- U.S. EPA. 2008. *Child-Specific Exposure Factors Handbook*. United States Environmental Protection Agency. Washington, D.C. EPA/600/R-06/096F. September.
- U.S. EPA. 2008. *Risk Assessment Portal. Step 2: Dose-Response Assessment.* United States Environmental Protection Agency. Washington, D.C.
- U.S. EPA. 2011. *Exposure Factors Handbook*. Office of Research and Development, United States Environmental Protection Agency. Washington, D.C. EPA/600/R-090/052F. September.
- U.S. EPA. 2012. *Guidance for Considering and Using Open Literature Toxicity Studies to Support Human Health Risk Assessment.* Office of Pesticide Programs. United States Environmental Protection Agency. Washington, D.C.
- U.S. EPA. 2015. *Calculation of Preliminary Remediation Goals*. U.S. Environmental Protection Agency. Washington, D.C.
- U.S. EPA. 2017. *Regional Guidance on Handling Chemical Concentration Data Near the Detection Limit in Risk Assessments.* Regional Technical Guidance Manual, Risk Assessment. U.S. Environmental Protection Agency. Washington, D.C.
- U.S. EPA. 2017. *Risk Assessment Guidance for Superfund (RAGS): Part E, Supplemental Guidance for Dermal Risk Assessment.* U.S. Environmental Protection Agency. Washington, D.C.
- U.S. EPA. 2018. *Region 4 Human Health Risk Assessment Supplemental Guidance*. United States Environmental Protection Agency. March.
- U.S. EPA. 2019. *Update for Chapter 3 of the Exposure Factors Handbook: Ingestion of Water and Other Select Liquids*. United States Environmental Protection Agency. Washington D.C. EPA/600/R-18-259F. February.
- U.S. EPA. 2019. *Guidelines for Human Exposure Assessment*. Risk Assessment Forum. United States Environmental Protection Agency. Washington D.C. EPA/100/B-19/001. October.

- U.S. EPA. 2021. *Regional Screening Levels (RSLs).* U.S. Environmental Protection Agency. Washington, D.C.
- Washington State Department of Ecology. 2007. Model Toxics Control Act Statute and Regulation. Publication No. 94-06. November.
- Washington State Department of Ecology. 2007. *Workbook Tools for Calculating Soil and Groundwater Cleanup Levels Under the Model Toxics Control Act Cleanup Regulation.* User's Guide for MTCATPH 11.1 & MTCASGL 11.0. Publication No. 01-09-073. December.

The methods and results of the HHRA are described in the following sections.

2.0 DATA EVALUATION AND HAZARD CHARACTERIZATION

The objectives of the Data Evaluation and Hazard Characterization step are to describe the areas and media of interest considered in the HHRA, identify the COIs selected during the screening-level evaluation for consideration in the HHRA, and refine the list of COIs based on results of monitoring for the chemicals in groundwater.

The results of this step are described below.

2.1 Characterization of Areas and Media of Interest

In Tasks 1 and 2 of the RWIS, samples of reclaimed water, porewater, and groundwater were collected and analyzed for residual chemicals and other water quality indicators. Residual chemicals screened included pharmaceutical and personal care product ingredients (PPCPs), hormones, pesticides, organobromine compounds (including polybrominated diphenyl ethers [PBDEs], ethylene dibromide [EDB], and dibromochloropropane [DBCP]), polyfluoroalkyl substances (PFAS), and other industrial chemicals.

Samples of reclaimed water were collected at the Budd Inlet Reclaimed Water Plant (BIRWP), the Martin Way Reclaimed Water Plant (MWRWP), and the Hawks Prairie Reclaimed Water Basin 4, to identify chemicals present in LOTT's reclaimed water and to assess the effectiveness of treatment performance on these chemicals (HDR, 2017c). Specifically:

- Sampling at the BIRWP was of Class A reclaimed water produced at the BIRWP, prior to entering the downtown Olympia reclaimed water distribution system. Samples were collected at the Autosampler port normally used by LOTT for Class A reclaimed water quality monitoring. Sampling was conducted on November 13, 2014, February 18, 2015, May 20, 2015, and August 19, 2015. Analyses were for residual chemicals and other water quality indicators.
- Sampling at the MWRWP was conducted on November 12, 2014, February 17, 2015, May 20, 2015, and October 7, 2015. Analyses were for residual chemicals and other water quality indicators. Water that was sampled included the following:
    - Class A reclaimed water produced at the MWRWP treatment plant, prior to leaving the plant site, at the Autosampler port normally used by LOTT for Class A reclaimed water quality monitoring
    - Reclaimed water at the inflow point to the constructed wetlands at LOTT's Hawks Prairie site (i.e., at the end of the conveyance line that extends from the MWRWP to the Hawks Prairie site; "Pre-Wetlands")

    - Reclaimed water that has been conveyed through the constructed wetlands at the inflow point to the infiltration basins at LOTT's Hawks Prairie site (i.e., water flowing out of the high-density polyethylene (HDPE) distribution header pipe lining the active infiltration basin; "Post-Wetlands").
- Sampling at the Hawks Prairie Reclaimed Water Basin 4 was conducted monthly from January–October, 2018, during a period when reclaimed water was conveyed directly from the MWRWP to the infiltration basins, bypassing the wetlands. Infiltration of Class A Reclaimed Water has occurred at this basin since 2006. Only samples collected during January, April, June, and August were analyzed for residual chemicals (not including the organobromine compounds).

Samples of vadose zone porewater were collected monthly from January–October, 2018 from the west and east halves of the Hawks Prairie Reclaimed Water Basin 4 (HDR, 2017c). Samples collected during January, April, June, and August were analyzed for residual chemicals (not including the organobromine compounds).

In addition, samples of groundwater and surface water were collected and analyzed for residual chemicals (not including the organobromine compounds) and other parameters of interest (HDR, 2017a, b).

Samples of groundwater were collected in 2013, 2015, 2016, and 2018 from domestic and municipal water wells and monitoring wells, to characterize groundwater quality across a wide geography and in both shallow and deep aquifers (HDR, 2017a). Samples were collected in the following two study areas:

- The Hawks Prairie Study Area, located in the vicinity of north Lacey—Samples were collected from residential wells, public supply wells, monitoring wells, and springs. Samples were collected in November, 2013 (MW-1, -2, -3, -6, -8, -10, and -11 only) and from April to September, 2015 from 20 residential wells, 12 public supply wells, one monitoring well (Thurston County well MW-1), and two springs (the Salmon Lane-area springs and the Beatty Spring). Resampling was also conducted at three of the Hawks Prairie wells (residential well RES-983 and the City of Lacey wells S-16 (MUN-1217) and S-31) on May 2, 2016 because of errors in the original sample collection and laboratory mislabeling of sample bottles, as well as at MW-7 on November 15, 2016. Additional groundwater samples were collected monthly from January–October, 2018 at 14 monitoring wells (only samples collected during January, April, June, and August, 2018 were analyzed for residual chemicals (not including the organobromine compounds)).
- The Tumwater Study Area, located in the vicinity of Tumwater—While reclaimed water has never been used for infiltration to groundwater within this study area, it is used for irrigation at several sites and LOTT may develop an infiltration site in this area in the future. Samples were collected from 20 residential wells and 10 public supply wells. Samples were collected from August to September, 2015.

Both the Hawks Prairie Study Area and the Tumwater Study Area are characterized as having residential and rural-residential land uses, with moderate commercial activity. Drinking water is obtained from groundwater, provided to some residents by public supply wells and to others by individual residential wells.

Samples of surface water were collected from August–December, 2015 from the Deschutes River and Woodland Creek and their tributaries (HDR, 2017b), as follows:

- Deschutes River water—Sampling was conducted at six locations, including Upper Deschutes River (River Mile (RM) 4.8), Lower Deschutes River (RM 0.5), and tributary monitoring locations on Chambers Creek, Munn Lake, and Percival Creek, as well as one reference location on the Deschutes River (RM 9.4).
- Woodland Creek watershed—Sampling was conducted at six locations, including Upper Woodland Creek (RM 3.4), Lower Woodland Creek (RM 1.6), and tributary monitoring locations on Fox Creek, Beatty Springs, and Eagle Creek, as well as one reference location on Woodland Creek (RM 5.2).

Surface water samples were collected at various times of the year to assess variability under different flow conditions: two samples during late summer low flow conditions, one sample after the first large fall storm, and one sample during winter high flow conditions. Analyses were for residual chemicals and other water quality indicators but did not include organobromine compounds, PFAS, or some other compounds (e.g., 1,4-dioxane, N-nitroso dimethylamine (NDMA), salicylic acid, and theophylline).

2.2 Summary of Screening-Level Evaluation and Identification of Chemicals of Interest

Water samples collected during Tasks 1 and 2 of the RWIS were analyzed for a range of water quality parameters including 134 residual chemicals.[1] These chemicals were selected for analysis because they have been reported at very low concentrations (on the order of parts per trillion (ppt), or nanograms per liter (ng/L)) in previous studies of treated wastewater, groundwater, and surface water, and were selected from among the thousands of commonly used compounds of this type to include compounds that are:

- Representative of large classes of compounds,
- Frequently detected in reclaimed water,
- Routinely used in the wastewater industry for evaluating treatment effectiveness, and
- Reliably quantified in laboratory analysis.

All chemicals within the residual chemical groups that were analyzed in reclaimed water or porewater were considered in the screening-level evaluation.

Overall, 84 residual chemicals out of the 134 considered[2] were detected in at least one sample. Following the process described in the screening-level evaluation, the maximum concentration of each residual chemical that was detected in reclaimed water or porewater was compared to a toxicity

[1] The Screening-Level Evaluation (Intertox, 2021) indicates that the assessment considered 122 chemicals of potential interest, including 109 residual chemicals (not including PFAS) and 13 PFAS. In the current HHRA document, an additional 14 compounds (10 organobromine compounds and 4 insecticides) were screened using the same initial screening process applied in the Screening-Level Evaluation. In addition, two residual chemicals were erroneously double-counted in the Screening-Level Evaluation [azithromycin, which was counted as both detected and not detected in recharge water (it was not detected) and estradiol, 17beta-, which was counted as both estradiol, 17beta- and estradiol (they are the same chemical)]. In the revised count, these chemicals were included only once in the total chemical count. Finally, all chemicals, including PFAS, are classified here as "residual chemicals." Overall, the final number of residual chemicals considered in the HHRA is 134 chemicals.

[2] The Screening-Level Evaluation (Intertox, 2021) indicates that 76 residual chemicals (not including PFAS) and 7 PFAS, or a total of 83 chemicals, were detected. However, as indicated above, azithromycin was erroneously double-counted as both detected and not detected in recharge water (it should be counted as not detected). In addition, two compounds of the 14 additional compounds considered in this assessment were detected at least once in reclaimed water (DBCP and fipronil). Consequently, the final total number of residual chemicals (including PFAS) detected at least once in reclaimed water or porewater is 84 chemicals.

benchmark concentration (a Drinking Water Equivalent Level (DWEL)), to determine which chemicals might present health risks exceeding U.S. EPA's allowable risk ranges to people who contact the water.

As described in the screening-level evaluation, using a hierarchical approach, DWELs in units of ng/L (nanogram per liter, equivalent to a part per trillion or ppt) were set at levels equal to existing state or federal water quality standards (such as State of Washington or U.S. EPA Maximum Contaminant Levels (MCLs), or State of Washington water quality standards for groundwater), or were derived from published toxicity criteria. If a chemical did not have an existing water quality standard or toxicity criterion (as was the case for many of the pharmaceutical compounds), acceptable daily intakes (ADIs) were derived from toxicological data or therapeutic doses and converted to DWELs.

The results of the comparison of maximum-detected concentrations in reclaimed or porewater to the DWELs, as presented in the screening-level evaluation, are summarized in Table 2-1. These results show that of the 75 detected residual chemicals and 7 detected PFAS considered in the screening-level evaluation, 15 were detected at least once in reclaimed water or porewater at a concentration in excess of a corresponding DWEL. These 15 chemicals were selected for further evaluation in the HHRA. In addition, because these chemicals included four hormones and two PFAS, the remaining chemicals in these chemical classes that were detected in reclaimed water or porewater (four additional hormones and 11 additional PFAS) were also considered further in the HHRA. In addition, 14 other compounds that were detected at a maximum concentration of 10% or more of their DWEL (i.e., within an order of magnitude) were also selected for further consideration.

Table 2-2 shows the results of application of the screening-level evaluation process to the 14 additional residual chemicals that were analyzed for in reclaimed water samples but were not considered in the initial (Intertox, 2021) screening-level evaluation (10 organobromine compounds and four insecticides). Of these 14 chemicals, only two—fipronil and DBCP—were detected at least once in reclaimed water (the chemicals were not analyzed for in porewater). Comparison of the maximum-detected concentrations of these chemicals to DWELs shows the following:

- The maximum-detected concentration of fipronil in reclaimed water (it was detected in approximately 50% of the samples) was 51 ng/L. This concentration is more than 19-fold below the DWEL for fipronil of 1,000 ng/L, which was set equal to the U.S. EPA chronic Human Health Benchmark for Pesticides (HHBP) for fipronil in drinking water. This value in turn was derived from a U.S. EPA chronic oral reference dose (RfD) for fipronil that is based on noncancer effects observed in a chronic study in rats (specifically, effects on clinical chemistry and thyroid parameters; U.S. EPA, 2007a; U.S. EPA, 2021a,b). Because the maximum-detected concentration of fipronil in reclaimed water is less than 10% of its DWEL, fipronil was not considered further in the HHRA.
- The maximum-detected concentration of DBCP in reclaimed water (it was detected in one sample) was 11 ng/L. This concentration is more than 18-fold below its DWEL of 200 ng/L, which was set equal to the U.S. EPA Maximum Contaminant Level (MCL) for DBCP, which is set to protect against reproductive difficulties and increased risk of cancer (U.S. EPA, 2022). Because the maximum-detected concentration of DBCP in reclaimed water is less than 10% of its DWEL, DBCP was not considered further in the HHRA.

Overall, based on the results of the screening-level evaluation, 8 hormones, 16 PPCPs, 7 industrial chemicals or pesticides, and 13 PFAS (44 chemicals total) were selected for further evaluation in the HHRA.

2.3 Refinement of the COI List Based on Comparison of Estimated Exposure Point Concentrations (EPCs) to DWELs

Following the approach described in the screening-level evaluation, a preliminary list of COIs was selected based on concentrations detected in reclaimed water or porewater. However, residents or other populations downgradient of the infiltration basins will not be directly exposed to this water. Rather, people could be exposed to tap water from domestic or municipal wells that obtain water from shallow or deep aquifers downgradient of the infiltration basins, or they could come in contact with surface water impacted by these aquifers. Since chemicals in reclaimed water will be subject to advection, dispersion, diffusion, sorption, decay, and other attenuation processes during subsurface transport, downgradient concentrations will be lower than concentrations in reclaimed water (HDR, 2021). Consequently, in the HHRA, the list of COIs identified for further consideration using the screening-level evaluation approach was further refined by comparing EPCs estimated at downgradient locations to corresponding DWELs.

EPCs were estimated for each COI as follows:

- For chemicals analyzed for but never detected in samples of groundwater collected from domestic, municipal, or monitoring wells downgradient of the infiltration basins, it was assumed that the chemical attenuates completely as it moves through groundwater and is not available for exposure (i.e., the EPC is zero).
- For chemicals that were detected at least once in downgradient groundwater, HDR (2021) conducted fate and transport modeling to estimate EPCs in groundwater in the shallow and deep aquifers at points along concentric radii that are 200, 1,000, 2,000, 4,000, and 8,000 feet downgradient of the infiltration basins, as well as incoming into Woodland Creek and McAllister Creek. If the maximum-estimated EPC at any location was equal to or greater than 10% of the chemical's DWEL, the chemical was retained for further consideration in the HHRA. All other chemicals were excluded from further evaluation.

The refinement of the COI list is summarized in Table 2-3. For each COI selected using the screening-level evaluation approach, Table 2-3 summarizes whether it was detected in downgradient groundwater and, if detected, the maximum-estimated EPC in the shallow aquifer and the deep aquifer based on fate and transport modeling (HDR, 2021). For detected chemicals with estimated EPCs, the corresponding DWEL is also shown. The final column summarizes whether the chemical was selected for further evaluation in the HHRA and the reason for its inclusion or exclusion.

Based on these evaluations, eight chemicals were retained for further evaluation in the HHRA. These chemicals are:

- 1,4-Dioxane, an industrial chemical with widespread use as a stabilizer in certain chlorinated solvents, paint strippers, greases, and waxes.
- Carbamazepine, a pharmaceutical used to treat certain types of seizures such as epilepsy and typically classified as an anticonvulsant.
- N-Nitroso dimethylamine (NDMA), a chemical that was formerly used in the production of rocket fuel, antioxidants, and softeners for copolymers that is currently used for research purposes and is also produced as a byproduct of water chlorination disinfection processes undertaken at some water treatment facilities. NDMA also occurs in some cosmetics and other products and is produced in the human body from nitrosamines and nitrates that are present in some foods such as smoked or cured meats and fish, dried milk, formula, and vegetables, as well as in some beverages such as beer and whiskey.

- Perfluoro octanoic acid (PFOA), perfluoro-n-hexanoic acid (PFHxA), and perfluoropentanoic acid (PFPeA), three members of a class of human-made compounds known as polyfluoroalkyl substances (PFAS) that have been used in surface coating and protectant formulations because of their unique surfactant properties, including in paper and cardboard packaging products, carpets, leather products, textiles, firefighting foams, and nonstick coatings.[3]
- Primidone, a pharmaceutical used to treat seizure disorders and typically classified as an anticonvulsant.
- Quinoline, an industrial chemical used mainly as an intermediate in the manufacture of other products, and also as a catalyst, corrosion inhibitor, preservative for anatomical specimens, and solvent for resins and terpenes, as well as in metallurgical processes, dye manufacture, and production of polymers and agricultural chemicals.

[3] DWELs for several PFAS are updated from those presented in the Screening-Level Assessment (Intertox, 2021) to reflect newly published values, as indicated in a footnote in Table 2-3.

Table 2-1. Chemicals Identified in the Screening-Level Evaluation (Intertox, 2021) for Further Evaluation in the HHRA

Chemical	CAS Number	Category or Pharmaceutical Class	Reason Retained Using the Screening-Level Evaluation Process			
			Maximum Reclaimed or Porewater Concentration is…		Chemical is Part of Chemical Group	
			≥ DWEL	≥ 10% of DWEL but < DWEL	Hormone	PFAS
Hormones						
Androstenedione	63-05-8	Steroid hormone			•	
Estradiol, 17beta-	50-28-2	Estrogenic hormone	•		•	
Estriol	50-27-1	Estrogenic hormone			•	
Estrone	53-16-7	Estrogenic hormone	•		•	
Ethinyl estradiol, 17alpha-	57-63-6	Estrogenic hormone	•		•	
Norethisterone	68-22-4	Steroid hormone	•		•	
Progesterone	57-83-0	Steroid hormone			•	
Testosterone	58-22-0	Steroid hormone		•	•	
PPCP Ingredients and Other Personal Products						
Acesulfame-K	55589-62-3	Sugar substitute		•		
Albuterol	18559-94-9	Anti-asthmatic	•			
Atenolol	29122-68-7	Beta blocker		•		
Carbamazepine	298-46-4	Antiseizure	•			
Chloramphenicol	56-75-7	Antibiotic	•			
Cotinine	486-56-6	Nicotine degradant		•		
Diazepam	439-14-5	Antianxiety		•		
Diclofenac	15307-86-5	Anti-inflammatory		•		
Dilantin	57-41-0	Antiseizure		•		
Fluoxetine	54910-89-3	Antidepressant		•		
Gemfibrozil	25812-30-0	Antilipidemic		•		
Lopressor	51384-51-1	Beta blocker		•		
Primidone	125-33-7	Anti-convulsant	•			
Sucralose	56038-13-2	Sugar substitute		•		
Sulfamethoxazole	723-46-6	Sulfa antibiotic		•		

Chemical	CAS Number	Category or Pharmaceutical Class	Reason Retained Using the Screening-Level Evaluation Process: Maximum Reclaimed or Porewater Concentration is… ≥ DWEL	Maximum Reclaimed or Porewater Concentration is… ≥ 10% of DWEL but < DWEL	Chemical is Part of Chemical Group: Hormone	Chemical is Part of Chemical Group: PFAS
Theophylline	58-55-9	Anti-asthmatic		•		
Industrial chemicals and Pesticides						
1,4-Dioxane	123-91-1	Industrial chemical	•			
4-Nonylphenol	104-40-5	Surfactant	•			
N-Nitroso dimethylamine (NDMA)	62-75-9	Industrial solvent	•			
Quinoline	91-22-5	Industrial chemical	•			
Thiabendazole	148-79-8	Fungicide		•		
Tris(2-carboxyethyl)phosphine (TCEP)	115-96-8	Flame retardant		•		
Tris(1,3-dichloroisopropyl)phosphate (TDCPP)	13674-87-8	Flame retardant	•			
Polyfluoroalkyl substances (PFAS)						
Perfluoro butanoic acid (PFBA)	375-22-4	PFAS				•
Perfluoro octanesulfonate (PFOS)	45298-90-6	PFAS				•
Perfluoro octanesulfonic acid	1763-23-1	PFAS				•
Perfluoro octanoic acid (PFOA)	15899-31-7	PFAS		•		•
Perfluoro-1-butanesulfonate (PFBuS)	194999-85-4	PFAS				•
Perfluoro-1-butanesulfonic acid	375-73-5	PFAS				•
Perfluoro-1-hexanesulfonate (PFHxS)	108427-53-8	PFAS				•
Perfluoro-1-hexanesulfonic acid	355-46-4	PFAS				•
Perfluoro-n-decanoic acid (PFDeA)	335-76-2	PFAS				•
Perfluoro-n-heptanoic acid (PFHpA)	375-85-9	PFAS				•
Perfluoro-n-hexanoic acid (PFHxA)	307-24-4	PFAS	•			•
Perfluoro-n-nonanoic acid (PFNA)	375-95-1	PFAS		•		•
Perfluoropentanoic acid (PFPeA)	2706-90-3	PFAS	•			•

DWEL – Drinking Water Equivalent Level (established in Screening-Level Evaluation); PFAS – Polyfluoroalkyl substance; PPCP – Pharmaceutical or personal care product ingredient

Table 2-2. Assessment of Additional Residual Chemicals for Further Evaluation in the HHRA Using the Screening-Level Evaluation Approach

Chemical	CAS Number	Category or Pharmaceutical Class	Maximum-Detected Concentration (ng/L)*		
			Reclaimed Water	Porewater	DWEL (ng/L)
BDE-100	189084-64-8	PBDE	<5	NS	NA
BDE-153	68631-49-2	PBDE	<5	NS	NA
BDE-154	207122-15-4	PBDE	<5	NS	NA
BDE-183	207122-16-5	PBDE	<5	NS	NA
BDE-209	1163-19-5	PBDE	<100	NS	NA
BDE-28	41318-75-6	PBDE	<5	NS	NA
BDE-47	5436-43-1	PBDE	<5	NS	NA
BDE-99	60348-60-9	PBDE	<5	NS	NA
Fipronil	120068-37-3	Insecticide	51	NS	1,000†
Bifenthrin	82657-04-3	Insecticide	<5	NS	NA
cis-Permethrin	61949-76-6	Insecticide	<5	NS	NA
trans-Permethrin	61949-77-7	Insecticide	<5	NS	NA
Dibromochloropropane (DBCP)	96-12-8	Pesticide/Fumigant	11	NS	200‡
Ethylene Dibromide (EDB)	106-93-4	Pesticide/Industrial chemical	<10	NS	NA

*For compounds never detected in a medium, the detection limit or range of detection limits is given (<).
† The DWEL for fipronil is set equal to its U.S. EPA chronic Human Health Benchmark for Pesticides (HHBP) level for drinking water exposure of 1 µg/L (1,000 ng/L). This level is based on a U.S. EPA chronic oral reference dose (RfD) of 0.0002 mg/kg-d (U.S. EPA, 2007a), with an assumed water ingestion rate of 0.0338 L/kg body weight/d for general population exposure and a Relative Source Contribution of 20% (U.S. EPA, 2021a,b).
‡ The DWEL for DBCP is based on its U.S. EPA Maximum Contaminant Level (MCL) of 0.2 µg/L (200 ng/L), which is set to protect against reproductive difficulties and increased risk of cancer (U.S. EPA, 2022).
DWEL – Drinking Water Equivalent Level (established in Screening-Level Evaluation); NA – Not applicable (compound never detected); NS – Not sampled; PBDE – Polybrominated diphenyl ether

Table 2-3. Summary of Refinement of COI List for the HHRA Based on Detection in Downgradient Groundwater and Comparison of Maximum Modeled EPCs in Groundwater to DWELs*

Chemical	CAS Number	Category or Pharmaceutical Class	Detected in Downgradient Groundwater?	Maximum Modeled EPC in Groundwater		DWEL (ng/L)	Retained in HHRA? (Reason)
				Shallow Aquifer (ng/L)	Deep Aquifer (ng/L)		
Hormones							
Androstenedione	63-05-8	Steroid hormone	No	---	---	---	No (Not detected in groundwater)
Estradiol, 17beta-	50-28-2	Estrogenic hormone	No	---	---	---	No (Not detected in groundwater)
Estriol	50-27-1	Estrogenic hormone	No	---	---	---	No (Not detected in groundwater)
Estrone	53-16-7	Estrogenic hormone	No	---	---	---	No (Not detected in groundwater)
Ethinyl estradiol, 17alpha-	57-63-6	Estrogenic hormone	No	---	---	---	No (Not detected in groundwater)
Norethisterone	68-22-4	Steroid hormone	No	---	---	---	No (Not detected in groundwater)
Progesterone	57-83-0	Steroid hormone	No	---	---	---	No (Not detected in groundwater)
Testosterone	58-22-0	Steroid hormone	No	---	---	---	No (Not detected in groundwater)
PPCP Ingredients and Other Personal Products							
Acesulfame-K	55589-62-3	Sugar substitute	Yes	6,582	---	120,000	No (EPC < 10% DWEL)
Albuterol	18559-94-9	Anti-asthmatic	No	---	---	---	No (Not detected in groundwater)
Atenolol	29122-68-7	Beta blocker	No	---	---	---	No (Not detected in groundwater)
Carbamazepine	**298-46-4**	**Antiseizure**	**Yes**	**280.34**	**---**	**330**	**Yes (EPC ≥ 10% of DWEL)**
Chloramphenicol	56-75-7	Antibiotic	No	---	---	---	No (Not detected in groundwater)
Cotinine	486-56-6	Nicotine degradate	No	---	---	---	No (Not detected in groundwater)
Diazepam	439-14-5	Antianxiety	No	---	---	---	No (Not detected in groundwater)

Chemical	CAS Number	Category or Pharmaceutical Class	Detected in Downgradient Groundwater?	Maximum Modeled EPC in Groundwater		DWEL (ng/L)	Retained in HHRA? (Reason)
				Shallow Aquifer (ng/L)	Deep Aquifer (ng/L)		
Diclofenac	15307-86-5	Anti-inflammatory	No	---	---	---	No (Not detected in groundwater)
Dilantin	57-41-0	Antiseizure	No	---	---	---	No (Not detected in groundwater)
Fluoxetine	54910-89-3	Antidepressant	No	---	---	---	No (Not detected in groundwater)
Gemfibrozil	25812-30-0	Antilipidemic	No	---	---	---	No (Not detected in groundwater)
Lopressor	51384-51-1	Beta Blocker	No	---	---	---	No (Not detected in groundwater)
Primidone	**125-33-7**	**Anti-convulsant**	**Yes**	**177.99**	**---**	**410**	**Yes (EPC ≥ 10% of DWEL)**
Sucralose	56038-13-2	Sugar substitute	Yes	45,888.30	---	1,500,000	No (EPC < 10% DWEL)
Sulfamethoxazole	723-46-6	Sulfa antibiotic	Yes	145.60	144.14	5,300	No (EPC < 10% DWEL)
Theophylline	58-55-9	Anti-asthmatic	No	---	---	---	No (Not detected in groundwater)
Industrial Chemicals and Pesticides							
1,4-Dioxane	**123-91-1**	**Industrial chemical**	**Yes**	**544.23**	**---**	**370**	**Yes (EPC ≥ 10% of DWEL)**
4-Nonylphenol	104-40-5	Surfactant	Yes	1,221.00	1,208.79	20,000	No (EPC < 10% DWEL)
N-Nitroso dimethylamine (NDMA)	**62-75-9**	**Industrial solvent**	**Yes**	**3.28**	**3.25**	**0.86**	**Yes (EPC ≥ 10% of DWEL)**
Quinoline	**91-22-5**	**Industrial chemical**	**Yes**	**9.75**	**---**	**3.3**	**Yes (EPC ≥ 10% of DWEL)**
Thiabendazole	148-79-8	Fungicide	No	---	---	---	No (Not detected in groundwater)
Tris(2-carboxyethyl)phosphine (TCEP)	115-96-8	Flame retardant	Yes	4.41	---	500	No (EPC < 10% DWEL)
Tris(1,3dichloroisopropyl)-phosphate (TDCPP)	13674-87-8	Flame retardant	No	---	---	---	No (Not detected in groundwater)
Polyfluoroalkyl substances (PFAS)							
Perfluoro butanoic acid (PFBA)	375-22-4	PFAS	No	---	---	---	No (Not detected in groundwater)

Chemical	CAS Number	Category or Pharmaceutical Class	Detected in Downgradient Groundwater?	Maximum Modeled EPC in Groundwater		DWEL (ng/L)	Retained in HHRA? (Reason)
				Shallow Aquifer (ng/L)	Deep Aquifer (ng/L)		
Perfluoro octanesulfonate (PFOS)	45298-90-6	PFAS	No	---	---	---	No (Not detected in groundwater)
Perfluoro octanesulfonic acid	1763-23-1	PFAS	No	---	---	---	No (Not detected in groundwater)
Perfluoro octanoic acid (PFOA)	**15899-31-7**	**PFAS**	**Yes**	**14.90**	**14.75**	**10†**	**Yes (EPC ≥ 10% of DWEL)**
Perfluoro-1-butanesulfonate (PFBuS)	194999-85-4	PFAS	Yes	8.94	8.85	860†	No (EPC <10% DWEL)
Perfluoro-1-butanesulfonic acid	375-73-5	PFAS	Yes	8.76	8.67	860†	No (EPC <10% DWEL)
Perfluoro-1-hexanesulfonate (PFHxS)	108427-53-8	PFAS	No	---	---	---	No (Not detected in groundwater)
Perfluoro-1-hexanesulfonic acid	355-46-4	PFAS	No	---	---	---	No (Not detected in groundwater)
Perfluoro-n-decanoic acid (PFDeA)	335-76-2	PFAS	No	---	---	---	No (Not detected in groundwater)
Perfluoro-n-heptanoic acid (PFHpA)	375-85-9	PFAS	No	---	---	---	No (Not detected in groundwater)
Perfluoro-n-hexanoic acid (PFHxA)	**307-24-4**	**PFAS**	**Yes**	**45.80**	**45.34**	**93†**	**Yes (EPC ≥ 10% of DWEL)**
Perfluoro-n-nonanoic acid (PFNA)	375-95-1	PFAS	No	---	---	---	No (Not detected in groundwater)
Perfluoropentanoic acid (PFPeA)	**2706-90-3**	**PFAS**	**Yes**	**79.26**	**78.47**	**93†**	**Yes (EPC ≥ 10% of DWEL)**

DWEL – Drinking Water Equivalent Level (established in Screening-Level Evaluation); EPC – Exposure point concentration; HBV – Health Based Value; PFAS – Polyfluoroalkyl substance; PPCP – Pharmaceutical or personal care product ingredient; PPRTV – Provisional Peer Reviewed Toxicity Value; SAL – State Action Level

*Chemicals retained for further evaluation in the HHRA are indicated in bold type

†DWELs for several PFAS are updated from those presented in the Screening-Level Assessment (Intertox, 2021) to reflect newly published values, as follows— PFOA: Previous value = 35 ng/L based on Minnesota Health Based Value (HBV; MDH, 2020a), current value = 10 ng/L based on Washington State Draft SAL (WDOH, 2019); PFBuS: Previous value = 2,000 ng/L based on Minnesota HBV (MDH, 2020a), current value = 860 ng/L based on Washington State Draft SAL (WDOH, 2019); Perfluoro-1-butanesulfonic acid: Previous value = 200,000 ng/L, based on previous U.S. EPA Provisional Peer Reviewed Toxicity Value (PPRTV; U.S. EPA, 2014), current value = 860 ng/L based on Washington State Draft SAL (WDOH, 2019) and current U.S. EPA PPRTV (U.S. EPA, 2021c); PFHxA and PFPeA: Previous values = 70 ng/L (based on Health Advisory for PFOA and PFOS, U.S. EPA, 2016a), current values = 93 ng/L based on Texas Screening PCLs (TCEQ, 2021)

3.0 EXPOSURE ASSESSMENT

The goal of the Exposure Assessment is to identify and characterize the scenarios and populations for which exposures to residual chemicals in reclaimed water will be evaluated in the HHRA and to develop chemical-specific estimates of average daily exposure levels (i.e., doses) for each based on estimated EPCs. For each selected chemical, scenario, and population, a dose was estimated in the HHRA using U.S. EPA recommended methodologies and pathway-specific equations, in a manner consistent with guidance documents listed in Section 1.2. Exposure scenarios and populations were selected to reflect a range of potential exposures that could occur.

The scenarios, populations, and pathways evaluated in the HHRA and the EPCs and exposure parameters applied to derive quantitative estimates of average daily doses are described below. A conceptual site model showing the sources, exposure media, scenarios/ populations, and exposure pathways evaluated in the HHRA is presented in Figure 3-1.

3.1 Exposure Scenarios and Populations

The HHRA focuses on characterizing potential exposures to hypothetical future populations that could be exposed to residual chemicals that are transported downgradient of the recharge basins, through the shallow or deep aquifers or to Woodland Creek or McAllister Creek, and are present at points of exposure. Several scenarios and populations were selected to represent a range of potential exposures. The scenarios and populations evaluated in the HHRA are:

- **Residents (child and adult)** exposed directly to potable water from domestic water supply wells via ingestion and dermal contact, and that could be exposed via inhalation of volatiles from the water into the domestic living space. For these populations, both a reasonable maximum exposure (RME) (defined as an upper bound estimate of exposure to a resident that could reasonably be expected to occur via a given exposure pathway) and a more likely exposure (MLE) (defined as an estimate of an "average" level of exposure to a resident that could reasonably be expected to occur via a given exposure pathway) are evaluated.
- **Maintenance/landscape workers (adult)** exposed to tap or well water via direct ingestion and dermal contact (e.g., while irrigating at a park or golf course).
- **Recreators (child)** exposed to tap or well water at a recreational water feature through dermal contact and incidental ingestion as well as through direct ingestion of tap water while engaged in play, e.g., at a playground or ball field.
- **Recreators (child and adult)** exposed to surface water in Woodland Creek or McAllister Creek through dermal contact and incidental ingestion during playing, fishing, wading, or swimming.
- **Fish consumers (child and adult)** who eat fish caught in Woodland Creek or McAllister Creek that took up residual chemicals that are assumed to have migrated through the shallow or deep aquifers to creek water.

3.2 Exposure Pathways

An exposure pathway describes the course a chemical takes from a source to an exposed individual. In order for an exposure pathway to be complete, it must have four elements (U.S. EPA, 1989):

- A source and mechanism of chemical release,
- A retention or transport medium,
- A point of potential human contact with the contaminated medium, and

- An exposure route (e.g., ingestion) at the contact point.

Based on these elements, the following exposure pathways to residual chemicals potentially present in downgradient groundwater or surface water were identified as potentially complete for one or more of the populations and scenarios of interest, and were evaluated in the HHRA:

- Ingestion (direct or incidental) of tap or well water
- Dermal contact with tap or well water during bathing or washing in the home or during work or recreational activities
- Inhalation of chemicals from tap or well water that volatilize into a home living space during bathing, showering, washing, or other activities
- Dermal contact with surface water (i.e., in creeks) during recreational activities (e.g., playing, wading, swimming, or fishing in the creeks)
- Incidental ingestion of surface water (i.e., in creeks) during recreational activities
- Consumption of fish caught from creeks

While inhalation of chemicals that volatilize from water into an airspace was considered to be a potentially complete exposure pathway, this pathway was only considered for the resident exposure scenario because this is the only scenario where chemicals could theoretically volatilize into an enclosed airspace throughout the day and persons could be exposed to the airborne chemicals for a sustained period. It is assumed that for all of the other exposure scenarios, potential exposures via this pathway would be much lower and, compared to the other exposure pathways evaluated for the scenarios, would not contribute significantly to total exposures and risk.

3.3 Quantification of Exposure

The exposure equations, EPCs, and exposure parameters used to quantify doses are described below.

3.3.1 *Exposure Equations*

In the HHRA, exposure is quantified as an estimated intake (dose) averaged over time (annually for noncarcinogenic compounds and over a lifetime for carcinogens). The equations used to quantify dose for each exposure pathway are provided below. The EPCs used to quantify dose are described in Section 3.3.2 and the values applied for each exposure parameter are described in Section 3.3.3 and summarized in Appendix B.

3.3.1.1 Ingestion of Tap or Well Water (as drinking water, by Child or Adult Resident, Adult Maintenance Worker, or Child Recreator)

$$Dose_{ing-ww}\ (mg/kg-d) = \frac{C_{ww} \times CF \times IR_{water} \times FI \times EF \times ED}{BW \times AT}$$

Where:

$Dose_{ing\text{-}ww}$	=	Average daily dose (ADD) for noncarcinogens or lifetime average daily dose (LADD) for carcinogens, from direct ingestion of tap or well water as drinking water by a child or adult resident, adult maintenance worker, or child recreator, mg/kg-d
C_{ww}	=	EPC of chemical in tap or well water, ng/L
CF	=	Conversion factor, mg/ng (10^{-6} mg/ng)

IR_{water}	=	Water ingestion rate, L/d
FI	=	Fraction ingested from contaminated source, unitless
EF	=	Exposure frequency, d/yr
ED	=	Exposure duration, yr
BW	=	Body weight, kg
AT	=	Averaging time, d (equal to ED × 365 d/yr for noncarcinogens and 70 years × 365 d/yr for carcinogens)

3.3.1.2 Incidental Ingestion of Well Water (Child Recreator at a Water Feature)

$$Dose_{inc\ ing-ww}\ (mg/kg-d) = \frac{C_{ww} \times CF \times IR_{inc-water} \times t_{event} \times EV \times FI \times EF \times ED}{BW \times AT}$$

Where:

$Dose_{inc\ ing-ww}$	=	Average daily dose (ADD) for noncarcinogens or lifetime average daily dose (LADD) for carcinogens, from incidental ingestion of tap or well water by a child recreator at a water feature, mg/kg-d
C_{ww}	=	EPC of chemical in tap or well water, ng/L
CF	=	Conversion factor, mg/ng (10^{-6} mg/ng)
$IR_{inc-water}$	=	Incidental water ingestion rate while recreating, L/h
t_{event}	=	Event duration, h/event
EV	=	Event frequency, event/d
FI	=	Fraction ingested from contaminated source, unitless
EF	=	Exposure frequency, d/yr
ED	=	Exposure duration, yr
BW	=	Body weight, kg
AT	=	Averaging time, d (equal to ED × 365 d/yr for noncarcinogens and 70 years × 365 d/yr for carcinogens)

3.3.1.3 Dermal Contact with Tap or Well Water (during bathing by Child or Adult Resident, as incidental contact by Adult Maintenance Worker, or while playing by Child Recreator at Water Feature)

$$Dose_{derm-ww}\ (mg/kg-d) = \frac{DA_{event} \times SA_{water} \times EV \times EF \times ED}{BW \times AT}$$

and:

$$DA_{event}\ (mg/cm^2-event) = 2 \times C_{ww} \times CF_1 \times K_p \times CF_2 \times \sqrt{\frac{6 \times \tau_{event} \times t_{event}}{\pi}}$$

Where:

$Dose_{derm-ww}$	=	Average daily dose (ADD) for noncarcinogens or lifetime average daily dose (LADD) for carcinogens, from dermal contact with tap or well water by a child or adult resident while bathing, or by an adult maintenance

		worker as incidental contact while working, or by a child recreator while playing at a water feature, mg/kg-d
DA_{event}	=	Dermally absorbed dose per event, mg/cm^2-event
SA_{water}	=	Skin surface area available for contact with tap or well water, cm^2
EV	=	Event frequency, event/d
EF	=	Exposure frequency, d/yr
ED	=	Exposure duration, yr
BW	=	Body weight, kg
AT	=	Averaging time, d (equal to ED × 365 d/yr for noncarcinogens and 70 years × 365 d/yr for carcinogens)
C_{ww}	=	EPC of chemical in tap or well water, ng/L
CF_1	=	Conversion factor, mg/ng (10^{-6} mg/ng)
K_p	=	Chemical-specific dermal permeability constant, cm/h
CF_2	=	Conversion factor, L/cm^3
τ_{event}	=	Lag time per event, h/event
t_{event}	=	Event duration, h/event

Consistent with U.S. EPA (2004), DA_{event} is estimated as the total dose in the stratum corneum of the skin that is available for absorption after exposure on the skin surface has ended, and lag time (τ_{event}) is a chemical-specific value that describes the time it takes for the chemical to penetrate through skin (see Section 3.3.3.6).

3.3.1.4 Inhalation of Volatiles Originating from the Household Water Supply (i.e., Tap or Well Water) (by Child or Adult Resident)

$$Dose_{inh-ww}\ (mg/kg-d) = \frac{C_{ww} \times CF \times K \times InhR \times EF \times ED}{BW \times AT}$$

Where:

$Dose_{inh\text{-}ww}$	=	Average daily dose (ADD) for noncarcinogens or lifetime average air concentration for carcinogens from inhalation of volatiles from tap or well water in the home by a child or adult resident, mg/kg-d
C_{ww}	=	EPC of chemical in tap or well water, ng/L
CF	=	Conversion factor, mg/ng (10^{-6} mg/ng)
K	=	Andelman volatilization factor for chemical pollutants, L/m^3 (equal to 0.5 L/m^3)
$InhR$	=	Indoor inhalation rate, m^3/d
EF	=	Exposure frequency, d/yr
ED	=	Exposure duration, yr
BW	=	Body weight, kg
AT	=	Averaging time, d (equal to ED × 365 d/yr for noncarcinogens and 70 years × 365 d/yr for carcinogens)

The Andelman volatilization factor (K) is a default upper bound estimate of the rate at which a chemical could volatilize from tap water into household air. The value, 0.5 L/m^3, is based on work by Andelman (1990; as cited in U.S. EPA, 1991a), who derived an equation to characterize the relationship between the concentration of a chemical in household water and the average

concentration of the volatilized chemical in air (U.S. EPA, 1991a). All uses of household water were considered (e.g., showering, laundering, dish washing) and it was assumed that the volume of water used in a residence for a family of four is 720 L/day, the volume of the dwelling is 150,000 L (5297.2 ft^3, which corresponds to a 662 ft^2 home with an 8 ft ceiling height; a smaller volume is more conservative as it results in an assumed higher air concentration), and the air exchange rate in the home is 0.25 m^3/h. In addition, the average transfer efficiency weighted by water use was assumed to be 50% (i.e., half of the concentration of each chemical in water is assumed to be transferred into air by all water uses; the estimated range is from 30% for toilets to 90% for dishwashers).

However, consistent with U.S. EPA risk assessment guidance for screening level assessment of chemicals in groundwater or surface water, inhalation of volatiles from the household water supply (e.g., originating during dish washing, cloth washing, and showering or bathing) may be a potentially relevant pathway only for chemicals that easily volatilize (U.S. EPA, 1991a; U.S. EPA, 2015). Per U.S. EPA (1991a; 2015), inhalation of volatile chemicals from water is considered routinely only for chemicals with a molecular weight of less than 200 g/mol and a Henry's Law constant of 1×10^{-5} atm-m^3/mol or greater. Of the COIs included in this assessment, none meet these criteria and so none are predicted to be sufficiently volatile to partition significantly into household air.

Specifically, of the eight COIs, only three have molecular weights less than 200 g/mol (1,4-dioxane = 88.11 g/mol; NDMA = 74.08 g/mol; quinoline = 129.16 g/mol; See Table A-1, Appendix A), and of these three chemicals, all have Henry's Law constants less than 1×10^{-5} atm-m^3/mol (1,4-dioxane = 4.8×10^{-6} atm-m^3/mol; NDMA = 2.6×10^{-7} to 5.3×10^{-7} atm-m^3/mol; quinoline = 2.5×10^{-7} to 8.7×10^{-6} atm-m^3/mol; see Table A-1, Appendix A). Henry's Law constants for the other five COIs (carbamazepine, primidone, PFOA, PFHxA, PFPeA) are all within the range of approximately 2×10^{-10} to 4×10^{-10} atm-m^3/mol indicating a very low potential to volatilize (Table A-1, Appendix A).

Because none of the COIs are predicted to be sufficiently volatile to partition significantly into household air, this pathway was not evaluated for any of the COIs included in this assessment.

3.3.1.5 Incidental Ingestion of Surface Water (by Child or Adult Creek Recreator)

$$Dose_{ing-sw}\ (mg/kg-d) = \frac{C_{sw} \times CF \times IR_{inc-sw} \times t_{event} \times FI \times EF \times ED}{BW \times AT}$$

Where:

$Dose_{ing-sw}$	=	Average daily dose (ADD) for noncarcinogens or lifetime average daily dose (LADD) for carcinogens, from incidental ingestion of surface water by a child or adult creek recreator, mg/kg-d
C_{sw}	=	EPC of chemical in surface (creek) water, ng/L
CF	=	Conversion factor, mg/ng (10^{-6} mg/ng)
IR_{inc-sw}	=	Incidental water ingestion rate while recreating, L/h
t_{event}	=	Event duration, h/event
FI	=	Fraction ingested from contaminated source, unitless
EF	=	Exposure frequency, d/yr
ED	=	Exposure duration, yr
BW	=	Body weight, kg
AT	=	Averaging time, d (equal to ED × 365 d/yr for noncarcinogens and 70 years × 365 d/yr for carcinogens)

3.3.1.6 Incidental Dermal Contact with Surface Water (by Child or Adult Creek Recreator)

$$Dose_{derm-sw}\ (mg/kg-d) = \frac{DA_{event} \times SA_{water} \times EV \times EF \times ED}{BW \times AT}$$

and:

$$DA_{event}\ (mg/cm^2-event) = 2 \times C_{sw} \times CF_1 \times K_p \times CF_2 \times \sqrt{\frac{6 \times \tau_{event} \times t_{event}}{\pi}}$$

Where:

$Dose_{derm-sw}$	=	Average daily dose (ADD) for noncarcinogens or lifetime average daily dose (LADD) for carcinogens, from incidental dermal contact with surface water by a child or adult creek recreator, mg/kg-d
DA_{event}	=	Dermally absorbed dose per event, mg/cm^2-event
SA_{water}	=	Skin surface area available for incidental contact with surface water, cm^2
EV	=	Event frequency, event/d
EF	=	Exposure frequency, d/yr
ED	=	Exposure duration, yr
BW	=	Body weight, kg
AT	=	Averaging time, d (equal to ED × 365 d/yr for noncarcinogens and 70 years × 365 d/yr for carcinogens)
C_{sw}	=	EPC of chemical in surface water, ng/L
CF_1	=	Conversion factor, mg/ng (10^{-6} mg/ng)
K_p	=	Chemical-specific dermal permeability constant, cm/h
CF_2	=	Conversion factor, L/cm^3 (0.001 L/cm^3)
τ_{event}	=	Lag time per event, h/event (chemical-specific)
t_{event}	=	Event duration, h/event

3.3.1.7 Consumption of Fish Caught in Creek (Child or Adult Fish Consumer)

$$Dose_{fish}\ (mg/kg-d) = \frac{C_{sw} \times CF_1 \times BCF \times IR_{fish} \times FI \times CF_2 \times EF \times ED}{BW \times AT}$$

Where:

$Dose_{fish}$	=	Average daily dose (ADD) for noncarcinogens or lifetime average daily dose (LADD) for carcinogens from consumption of fish from Woodland Creek or McAllister Creek by a child or adult, mg/kg-d
C_{sw}	=	EPC of chemical in surface water, ng/L
CF_1	=	Conversion factor, mg/ng (10^{-6} mg/ng)
BCF	=	Chemical-specific bioconcentration factor from water into fish, L/kg
IR_{fish}	=	Fish ingestion rate, g/d
FI	=	Fraction ingested from a contaminated source, unitless
CF_2	=	Conversion factor, kg/g (10^{-3} kg/g)
EF	=	Exposure frequency, d/yr
ED	=	Exposure duration, yr

BW = Body weight, kg
AT = Averaging time, d (equal to ED × 365 d/yr for noncarcinogens and 70 years × 365 d/yr for carcinogens)

3.3.2 *Exposure Point Concentrations (EPCs)*

For purposes of this HHRA, potential exposures to COIs by each population and scenario via the above exposure pathways were quantified using EPCs estimated for groundwater from the shallow and deep aquifers or for surface water in the creeks, as determined by fate and transport modeling conducted by HDR (2021). For exposure to tap or well water, the assumed EPC was the maximum-estimated concentration in each aquifer, and for exposure to surface water, the EPC was based on an estimated concentration at aquifer drain points to either Woodland Creek or McAllister Creek and the assumed dilution by flow within the creek.

HDR (2021) estimated concentrations of each COI in groundwater in both the shallow and deep aquifers for concentric circles at 200, 1,000, 2,000, 4,000, 6,000, and 8,000 feet downgradient of the infiltration basins over a 100-year simulation, assuming implementation of no additional treatment options. Concentrations were also estimated at model-defined drain points (locations where water is removed from the aquifer into creeks) at Eagle Creek (a tributary of Woodland Creek) to the west and McAllister Creek to the east.

As described in HDR (2021), groundwater concentrations for a given chemical at a given point were estimated using the following formula:

$$Conc_{gw} = \left(C_{ochem} \times \frac{C}{C_o}\right) \times (1 - (AF \times T_{loc}))$$

Where:

$Conc_{gw}$ = Concentration in groundwater in the shallow or deep aquifer or at the drain point into Woodland Creek or McAllister Creek, ng/L

C_{ochem} = Concentration of the residual chemical in reclaimed water based on the 95% UCL of the arithmetic mean reclaimed water concentration where data were sufficient for such a calculation, or the maximum detected concentration if data were not sufficient to calculate the UCL, ng/L

C/C_o = Model-predicted maximum C/C_0 at the exposure point, (ng/L)/(ng/L)

AF = Calculated attenuation factor, d^{-1}

T_{loc} = Model-predicted travel time to the exposure point, d

Maximum-estimated EPCs within each of the concentric circles and at the drain points to the creeks, and the year at which the maximum concentration is predicted to occur, based on fate and transport modeling for the shallow and deep aquifers are summarized in Table 3-1. The maximum-estimated concentration points were based on the entire 100-year model simulation.

Overall, in all cases, the highest estimated concentration in each aquifer was at a location 200 feet downgradient from the source and, for most chemicals, concentrations are predicted to continue to decrease further downgradient. While no domestic or municipal water supply wells are currently located as close as 200 feet to the infiltration basins, it is assumed that 200 feet represents the minimum buffer potentially required in future permitting to install a new groundwater supply well in

proximity to an infiltration basin. Use of concentrations corresponding to the 200 feet downgradient location as EPCs for groundwater is assumed to provide for a conservative (health-protective) estimate of potential risk to future downgradient populations.

With regard to EPCs for the creeks, it is assumed that concentrations estimated at points of entry into each creek will be diluted and reduced by mixing with existing flow within each creek. To estimate the effect of dilution on concentrations of COIs in the creeks, at each cell location (where a constant head or drain cell representing either Woodland Creek, McAllister Creek, or the springs along McAllister Creek is predicted to occur), the mass output calculated in the fate and transport model simulation based on an assumed unit concentration (1 ng/L) starting reclaimed water concentration was summed for each timestep. The summed masses were then compiled into a total mass by year at each surface water location. The maximum annualized unit concentration-based masses for Woodland Creek (0.0020 mg/d) and McAllister Creek plus springs (0.0096 mg/d) were then divided by the assumed flow rate in the corresponding creek (0.2 ft^3/s for Woodland Creek and 48 ft^3/s for McAllister Creek (see Windward, 2022 based on HDR, 2017b and WDOE, 2005)), to derive dilution-adjusted estimated creek concentrations associated with a unit reclaimed water concentration.

For Woodland Creek (WC) and McAllister Creek (MC), unit concentration-based dilution-adjusted concentration estimates were calculated as follows:

$$Conc_{WC-unit} = \frac{Max\ annualized\ mass\ \left(0.0020\frac{mg}{d}\right)}{Flow\ \left(0.2\frac{ft^3}{s}\right)} \times \frac{d}{86{,}400\ s} \times \frac{ft^3}{28.3168\ L} \times \frac{1{,}000{,}000\ ng}{mg}$$

$$= 0.004087\ ng/L$$

$$Conc_{MC-unit} = \frac{Max\ annualized\ mass\ \left(0.0096\frac{mg}{d}\right)}{Flow\ \left(48\frac{ft^3}{s}\right)} \times \frac{d}{86{,}400\ s} \times \frac{ft^3}{28.3168\ L} \times \frac{1{,}000{,}000\ ng}{mg}$$

$$= 0.00008175\ ng/L$$

These estimated per-unit reclaimed water concentration-based values were then multiplied by the assumed reclaimed water concentration of each COI to estimate in-creek surface water EPCs. However, if fate and transport modeling predicted that the concentration at the model-defined drain points into Woodland Creek or McAllister Creek is zero (0), then the dilution-adjusted in-creek concentration was assumed to be 0. Dilution-adjusted EPCs for the creeks are presented in Table 3-2.

In addition, HDR (email communication from HDR project manager, August 9, 2021) also modeled the effect of two possible treatment options on downgradient concentrations of the COIs. These two options are reverse osmosis-advanced oxidation process (RO-AOP; Option 1) and ozone-biological activated carbon-granular activated carbon (O3-BAC-GAC; Option 2). Estimated downgradient EPCs for these two scenarios are presented in Tables 3-3 and 3-4, respectively. Dilution-adjusted concentrations in the creeks corresponding to these two treatment options are included in Table 3-2—since concentrations in each creek are based on a maximum annualized mass into the creek corresponding to a unit starting concentration (which is the same regardless of chemical) that is then multiplied by a chemical-specific reclaimed water concentration, estimated concentrations in the creek are the same regardless of treatment scenario.

As shown, relative to the baseline scenario, both possible treatment options resulted in predicted reductions in EPCs, with Treatment Option 1 reducing 1,4-dioxane concentrations by approximately 3-fold and the other COIs by greater amounts including reduction to zero (0) for the PFAS and quinoline, and Treatment Option 2 having little effect on quinoline concentrations but reducing 1,4-dioxane concentrations by about 2-fold and other COIs by greater amounts (although not to 0). Noncancer hazards and cancer risks estimated using the EPCs predicted for these possible treatment options are discussed in Section 5.2.2.

Noncancer hazards and cancer risks associated with potential exposures to EPCs predicted for the baseline treatment scenario are calculated and described in Section 5.0. Potential noncancer hazards and cancer risks associated with the EPCs predicted for the other possible treatment scenarios are described in Section 5.2.2.

3.3.3 *Exposure Parameters*

As shown in the equations in Section 3.3.1, quantification of exposure requires information on the behavioral characteristics of the populations of interest (e.g., how frequently the population engages in an activity, how much is taken in, and how many years the population is exposed) as well as information on physiological characteristics such as body weight and exposed skin surface area.

In the absence of robust site-specific information describing population characteristics, for most exposure parameters considered in this assessment, characteristics considered descriptive of U.S. populations (e.g., as presented in U.S. EPA's *Exposure Factors Handbook* or *Child-Specific Exposure Factors Handbook*; U.S. EPA, 2008; U.S. EPA, 2011) or U.S. EPA standardized default exposure parameters for characterizing average or reasonable maximum exposures (U.S. EPA, 2021d) were used. As appropriate, locally relevant information and/or professional judgment was applied for some parameters, such as assumptions about frequency and duration of outdoor exposure during different seasons.

Consistent with U.S. EPA guidance, for the RME resident scenario, exposure parameters were selected to represent reasonable upper bound estimates of exposure (U.S. EPA, 1989). For the MLE resident scenario, exposure parameters were based on estimates of exposure more reflective of the population average or a central estimate.

In order to ensure that risk estimates account for potential hazards to sensitive subgroups (e.g., pregnant women, immunodeficient persons, the elderly), the HHRA uses toxicity criteria that incorporate safety or modifying factors intended to provide an additional level of conservatism to protect these individuals, per U.S. EPA guidelines (see Section 4.0).

Exposure parameters for the populations of interest for each scenario are summarized in Appendix B. Considerations for selection of specific exposure parameters are discussed below.

3.3.3.1 Exposure Durations

For most scenarios, assumed exposure durations (ED) are consistent with recommendations from U.S. EPA for current residence time, that is, the length of time a household (as opposed to individual persons in a household) has been in their current residence. This estimate is typically used as a surrogate for total residence time in a home. Per U.S. EPA (2011), using data from the U.S. Census Bureau (2008, *American Housing Survey for the United States: 2007*, as cited in U.S. EPA, 2011), the 50th and 90th percentiles for current residence time of households in the U.S. are 8 years and 32 years, respectively, with mean and 95th percentile residence times in the U.S. of 13 years and 46 years, respectively.

Consistent with the 90th percentile current residence time value, U.S. EPA (2021d) Regional Screening Levels (RSLs) apply an upper bound estimate for residential exposure duration of 6 years for a child and 26 years for an adult (32 years total)—these values were applied for the child and adult RME resident scenario (6 years for a child and 26 years for adult) as well as the child water feature/playfield recreator scenario (6 years). RSLs are screening-level calculations used to estimate "acceptable" exposure levels of chemicals in different media corresponding to different exposure assumptions, and were developed by U.S. EPA to assist risk assessors, remedial project managers, and others involved with risk assessment and decision-making at Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) (i.e., Superfund) sites. In general, the RSLs incorporate exposure factors that, when combined, result in estimates of exposure assumed to represent RME conditions.

For the child and adult MLE resident scenarios, values for ED were set to correspond to the mean U.S. current residence time (13 years) distributed across the child and adult scenarios (specifically, assuming 5 years as a child and 8 years as an adult).

For the creek recreator/fish consumer scenarios, values for ED were set based on the 95th percentile U.S. current residence time (46 years) distributed across the child and adult scenarios (specifically, assuming 12 years as a child and 34 years as an adult).

For the adult maintenance worker scenario, an ED of 25 years was applied, consistent with the recommended upper bound exposure duration applied in U.S. EPA's RSL calculations for an outdoor worker (U.S. EPA, 2021d). While statistical data on the distribution of duration of job tenure in the U.S. were not located, per U.S. EPA (2011), the median tenure in an occupation (as contrasted to the shorter term tenure in a specific job within an occupation) varies between men and women, with values that increase with age (e.g., at age 50, the median occupational tenure is 20.0 years for men and 10.8 years for women, and at age 65 it is 26.9 years for men and 15.6 years for women). Thus, an assumed exposure duration of 25 years somewhat exceeds the median lifetime occupational exposure duration for men and likely overestimates tenure for a particular job.

3.3.3.2 Residential Activity Patterns and Intake or Exposure Rates

For the RME resident exposure scenarios (both adult and child), an exposure frequency (EF) to water via ingestion or dermal contact of 350 days per year is assumed, consistent with the recommended upper bound value applied in U.S. EPA's RSL calculations for a resident (U.S. EPA, 2021d). This value assumes a person spends 15 days per year away from their place of residence (e.g., on vacation, traveling for work, etc.). For the MLE resident scenarios, an EF of 234 days per year is assumed, equal to the average fraction of time a person annually spent at home (64% of the year; U.S. EPA, 1993a).

For the RME resident scenarios, tap water ingestion rates (IR_{water}) of 0.985 L/d for a child and 2.645 L/d for an adult are assumed, equal to the 90th percentile consumers only combined direct and indirect water ingestion rates for "community water" for a child age 2 to <16 years and an adult age 16 to <70 years, per the National Health and Nutrition Examination Survey (NHANES) 2005−2010 (U.S. EPA, 2019a). These rates are slightly above the recommended default values applied in U.S. EPA's RSL calculations for a resident (0.78 L/d for a child and 2.5 L/d for an adult; U.S. EPA, 2021d), but are assumed to represent reasonable upper bound tap water ingestion rates for residents.

For the MLE resident scenarios, tap water ingestion rates (IR_{water}) of 0.458 L/d for a child and 1.269 L/d for an adult are assumed, equal to the mean consumers only combined direct and indirect water

ingestion rates for "community water" for a child age 2 to <16 years and an adult age 16 to <70 years, respectively, per NHANES 2005−2010 (U.S. EPA, 2019a).

For the RME resident scenarios, skin surface areas available for tap water contact during showering or bathing (SA_{water}) of 11,484 cm^2 for a child and 18,090 cm^2 for an adult were assumed. These values are based on age-weighted 90th percentile whole body surface areas for a child (age 3 to <16 years) and an adult (age 16 to 49) of 14,700 cm^2 and 23,200 cm^2, respectively (U.S. EPA, 2011) combined with average values for total body surface area corresponding to specific body parts for children and adults (U.S. EPA, 2008; U.S. EPA, 2011) and the assumption that for 75% of the time spent bathing, the whole body is exposed and for 25% of the time, only the hands and lower arms are exposed. For the MLE resident scenario, mean whole body surface areas were applied (U.S. EPA, 2011) but other assumptions remained the same. The resulting skin surface area values applied for the MLE resident scenario were 9,363 cm^2 for a child and 10,968 cm^2 for an adult.

For both the resident RME and MLE resident scenarios, event durations for dermal exposure to tap or well water (t_{event}) of 0.54 h/event for the child and 0.71 h/event for the adult were assumed (assuming one event per day, i.e., that these values reflect total time showering or bathing per day), based on default U.S. EPA RSL calculation parameters for the resident dermal contact with tap water scenario (U.S. EPA, 2021d). Note that U.S. EPA's *Exposure Factors Handbook* (U.S. EPA, 2011) presents median values for duration of a bath by a child (age 2 to 16) ranging from 20 to 25 minutes (0.33 to 0.42 h/event) and 90th percentile values ranging from 30 to 40 minutes (0.50 to 0.67 h/event), depending on age, with no estimate of average numbers of events per day. These values bracket the value used in the HHRA for the resident child scenarios, suggesting that the applied value is a reasonable central to upper bound estimate. For an adult, the estimated median time spent bathing or showering for an adult (age 18 to 64) is 17.1 minutes per day (0.29 h/d; U.S. EPA, 2011).

3.3.3.3 Adult Worker Activity Patterns and Intake or Exposure Rates

For the adult maintenance worker scenario, an exposure frequency (EF) of 225 days per year (equal to 4.5 days per week for 50 weeks per year) was assumed, equal to the recommended upper bound value applied in U.S. EPA's RSL calculations for an outdoor worker (U.S. EPA, 2021d). The daily exposure time for contact of water with skin (t_{event}) was assumed to be an annualized average of 1.5 h/d, based on an assumption of 2 h/d for one-half of the year and 1 h/d for one-half of the year, based on professional judgment.

For the adult maintenance worker scenario, the tap water ingestion rate (IR_{water}) was set equal to two-thirds of the daily water ingestion rate applied for the adult resident RME scenario (see Section 3.3.3.2; U.S. EPA, 2019a), or 1.763 L/d. Although it is likely that the length of a working day is less than half a day, a water ingestion rate equal to two-thirds of the daily ingestion rate is assumed to account for the possibility of relatively greater exertion by a worker during this period.

For the adult maintenance worker scenario, an annualized average exposed skin surface area for dermal contact with water (SA_{ww}) of 3,527 cm^2 was assumed, consistent with the recommended value applied in U.S. EPA's RSL calculations for dermal contact with water by an outdoor worker (U.S. EPA, 2021d). Note that this slightly exceeds the estimated mean surface area of the hands (1,070 cm^2) plus two-thirds of the arms (2/3 × 3,140 cm^2, or 2,093 cm^2) for an adult male, as presented in U.S. EPA (2011).

3.3.3.4 Recreational Activity Patterns and Intake or Exposure Rates

Frequency and duration of participation in recreational activities at water features and on playfields by a child or in or at the creeks by a child or adult were based on professional judgment, considering seasonal factors.

For the child water feature recreator scenario, the assumed exposure frequency (EF) for a child who plays in water at a water feature was assumed to be 3 days/week for 3 months/year (i.e., 39 days total during the summer) plus 2 days/month for 3 months per year (i.e., "shoulder" periods before or after summer), or a total of 45 days per year. The duration of exposure during each event (t_{event}) was assumed to be an average of 2 hours per event day, based on professional judgment.

For creek recreators, it was assumed that a person (child or adult) could come in contact with creek water (EF) for 4 days/month during the summer (3 months/year), 2 days/month during the spring and fall (6 months/year), and 1 day/month in the winter (3 months/year), or a total of 27 days per year. The event duration (t_{event}) was assumed to be an annualized average of 1.39 hour per event day for both the child and adult, based on an assumption of 2 hours per event day during the summer, 1 hour per event day during the spring and fall, and 0.5 hours per event day during the winter, based on professional judgment.

For the child playfield recreator scenario, a tap water ingestion rate (IR_{water}) equal to two-thirds of the daily ingestion rate for the child resident RME scenario (see Section 3.3.3.2; U.S. EPA, 2019a) was assumed, or 0.657 L/d. Although it is assumed that a child spends only a fraction of the day at the playfield, a higher fractional ingestion rate is assumed to account for the possibility of greater exertion during this period.

For the child water feature and creek recreator scenarios, an incidental water ingestion rate ($IR_{inc\text{-}water}$) of 0.12 L/h is assumed, based on the recommended value applied in U.S EPA's RSL calculations for recreator ingestion of surface water by a child (U.S. EPA, 2021d). Note that this value is equal to the 97th percentile incidental water ingestion rate while swimming in a pool for children, as reported by Dufour et al. (2006; as cited in U.S. EPA, 2011). For the adult creek recreator, an incidental water ingestion rate of 0.11 L/h is assumed, based on the recommended value applied in U.S EPA's RSL calculations for recreator ingestion of surface water by an adult (U.S. EPA, 2021d).

For dermal contact of a child with water at the recreational water feature, it was assumed that 50% (one-half) of exposures were to the whole body and 50% were only to the hands, feet, lower arms, and lower legs. The whole body surface area of a child was assumed to be 14,700 cm^2 based on the whole body surface area applied in the child resident RME scenario (U.S. EPA, 2011), and percentages of total body surface area for specific body parts were based on values presented in the *Child-Specific Exposure Factors Handbook* (U.S. EPA, 2008). The resulting annualized average surface area of skin exposed for a child (SA_{water}) was estimated to be 9,570 cm^2.

For child and adult recreators in the creeks, it was assumed that 25% of exposures were to the whole body (consistent with swimming), 25% were to the hands, lower arms, feet, and lower legs only, and 50% were to the hands and lower arms only. The whole body surface areas of a child and an adult were assumed to be 14,700 cm^2 and 23,200 cm^2, respectively, based on the whole body surface areas applied in the RME resident scenarios (U.S. EPA, 2011), and percentages of total body surface area for specific body parts for a child and adult were based on values presented in the *Child-Specific Exposure Factors Handbook* and *Exposure Factors Handbook*, respectively (U.S. EPA, 2008; U.S. EPA, 2011). The resulting values for annualized average surface area of skin exposed (SA_{water}) were estimated to be 5,633 cm^2 for the child and 9,080 cm^2 for the adult creek recreators.

3.3.3.5 Fish Consumption Rates

Fish consumption rates (IR_{fish}) for the fish consumption scenarios evaluated in the HHRA assume that the populations of interest catch fish from Woodland Creek or McAllister Creek and that they and/or their family members consume the caught fish.

Overall, it is assumed that the fish consumers evaluated in this assessment consume locally caught fish at a higher average rate than the general U.S. population. However, no data on consumption rates of fish from these creeks or similarly sized creeks in the Puget Sound or western Washington area were located. Therefore, for the fish consumer scenario evaluated in this HHRA, doses and risks were calculated using several different consumption values, including estimates based on a range of number of servings consumed per year (10, 25, or 50 servings/year) as well as values based on a survey of fish consumption rates by members of the Squaxin Tribe and published by Toy et al. (1996) and U.S. EPA (2013b).

The values considered are:

1. Estimates assuming consumption of 10, 25, and 50 servings of fish per year (at 7 ounces or 198 g/serving), by an adult or a child. These values correspond to fish consumption rates of 1,980, 4,950, or 9,900 g/year, respectively, or an average of 5.4, 13.6, or 27.1 g/d, respectively.
2. Estimates based on data gathered between February 25 and May 15, 1994 by Toy et al. (1996) in a survey of fish consumption patterns by members of the Squaxin Tribe, who locally caught and consumed fish (largely from the Puget Sound region). The fish consumption rate estimates were:
    a) A high end estimate of 330.5 g/d reported in U.S. EPA (2013b) and supported by the Squaxin Tribe (Whitener, 2018). This estimate is based on the 95th percentile "consumers-only" consumption rate of "total, all fish" (including finfish and shellfish, from all areas including from inside and outside the Puget Sound and purchased at grocery stores, restaurants, or elsewhere) by adults. This rate is equal to approximately 609 average-sized (7 ounce) servings per year. The same rate was applied to children.
    b) An estimate based on consumption rates of "other fish"—specifically, for adults, an estimate of 9.84 g/d, based on the 95th percentile per capita consumption rate of "other fish", which includes trout, but also canned tuna, for adults, or approximately 18 average-sized servings of fish per year, and for children, a value of 2.37 g/d, based on the 90th percentile per capita "total, all fish" consumption rate for children multiplied by the assumption that 5% of "all fish" is "other fish" (an "other fish" category was not reported for children, but for adults, "other fish" comprised 2% of all fish), or approximately 4.4 (adult-sized) servings of fish per year from the creeks.

Regarding values based on the fish consumption survey, Toy et al. (1996) describes the results of a survey of fish consumption patterns of members of the Squaxin Tribe based on interviews that were conducted at a central location on the Squaxin Reservation, at the south end of the Puget Sound. The target population surveyed consisted of enrolled tribal members 18 years of age and older and children under age 5 in the enrolled person's household, who lived on or within 50 miles of the reservation. Data were collected by in-person interview with reinterview of 10% of participants by phone. Collected information included species consumed, fish parts consumed, preparation methods, sources of fish, and children's consumption rates. Weight-adjusted consumption rates were calculated by age, gender, income, and species groups. Species groups [which included anadromous (including salmon, steelhead, and smelt), bottom (including halibut, sole/flounder, and sturgeon),

pelagic (including cod, pollock, sablefish, rockfish, greenling, herring, spiny, dogfish, and perch), and shellfish (including clams, shrimp, mussels, oysters, crab, scallops, and sea urchin)] were defined by life history and distribution in the water column. Consumption rates for an "other" category that consisted of trout and canned tuna were also recorded. Fish consumption rates for adults and children were calculated in terms of grams per kilogram body weight per day (g/kg-d).

For the Squaxin Tribe, Toy et al. (1996) reported an estimated 95th percentile "total fish" per capita (i.e., including both consumers and nonconsumers) consumption rate for adults (based on data collected from 117 individuals) of 3.016 g/kg-d. This included consumed fish and shellfish from any of the above noted species categories from any source, including caught in or outside of the Puget Sound region and purchased at grocery stores, restaurants, etc. The mean "total fish" consumption rate for adults was 0.891 g/kg-d. The estimated 95th percentile consumption rate for adults for finfish consumption only (excluding shellfish) was 2.538 g/kg-d.

In a reanalysis of the survey data to characterize consumption rates for consumers only, U.S. EPA (2013b) reported a 95th percentile consumption rate for adult members of the Squaxin tribe of 3.417 g/kg-d. The mean "total fish" consumption rate for adults was 1.021 g/kg-d. The estimated 95th percentile consumption rate for adults for finfish consumption only (excluding shellfish) was 2.537 g/kg-d.

An estimate of an upper bound "total fish" consumption rate for adults in g/d, based on the consumers-only estimates presented by U.S. EPA (2013b), can be derived by multiplying the 95th percentile estimate by the assumed adult body weight applied in this assessment (80 kg; U.S. EPA, 2021d), to yield a 95th percentile "total fish" consumption rate for consumers only adults of 273.5 g/d. Note, however, that elsewhere in the U.S. EPA report (Appendix D), U.S. EPA reports a 95th percentile consumption for adult Squaxin tribe members (consumers only) of 330.5 g/d; they do not indicate the assumptions used to arrive at this value. However, assuming the reported 95th percentile total fish consumers only consumption rate of 3.417 g/kg-d, this g/d estimate implies a body weight of 96.7 kg (213 lbs) (mean body weights reported by U.S. EPA (2013b) for adult Squaxin Tribe survey participants were 93 kg for males and 68 kg for females). Regardless, to put this g/d estimate in perspective, an average serving size of fish is assumed to be approximately 7 ounces (the average of the "uncooked" serving size of 8 ounces and the "cooked" serving size of 6 ounces; WDOH, 2021), or about 198 g. At an upper bound "total fish" consumption rate of 330.5 g/d, the annual consumption rate would be 120,632 g/year, or approximately 609 average-sized servings of fish annually.

For children, an estimate of an upper bound "total fish" consumption rate in g/d can be estimated based on the consumer-only estimates for children less than 6 years of age presented by U.S. EPA (2013b). Because of the small number of children included in the survey (36), a reliable 95th percentile estimate was not reported. The 90th percentile consumer-only "total fish" consumption rate for children is 2.831 g/kg-d. To obtain a rate in g/d, this can be multiplied by the age-weighted mean body weight for male and female children age 3 to 16 years from the *Exposure Factors Handbook* (23 kg; U.S. EPA, 2011) to yield an assumed consumer-only fish consumption rate by children of 65.1 g/d or 23,766.2 g/year. At an average serving size of 7 ounces or 198 g, this would correspond to 120 (adult-sized) servings of fish per year. However, for purposes of this assessment, the high end estimate of 330.5 g/d was applied to children as well.

However, it is expected that these fish consumption rates overestimate consumption rates of fish from Woodland Creek and McAllister Creek for several reasons. First, the "total fish" consumption rate is dominated by consumption of anadromous fish species (fish that are born in freshwater but

spend most of their life at sea, and migrate up rivers from the sea to spawn) such as salmon (66.2% of the mean "total fish" consumption rate, and 72.3% of the 95th percentile "total fish" consumption rate). While it is possible that spawning salmon migrating up fresh water creeks could be caught for consumption, it is assumed that adult salmon spend most of their lives in open saltwater and would take up bioaccumulative and persistent contaminants almost exclusively via the food chain in that environment (U.S. EPA, 2007b). It is also likely that chemicals related to a particular localized inland site will not be transported to a relatively distant aquatic environment, where adult salmon might be exposed to them through the food chain. As such, it is assumed that an anadromous fish that might be caught and consumed from the creeks would not be contaminated with site-related residual chemicals (i.e., associated with downgradient transport from the reclaimed water basins).

Second, two other groups of finfish species also comprise a significant fraction of the "total fish" consumption rate: pelagic fish, which spend their lives in the ocean (such as cod, pollock, rockfish, and perch) (4.8% of the mean "total fish" consumption rate) and "bottom" fish such as halibut, sole/flounder, and sturgeon (7.0% of the mean "total fish" consumption rate). It is not expected that these fish would have habitat in Woodland Creek or McAllister Creek or would reach a size within the creeks where they could be caught and consumed. The Squaxin Tribe survey notes that on average, 30% of reported consumed pelagic fish was from grocery stores, 21% was from restaurants, 25% was caught outside the Puget Sound, and 23% was caught inside Puget Sound. For bottom fish, on average, 26% was from grocery stores, 17% was from restaurants, 41% was caught outside Puget Sound, and 13% was caught in Puget Sound. For fish caught in Puget Sound, it is not expected that site-related residual chemicals (i.e., associated with downgradient transport from the reclaimed water basins) would be transported in significant amounts to relatively distant aquatic environments within the Sound where adult fish of these species might be exposed to them through the food chain.

Third, one other species subgroup—shellfish, including various species of clams, mussels, oysters, and shrimp—contributes 20.3% to the mean "total fish" consumption rate estimated in the Squaxin Tribe survey. The relative distribution of such species at or near the mouths of Woodland Creek or McAllister Creek is not known; however, it is assumed that the majority of such species are caught from more desirable locations of greater abundance within the Puget Sound (on average, 62% of shellfish reported as consumed by members of the Squaxin Tribe was from the Puget Sound). Further, estimated concentrations of COIs estimated in fish in Woodland Creek and McAllister Creek in the HHRA are calculated based on estimated surface water concentrations and chemical-specific bioconcentration factors (BCFs) that predict uptake of chemicals into fish from surface water and are derived from studies that assess concentrations of these chemicals in finfish (not shellfish) relative to concentrations in their immediate surface water environment (not sediment or other media). Thus, the BCFs are not intended to predict shellfish concentrations, and no adequate data to predict shellfish concentrations of the COIs were identified.

Fourth, the productivity of Woodland Creek and McAllister Creek is not known, but it is likely that it is not sufficient to support repeated sustainable fish consumption (i.e., considering edible size vs forage-size fish) (Pfieffer and Anderson, 2021).

Overall, the consumption rate attributed to "other fish" (which was comprised of trout, as well as canned tuna) was assumed to provide a reasonable, though conservative, estimate of fish that could be consumed from creeks, if they are sufficiently productive. The reported "other fish" consumption rate for Squaxin Tribe adults was lower than for other categories of fish (approximately 1.6% of "total fish" at the mean). For Squaxin Tribe adults, the 95th percentile per capita consumption rate of "other fish" was 0.123 g/kg-d and the mean was 0.014 g/kg-d. An estimate of an upper bound "other fish" per capita consumption rate for adults in g/d can be derived by multiplying the 95th percentile

estimate by the assumed adult body weight applied in this assessment (80 kg; U.S. EPA, 2021d), to yield a 95th percentile per capita "other fish" consumption rate for adults of 9.84 g/d. To put this rate in perspective, an average serving size of fish is assumed to be approximately 7 ounces (the average of the "uncooked" serving size of 8 ounces and the "cooked" serving size of 6 ounces; WDOH, 2021), or about 198 g. At an "other fish" consumption rate of 9.84 g/d, the annual per capita consumption rate would be 3,592 g/year, or approximately 18 average-sized servings of fish annually.

For children, consumption rates for the "other fish" category are not reported. The reported 90th percentile "Total, all fish" per capita consumption rate for children for the Squaxin Tribe, age birth to 5 years, is 2.056 g/kg-d (a 95th percentile rate was not reported). An upper bound estimate of the child per capita consumption rate for "other fish," assumed to include creek-caught trout, was estimated by multiplying the 90th percentile "Total, all fish" consumption rate for children by 5% (based on the estimated percentage of "total fish" comprised by "other fish" for adults of 2%, as described above), to yield an estimate of 0.103 g/kg-d. To obtain a rate in g/d, this was multiplied by the age-weighted mean body weight for male and female children age 3 to 16 years from the *Exposure Factors Handbook* (23 kg; U.S. EPA, 2011) to yield an assumed per capita fish consumption rate by children of 2.37 g/d or 865.1 g/year. At an average serving size of 7 ounces or 198 g, this would correspond to 4.4 (adult-sized) servings of fish per year. This is assumed to represent a more moderate potential consumption rate of fish from the creeks for a child.

3.3.3.6 Chemical-Specific Parameters

Chemical-specific parameters are used to estimate uptake of chemicals into tissue. For the HHRA, chemical-specific uptake factors were obtained from U.S. EPA guidance documents and the scientific literature. Chemical-specific uptake factors used in the HHRA include:

- Permeability constants (K_p), used to estimate the rate at which a chemical absorbs through the skin upon dermal contact with the chemical in water.
- Lag times (τ), used to estimate the permeation lag time of a chemical from surface water through human skin.
- Bioconcentration factors (BCF), used to estimate the rate at which a chemical is accumulated from surface water into fish tissue.
- Gastrointestinal absorption factors (GAF), used to estimate the rate at which an orally administered chemical in a study that is the basis for an oral toxicity criterion (e.g., administered in food or water, or via gavage) is absorbed through the gastrointestinal tract, for use in adjusting administered dose oral reference doses (RfDs) or slope factors (SFs) to absorbed dose dermal RfDs or SFs (see Section 4.3).

Per U.S. EPA, K_p can be calculated as follows (Equation 3.8 of U.S. EPA, 2004):

$$log\ K_p = -2.80 + 0.66\ log\ K_{ow} - 0.0056\ MW$$

where K_{ow} is the chemical-specific octanol/water partition coefficient of the non-ionized chemical species (dimensionless), and MW is the molecular weight (g/mol). To estimate K_p for each of the COIs, the chemical-specific log K_{ow} was retrieved from the literature (see log K_{ow}s and K_p values listed in Table A-1 in Appendix A).

Per U.S. EPA, lag time (τ_{event}) can be calculated as follows (Equation A.4 of U.S. EPA, 2004):

$$\tau_{event} = \frac{(l_{sc})^2}{6D_{sc}} = 0.105 \times 10^{0.0056MW}$$

where l_{sc} is the thickness of the stratum corneum, assumed to be 10^{-3} (cm) (U.S. EPA, 2004), D_{sc} is a chemical-specific diffusion coefficient for chemical transfer through the stratum corneum (cm^2/h) (calculated in the "ORG04_01.XLS" spreadsheet for "Organic Chemicals in Water (Excel)" at U.S. EPA, 2017b), and MW is the chemical's molecular weight. Per U.S. EPA (2004), the initial form of the equation can be simplified to estimate lag time based on the molecular weight (MW; g/mol) of the chemical. Estimated chemical-specific lag times based on MW are listed in Table A-1 in Appendix A.

BCF is the ratio between the concentration of chemical in the tissue of an organism (e.g., fish) and the concentration in the water column (U.S. EPA, 2003), as follows:

$$BCF\ (L/kg) = \frac{Concentration\ tissue\ (mg/kg)}{Concentration\ water\ (mg/L)}$$

Chemical-specific estimates of BCF for each COI, obtained from the literature, are listed in Table A-1 in Appendix A.

3.4 Derivation of Dose Estimates

For each exposure population and scenario, doses for each pathway and COI were estimated using the assumed exposure parameters and EPCs, and presented in units of milligrams per kilogram body weight per day (mg/kg-d). For evaluation of noncarcinogenic effects, doses were averaged over one year and presented as annual average daily doses (ADDs). For evaluation of cancer risk, doses were averaged over a lifetime (assumed to be 70 years) and presented as lifetime average daily doses (LADDs). These estimates were then combined with chemical- and endpoint-specific toxicity criteria to derive estimates of noncancer hazard and cancer risk associated with the exposures (Section 5.0).

3.5 Exposure Assessment Uncertainties

Actual rates of exposure to individuals who contact well water or surface water that might be impacted by LOTT's reclaimed water after treatment have not been measured. Instead, in this assessment, doses to hypothetical future populations are estimated using exposure parameters representing a combination of average and upper bound exposure rates (e.g., values representing the mean and 90th or greater percentiles of distributions of the exposure rates), or default values compiled by U.S. EPA and used in RSL calculations (which are considered by U.S. EPA to yield screening levels protective for humans, including sensitive subgroups, over a lifetime, and are designed to assess if levels of contamination warrant further investigation; U.S. EPA, 2021d). Multiplicatively combining average and upper-bound exposure values is expected to yield estimates of exposure at the upper end of the exposure distribution, and will likely overestimate actual exposures to most individuals who are exposed to COIs in an HHRA. The relative impact of selected exposure parameter values for the RME resident scenario on estimated dose is discussed further in Section 5.3.

For each COI, exposures to water from the shallow or deep aquifer were estimated using the maximum concentration estimated for that aquifer. As shown in Table 3-1, for two of the eight COIs in the shallow aquifer (carbamazepine and primidone), fate and transport modeling predicted that the chemical would not persist beyond the closest assumed point of potential contact (200 feet from the source), and for two additional COIs (1,4-dioxane and quinoline), modeling predicted the chemical would not persist further than 1,000 feet from the source. However, for all eight of the COIs in the shallow aquifer, exposures to tap or well water were estimated assuming persons would be exposed

to the maximum-estimated concentration in the aquifer regardless of distance from source. This assumption overestimates potential exposures to persons who might contact water from the shallow aquifer at locations further from the source.

Further, while risks were evaluated assuming resident, worker, or recreator exposure could occur to water from both aquifers, it is more likely that domestic or municipal wells would be drilled to the deeper aquifer, where only four of the eight COIs were predicted to be present (fate and transport modeling predicted 1,4-dioxane, carbamazepine, primidone, and quinoline would not be present in the deep aquifer). Risk estimates based on exposure to water from the shallow aquifer likely overestimate risks that could be associated with exposure to well water downgradient from the infiltration basins.

Figure 3-1. Conceptual Site Model for the HHRA

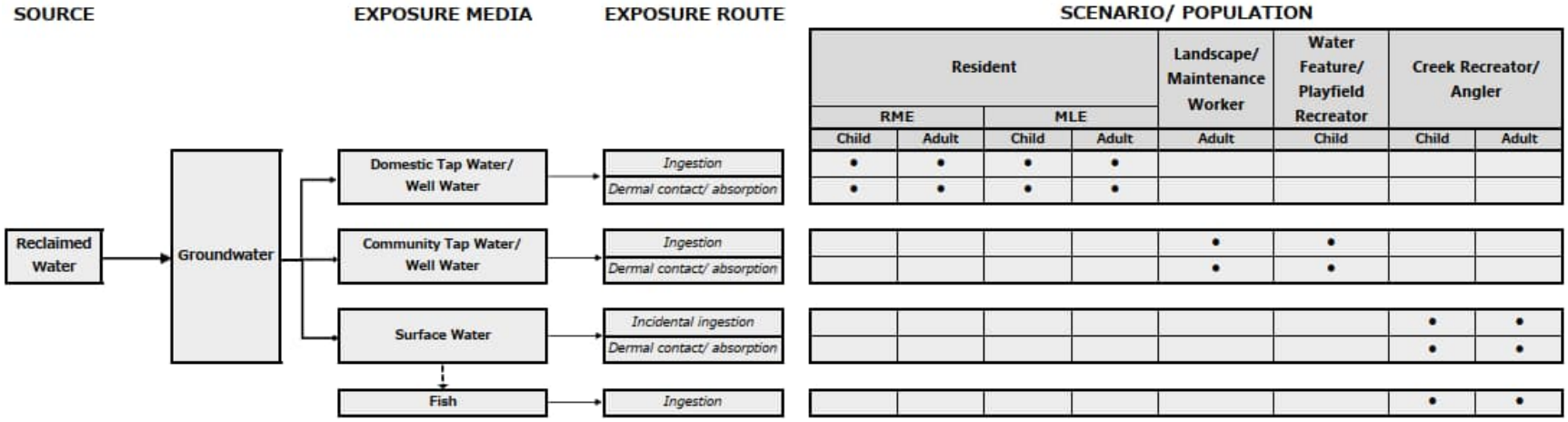

Table 3-1. Estimated Exposure Point Concentrations (EPCs) in the Shallow and Deep Aquifers (by Distance Downgradient) and at Surface Water Points of Entry, Assuming No Additional Treatment (Baseline Scenario)

	Exposure Point Concentrations (EPCs) (ng/L)													
	Qva (Model Layer 2; Shallow Aquifer)							Qc (Model Layer 4; Deep, Sea-Level Aquifer)						
Chemical	**200 ft**	**1,000 ft**	**2,000 ft**	**4,000 ft**	**6,000 ft**	**8,000 ft**	**Wood-land Creek***	**200 ft**	**1,000 ft**	**2,000 ft**	**4,000 ft**	**6,000 ft**	**8,000 ft**	**McAll-ister Creek***
*Year of Max Concentration Estimate***	***2008***	***2009***	***2025***	***2061***	***2074***	***2083***	***2080***	***2039***	***2042***	***2047***	***2124***	***2132***	***2124***	***2110***
1,4-Dioxane	544.2	254.9	0	0	0	0	0	0	0	0	0	0	0	0
Carbamazepine	280.3	0.0	0	0	0	0	0	0	0	0	0	0	0	0
N-Nitroso dimethylamine (NDMA)	3.28	3.28	3.28	3.28	3.25	3.12	2.46	3.25	3.25	3.25	3.15	3.05	2.89	1.05
Perfluoro octanoic acid (PFOA)	14.9	14.9	14.9	14.9	14.8	14.2	11.2	14.8	14.8	14.8	14.3	13.9	13.1	4.77
Perfluoro-n-hexanoic acid (PFHxA)	45.8	45.8	45.8	45.8	45.3	43.5	34.4	45.3	45.3	45.3	44.0	42.6	40.3	14.7
Perfluoropentanoic acid (PFPeA)	79.3	79.3	79.3	79.3	78.5	75.3	59.4	78.5	78.5	78.5	76.1	73.7	69.7	25.4
Primidone	178	0.0	0	0	0	0	0	0	0	0	0	0	0	0
Quinoline	9.8	5.56	0	0	0	0	0	0	0	0	0	0	0	0

*At model-defined drain points into the creeks (not considering dilution)

**Year at which the maximum concentration is predicted to occur at each location depicted. Note that the distances refer to concentric circles located at the stated radii from the point of infiltration. Concentrations are expected to not be uniform at every point along a given circle. The concentrations shown represent the maximum along each circle.

Source: HDR, 2021

Table 3-2. Dilution-Adjusted Exposure Point Concentrations (EPCs) in the Creeks Applied in the HHRA

	Dilution-Adjusted Exposure Point Concentrations (EPCs) (ng/L)					
	Baseline scenario (No additional treatment)		RO-AOP scenario (Treatment Option 1)		O3-BAC-GAC scenario (Treatment Option 2)	
Chemical	**Woodland Creek**	**McAllister Creek**	**Woodland Creek**	**McAllister Creek**	**Woodland Creek**	**McAllister Creek**
1,4-Dioxane	0	0	0	0	0	0
Carbamazepine	0	0	0	0	0	0
N-Nitroso dimethylamine (NDMA)	0.013	0.00027	0.013	0.00027	0.013	0.00027
Perfluoro octanoic acid (PFOA)	0.061	0.0012	0	0	0.061	0.0012
Perfluoro-n-hexanoic acid (PFHxA)	0.187	0.0037	0	0	0.187	0.0037
Perfluoropentanoic acid (PFPeA)	0.324	0.0065	0	0	0.324	0.0065
Primidone	0	0	0	0	0	0
Quinoline	0	0	0	0	0	0

Source: HDR, 2021

Table 3-3. Estimated Exposure Point Concentrations (EPCs) in the Shallow and Deep Aquifers (by Distance Downgradient) and at Surface Water Points of Entry, Assuming RO-AOP (Treatment Option 1)

	Exposure Point Concentrations (EPCs) (ng/L)													
	Qva (Model Layer 2; Shallow Aquifer)							Qc (Model Layer 4; Deep, Sea-Level Aquifer)						
Chemical	**200 ft**	**1,000 ft**	**2,000 ft**	**4,000 ft**	**6,000 ft**	**8,000 ft**	**Wood-land Creek***	**200 ft**	**1,000 ft**	**2,000 ft**	**4,000 ft**	**6,000 ft**	**8,000 ft**	**McAll-ister Creek***
1,4-Dioxane	136.1	63.7	0	0	0	0	0	0	0	0	0	0	0	0
Carbamazepine	14.0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Nitroso dimethylamine (NDMA)	0.066	0.066	0.066	0.066	0.065	0.062	0.049	0.065	0.065	0.065	0.063	0.061	0.058	0.021
Perfluoro octanoic acid (PFOA)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perfluoro-n-hexanoic acid (PFHxA)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perfluoropentanoic acid (PFPeA)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Primidone	4.0	0	0	0	0	0	0	0	0	0	0	0	0	0
Quinoline	0	0	0	0	0	0	0	0	0	0	0	0	0	0

*At model-defined drain points into the creeks (not considering dilution)
Source: Email communication from HDR project manager, August 9, 2021

Table 3-4. Estimated Exposure Point Concentrations (EPCs) in the Shallow and Deep Aquifers (by Distance Downgradient) and at Surface Water Points of Entry, Assuming O3-BAC-GAC (Treatment Option 2)

	Exposure Point Concentrations (EPCs) (ng/L)													
	Qva (Model Layer 2; Shallow Aquifer)							Qc (Model Layer 4; Deep, Sea-Level Aquifer)						
Chemical	200 ft	1,000 ft	2,000 ft	4,000 ft	6,000 ft	8,000 ft	Wood-land Creek*	200 ft	1,000 ft	2,000 ft	4,000 ft	6,000 ft	8,000 ft	McAll-ister Creek*
1,4-Dioxane	272.1	127.4	0	0	0	0	0	0	0	0	0	0	0	0
Carbamazepine	5.6	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Nitroso dimethylamine (NDMA)	0.164	0.164	0.164	0.164	0.162	0.156	0.123	0.162	0.162	0.162	0.157	0.153	0.144	0.052
Perfluoro octanoic acid (PFOA)	0.149	0.149	0.149	0.149	0.148	0.142	0.112	0.148	0.148	0.148	0.143	0.139	0.131	0.048
Perfluoro-n-hexanoic acid (PFHxA)	0.149	0.149	0.149	0.149	0.148	0.142	0.112	0.148	0.148	0.148	0.143	0.139	0.131	0.048
Perfluoropentanoic acid (PFPeA)	0.793	0.793	0.793	0.793	0.785	0.753	0.594	0.785	0.785	0.785	0.761	0.737	0.697	0.254
Primidone	7.12	0	0	0	0	0	0	0	0	0	0	0	0	0
Quinoline	9.75	5.56	0	0	0	0	0	0	0	0	0	0	0	0

*At model-defined drain points into the creeks (not considering dilution)
Source: Email communication from HDR project manager, August 9, 2021

4.0 TOXICITY ASSESSMENT

The goal of the Toxicity Assessment step is to identify toxicity criteria for each of the COIs. In the Risk Characterization section of the HHRA (Section 5.0), these toxicity criteria are then combined with dose estimates (Section 3.0) to estimate the likelihood of effect.

The following sections describe the toxicity criteria identified for the COIs to assess noncancer hazard and cancer risk.

4.1 The Dose-Response Concept

Detection of a chemical in water does not mean that adverse health effects will occur or are likely. While all chemicals are potentially toxic at some dose, many factors play a role in whether a chemical is toxic or harmful to humans or animals. In particular, the dose, or amount, of a chemical a person receives is important in determining the likelihood that it will cause an adverse effect. The duration that a person is exposed is also important: exposure to low levels of some substances over a short period of time (acute exposure) may not be harmful while exposure over many years (chronic exposure) can cause adverse health effects.

The nature of toxicological effects from exposure to different substances varies depending on how the chemicals act in the body. Effects that have been associated with repeated exposure to certain substances include effects on organ systems (e.g., liver, kidney, skin, lungs, nervous system), reproductive capacity, growth and development, and immune parameters. Exposure to some chemicals has been associated with an increase in certain types of cancers. To predict the potential for a given substance at particular levels of exposure to cause toxicological effects, scientists conduct tests in animals that are exposed to a controlled series of doses or evaluate humans that have been unintentionally (e.g., in the workplace) or intentionally (e.g., to medications) exposed. Newer methods that use laboratory desktop systems (*in vitro*) or computer models (*in silico*) can also predict toxicity. With this information, scientists can determine the types of adverse effects that can occur and the exposure level (including the amount and frequency of exposure) at which these effects can develop (the "dose-response"). Data that show a gradient of effects with increasing dose can be used to establish the threshold level of exposure at which effects first appear and to develop toxicity criteria that characterize the likelihood of a particular effect at a given exposure level.

For each COI considered in the HHRA, toxicity criteria were identified or derived to characterize the potential for noncancer or cancer effects associated with estimated doses. The sources of toxicity criteria applied in the HHRA are described below. The values selected for use in this assessment are presented in Table 4-1 (Noncancer Toxicity Criteria) and Table 4-2 (Cancer Toxicity Criteria). A more complete summary of published toxicity criteria for each COI and the basis of derived values considered in this assessment is provided in Appendix C.

4.2 Sources of Toxicity Criteria

For purposes of this assessment, toxicity criteria for noncancer and cancer effects of the COIs were identified according to a hierarchical approach, based on existing published criteria or, in the absence of such values, derived from toxicity data or other information. In addition, where they are available, existing water quality criteria for the COIs were identified (i.e., state or federal MCLs) and compared to EPCs.

The hierarchies applied and sources of data are described below.

4.2.1 *Hierarchies of Data Considered in the Selection of Toxicity Criteria for the Characterization of Noncancer or Cancer Effects*

For characterization of noncancer effects, the hierarchy of data considered is as follows:

- If a published and verified (i.e., peer-reviewed) acceptable daily intake (ADI) for noncancer effects from an authoritative body is available (e.g., a U.S. EPA reference dose (RfD) or an Agency for Toxic Substances and Disease Registry minimal risk level (MRL); see Section 4.2.2), apply this value. Consistent with U.S. EPA risk assessment guidance (U.S. EPA, 1989), toxicity criteria provided in U.S. EPA's Integrated Risk Information System (IRIS; https://www.epa.gov/iris) supersede all other sources. Values in IRIS undergo external peer review and are used by U.S. EPA, state and local health agencies, other federal agencies, and international health organizations to assess chemical risk. Otherwise, if more than one value of sufficient quality from another non-U.S. EPA IRIS source is available, select the lowest of these values (i.e., corresponding to a more stringent estimate of noncancer hazard) for use in the HHRA.
- If a published and verified noncancer ADI is not available, search the toxicological literature for relevant data on health effects from studies in animals or humans and derive an ADI for noncancer effects using data for the most sensitive toxicological endpoint combined with standard and accepted methodologies for deriving toxicity criteria of this type. If the chemical is a pharmaceutical, identify the lowest therapeutic dose and derive an ADI based on this value using an analogous approach to that used to derive values from toxicity data (see Section 4.2.3).

For evaluation of carcinogenic effects, the hierarchy of data considered is as follows:

- If a published and verified (i.e., peer-reviewed) cancer slope factor (SF; a quantitative measure of cancer risk associated with a given daily dose) from an authoritative body is available (see Section 4.2.2), apply this value. Consistent with U.S. EPA risk assessment guidance (U.S. EPA, 1989), information in the IRIS database supersedes all other sources. Otherwise, if more than one value from another non-U.S. EPA IRIS source is available, select the highest of these values (which corresponds to a more stringent estimate of cancer risk) for use in the HHRA.
- If a published and verified cancer SF is not available, search the toxicological literature for information on carcinogenicity and mutagenicity/genotoxicity from *in vitro* or *in vivo* studies. If a chronic animal study is available that shows evidence of dose-related carcinogenicity and evidence suggests that the chemical is mutagenic (i.e., that the carcinogenic response does not proceed through non-genotoxic, threshold mechanisms such as development of hyperplasia followed by tumor development), and if tumor incidence data are available, use the tumor incidence data to derive a cancer SF using U.S. EPA methodologies (see Section 4.2.3).

The assumptions and methods used to identify or derive toxicity criteria for noncancer and cancer effects are described in more detail below. All identified toxicity criteria applied in the HHRA for noncancer and cancer effects are listed in Tables 4-1 and 4-2, respectively. MCLs are listed in Table 4-3.

4.2.2 *Identification of Existing Criteria from Authoritative Bodies for Noncancer and Cancer Effects*

Availability of the following types of published and verified toxicity criteria from authoritative bodies was determined for each of the COIs:

- U.S. EPA reference doses (RfDs) for evaluation of noncarcinogenic effects

- U.S. EPA cancer slope factors (SFs) for evaluation of cancer risks
- Agency for Toxic Substances and Disease Registry (ATSDR) minimal risk levels (MRLs) for evaluation of noncarcinogenic effects
- U.S. EPA Unregulated Contaminant Monitoring Rule (UCMR) Contaminant Candidate List (CCL) Health Reference Levels (HRLs)
- U.S. EPA Drinking Water Health Advisories (HAs)
- California EPA Public Health Goals (PHGs) for drinking water
- California EPA No Significant Risk Levels (NSRLs) for cancer and reproductive/ developmental toxicity developed as part of the Proposition 65 program
- California EPA oral SFs for cancer
- Minnesota Department of Health (MDH) Human Health-Based Values (HBVs) or noncancer Human Risk Limits (nHRL) for drinking water
- Washington State Draft State Action Levels (SALs) for per-and polyfluoroalkyl substances (PFAS)
- Texas Risk Reduction Program (TRRP) Protective Concentration Levels for PFAS
- European Food Safety Authority (EFSA) ADIs
- Joint FAO/WHO Expert Committee on Food Additives (JEFCA) ADIs
- Joint FAO/WHO Meeting on Pesticide Residues (JMPR) ADIs
- Other sources of values as appropriate

Note that where final peer-reviewed values are available, preference was given to these as opposed to "draft" values that have not undergone full peer-review.

The approach used by the U.S. EPA and other regulatory agencies to assess risks associated with noncarcinogenic effects is to identify an exposure threshold below which adverse effects are not observed. The first adverse effect that occurs as the dose or concentration increases beyond the threshold is called the "critical effect" (U.S. EPA, 1993b; 2002). Selection of regulatory levels for noncarcinogenic effects assumes that if the critical effect is prevented, then all toxic effects are prevented. For evaluation of noncarcinogenic effects, U.S. EPA has established RfDs, which are estimates of a daily oral exposure of a chemical to the human population (including sensitive subgroups) that are likely to be without an appreciable risk of deleterious effects during a lifetime (U.S. EPA, 1993b). U.S. EPA derives RfDs from such threshold doses as No Observed Adverse Effect Levels (NOAELs), Lowest Observed Adverse Effect Levels (LOAELs), or benchmark doses, for noncarcinogenic endpoints including effects on reproduction, developmental effects, behavioral effects, or immunological effects. A NOAEL is the highest dose in a given study at which no statistically or biologically significant indication of a toxic effect of concern is identified, while a LOAEL is the lowest dose at which a toxic effect is identified. NOAELs and LOAELs are typically established from studies in animals or on occupational exposure in humans. The selected threshold dose is then divided by multiple uncertainty factors to account for limitations in extrapolating the doses to general human exposure, to develop an RfD. An ATSDR MRL is developed similarly to a U.S. EPA RfD, although different MRLs may be established for a chemical for different time periods, specifically acute (about 1 to 14 days), intermediate (15 to 364 days), or chronic (more than 364 days) exposure durations.

RfDs and other noncancer ADIs are typically expressed in units of milligram per kilogram of body weight per day (mg/kg-d) of exposure. For evaluation of noncancer hazards from inhalation exposure, reference concentrations (RfCs) may be used—these are typically expressed in units of micrograms per cubic meter ($\mu g/m^3$) of chemical in exposure air.

U.S. EPA evaluates cancer risks based on extrapolation of estimates of the increase in cancer incidence associated with exposure to known or estimated doses of a substance in animal or worker exposure studies. To evaluate cancer, U.S. EPA develops cancer SFs, which are upper bound estimates, approximating 95% confidence limits, of the increased cancer risk from a lifetime exposure to a unit dose or exposure level of an agent. SFs are typically expressed in units of proportion of a population affected per one milligram per kilogram of body weight per day of exposure to a chemical ($(mg/kg\text{-}d)^{-1}$), and are applied to exposures corresponding to risks less than 1 in 100 (U.S. EPA, 2005). For evaluation of cancer from inhalation exposure, unit risk (UR) values are sometimes derived. These are comparable to SFs and are typically expressed in units of proportion of a population affected per one microgram per cubic meter ($(\mu g/m^3)^{-1}$) of chemical in exposure air.

Available published noncancer ADIs and cancer SFs for the COIs are summarized in Appendix C, Table C-1.

Published noncancer ADIs from authoritative bodies suitable for use in the HHRA are available for six of the eight COIs (1,4-dioxane, carbamazepine, PFOA, PFHxA, PFPeA, and quinoline)—the noncancer ADIs selected for use in the HHRA for these COIs are listed in Table 4-1. Several authoritative bodies including U.S. EPA, the State of California, and others have concluded that data are insufficient to derive a noncancer toxicity criterion for NDMA and that it is more appropriate and health protective to assess this compound based on its carcinogenicity potential (i.e., at exposure levels with no concern for carcinogenicity, it is assumed there is no concern for noncarcinogenic effects) (U.S. EPA, 1987; OEHHA, 2006). For example, the State of California Office of Environmental Health Hazard Assessment (OEHHA, 2006) has stated, "A protective level has not been developed for non-cancer effects [of NDMA] due to the lack of adequate toxicological studies that investigated non-carcinogenic toxic endpoints. The high cancer potency and unequivocal nature of this chemical as a carcinogen would make a non-cancer health-protective value of very limited relevance." Based on these observations, in this HHRA, NDMA was evaluated based only on its carcinogenicity. For the remaining compound without a noncancer criterion (primidone), a noncancer ADI was derived as described in Section 4.2.3.

Cancer toxicity criteria from authoritative bodies are available for four of the eight chemicals (1,4-dioxane, NDMA, PFOA, and quinoline)—the cancer toxicity criteria selected for use in the HHRA for these COIs are listed in Table 4-2. Because of their structural similarity to PFOA and the lack of cancer toxicity criteria for other PFAS compounds, the same cancer SF applied to PFOA was applied to the two other PFAS COIs (PFHxA and PFPeA). Published assessments of the carcinogenicity potential of the two remaining COIs (carbamazepine and primidone) from authoritative bodies were not identified. Consideration of data for these compounds with regard to assessing their carcinogenicity potential is discussed in Section 4.2.3.

4.2.3 *Characterization of Toxicity of COIs without Existing Criteria*

For one of the COIs (primidone), a published and verified noncarcinogenicity assessment and ADI were not identified. Consequently, an ADI for this compound was derived based on review of data from animal toxicity studies and, since it is a pharmaceutical, information on therapeutic doses. The lowest (most health-protective) value was then selected as the basis of the noncancer ADI for use in

the HHRA. The methodologies and data used to derive values considered are described in Appendix C.

In addition, two of the COIs (carbamazepine and primidone) do not have published carcinogenicity assessments from authoritative bodies. For chemicals that are mutagenic and where data from chronic animal studies show evidence of carcinogenicity, a cancer SF can be derived using linear dose-response models. The methods and data used to assess the potential carcinogenicity of these compounds are discussed in Appendix C. While both of these compounds show some evidence of an increase in liver carcinomas in rodent studies, and primidone also shows an increase in thyroid gland follicular cell adenomas in mice (Novartis, 2010; Singh et al., 2005; NTP, 2000), neither of the chemicals is considered to be mutagenic based on data from *in vitro* (including bacterial) and *in vivo* (including mammalian) test systems. Therefore, for carbamazepine and primidone, a cancer SF was not derived but an additional UF of 10 was applied to the estimated ADIs for noncancer effects to add an additional margin of safety to protect against precursor effects that could increase the potential for nongenotoxic carcinogenic responses at higher exposure levels.

4.3 Extrapolation of Oral Toxicity Criteria to Dermally Absorbed Doses

The equations used to estimate exposure to COIs via dermal uptake that are presented in Section 3.3.1 generate estimates of internal (i.e., absorbed) dose. In contrast, the toxicity criteria identified for all of the COIs are based on orally administered doses (e.g., in food or water, or administered via gastric gavage). To be applicable to assessing toxicity corresponding to internal doses, the oral criteria must be adjusted to equivalent absorbed values using chemical-specific assumed oral absorption rates (represented by the gastrointestinal absorption factor, or GAF) (U.S. EPA, 1989).

To adjust an administered dose (oral) noncancer toxicity criterion (ADI) to an absorbed value, the following equation is used:

$$ADI\text{-}NC_{abs}(mg/kg-d) = ADI\text{-}NC_{oral}(mg/kg-d) \times GAF$$

To adjust an administered dose (oral) cancer toxicity criterion or SF to an absorbed value, the following equation is used:

$$SF\text{-}Cancer_{abs}(mg/kg-d)^{-1} = \frac{SF_{oral}(mg/kg-d)^{-1}}{GAF}$$

U.S. EPA (2004) recommends using a GAF to adjust oral toxicity criteria to values for dermal exposure when gastrointestinal absorption appears to be well below 100% (e.g., <50%). However, most organic compounds including pharmaceuticals are well absorbed following oral administration, and no data for the COIs considered in this assessment indicating otherwise was identified. As such, application of a GAF of 1.0 for all COIs in this assessment was considered appropriate. Thus, the same toxicity criteria are applied to assess dermal exposure as are applied to assess oral exposure.

4.4 Toxicity Assessment Uncertainties

For both noncancer and cancer endpoints, toxicity criteria are generally based on observations of adverse health effects in animals that are exposed to very high doses of chemicals in the diet, in water, or via gastric gavage. Because of differences between the nature and magnitude of exposures that are the basis for these criteria and exposures evaluated in this HHRA, these criteria may under- or overestimate, but most likely overestimate, actual risks to people from exposure to lower concentrations in environmental media.

Overall, all of the toxicity criteria applied in the HHRA incorporate multiple uncertainty factors and are intended to be health protective. Thus, it is assumed that they are unlikely to underestimate, and more likely overestimate, potential risks from exposure to COIs. For example, noncancer ADIs are set using a number of conservative (health protective) assumptions, including selecting a point of departure that corresponds to the lowest effective dose level for any adverse effect from the database of studies, and use of multiple individual UFs (with a total UF ranging from 1,000 to 3,000 for most compounds) to further lower the ADI below the assumed threshold dose level.

Peer-reviewed and published toxicity assessments by regulatory agencies or other authoritative bodies are not available for all COIs considered in this assessment. For primidone, an ADI was derived using standard and accepted approaches established by regulatory bodies. For PFHxA and PFPeA, toxicity criteria based on animal studies that assess these chemicals specifically have not been established by state or federal agencies. In this HHRA, the noncancer toxicity criteria applied to PFHxA and PFPeA are set equal to chronic RfDs assigned to these chemicals by the Texas Commission on Environmental Quality (TCEQ, 2016), which are in turn based on data for perfluorohexane sulfonate (PFHxS)—TCEQ applied the same value to all three of the compounds because of their structural similarity. Of note, in a more recent assessment, ATSDR (2021) stated that "the chronic duration oral database for PFHxA is not considered adequate for derivation of a chronic MRL [minimal risk level] because the only study available did not measure serum PFHxA levels and elimination half-life data are not available for humans. These toxicokinetic data are needed to derive HEDs," and ATSDR (2021) did not discuss the toxicity of PFPeA. As such, ATSDR (2021) did not derive toxicity criteria for these two compounds. However, in order to avoid excluding these COIs from quantitative assessment of noncancer hazard in the HHRA, the TCEQ values were applied in this assessment. This is assumed to be a health-protective approach.

Likewise, no cancer toxicity assessments are available for PFHxA and PFPeA. To be conservative (health-protective), the cancer SF applied to PFOA (7.2×10^{-2} $(mg/kg\text{-}d)^{-1}$) from U.S. EPA (2016b) was applied to these compounds because of their structural similarity. Use of these values to assess the cancer risk of PFHxA and PFPeA is assumed to be a health-protective approach.

Overall, because of the multiple conservative assumptions incorporated into all of the applied toxicity criteria, if the average daily dose estimated for a chemical in the HHRA is below toxicity benchmarks that are associated with these criteria, one can be reasonably confident that adverse health effects due to exposure to these chemicals by potentially exposed populations are not likely. However, if a dose is at or above a toxicity benchmark, it does not mean that adverse health effects from exposure to the chemical are likely or will occur. Rather, more detailed evaluation of the chemical's toxicity and of the occurrence and exposure to the chemical (including examining how realistic the exposure estimates are for a particular population) may be warranted.

Table 4-1. Noncancer Toxicity Criteria for COIs Evaluated in the HHRA*

Chemical	Oral and Dermal ADI (mg/kg-d)	ADI Source	Effect at Point of Departure for ADI	ADI Reference
1,4-Dioxane	0.03	U.S. EPA RfD	Liver and kidney degeneration in male rats exposed for 2 years via drinking water (NOAEL = 9.6 mg/kg-d; total UF = 300; Kociba et al., 2014 as cited in U.S. EPA, 2013a).	U.S. EPA, 2013a
Carbamazepine	0.00057	Minnesota Chronic RfD	Human minimum therapeutic dose for adults (400 mg/d, converted to 5.7 mg/kg-d based on 70 kg adult and total UF = 1,000, to yield an RfD of 0.0057 mg/kg-d; Novartis, 2011 as cited in MDH, 2013). *Since the chemical shows evidence of being a nongenotoxic carcinogen (see Table C-4) and a cancer SF is not derived, an additional UF of 10 is applied.*	MDH, 2013
N-Nitroso dimethylamine (NDMA)	NA	NA	All available published toxicity criteria are based on cancer endpoint, and so chemical is evaluated as a carcinogen only (see Table 4-2 and D-1).	NA
Perfluoro octanoic acid (PFOA)	0.0000030	ATSDR Intermediate Duration MRL; Washington State Draft SAL	Skeletal alterations at 13 and 17 months of age in offspring of mice administered PFOA in diet on GD1–21 (LOAEL = 0.000821 mg/kg-d; total UF = 300; Koskela et al. 2016 as cited in ATSDR, 2021).	ATSDR, 2021; WDOH, 2019, 2020
Perfluoro-n-hexanoic acid (PFHxA)	0.0000038	Texas Chronic RfD	Hematological alterations in male rats exposed to PFHxS for 42–56 days via oral gavage from pre-mating through PND21 in females (LOAEL = 0.3 mg/kg-d; total UF = 300 × 263 for adjustment of rat to human half-life; Hoberman and York, 2003 and ATSDR, 2009 as cited in TCEQ, 2016).	TCEQ, 2016

Chemical	Oral and Dermal ADI (mg/kg-d)	ADI Source	Effect at Point of Departure for ADI	ADI Reference
Perfluoropentanoic acid (PFPeA)	0.0000038	Texas Chronic RfD	Set equal to value for PFHxS from TCEQ (2016).	TCEQ, 2016
Primidone	0.00012	Derived from the minimum therapeutic dose (see Table C-3)	Human minimum therapeutic dose for adults (100 mg/d; equivalent to 1.25 mg/kg-d for 80 kg adult; total UF = 1,000; RxList.com, 2021). Since this chemical shows evidence of being a nongenotoxic carcinogen (see Table C-4) and a cancer SF is not derived, an additional UF of 10 is applied.	RxList.com, 2021
Quinoline	0.00079	Minnesota Chronic RfD	Increased cellular changes in the liver and kidney including necrosis, increased hematopoiesis in the bone marrow of both sexes, increased extramedullary hematopoiesis in the spleen of male rat administered in drinking water for 96 weeks (LOAEL = 8.8 mg/kg-d converted to HED = 2.38 mg/kg-d; total UF = 3,000; Matsumoto et al., 2018; MDH, 2020b).	MDH, 2020b

ADI –Acceptable Daily Intake; ATSDR – Agency for Toxic Substances and Disease Registry; GAF–Gastrointestinal absorption factor; GD – Gestation day; HED – Human equivalent dose; LOAEL – Lowest observed adverse effect level; NA – Not available; NOAEL – No observed adverse effect level; PND – Postnatal day; RfD – Reference Dose; SAL – State Action Level; UF – Uncertainty factor
* Because GAF is assumed is be 1.0 for all chemicals, absorbed dermal ADIs are assumed to be equivalent to administered oral ADIs.

Table 4-2. Cancer Toxicity Criteria and Assumptions for COIs Evaluated in the HHRA*

Chemical	Slope Factor ((mg/kg-d)$^{-1}$)	Criterion Basis	Criterion Reference	U.S. EPA and IARC Cancer Classification†
1,4-Dioxane	0.1	Increase in liver tumors in female mice exposed in drinking water for 2 years	U.S. EPA, 2013a	B2 (U.S. EPA); 2B (IARC)
Carbamazepine	NA	NA	NA	NA (U.S. EPA); NA (IARC)
N-Nitroso dimethylamine (NDMA)	51	Increase in liver tumors in female rats exposed in drinking water for 2 years	U.S. EPA, 1987	B2 (U.S. EPA); 2A (IARC)
Perfluoro octanoic acid (PFOA)	0.07	Increase in Leydig cell tumors in male rats exposed in diet for 2 years	U.S. EPA, 2016b	NA (U.S. EPA), 2B (IARC)
Perfluoro-n-hexanoic acid (PFHxA)	0.07	Same value as for PFOA applied due to chemical structure similarity	U.S. EPA, 2016b	NA (U.S. EPA); NA (IARC)
Perfluoropentanoic acid (PFPeA)	0.07	Same value as for PFOA applied due to chemical structure similarity	U.S. EPA, 2016b	NA (U.S. EPA); NA (IARC)
Primidone	NA	NA	NA	NA (U.S. EPA), 2B (IARC)
Quinoline	3	Increase in liver tumors in male rats exposed in diet for 2 years	U.S. EPA, 2001a	B2 (U.S. EPA), 2B (IARC)

IARC – International Agency for Research on Cancer; NA – Not available; SF – Slope Factor

* Because the gastrointestinal absorption factor (GAF) is assumed is to be 1.0 for all chemicals, absorbed dermal SF are assumed to be equivalent to administered oral SFs.

† U.S. EPA classifications: A – Human carcinogen; B(1 and 2) – Probable human carcinogen; C – Possible human carcinogen; D – Not classifiable as to human carcinogenicity; E – Evidence of noncarcinogenicity for humans; IARC classifications: 1 – Carcinogenic to humans; 2A – Probably carcinogenic to humans; 2B – Possibly carcinogenic to humans; 3 – Not classifiable as to its carcinogenicity to humans

Table 4-3. State or Federal Water Quality Criteria for COIs Evaluated in the HHRA

Chemical	Estimated Maximum EPC (ng/L)		U.S. EPA MCL (ng/L)	WA MCL (ng/L)
	Shallow Aquifer	Deep Aquifer		
1,4-Dioxane	272.1	0	NA	440
Carbamazepine	5.60	0	NA	NA
N-Nitroso dimethylamine (NDMA)	0.164	0.162	NA	2.0 (WA State groundwater quality criterion; WAC 173-200-040)
Perfluoro octanoic acid (PFOA)	0.149	0.148	70 (U.S. EPA Lifetime Drinking Water Health Advisory; U.S. EPA, 2016b)	NA
Perfluoro-n-hexanoic acid (PFHxA)	0.149	0.148	NA	NA
Perfluoropentanoic acid (PFPeA)	0.793	0.785	NA	NA
Primidone	7.12	0	NA	NA
Quinoline	9.75	0	NA	15

MCL – Maximum contaminant level; NA – Not available

5.0 RISK CHARACTERIZATION

In the Risk Characterization section, the results of the Exposure Assessment (Section 3.0) and Toxicity Assessment (Section 4.0) are integrated to develop quantitative measures of the potential for adverse health effects. Specifically, dose estimates are compared to toxicity criteria to provide a quantitative measure of the likelihood of noncarcinogenic effects or lifetime excess cancer risks. This section also provides perspective on the relative significance of the estimated hazards and risks compared to risk benchmarks and other sources of exposure, to support risk communication efforts.

5.1 Methodology for Estimating Noncancer Hazards and Cancer Risks

Different methods were used to estimate the potential for noncarcinogenic effects and the increase in lifetime excess cancer risks based on the estimates of dose for each of the COIs, as described below.

5.1.1 *Noncarcinogenic Effects*

The potential for noncarcinogenic effects was evaluated using the hazard index (HI) approach. This approach assumes that for a particular exposure scenario, simultaneous exposures of a person to a chemical via several pathways is additive, and that the relative magnitude of the adverse effect associated with the total exposure to that chemical is proportional to the summed ratios of pathway-specific exposures to allowable exposures (U.S. EPA, 1989).

Per this approach, for a given exposure scenario and chemical, Hazard Quotients (HQs) are first calculated for each exposure pathway by dividing the estimated ADD for each pathway by the appropriate noncancer ADI for the chemical and exposure route (e.g., oral or dermal exposure), using the following equation:

$$HQ_{Pathway\ i} = \frac{ADD_{Pathway\ i}\ (mg/kg-d)}{ADI\ (mg/kg-d)}$$

Then, HQs for individual exposure pathways are summed to obtain a chemical-specific HI for the scenario and population, as follows (where *n* is the number of pathways evaluated for a given chemical for that scenario/population):

$$HI = \sum_{i=1}^{n} HQ_n$$

According to U.S. EPA (1989) guidance, if the resulting chemical-specific HI is below unity (<1), then adverse health effects from exposure to that chemical are not expected. If an HI is equal to or exceeds 1, it does not mean that adverse health effects from exposure to that chemical are expected or will occur, but that further evaluation of the assumptions applied in the assessment and the significance of the findings is warranted.

5.1.2 *Cancer Risks*

Where cancer SFs were identified for a given chemical and exposure route, lifetime excess cancer risks (LECRs) were calculated for each scenario, chemical, and exposure pathway. Similar to the noncancer approach, this approach assumes that, for a given exposure scenario, the risks associated with simultaneous exposures of a person to a chemical via several pathways are additive.

Per this approach, for a given exposure scenario and chemical, LECRs are first calculated for all of the assumed exposure pathways by multiplying the estimated LADD for each pathway by the

appropriate cancer SF for the chemical and exposure route (e.g., oral, dermal), using the following equation:

$$LECR_{Pathway\,i} = LADD_{Pathway\,i}\ (mg/kg-d) \times SF\ (mg/kg-d)^{-1}$$

Then, LECRs for individual exposure pathways are summed to obtain a chemical-specific LECR for the scenario and population, as follows (where *n* is the number of pathways evaluated for a given chemical and scenario/population):

$$LECR = \sum_{i=1}^{n} LECR_n$$

LECR represents the probability of cancer occurring as the result of exposure at some point during an individual's lifetime (U.S. EPA, 1989). That is, it is the additional or extra cancer risk incurred over the lifetime of an individual as a result of exposure to a toxic substance. For perspective, the average male has an approximately 2 in 5 chance (0.405000) of being diagnosed with cancer at some point in his lifetime, and a female has a slightly lower chance (0.389000) of the same (ACA, 2021). If the result of this cancer risk analysis estimated a 1 in a million LECR (0.000001, also written as 1×10^{-6} or 1E-06), the total lifetime cancer risk to an exposed man or woman would be 0.405001 or 0.389001, respectively.

Although there is no universally accepted allowable risk standard, the U.S. EPA Superfund program established under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) generally considers LECRs below 1×10^{-6} (1 in 1,000,000, also known as the *de minimis* risk level) to be allowable in nearly all circumstances and risks within the range of 1×10^{-4} to 1×10^{-6} (1 in 10,000 to 1 in 1,000,000) to be allowable depending on specific site and exposure characteristics (U.S. EPA, 1989; U.S. EPA, 1991b). The National Contingency Plan (U.S. EPA, 1994), which provides the guidelines and procedures needed to respond to releases and threatened releases of hazardous substances, pollutants, or contaminants under CERCLA, defines the 1×10^{-6} (1 in a million) risk level as the "point of departure" for establishing remediation goals at contaminated sites. Risks above 1×10^{-4} are nearly always considered unacceptable. More specific allowable risk levels have been identified for certain circumstances. For example, under U.S. EPA's Great Lakes Initiative (U.S. EPA, 1995), a 1×10^{-5} (1 in 100,000) risk level is identified for use in deriving criteria and values for individual carcinogens in Great Lakes surface water and fish. Under the Health Advisory (HA) program for drinking water, U.S. EPA's Office of Water publishes Drinking Water Specific Risk Level Concentrations of drinking water contaminants corresponding to a lifetime excess cancer risk of 1×10^{-4} (1 in 10,000) (U.S. EPA, 2018).

5.2 HHRA Results

Noncancer hazards and cancer risks were calculated for each of the exposure scenarios and populations for the eight COIs. Hazards and risks estimated assuming continuation of the current reclaimed water treatment scenario ("baseline" scenario) and applying EPCs for tap or well water estimated for the closest potential point of exposure (200 feet downgradient of the recharge basins) are discussed in Section 5.2.1. This baseline scenario represents the most conservative (i.e., health-protective) estimate of hazards and risks. For comparison, hazards and risks associated with different potential water treatment scenarios are discussed in Section 5.2.2. In addition, hazards and risks estimated for a range of fish consumption rates are discussed in Section 5.2.3.

Note that in this HHRA, estimated noncancer hazards and cancer risks are presented to two significant figures because most inputs to the dose and risk calculations are estimated to two or more

significant figures (including the EPCs, most exposure parameters, and some toxicity criteria) and to distinguish between calculated hazard and risk estimates for different chemicals and scenarios that have slightly different values for input parameters. However, some risk assessment guidance, including U.S. EPA's *Risk Assessment Guidance for Superfund: Volume I – Human Health Evaluation Manual (Part A)* (U.S. EPA, 1989), recommends that risk estimates be expressed using one significant figure only because of limitations in the number of significant figures in some input parameters. Consequently, resulting hazards and risks estimated to only one significant figure are also noted in the discussion below.

5.2.1 *Estimated Upper Bound Noncancer Hazards and LECRs for the Baseline Treatment Scenario*

Upper bound estimates of noncancer hazards (HIs) and chemical-specific LECRs for residents, maintenance workers, and playfield/water feature recreators associated with the current treatment scenario (i.e., applying the EPCs presented in Table 3-1, and not implementing RO-AOP or O3-BAC-GAC or other potential treatment options) assuming exposure to tap or well water 200 feet downgradient of the infiltration basins are presented in Table 5-1 (HIs) and Table 5-2 (LECRs). Results reflect the sum of chemical-specific upper bound HQs or LECRs for individual pathways for each scenario and population. Detailed results for each pathway are presented in Appendix D. Upper bound estimates of noncancer HIs that exceed 1.0 and of LECRs that exceed a *de minimis* risk level of 1 in 1,000,000 (1×10^{-6}) are bolded in Table 5-1 and Table 5-2, respectively.

Estimated upper bound noncancer HIs exceed 1.0 for only one chemical and scenario—PFPeA for the RME child resident exposure scenario, with an estimated HI of 1.3 (if rounded to one significant figure, HI = 1). Estimated HIs for PFPeA for the shallow and deep aquifers are nearly the same because the estimated EPCs for these aquifers are nearly the same (with the EPCs for the deep aquifer being slightly lower). As shown in the detailed results in Appendix D, more than 99% of the estimated HI for the child or adult is contributed by the water ingestion pathway. Estimated upper bound HIs for all other chemicals and scenarios, including the RME adult resident scenario and the MLE child and adult resident scenarios, are below 1.0. For the resident scenarios, estimated upper bound HIs for the child are approximately two times those of the adult (HIs are estimated based on an annualized average dose and typically, average intakes on a per kilogram body weight basis are greater for a child than an adult).

Estimated upper bound LECRs exceed the *de minimis* cancer risk benchmark of 1 in 1,000,000 (1×10^{-6}) for only one chemical and scenario—NMDA for the RME resident scenario, with an estimated LECR of 2.9×10^{-6} (if rounded to one significant figure, LECR = 3×10^{-6}). This can be interpreted as a probability that, at the upper bound of the risk estimates, 2.9 persons in one million (10^6) people could develop cancer if they are exposed to this chemical at this rate over their lifetime. Estimated upper bound LECRs for NDMA for the shallow and deep aquifers are nearly the same because the estimated EPCs for these aquifers are nearly the same (with the EPCs for the deep aquifer being slightly lower). As shown in the detailed results in Appendix D, more than 99% of the estimated upper bound risk is contributed by the water ingestion pathway. Estimated upper bound LECRs for all other chemicals and scenarios, including the MLE resident scenario, are below 1×10^{-6}.

Note that while the upper bound LECR estimate for NDMA for the RME resident scenario slightly exceeds a *de minimis* one-in-a-million LECR, it falls within the range of risks considered to be allowable by U.S. EPA and others at different sites depending on specific site characteristics (1×10^{-4} to 1×10^{-6}, or 1 in 10,000 to 1 in 1,000,000; see Section 5.1.2).

The noncancer hazard and cancer risk estimates presented in Tables 5-1 and 5-2 are based on the current treatment scenario and assume exposure to tap or well water at EPCs estimated for the location 200 feet downgradient of the infiltration basins. As shown in Table 3-1, for some COIs, predicted concentrations further downgradient decrease dramatically with distance (e.g., for 1,4-dioxane, carbamazepine, primidone, and quinoline). However, for NDMA and the PFAS chemicals, estimated EPCs do not change substantially with downgradient distance.

5.2.2 *Estimated Noncancer Hazards and LECRs for Different Treatment Scenarios*

For comparison, noncancer hazards and cancer risks corresponding to predicted EPCs assuming implementation of two possible enhanced reclaimed water treatment options (RO-AOP or O3-BAC-GAC) were also estimated.

Effects of the two possible treatment options on estimated chemical-specific upper bound noncancer HIs for the child resident RME scenario for the shallow and deep aquifers are illustrated in Figures 5-1 and 5-2, respectively, and effects on chemical-specific upper bound LECRs are illustrated in Figures 5-3 and 5-4, respectively. Estimates are based on EPCs estimated for the 200-ft downgradient location. As shown, both treatment options resulted in reduction of the upper bound HIs and LECRs to levels that do not exceed U.S. EPA's allowable risk range.

5.2.3 *Estimated Noncancer Hazards and LECRs for Creek Recreator/ Fish Consumer Scenarios, Based on Different Fish Consumption Assumptions*

As described in Section 3.3.3.5, given the uncertainty regarding actual consumption rates of fish from McAllister Creek and Woodland Creek, potential upper bound noncancer hazards and cancer risks associated with the creek recreator/ fish consumer scenarios were estimated based on several different fish consumption rates. Noncancer hazards and LECRs for the different fish consumption assumptions scenarios are presented in Tables 5-3 and 5-4, respectively. Noncancer hazards and cancer risks were not estimated for 1,4-dioxane, carbamazepine, primidone, and quinoline because they were not predicted to be transported to the creeks. In addition, noncancer hazards were not estimated for NDMA because it is not evaluated as a noncarcinogen, but is evaluated as a carcinogen.

None of the estimated noncancer hazards and LECRs based on these assumed fish consumption rates exceed U.S. EPA's allowable risk ranges.

5.3 Risk Discussion and Relative Risk Estimates

The following sections provide context on results of the HHRA to support interpretation of risk estimates, including comparisons to allowable risk ranges and to other types of exposures and risks.

5.3.1 *Interpretation of Noncancer Hazard Estimates for PFPeA and Cancer Risk Estimates for NDMA*

As discussed in Section 5.2.1, for the baseline treatment scenario, estimated upper bound noncancer HIs slightly exceed unity (1.0) for only one chemical and scenario (PFPeA, for the RME child resident scenario, with an estimated HI of 1.3) and estimated upper bound cancer LECRs slightly exceed the lower limit of U.S. EPA's allowable LECR range (which ranges from 1×10^{-6} to 1×10^{-4}) for one chemical and scenario for the cancer assessment (NDMA, with an estimated LECR of 2.9×10^{-6} for the RME resident scenario). In both cases, the estimated hazard and risk estimates are the same whether exposure is assumed to be from the shallow aquifer or the deep aquifer.

One can interpret the upper bound HI estimate of 1.3 for PFPeA for the RME child resident scenario as follows:

- If a child is exposed to the assumed EPC concentration of PFPeA in water from either aquifer (concentration = approximately 79 ng/L) within their home nearly every day year round (350 days per year) and consumes all of their daily drinking water as tap water from the home (approximately 1 L/d for a child), bathes daily at home, and resides in and breathes air continuously within the home, the upper bound estimate of their average daily dose could slightly exceed U.S. EPA's allowable daily dose for this chemical (that is, the estimated HI slightly exceeds unity, or 1.0).
- However, if a child drinks less water or spends less time in the home (e.g., goes to school, recreates, or travels away the home for a portion of the day or for more than 15 days per year), their HI would be lower. If exposure rates are more consistent with average rather than upper bound rates (e.g., consistent with the MLE rather than the RME scenario), estimated average daily doses do not exceed U.S. EPA's allowable daily dose for this chemical (that is, the estimated HI is less than 1.0).
- An HI >1 does not mean that adverse health effects are expected or will occur. In fact, if the HI is close to 1 (as is the case here), adverse health effects are unlikely even if a person's exposure is at the estimated upper bound level. This is because multiple uncertainty factors are incorporated into the derived the toxicity criterion for noncancer effects (i.e., the allowable daily dose) to ensure it is a level at or below which adverse health effects are not expected.
- For PFPeA, the estimated allowable daily dose for noncarcinogenic effects applied in this assessment is a "chronic reference dose" (RfD) set by the TCEQ. No other regulatory agency has established a toxicity criterion for PFPeA, including the U.S. EPA, ATSDR, or the State of California. Because no toxicological studies of sufficient quality have been conducted for PFPeA, the TCEQ set its RfD equal to that for PFHxS, a structurally similar compound. TCEQ noted that toxicological data for PFHxS are also limited, and the RfD was based on findings of effects on the liver of male rats administered large doses of this compound. To derive the RfD, the lowest dose of PFHxS that caused an effect in rats was divided by a factor to account for the assumed difference in the half-life of this compound in the bodies of humans compared to rodents, as well as multiple other uncertainty factors, to yield an assumed allowable dose that is nearly 80,000-fold lower than the dose that caused an effect in rats.

One can interpret the upper bound LECR estimate of 2.9×10^{-6} for NDMA for the RME resident scenario as follows:

- If a person is exposed to the assumed EPC of NDMA in water from either aquifer (approximately 3.2 ng/L) within their home nearly every day of the year (350 days per year) for the entire duration of their residential tenure (initially as a child and then as an adult, for a total of 32 years), and consumes all of their daily drinking water as tap water from the home (approximately 1 L/d for a child and 2.6 L/d for an adult), bathes daily at home, and resides in and breathes air continuously within the home, their upper bound estimated LECR could slightly exceed the U.S. EPA's most stringent estimate of the allowable risk range (i.e., the *de minimis* risk level of 1×10^{-6}).
- If a person drinks less water or spends less time in the home (e.g., goes to school, works, recreates, or travels outside the home for a portion of the day or for more than 15 days per year), their LECR would be less than estimated for the RME scenario. If their exposure rates are consistent with average rather than upper bound exposure rates (e.g., consistent with the MLE rather than the RME scenario), their estimated LECR would be predicted to fall below the lower limit of U.S. EPA's allowable risk range (i.e., the *de minimis* risk level of 1×10^{-6}).

- For perspective, the average person in the U.S. has an approximately 2 in 5 chance of being diagnosed with cancer at some point in their lifetime (0.405000 for a male and 0.389000 for a female; ACA, 2021). For the above cancer risk estimate of 2.9×10^{-6} (equivalent to 2.9 in a million or 0.0000029), the estimated upper bound total lifetime cancer risk to an exposed man or woman would be 0.4050029 or 0.3890029, respectively.

Note that while the upper bound LECR estimate for the residential resident scenario slightly exceeds a *de minimis* one-in-a-million risk level, it falls within the range of risks considered to be allowable by U.S. EPA and others at different sites depending on specific site characteristics (1×10^{-4} to 1×10^{-6}, or 1 in 10,000 to 1 in 1,000,000; see Section 5.1.2).

As discussed in Section 5.1.2, although there is no universally accepted allowable risk standard, the U.S. EPA Superfund program established under CERCLA generally considers LECRs below 1×10^{-6} (1 in 1,000,000, also known as the *de minimis* risk level) to be allowable in nearly all circumstances and risks within the range of 1×10^{-4} to 1×10^{-6} (1 in 10,000 to 1 in 1,000,000) to be allowable depending on specific site and exposure characteristics (U.S. EPA, 1989; U.S. EPA, 1991b). For example, per U.S. EPA (2015), where the estimated cumulative carcinogenic risk to the RME individual is less than 1×10^{-4} and the non-carcinogenic HI is less than or equal to 1, remedial action is not warranted under Superfund unless there are adverse environmental impacts, or the applicable or relevant and appropriate requirements (ARARs) are not met.

5.3.2 *Comparison of Selected Input Variables to the Range of Potential Values for These Variables*

As discussed in Section 5.2.1, estimated upper bound noncancer HIs and LECRs for the baseline treatment scenario slightly exceed allowable risk thresholds under the RME resident scenario, for one chemical in the noncancer assessment (PFPeA, with an estimated upper bound HI of 1.3 for the RME child resident scenario) and one chemical in the cancer assessment (NDMA, with an estimated upper bound LECR of 2.9×10^{-6} for the RME resident scenario).

The RME scenario is intended to reflect a high end estimate of potential exposures. Per U.S. EPA (1989), the RME is defined as the highest exposure that is reasonably expected to occur at a site, and is intended to estimate a conservative exposure case (i.e., well above the average case) that is still within the range of possible exposures, e.g., within approximately the 90^{th} to 99.9^{th} percentiles of the risk distribution for an exposure scenario. Consistent with U.S. EPA (1989) recommendations, exposure parameters for this scenario were selected such that the combination of intake variables for a pathway results in an estimate of the reasonable maximum exposure for that pathway, using for some variables values that are near the upper bound of reasonably possible estimates and others representing more average values. When the parameters are multiplicatively combined, the resulting estimates of exposure and risk are at the upper bounds of the exposure and risk distributions.

To provide perspective on where the input parameters, and as such the estimated doses, for the RME resident scenarios (and corresponding estimated noncancer hazards and cancer risks) fall within the range of possible exposures and risks, the values selected for several key input parameters in the tap water ingestion calculation are elaborated upon in Appendix B and summarized in Table 5-5.

As described:

- The selected tap water ingestion rates (IR_{water}) for the child and adult RME residents fall at approximately the 90^{th} percentiles of their distributions (based on data for consumer-only combined direct and indirect water ingestion rates of community water, collected as part of the

National Health and Nutrition Examination Survey (NHANES) for the U.S. for 2005−2010 (U.S. EPA, 2019a) (see Figures B-1 and B-2 in Appendix B).

- The selected total exposure duration (ED) for the RME resident (child and adult combined) (6 for a child and 26 for an adult, or 32 years combined) falls at approximately the 90th percentile of total lifetime residence time in a home in the U.S., based on 2007 U.S. Census Bureau data (U.S. EPA, 2011) (see Figure B-3 in Appendix B).
- The selected body weights (BW) for the child and adult RME residents fall at the 2nd percentile and mean, respectively of body weights for children age 2 to 11 and adults age 16 to <70 years (based on U.S. EPA's analysis of NHANES data for 1999−2006; U.S. EPA, 2011) (since the BW parameter is in the denominator of the dose equation, a relatively lower value will result in a higher dose and risk estimate) (see Figures B-4 and B-5 in Appendix B)

5.3.3 *Comparison to Exposures from Other Sources*

People can be exposed to PFPeA and NDMA from other sources. To provide perspective on the relative magnitude of the doses of these chemicals that were estimated in the HHRA, potential exposures from other sources are described below.

5.3.3.1 Other Sources of Exposure to PFPeA

Major potential pathways of exposure to PFAS (based largely on exposure data for PFOA and PFOS) include general food and water ingestion, ingestion of foods contaminated by migration of PFAS from paper packaging and wrapping into food, ingestion of house dust, inhalation from impregnated clothes, and hand-to-mouth transfer from mill-treated carpets (Trudel et al., 2008; ATSDR, 2021).

Very limited data are available on sources of exposure to PFPeA other than drinking water, due to a lack of investigations focusing on this chemical. No data on PFPeA exposures specific to the United States were located. The European Food Safety Authority (EFSA, 2020) reported estimated dietary exposure levels for PFPeA and other PFAS for infants (<12 months), toddlers (≥ 12 months to <36 months), "other children" (≥ 36 months to <10 years), adolescents (≥ 10 to <18 years), adults (≥18 to <65 years), elderly persons (≥ 65 to <75 years), and "very elderly" persons (≥ 75 years), based on dietary surveys conducted between 2010 and 2018 in as many as 25 European countries. The majority of data were provided by France, Germany, and Norway. Lower- and upper-bound estimates of average daily exposure were derived by assigning a value of zero to nondetected measurements in the derivation of lower bound estimates and a value equal to the detection limit to nondetected measurements in the derivation of upper bound estimates.

Table 5-6 summarizes estimates of daily dietary exposure levels to PFPeA reported in EFSA (2020). Given that the "lower bound" mean estimate assumes a concentration of "zero" for all nondetects (a likely underestimate) and the "upper bound" mean estimate assumes that all nondetect values are at the detection limit (a likely overestimate), the true mean exposure level is expected to be between the two values. For example, for a child age 3 to 10 years, the lower bound estimate of mean dietary exposure to PFPeA is 0.28 ng/kg-d and the upper bound estimate is 14.49 ng/kg-d; a more likely exposure level can be approximated as around 7.3 ng/kg-d. For an adult, the lower bound estimate of mean daily dietary exposure to PFPeA is 0.07 ng/kg-d, and the upper bound estimate is 4.80 ng/kg-d; a more likely exposure level can be approximated as around 2.4 ng/kg-d.

Per EFSA (2020), fish and other seafood and liquid milk were the major dietary contributors to PFPeA exposure for all age groups. However, specific dietary intakes by food type are not reported

in the document. Other significant dietary sources of exposure to PFAS (specifically PFOA and PFOS) include cereal products, fruits and vegetables, and meats (ATSDR, 2021).

For comparison, the estimated upper bound ADD of PFPeA for the RME resident scenario is approximately 5.0 ng/kg-d for a child and 2.5 ng/kg-d for an adult, based on exposure through ingestion and dermal contact with tap water. If the values in Table 5-6 are assumed to be reasonable estimates of exposure to PFPeA for U.S. populations, estimated upper bound RME resident exposures to PFPeA from tap water are predicted to be comparable to exposures from dietary sources.

While data on exposure levels to PFPeA specific to the U.S. were not identified, abundant data have been collected on potential sources of exposure to PFOA and PFOS in the U.S. Data collected by EFSA (2020) for PFOA and PFOS for each age group suggest that estimated average daily doses of PFOA and PFOS are similar to estimated average daily doses for PFPeA (e.g., within the same order of magnitude). Per U.S. EPA (2016b), estimates of the relative contribution of dietary sources to total daily exposure to PFOA range from about 20 to 50%, with drinking water contributing up to 20% of daily exposure. Other sources of exposure to PFOA identified in U.S. EPA's assessment include dust and air, with an undetermined contribution from dermal exposure. These estimates of relative source contributions are consistent with the above estimates of relative average daily doses of PFPeA from diet compared to drinking water based on European data, and support the assumption that contributions from drinking water are comparable to or somewhat less than from diet.

5.3.3.2 Other Sources of Exposures to NDMA

Other than drinking water, NDMA exposure can occur through ingesting food that contains nitrosamines, such as smoked or cured meats and fish, dried milk and formula, and vegetables, ingesting food that contains nitrates such as cured meats and fish and vegetables, which can result in formation of NDMA in the stomach, and drinking malt beverages such as beer and whiskey, that may contain low levels of nitrosamines formed during processing (ATSDR, 1989; U.S. EPA, 2017c). Use of toiletry and cosmetic products, such as shampoos and cleansers, that contain NDMA and inhaling cigarette smoke can also lead to dermal or inhalation exposures. However, the oral route is assumed to be the primary pathway of exposure to NDMA (ATSDR 1989; U.S. EPA, 2017c).

Average daily intakes of NDMA from sources outside the body (exogenous sources) other than drinking water for children and adults in the U.S. were estimated by Fristachi and Rice (2007) and Chowdhury (2014) and are summarized in Table 5-7. These estimates do not include NDMA formed endogenously (in the body) from nitrates. Estimates of endogenous NDMA formation are not known precisely, but Fristachi and Rice (2007) estimated an endogenous production rate of NDMA of 0.37 µg/d, based on a study that predicted production rates *in vitro* under simulated gastric conditions. Assuming a mean adult body weight of 71.9 kg (which the authors assumed in their study), this is equal to 5.146 ng of endogenously produced NDMA per kilogram of body weight per day (ng/kg-d).

Table 5-8 compares the estimated upper bound LADD of NDMA for the RME resident scenario (0.056 ng/kg-d) to estimated total daily oral doses of NDMA from nondrinking water exogenous sources and endogenous sources. As shown, the estimated LADD of NDMA for the RME resident ranges from about 1.0 to 3.0% of doses estimated for either exogenous (nondrinking water) or endogenous exposure.

5.3.4 *Potential Additive Effects of PFAS Compounds*

Three of the COIs evaluated in the HHRA are classified as PFAS: perfluoroactanoic acid (PFOA), perfluoro-n-hexanoic acid (PFHxA), and perfluoropentanoic acid (PFPeA). These chemicals belong

to a large family of human-made compounds that have been used extensively worldwide in surface coating and protectant formulations due to their unique surfactant properties, including in paper and cardboard packaging products, carpets, leather products, and textiles, in firefighting foams, and in nonstick coatings on cookware (ATSDR, 2021). Structurally, all of the chemicals are organic compounds comprised of a linear or branched carbon backbone with fluorine atoms substituting for all of the hydrogen atoms. Due to the strength of the carbon-fluorine bonds, they are very stable in the environment and are resistant to biodegradation, photooxidation, direct photolysis, and hydrolysis. Of the chemicals in this family, PFOA and PFOS have undergone the most toxicological study, while toxicological data for the other chemicals is limited. Specifically, several have been investigated in acute duration oral studies [perfluorohexane sulfonate (PFHxS, perfluorononanoic acid (PFNA), perfluorodecanoic acid (PFDA), perfluorobutyric acid (PFBA), perfluorododecanoic acid (PFDoDA), PFHxA, and perfluorooctane sulfonamide (PFOSA)] or intermediate-duration oral studies [PFHxS, PFNA, PFDA, perfluoroundecanoic acid (PFUnA), PFBS, PFBA, PFDoDA, and PFHxA], one has been investigated in a chronic-duration oral study (PFHxA), and one has been investigated in an acute-duration-inhalation study (PFNA) (ATSDR, 2021).

Given the structural similarity of these compounds and the finding from mechanistic studies that the toxicity of at least some of these compounds is mediated in part by the peroxisome proliferator-activated receptor alpha (PPARα), it is likely that some interaction of toxicological response (e.g., additivity or synergism) may occur with coexposures (i.e., simultaneous exposure to multiple compounds, as may occur if they are present in drinking water) (Wolf et al., 2014). However, very little data are available on the potential additive effects of combinations of these compounds. While data from some *in vitro* studies suggest that at higher concentrations, effects of combinations of compounds may be less than additive (Carr et al., 2013; Wolf et al., 2014), the relationship of these findings to effects in living systems is not known.

Regardless, if it is assumed that the three PFAS COIs evaluated in this HHRA act toxicologically through a similar mechanism of action, a conservative (health-protective) and simplistic upper bound estimate of the potential for an additive response could be derived by adding the estimated HIs and LECRs for the three COIs for each of the scenarios. Using the data for the baseline treatment scenario (see Table 5-1), summed HIs for the child scenarios, excluding the creek recreator/ fish consumption scenarios, range from 0.57 (deep aquifer, playfield scenario) to 2.5 (shallow aquifer, RME resident scenario) and for the adult scenarios, excluding the creek recreator/ fish consumption scenarios, range from 0.39 (deep aquifer, MLE resident scenario) to 1.3 (shallow aquifer, RME resident scenario), with upper estimates exceeding 1.0 only for the RME resident scenarios. Summed LECRs (see Table 5-2), excluding the creek recreator/ fish consumption scenarios, range from 1.3×10^{-8} (shallow and deep aquifer, playfield/water feature recreator scenarios) to 1.8×10^{-7} (shallow aquifer, RME resident scenario). For the creek recreator/ fish consumption scenarios, summed HIs under the high end fish consumption scenario range from 0.018 (McAllister Creek) to 0.90 (Woodland Creek) for the child and from 0.0034 to 0.17 for the adult, and summed LECRs range from 1.1×10^{-9} to 5.7×10^{-8}.

Thus, upper bound estimates of combined noncancer HIs slightly exceed risk thresholds for the most conservative exposure scenario (RME resident) but are less than 1.0 for all other scenarios, and no carcinogenic risks that exceed U.S. EPA's allowable risk range are estimated for any scenario.

Under the two evaluated additional possible treatment options, no noncancer hazard is predicted for any of the PFAS following treatment by RA-AOP (Option 1) as these compounds are predicted to be completely removed, and estimated hazards based on the summation of the three chemicals for the other option (O3-BAC-GAC, Option 2) are below 1.0 for all scenarios.

5.3.5 *Characterization of Hazards and Risks for Pharmaceutical Compounds*

Two pharmaceutical compounds were considered as COIs in the HHRA. These chemicals—carbamazepine and primidone—are anticonvulsants, administered to control seizures. One way to characterize estimates of relative risks determined in the HHRA for these compounds is to estimate the amount of water with the EPC corresponding to that compound that a person would have to consume, in 8-ounce glasses of water per day, to reach a dose equal to the amount in one standard pharmaceutical dose (e.g., one tablet) of the chemical.

For example, one standard tablet of carbamazepine contains 100 mg of the compound (Novartis, 2010). The EPC of carbamazepine estimated for the shallow aquifer at the point 200-feet downgradient of the discharge basins that was applied in the HHRA is 280 ng/L (at locations more distant from the source, the predicted concentration is zero). To estimate the number of 8-ounce glasses of water with this concentration one would have to consume to receive a dose equivalent to a single tablet of carbamazepine, the calculation is as follows:

$$1\ tablet \times \frac{100\ mg}{tablet} \times \frac{L}{280\ ng} \times \frac{1{,}000{,}000\ ng}{mg} \times \frac{33.814\ ounces}{L} \times \frac{glass}{8\ ounce} = \sim 1{,}500{,}000\ \text{8-oz glasses}$$

Based on these results, a person would have to drink at least 1,500,000 8-oz glasses of water a day (about 94,000 gallons) to reach a dose equal to one tablet of carbamazepine.

For primidone, a standard tablet contains 50 mg of the compound (RxList.com, 2021), and the EPC estimated for the shallow aquifer and applied in the HHRA is 178 ng/L (this is at 200-feet downgradient of the discharge basins; at all more distant locations, the predicted concentration is zero). To estimate the number of 8-ounce glasses of water with this concentration one would have to consume to get a dose equivalent to a single tablet of primidone, the calculation is as follows:

$$1\ tablet \times \frac{50\ mg}{tablet} \times \frac{L}{178\ ng} \times \frac{1{,}000{,}000\ ng}{mg} \times \frac{33.814\ ounces}{L} \times \frac{glass}{8\ ounce} = \sim 1{,}200{,}000\ \text{8-oz glasses}$$

Based on these results, a person would have to drink approximately 1,200,000 8-oz glasses of water a day (about 74,000 gallons) to reach a dose equal to one tablet of primidone.

5.4 Risk Characterization Uncertainties

In the HHRA, if a COI selected in the screening-level evaluation was not detected in monitoring wells downgradient of the infiltration site, it was excluded from further quantitative evaluation because it is assumed that attenuation and degradation processes result in the chemical's removal from groundwater. This approach is consistent with U.S. EPA's (2017a) recommendation to assume a concentration of "zero" if one can be reasonably confident a chemical is not present (for example, if it has not been detected in any samples downgradient of a source).

However, several of the chemicals considered in the screening-level evaluation that were not detected in groundwater monitoring have minimum reporting limits (MRLs) for groundwater samples that exceed the chemical's DWEL or 10% of the DWEL. These include the following:

- Chloramphenicol: MRL = 10 ng/L; DWEL = 4.3 ng/L
- Estradiol, 17beta-: MRL = 5 ng/L; DWEL = 0.25 ng/L
- Estrone: MRL = 5 ng/L; DWEL = 0.58 ng/L
- Ethinyl estradiol, 17alpha-: MRL = 5 ng/L; DWEL = 0.083 ng/L
- Norethisterone: MRL = 5 ng/L; DWEL = 0.86 ng/L
- Albuterol: MRL = 5 ng/L; DWEL = 6.7 ng/L

- Perfluoro octanesulfonate (PFOS): MRL = 5 ng/L; DWEL = 15 ng/L
- Perfluoro octanesulfonic acid (PFOS): MRL = 5 ng/L; DWEL = 15 ng/L
- Perfluoro-n-nonanoic acid (PFNA): MRL = 5 ng/L; DWEL = 14 ng/L
- TDCPP: MRL = 100 ng/L; DWEL = 80 ng/L

In cases where a chemical is not detected, it is possible that it could be present at some concentration below the MRL. However, for most of these chemicals (excluding the hormones), the MRL is actually less than or only slightly above the DWEL. Because of the conservative assumptions made in the HHRA (as discussed in Section 5.3), is not likely that even if present in some samples at just below the MRL, that exposures to the chemical would be associated with a significant human health risk.

For the hormones (estradiol, 17beta-; estrone; ethinyl estradiol, 17alpha-; norethisterone), MRLs are in some cases much higher than the DWEL. When conducting baseline (screening-level) risk assessment, U.S. EPA suggests that if a chemical is not detected but one is reasonably confident that it might be present (based on site history, etc.), one can assume the nondetected chemical is present at one-half its MRL (U.S. EPA, 2017a; U.S. EPA, 2019b). This approach essentially assumes that on average, all values between zero and the detection limit could be present and that the average value of non-detects could be as high as half the detection limit. This approach seeks to achieve a balance between the potential bias towards underpredicting risk if one were to assume that the chemical is not present at all (i.e., EPC = 0) and overpredicting risk if one were to assume the chemical is present at or just under the MRL (i.e., EPC = MRL).

However, for chemicals with no supporting information to suggest they could be present (i.e., they are never detected) and evidence suggests these types of chemicals would be likely to attenuate or degrade, assuming an EPC equal to one-half the MRL could inappropriately bias risks high, as it is more likely that any concentrations that could be present would be very minimal and closer to zero. For example, as indicated in HDR (2021), the literature consistently shows rapid attenuation of estrogenic hormones through soil aquifer treatment (SAT). Thus, it is not likely that these hormones will persist in groundwater downgradient of the recharge basins. Thus, these chemicals were not included in the HHRA. Regardless, if such a chemical does persist at some locations at a concentration less than the detection limit, it could be present at a level that exceeds a threshold level of concern, and its exclusion from the HHRA could result in underprediction of risks.

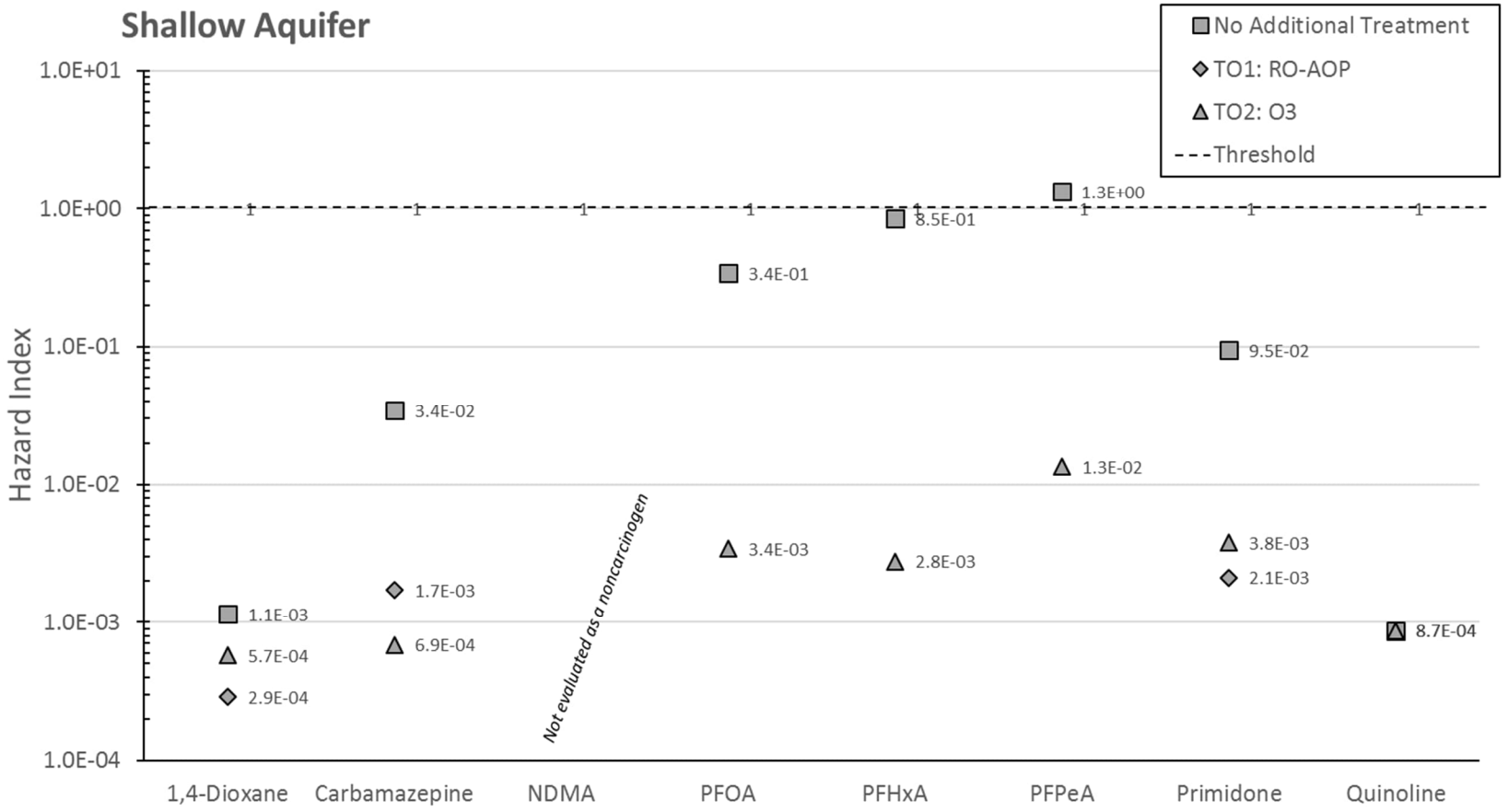

Figure 5-1. Comparison of Estimated Noncancer Hazard Indices (HIs) for the Child Resident-RME Scenario, Assuming Exposure to Water from the Shallow Aquifer, for Different Possible Treatment Options

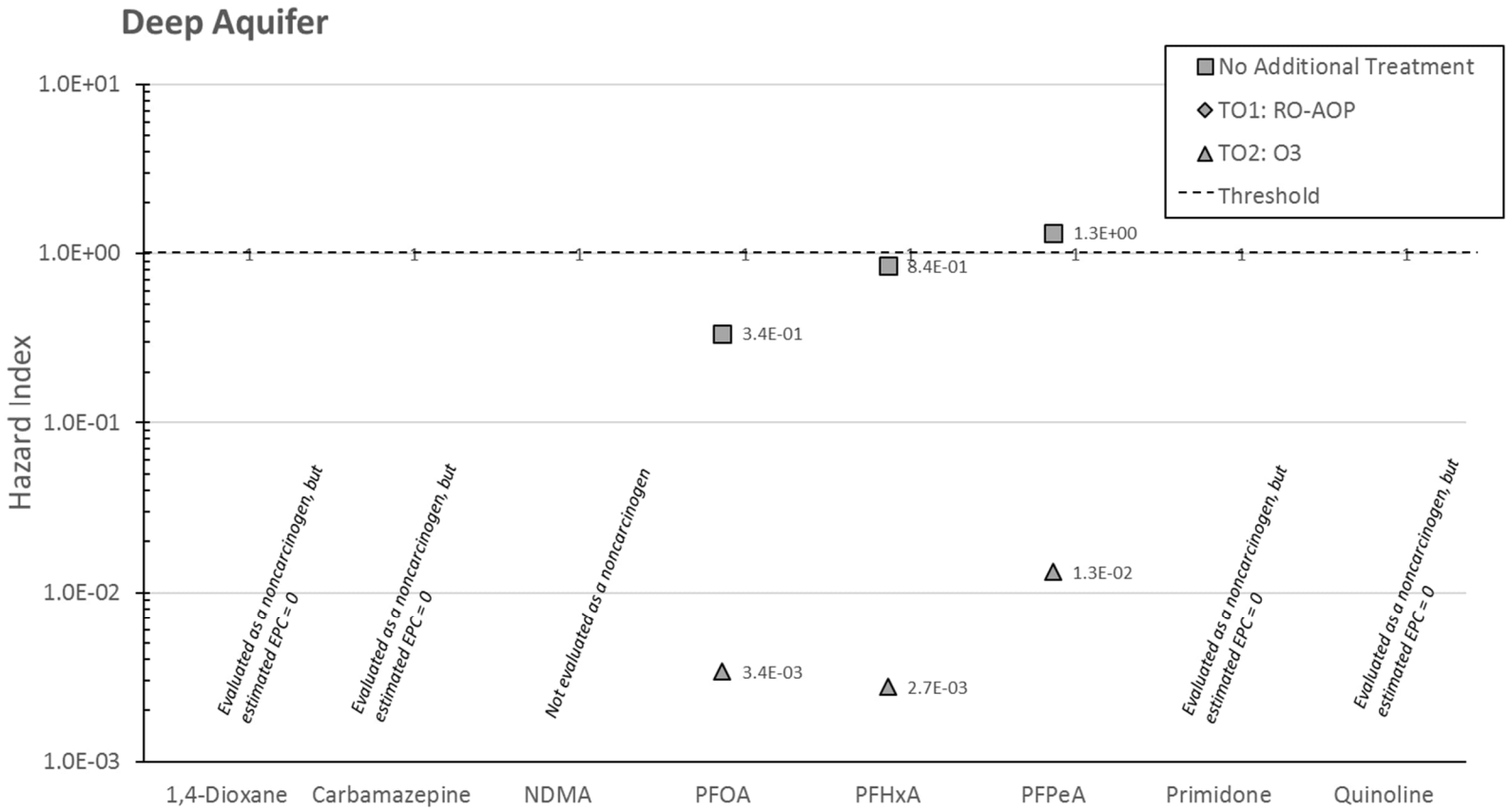

Figure 5-2. Comparison of Estimated Noncancer Hazard Indices (HIs) for the Child Resident-RME Scenario, Assuming Exposure to Water from the Deep Aquifer, for Different Possible Treatment Options

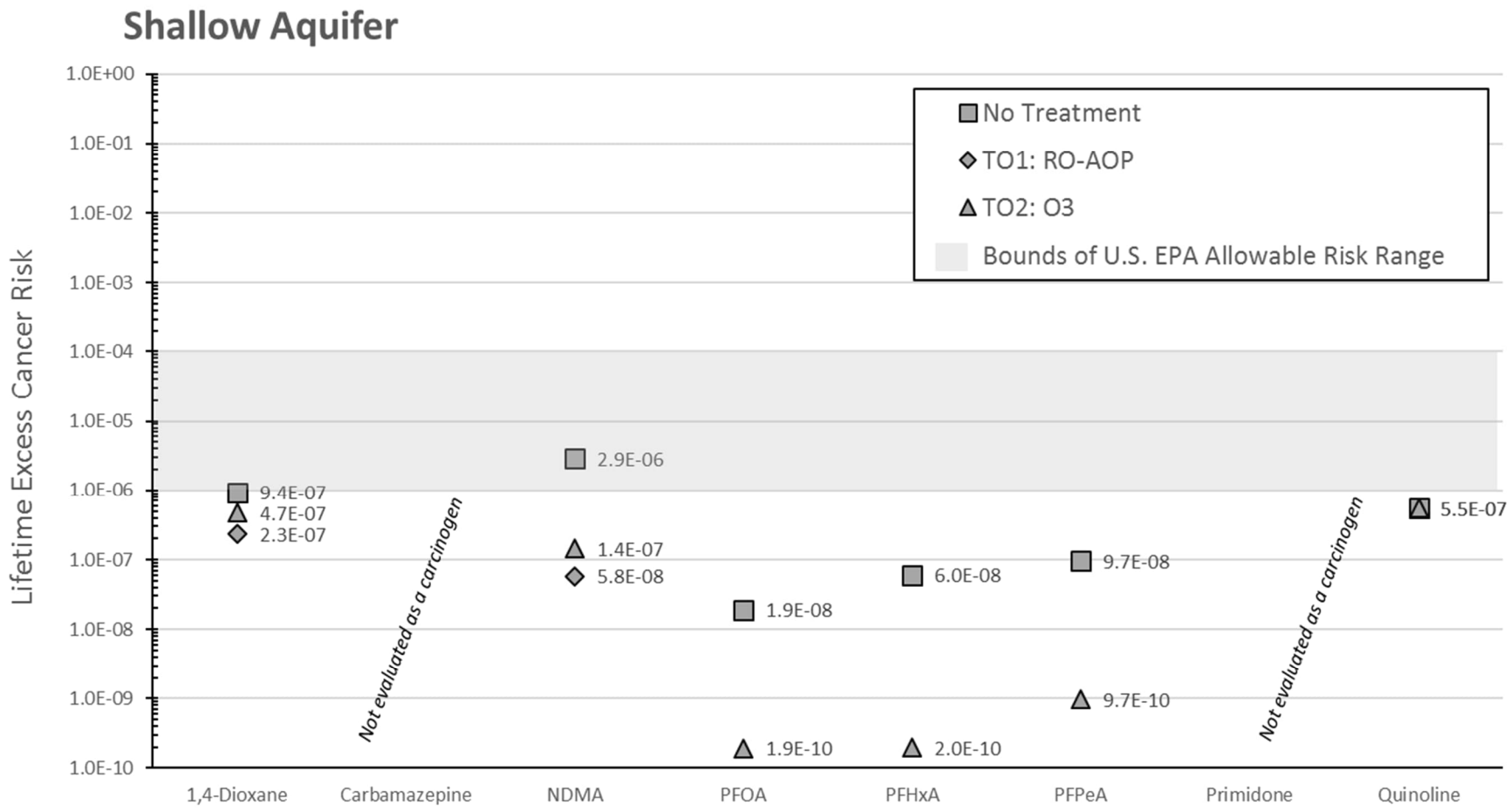

Figure 5-3. Comparison of Estimated Lifetime Excess Cancer Risks (LECRs) for the Resident-RME Scenario, Assuming Exposure to Water from the Shallow Aquifer, for Different Possible Treatment Options

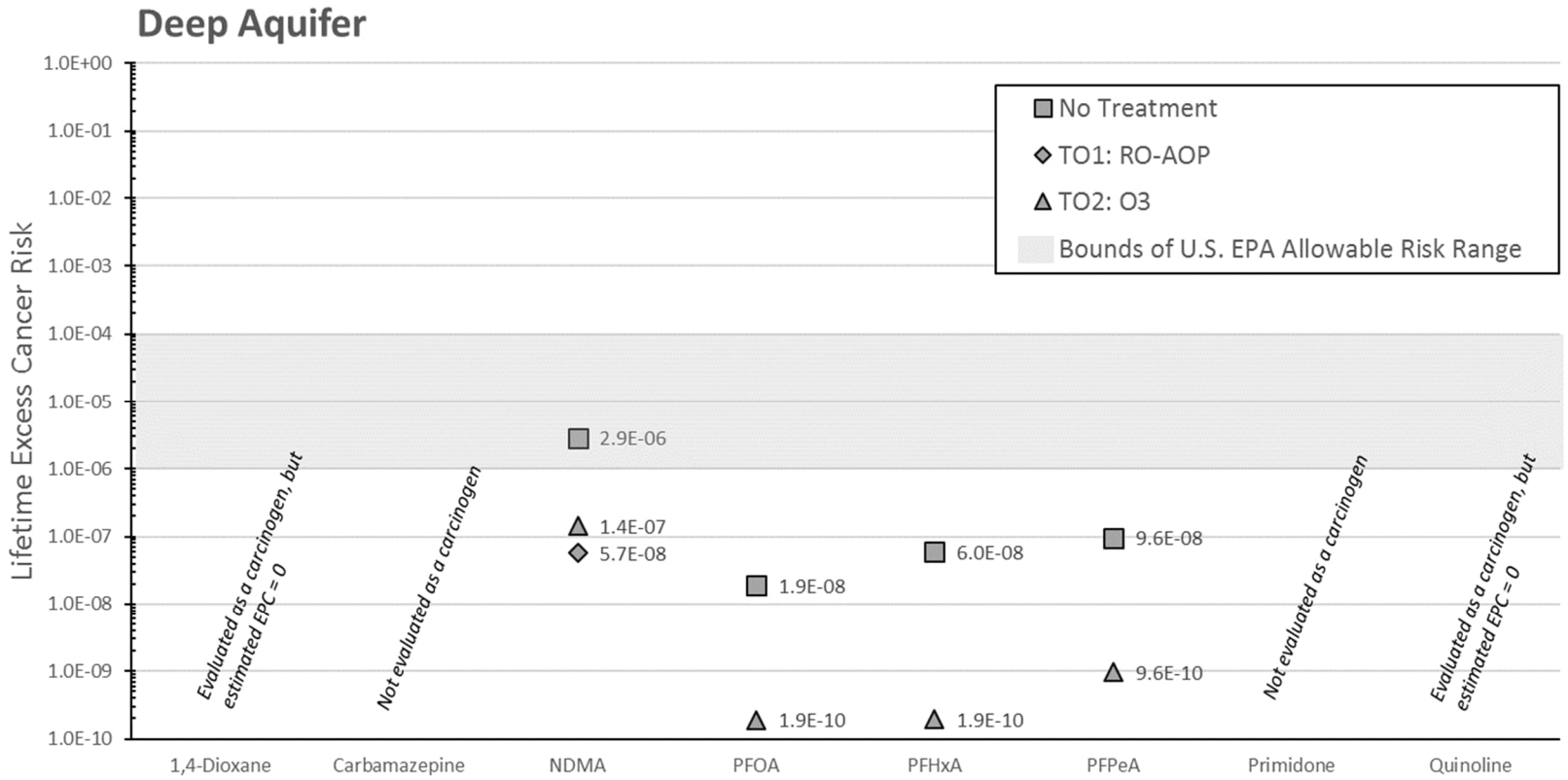

Figure 5-4. Comparison of Estimated Lifetime Excess Cancer Risks (LECRs) for the Resident-RME Scenario, Assuming Exposure to Water from the Deep Aquifer, for Different Possible Treatment Options

Table 5-1. Estimated Chemical- Specific Noncancer Hazard Indices (HIs) for Residents, Maintenance Workers, and Playfield/Water Feature Recreators, Assuming Exposure to Water from the Shallow or Deep Aquifers Under Baseline Treatment Conditions*

Chemical of Interest		Shallow Aquifer				Deep Aquifer			
		Resident-RME	Resident-MLE	Maintenance Worker	Playfield/ Water Feature Recreator	Resident-RME	Resident-MLE	Maintenance Worker	Playfield/ Water Feature Recreator
1,4-Dioxane	Child	0.0011	0.00036	---	0.00026	0†	0†	---	0†
	Adult	0.00058	0.00019	0.00025	---	0†	0†	0†	---
Carbamazepine	Child	0.034	0.011	---	0.0078	0†	0†	---	0†
	Adult	0.017	0.0055	0.0069	---	0†	0†	0†	---
N-Nitroso dimethylamine (NDMA)	Child	Not calculated‡	Not calculated‡	---	Not calculated‡	Not calculated‡	Not calculated‡	---	Not calculated‡
	Adult	Not calculated‡	Not calculated‡	Not calculated‡	---	Not calculated‡	Not calculated‡	Not calculated‡	---
Perfluoro octanoic acid (PFOA)	Child	0.34	0.11	---	0.078	0.34	0.11	---	0.077
	Adult	0.17	0.055	0.069	---	0.17	0.054	0.069	---
Perfluoro-n-hexanoic acid (PFHxA)	Child	0.85	0.29	---	0.19	0.84	0.28	---	0.19
	Adult	0.41	0.14	0.17	---	0.41	0.13	0.17	---
Perfluoropentanoic acid (PFPeA)	Child	**1.3**	0.42	---	0.31	**1.3**	0.42	---	0.30
	Adult	0.67	0.22	0.28	---	0.66	0.21	0.28	---
Primidone	Child	0.095	0.030	---	0.022	0†	0†	---	0†
	Adult	0.047	0.015	0.020	---	0†	0†	0†	---
Quinoline	Child	0.00087	0.00029	---	0.00020	0†	0†	---	0†
	Adult	0.00042	0.00014	0.00017	---	0†	0†	0†	---

*Exposures estimated using EPCs for the closest modeled point (200-ft down gradient of the infiltration basins), assuming no additional treatment options are implemented (baseline scenario). The presented values are derived by dividing the estimated annual average dose of the chemical by its Acceptable Daily Intake (ADI). Values less than one (1.0) indicate that the estimated dose is less than the ADI.
†Estimated EPC is zero (0).
‡Chemical is not evaluated for these scenarios because it is assessed based on its cancer risk, not based on its noncancer hazards.

Table 5-2. Estimated Chemical- Specific Lifetime Excess Cancer Risks (LECRs) for Residents, Maintenance Workers, and Playfield/Water Feature Recreators, Assuming Exposure to Water from the Shallow or Deep Aquifers Under Baseline Treatment Conditions*

	Shallow Aquifer				Deep Aquifer			
Chemical of Interest	**Resident-RME**	**Resident-MLE**	**Maintenance Worker**	**Playfield/ Water Feature Recreator**	**Resident-RME**	**Resident-MLE**	**Maintenance Worker**	**Playfield/ Water Feature Recreator**
1,4-Dioxane	9.4×10^{-7}	1.2×10^{-7}	2.6×10^{-7}	6.8×10^{-8}	0†	0†	0†	0†
Carbamazepine	Not calculated‡	Not calculated‡	Not calculated‡	Not calculated‡	Not calculated‡	Not calculated‡	Not calculated‡	Not calculated‡
N-Nitroso dimethylamine (NDMA)	**2.9×10^{-6}**	3.8×10^{-7}	8.1×10^{-7}	2.1×10^{-7}	**2.9×10^{-6}**	3.8×10^{-7}	8.0×10^{-7}	2.1×10^{-7}
Perfluoro octanoic acid (PFOA)	1.9×10^{-8}	2.7×10^{-9}	5.2×10^{-9}	1.4×10^{-9}	1.9×10^{-8}	2.6×10^{-9}	5.1×10^{-9}	1.4×10^{-9}
Perfluoro-n-hexanoic acid (PFHxA)	6.0×10^{-8}	8.5×10^{-9}	1.6×10^{-8}	4.4×10^{-9}	6.0×10^{-8}	8.4×10^{-9}	1.6×10^{-8}	4.4×10^{-9}
Perfluoropentanoic acid (PFPeA)	9.7×10^{-8}	1.3×10^{-8}	2.7×10^{-8}	7.0×10^{-9}	9.6×10^{-8}	1.3×10^{-8}	2.7×10^{-8}	6.9×10^{-9}
Primidone	Not calculated‡	Not calculated‡	Not calculated‡	Not calculated‡	Not calculated‡	Not calculated‡	Not calculated‡	Not calculated‡
Quinoline	5.5×10^{-7}	7.7×10^{-8}	1.5×10^{-7}	4.0×10^{-8}	0†	0†	0†	0†

*Exposures estimated using EPCs for the closest modeled point (200-ft down gradient of the infiltration basins), assuming no additional treatment options are implemented (baseline scenario). The notation "$\times 10^{-\cdots}$" indicates the estimated probability that a person will develop the particular form of cancer (that is the basis for the chemical's toxicity criterion) due to exposure to this chemical in their lifetime. For example, 9.4×10^{-7} is equivalent to a probability that 9.7 persons in 10^7 (10 million) people will develop the cancer due to the exposure in their lifetime.
†Estimated EPC is zero (0).
‡Chemical is not evaluated for these scenarios because it is not classified as a carcinogen.

Table 5-3. Estimated Chemical- Specific Noncancer Hazard Indices (HIs) for the Creek Recreator/ Fish Consumer Scenarios, Under Baseline Water Treatment Conditions*

Chemical		Woodland Creek Recreator/ Fish Consumer					McAllister Creek Recreator/ Fish Consumer				
		Based on Servings/ year			Based on Squaxin survey		Based on Servings/ year			Based on Squaxin survey	
		10 (5.4 g/d)	25 (13.6 g/d)	50 (27.1 g/d)	"Other fish" consumer (2.37 g/d, child; 9.84 g/d, adult)	High-end consumer (330.5 g/d)	10 (5.4 g/d)	25 (13.6 g/d)	50 (27.1 g/d)	"Other fish" consumer (2.37 g/d, child; 9.84 g/d, adult)	High-end consumer (330.5 g/d)
1,4-Dioxane	Child	0†	0†	0†	0†	0†	0†	0†	0†	0†	0†
	Adult	0†	0†	0†	0†	0†	0†	0†	0†	0†	0†
Carbamazepine	Child	0†	0†	0†	0†	0†	0†	0†	0†	0†	0†
	Adult	0†	0†	0†	0†	0†	0†	0†	0†	0†	0†
N-Nitroso dimethylamine (NDMA)	Child	Not calculated‡	Not calculated‡	Not calculated‡	Not calculated‡	Not calculated‡	Not calculated‡	Not calculated‡	Not calculated‡	Not calculated‡	Not calculated‡
	Adult	Not calculated‡	Not calculated‡	Not calculated‡	Not calculated‡	Not calculated‡	Not calculated‡	Not calculated‡	Not calculated‡	Not calculated‡	Not calculated‡
Perfluoro octanoic acid (PFOA)	Child	0.0066	0.016	0.033	0.0029	0.40	0.00013	0.00033	0.00066	0.000058	0.0080
	Adult	0.0012	0.0031	0.0062	0.0022	0.075	0.000025	0.000062	0.00012	0.000045	0.0015
Perfluoro-n-hexanoic acid (PFHxA)	Child	0.0057	0.014	0.028	0.0025	0.34	0.00011	0.00028	0.00057	0.000051	0.0069
	Adult	0.0011	0.0027	0.0053	0.0019	0.065	0.000021	0.000053	0.00011	0.000039	0.0013
Perfluoropentanoic acid (PFPeA)	Child	0.0026	0.0065	0.013	0.0012	0.16	0.000053	0.00013	0.00026	0.000024	0.0031
	Adult	0.00049	0.0012	0.0024	0.00089	0.029	0.0000098	0.000024	0.000048	0.000018	0.00059
Primidone	Child	0†	0†	0†	0†	0†	0†	0†	0†	0†	0†
	Adult	0†	0†	0†	0†	0†	0†	0†	0†	0†	0†
Quinoline	Child	0†	0†	0†	0†	0†	0†	0†	0†	0†	0†
	Adult	0†	0†	0†	0†	0†	0†	0†	0†	0†	0†

* The presented values are derived by dividing the estimated annual average dose of the chemical by its Acceptable Daily Intake (ADI). Values less than one (1.0) indicate that the estimated dose is less than the ADI.
†Estimated EPC is zero (0).
‡Chemical is not evaluated for these scenarios because it is assessed based on its cancer risk, not based on its noncancer hazards.

Table 5-4. Estimated Chemical- Specific Lifetime Excess Cancer Risks (LECRs) for the Creek Recreator/ Fish Consumer Scenarios, Under Baseline Water Treatment Conditions*

Chemical	Woodland Creek Recreator/ Fish Consumer					McAllister Creek Recreator/ Fish Consumer				
	Based on Servings/ year			Based on Squaxin survey		Based on Servings/ year			Based on Squaxin survey	
	10 (5.4 g/d)	25 (13.6 g/d)	50 (27.1 g/d)	"Other fish" consumer (2.37 g/d, child; 9.84 g/d, adult)	High-end consumer (330.5 g/d)	10 (5.4 g/d)	25 (13.6 g/d)	50 (27.1 g/d)	"Other fish" consumer (2.37 g/d, child; 9.84 g/d, adult)	High-end consumer (330.5 g/d)
1,4-Dioxane	0†	0†	0†	0†	0†	0†	0†	0†	0†	0†
Carbamazepine	Not calculated‡	Not calculated‡	Not calculated‡	Not calculated‡	Not calculated‡	Not calculated‡	Not calculated‡	Not calculated‡	Not calculated‡	Not calculated‡
N-Nitroso dimethylamine (NDMA)	3.4×10^{-10}	6.3×10^{-10}	1.1×10^{-9}	3.2×10^{-10}	1.2×10^{-8}	6.8×10^{-12}	1.3×10^{-11}	2.2×10^{-11}	6.5×10^{-12}	2.4×10^{-10}
Perfluoro octanoic acid (PFOA)	3.6×10^{-10}	9.1×10^{-10}	1.8×10^{-9}	3.3×10^{-10}	2.2×10^{-8}	7.2×10^{-12}	1.8×10^{-11}	3.6×10^{-11}	6.6×10^{-12}	4.4×10^{-10}
Perfluoro-n-hexanoic acid (PFHxA)	4.0×10^{-10}	9.9×10^{-10}	2.0×10^{-9}	3.7×10^{-10}	2.4×10^{-8}	7.9×10^{-12}	2.0×10^{-11}	4.0×10^{-11}	7.3×10^{-12}	4.8×10^{-10}
Perfluoropentanoic acid (PFPeA)	1.8×10^{-10}	4.5×10^{-10}	9.0×10^{-10}	1.7×10^{-10}	1.1×10^{-8}	3.7×10^{-12}	9.1×10^{-12}	1.8×10^{-11}	3.4×10^{-12}	2.2×10^{-10}
Primidone	Not calculated‡	Not calculated‡	Not calculated‡	Not calculated‡	Not calculated‡	Not calculated‡	Not calculated‡	Not calculated‡	Not calculated‡	Not calculated‡
Quinoline	0†	0†	0†	0†	0†	0†	0†	0†	0†	0†

* The notation "$\times 10^{-\cdots}$" indicates the estimated probability that a person will develop the particular form of cancer (that is the basis for the chemical's toxicity criterion) due to exposure to this chemical in their lifetime. For example, 3.4×10^{-10} is equivalent to a probability that 3.4 persons in 10^{10} (10 billion) people will develop the cancer due to the exposure in their lifetime.
†Estimated EPC is zero (0).
‡Chemical is not evaluated for these scenarios because it is not classified as a carcinogen.

Table 5-5. Summary of Selected Values for the Tap Water Ingestion Pathway Calculation and Where they Fall in their Respective Distributions, Child and Adult RME Resident Scenarios

Parameter	Population	Selected Value and Location in Distribution	Mean and Range of Values (5^{th} – 95^{th} Percentile, unless otherwise noted)
Tap water ingestion rate (IR_{water}), L/d	Child RME resident	0.985 L/d, 90^{th} percentile	0.458 L/d (0.034 – 1.348 L/d)
	Adult RME resident	2.645 L/d, 90^{th} percentile	1.269 L/d (0.103 – 3.250 L/d)
Exposure frequency (EF), d/yr	Child and Adult RME resident	350 d/year	Not available
Exposure duration (ED), yr	Child and Adult RME resident	32 yr, 90^{th} percentile (combined child and adult total lifetime residence time in home)	13 yr (8* – 46 yr) *50^{th} percentile
Body weight (BW), kg	Child RME resident	15 kg, ~2^{nd} percentile	25.4 kg (17.9* – 39.8 kg) *10^{th} percentile
	Adult RME resident	80 kg, ~ mean	80.9 kg (57.4* – 117.8 kg) *10^{th} percentile

Table 5-6. Estimates of Mean Dietary Exposure to PFPeA in European Countries (data collected 2010–2018)

Age Group	Mean Daily Dietary Exposure to PFPeA (ng/kg-d)	
	Lower bound	Upper bound
Infant (<12 mo)	0.38	13.20
Toddler (≥ 12 mo to <36 mo)	0.40	20.76
Other children (≥ 36 mo to <10 yr)	0.28	14.49
Adolescent (≥ 10 to <18 yr)	0.11	6.96
Adult (≥18 to <65 yr)	0.07	4.80
Elderly (≥ 65 to <75 yr),	0.08	5.45
Very elderly (≥ 75 yr)	0.09	5.56

Source: EFSA (2020)

Table 5-7. Summary of Estimated Oral Exogenous Intake of NDMA from Sources Other Than Drinking Water

Pathway	Estimated exogenous intake of NDMA (ng/kg body weight-d)			
	Fristachi and Rice (2007)		Chowdhury (2014)	
	Child (age 6 mo to 17 yr)	Adult (18+ yr)	Child (age 1 to 11 yr)	Adult (20 to 65 yr)
Meat and meat products	1.187	0.695	1.300	0.618
Milk products	0.890	0.417	0.608	0.216
Vegetables and fruits	0.297	0.139	0.601	0.263
Cereals	0.119	0.042	1.162	0.508
Fish	1.187	0.278	2.966	1.297
Beer	0.000	0.278	0.000	0.286
Total	**3.680**	**1.850**	**6.637**	**3.189**

Table 5-8. Comparison of Estimates of Exogenous and Endogenous Intake of NDMA from Oral Sources Other than Drinking Water to the Estimated RME Resident LADD for NDMA

	Child (ng/kg-d)		Adult	
Source	**Estimated dose from other sources**	**Comparative dose (LADD), RME resident**	**Estimated dose from other sources**	**Comparative dose (LADD), RME resident**
Exogenous, total				
Fristachi and Rice (2007)	3.680*	0.056 (1.5%)	1.850*	0.056 (3.0%)
Chowdhury (2014)	6.637*	0.056 (0.8%)	3.189*	0.056 (1.8%)
Endogenous, total				
Fristachi and Rice (2007)	Not estimated	NA	5.146	0.056 (1.1%)

ADD – average daily dose; LADD – lifetime average daily dose; NA – Not available
*Excluding drinking water

6.0 PROBABILISTIC RISK ASSESSMENT FOR CHILD AND ADULT RESIDENT TAP WATER INGESTION

The results of the HHRA presented in Section 5.0 reflect the application of a deterministic approach, wherein inputs to the dose equations are point estimates selected to represent either high-end (i.e., conservative) or central tendency (more-likely) estimates of exposure for a population or scenario, and the outputs are themselves point estimates that reflect either upper bound (e.g., for the RME scenario) or more-likely (e.g., for the MLE scenario) estimates of exposure and risk. For one scenario (the RME resident), noncancer HIs calculated in the HHRA slightly exceed 1.0 for one chemical (PFPeA, with an estimated HI of 1.3 for the RME child resident) and LECRs slightly exceed the *de minimis* cancer risk benchmark of 1 in 1,000,000 (1×10^{-6}) for one chemical (NMDA, with an estimated LECR of 2.9×10^{-6} for the RME resident). In both cases, the estimated hazards or risks are dominated by contribution from the water ingestion pathway (>99%). As noted in Section 5.3.3, the RME scenario is intended to estimate a conservative exposure case that is still within the range of possible exposures, i.e., well above the average case and within approximately the 90th to 99.9th percentiles of the risk distribution for an exposure scenario (U.S. EPA, 1989).

To provide further perspective on where estimated doses of PFPeA and NDMA, and corresponding noncancer hazards and cancer risks, respectively, for the RME resident fall within the range of possible exposures and risks, and to provide additional information to inform the cost-benefit analysis, a probabilistic risk assessment (PRA) was conducted for these chemicals for the resident scenario. The methods and results applied in the PRA are described in detail Appendix E. A summary of the methods and results is provided below.

6.1 PRA Methodology

Consistent with U.S. EPA's recommended tiered approach to conducting HHRAs (U.S. EPA, 2001b), the assessment of noncancer hazard for PFPeA and cancer risk for NDMA for the resident scenario was refined using PRA methods, in order to characterize the variability in risk estimates and the likelihood of different risk levels in a population. Per this approach, after conducting a screening assessment to identify chemicals, scenarios, and exposure pathways of interest, risks are assessed using deterministic approaches intended to overestimate exposures and risks for most members of a population (as was done for the eight COIs assessed in this HHRA). Then, for those scenarios and pathways that exceed allowable risk thresholds, further tiers of assessment can be conducted to more fully quantify the range of potential exposures and risks and the uncertainty and variability in the risk estimates.

A limitation of the deterministic approach is that the output does not reflect the range of possible exposure or risk in a population or characterize the relative likelihood of these outcomes. In particular, the use of multiple conservative inputs in a deterministic HHRA for an RME scenario can lead to an estimate of exposure that is well outside the range of values that actually occur in a population. As an alternative, inputs into an HHRA can be represented by distributions of possible parameter values rather than single point estimates. In a probabilistic risk assessment (PRA), exposure parameters are represented by a range of values represented as probability density functions (PDFs) that characterize the uncertainty and variability of values in a population. PDFs are quantitative expressions of existing knowledge about the occurrence of values within a population. They are characterized as frequency distributions that describe the range of possible values for a given parameter and provide information on the number of times or likelihood each value will occur.

For instance, a PDF might reflect the likelihood that members of a population have a particular body weight based on the range of measurements of body weights in a larger but representative population group (variability). Alternatively, the true value of some parameters, such as how many days per year a person spends at their home, may be uncertain because a sufficiently robust dataset to characterize the distribution of values for this parameter in a population may not have been collected, and so a PDF can be selected that reflects a reasonable estimate of the lower and upper bound number of days that a person might reside at that location as well as a value considered to be most likely (uncertainty).

When inputs to a dose equation are defined by distributions, each equation has many possible outcomes. Using a process known as Monte Carlo simulation, the equation can be solved repeatedly using, in each trial, different values selected from the PDFs for each uncertain or variable parameter. Selected values are more likely to be drawn from the areas of the PDF that have higher probabilities of occurrence. To develop an estimate of the possible range of average daily doses within a population in a PRA, PDFs are established such that parameter values that are more likely in a population will be selected more frequently. Such PDFs are typically described as normal, lognormal, discrete, uniform, or triangular distributions.

The resulting output distributions of dose and hazard or risk are intended to reflect the range of exposure and risk across an exposed population. That is, they reflect exposures to average or typical individuals within the population, as well as more highly and less exposed individuals.

6.2 PRA Inputs

In the PRA conducted to further assess noncancer hazards for PFPeA and cancer risks for NDMA for the resident scenario, point estimate values for most of the exposure parameters were replaced with PDFs. These PDFs were established based on a number of sources of information including site-specific data, national survey data, U.S. EPA guidance, or professional judgement after review of the literature (U.S. EPA, 2001b). For some parameters, point estimates were retained (fraction ingested from a contaminated source (FI) which was assumed to be 1.0, and exposure duration (ED) and averaging time (AT) in the noncancer assessment because these cancel out of the calculation). Exposure parameter inputs applied in the PRA are summarized in Table 6-1. For comparison, the value for each parameter that was applied in the deterministic HHRA is also shown.

For chemical-specific parameter values (C_{water}, K_p, $\tau_{event,}$, and cancer slope factor (SF) or noncancer reference dose (RfD)), the same values were applied in the PRA as were applied in the deterministic HHRA. These are summarized in Table 6-2. For these, point estimates were used because data were insufficient to support derivation of a PDF.

6.3 PRA Results

Results of the PRA are summarized in Table 6-3. Per U.S. EPA (2001b), risks corresponding to the 90^{th} to 99.9^{th} percentiles of the output distributions from a PRA are considered plausible high-end risks. However, U.S. EPA notes that risk estimates become more uncertain at very high percentiles of the output distributions (e.g., $\geq 99.9^{th}$ percentile), and results of PRA calculations at these extreme values should be considered with caution.

As shown, for PFPeA, for exposure to water from the shallow and deep aquifers, estimated noncancer HIs for the child resident range from 0.95 to 0.96 at the 90^{th} percentile and from 1.3 to 1.4 at the 95^{th} percentile. For the adult resident, estimated HIs for both the shallow and deep aquifers are 0.58 at the 90^{th} percentile and 0.75 at the 95^{th} percentile. By comparison, the HIs for PFPeA estimated in the deterministic HHRA were 1.3 for the RME child resident (for either aquifer; if

rounded to one significant figure, HI = 1) and 0.66 to 0.67 for the RME adult resident; these values fall at between the 90th and 95th percentiles of the output distributions from the PRA.

For NDMA, LECRs estimated in the PRA for the resident scenario for the shallow and deep aquifers range from 7.8×10^{-7} to 7.9×10^{-7} at the 90th percentile and from 1.2×10^{-6} to 1.3×10^{-6} at the 95th percentile. By comparison, the LECR for NDMA estimated in the deterministic HHRA for the RME resident was 2.9×10^{-6} (for contact with water from either aquifer; if rounded to one significant figure, LECR = 3×10^{-6}); this estimate from the deterministic HHRA exceeds the 99th percentile of the output distributions from the PRA.

Like the deterministic HHRA, in the PRA, the water ingestion pathway dominates estimated exposures, contributing approximately 99% of the estimated total dose of both chemicals at the 95th percentile of the output distributions. Estimated noncancer hazards and cancer risks for both chemicals are comparable for the shallow and deep aquifers because estimated EPCs at 200 feet downgradient of the recharge basins are nearly identical for both aquifers.

Results of the PRA indicate that estimated noncancer HIs for PFPeA meet human health protection goals set by the Florida Department of Environmental Protection and the Oregon Department of Environmental Quality, which are the only two regulatory agencies with PRA-based water quality goals corresponding to specific distribution percentiles for HIs and LECRs. Specifically, for noncancer:

- Florida has set a noncancer health protection goal equal to HI $\leq$1 at the 90th percentile (Florida Department of Environmental Protection, 2016).
- Oregon has set a noncancer health protection goal equal to HI $\leq$1 at the 90th percentile and <10 at the 95th percentile (Oregon Department of Environmental Quality, 1999).

For PFPeA, the estimated HIs at the 90th percentile for the child (HI=0.96 for the shallow aquifer and 0.95 for the deep aquifer, or 1 if rounded to one significant figure) and adult (HI=0.58 for both the shallow and deep aquifer, or 0.6 if rounded to one significant figure) meet both Florida's and Oregon's health protection targets for the 90th percentile ($\leq$1). The estimated HIs at the 95th percentile for the child (HI=1.4 for the shallow aquifer and 1.3 for the deep aquifer, or 1 if rounded to one significant figure) and adult (HI=0.75 for both the shallow and deep aquifer, or 0.7 if rounded to one significant figure) also meet Oregon's target for the 95th percentile (<10).

For cancer:

- Florida has set a cancer health protection goal equal to an LECR $\leq 1\times10^{-6}$ at the 50th percentile, $\leq 1\times10^{-5}$ at the 90th percentile, and $\leq 1\times10^{-4}$ at the 99th percentile (Florida Department of Environmental Protection, 2016).
- Oregon has set a cancer health protection goal equal to an LECR $\leq 1\times10^{-6}$ at the 90th percentile and $\leq 1\times10^{-5}$ at the 99th percentile (Oregon Department of Environmental Quality, 1999).

For NDMA, the estimated LECRs at all percentiles meet Florida's and Oregon's health protection goals, including at the 90th percentile (7.9×10^{-7} for the shallow aquifer and 7.8×10^{-7} for the deep aquifer, or 8×10^{-7} if rounded to one significant figure), the 95th percentile (1.3×10^{-6} for the shallow aquifer and 1.2×10^{-6} for the deep aquifer, or 1×10^{-6} if rounded to one significant figure), and the 99th percentile (2.6×10^{-6} for both aquifers, or 3×10^{-6} if rounded to one significant figure).

Overall, results of the PRA conducted for the two chemicals with upper-bound hazard or risk estimates that slightly exceed allowable thresholds in the deterministic risk assessment—PFPeA and NDMA, for the resident scenario—indicate that estimated HIs for PFPeA and the LECRs for NDMA

meet the human health protection goals set by the Florida Department of Environmental Protection and the Oregon Department of Environmental Quality (the only two regulatory agencies with PRA-based water quality goals that correspond to specific distribution percentiles for HIs and LECRs) and that even at the 99th percentile, the LECRs for NDMA are within U.S. EPA's allowable lifetime excess cancer risk range (10^{-6} to 10^{-4}).

6.4 PRA Uncertainties

Two key sources of uncertainty in the PRA for PFPeA and NDMA are noted. First, water concentrations applied in the PRA are point estimates and are the same values as used in the deterministic HHRA. For the resident scenario, these values were estimated by HDR (2021) and are based on the 95 percent UCL of the arithmetic mean concentrations of these chemicals in reclaimed water applied to the infiltration basins, modeled to locations in the shallow or deep aquifers 200 feet downgradient of the basins. Because empirical data demonstrating biodegradation and sorption were sparse for NDMA and data from groundwater monitoring for PFPeA showed concentrations were within the range of detected reclaimed water concentrations, no biodegradation or sorption downgradient of the source was assumed to occur for these chemicals. Further, while no domestic or municipal water supply wells are currently located as close as 200 feet to the infiltration basins, it is assumed that 200 feet represents the minimum buffer potentially required in future permitting to install a new groundwater supply well in proximity to an infiltration basin. In addition, given the relatively limited number of reclaimed water samples and the fact that available data sets reflect both spatial (different sample locations) and temporal (different sample times) variability, as well as uncertainty about the true distribution of sample concentrations over space and time, use of a 95% UCL as a representative of the long-term average exposure concentration potentially experienced by a receptor (rather than a PDF for this parameter) in the PRA is judged appropriate. Overall, these assumptions are assumed to result in conservative (health protective) estimates of potential EPCs for these chemicals.

Second, the toxicity criteria used to estimate noncancer hazards or cancer risk for these chemicals are the same as applied in the deterministic HHRA and are assumed to provide a conservative (health protective) estimate of potential hazards or risks at a given dose (see Section 5.3.1). Thus, even if exposures consistent with estimates at the upper bounds of the PRA output distributions were to occur, it does not mean that adverse health effects are expected or will occur.

Table 6-1. Probabilistic Risk Assessment Exposure Parameters

Parameter	Units	Description	Distribution	Source	Value(s) Applied in Deterministic HHRA
IR_{water}	L/kg-d	Ingestion rate of water on a per kg body weight basis	Child ADD calculation Beta: Minimum = 0.0; 50th%ile = 0.0049; 90th%ile = 0.0474; 99.9th% ile = 0.1412; Maximum = 0.1818 Adult ADD calculation Beta: Minimum = 0.0; 50th%ile = 0.0069; 90th%ile = 0.0287; 99.9th% ile = 0.0689; Maximum = 0.1032 LADD calculation Beta: Minimum = 0.0; 50th%ile = 0.0058; 90th%ile = 0.0286; 99.9th% ile = 0.0926; Maximum = 0.2675	U.S. EPA, 2019a	Child: 0.985 L/d Adult: 2.645 L/d
FI	unitless	Fraction ingested from a contaminated source	Point estimate: 1.0	Professional judgment	Same
EF	d/yr	Exposure frequency to tap water in home for drinking, showering/bathing, or handwashing	All calculations: Triangular: Minimum = 335 d/yr; Most likely = 350 d/yr; Maximum = 365 d/yr	U.S. EPA, 2021d; professional judgment	350 d/yr
ED	yr	Exposure duration	Child/ Adult ADD calculation Point estimate: 1.0 LADD calculation Beta: Minimum = 0.0; 50th%ile = 9; 90th%ile = 26; 99.9th% ile = 56; Maximum = 87	Johnson and Capel, 1992	Child: 6 yr Adult: 26 yr
AT	d	Averaging time	ADD calculation Point estimate: ED × 365 d/yr LADD calculation Point estimate: 70 yr × 365 d/yr (25,550 d)	U.S. EPA, 1989	Same

Parameter	Units	Description	Distribution	Source	Value(s) Applied in Deterministic HHRA
$SA/BW_{water\text{-}bath}$	cm^2/kg	Skin surface area available for contact with tap water to body weight ratio, for showering or bathing	Child ADD calculation Lognormal: Mean = 640; 95th%ile = 850 Adult ADD calculation Lognormal: Mean = 280; 95th%ile = 330 LADD calculation Lognormal: Mean = 490; 95th%ile = 790	U.S. EPA, 2011	Child: 11,484 cm^2 Adult: 18,090 cm^2
$SA/BW_{water\text{-}handwash}$	cm^2/kg	Skin surface area available for contact with tap water to body weight ratio, for handwashing	Child ADD calculation Lognormal: Mean = 37; 95th%ile = 50 Adult ADD calculation Lognormal: Mean = 15; 95th%ile = 18 LADD calculation Lognormal: Mean = 28; 95th%ile = 45	U.S. EPA, 2011	Not separately evaluated
EV_{bath}	event/d	Event events per day for dermal contact with tap water while showering or bathing	Child ADD calculation Lognormal: Mean = 1.26; SD = 0.51 Adult ADD calculation Lognormal: Mean = 1.36; SD = 0.62 LADD calculation Lognormal: Mean = 1.34; SD = 0.60	U.S. EPA, 1996	1 event/d (t_{event} is based on total time per day)
$EV_{handwash}$	event/d	Event events per day for dermal contact with tap water while handwashing	Child ADD calculation Lognormal: Mean = 5.2; SD = 4.0 Adult ADD calculation Lognormal: Mean = 9.7; SD = 8.2 LADD calculation Lognormal: Mean = 8.6; SD = 7.1	U.S. EPA, 2011	Not separately evaluated

Parameter	Units	Description	Distribution	Source	Value(s) Applied in Deterministic HHRA
$t_{event\text{-}bath}$	h/event	Event duration for dermal contact with tap water during an individual shower or bath	All calculations Lognormal: Geometric mean = 0.11; Geometric SD = 0.0082	Wilkes et al., 2005	0.54 h/event (based on total time per day)
$t_{event\text{-}handwash}$	h/event	Event duration for dermal contact with tap water during an individual handwashing event	All calculations Triangular: Minimum = 0.00139 hour (5 seconds); Most likely = 0.00556 hour (20 seconds); Maximum = 0.0333 hour (2 minutes)	CDC, 2021; professional judgment	Not separately evaluated

a The 95th percentile value predicted for this distribution (ingestion rate of water for the child ADD calculation) is approximately 0.0674 L/kg-d. If one were to multiply the 95th percentile value by the 50th percentile body weight for this age group from the same NHANES survey (14.34 kg for males and females combined, 0 to <6 years; U.S. EPA, 2011, Table 8-3), the estimated water ingestion rate on a L/d basis would be 0.97 L/d.

b The 95th percentile value predicted for this distribution (ingestion rate of water for the adult ADD calculation) is 0.0373 L/kg-d. If one were to multiply the 95th percentile value by the 50th percentile body weight for this age group from the same NHANES survey (78.16 kg for males and females combined; U.S. EPA, 2011, Table 8-3), the estimated water ingestion rate on a L/d basis would be 2.92 L/d.

c The 95th percentile value predicted for this distribution (ingestion rate of water for the LADD calculation) is 0.0390 L/kg-d. If one were to multiply the 95th percentile value by the 50th percentile body weight for this age group from the same NHANES survey (67.49 kg for males and females combined; U.S. EPA, 2011, Table 8-3), the estimated water ingestion rate on a L/d basis would be 2.63 L/d.

Table 6-2. Probabilistic Risk Assessment Chemical-Specific Inputs

Parameter	Units	Description	Value		Source
			PFPeA	NDMA	
C_{water}	ng/L	Exposure point concentration (EPC) of chemical in water from shallow or deep aquifer (estimated for location 200 feet downgradient from reclaimed water basins)	Shallow aquifer: 79.260 Deep aquifer: 78.467	Shallow aquifer: 3.280 Deep aquifer: 3.247	HDR, 2021
K_p	cm/h	Dermal permeability constant	0.00041	0.00026	Calculated based on log K_{ow} and molecular weight Section 3.3.3.6)
τ_{event}	h/event	Lag time per event	83.2	0.27	Calculated based on molecular weight (U.S. EPA, 2004; see Section 3.3.3.6)
CSF	$(mg/kg\text{-}d)^{-1}$	Cancer slope factor (for oral and dermal exposure)	Not applicable	51	U.S. EPA, 1987
RfD	(mg/kg-d)	Reference dose (for oral and dermal exposure)	0.0000038	Not applicable	TCEQ, 2016

Table 6-3. Distributions of Noncancer Hazard Indices (HIs) and Lifetime Excess Cancer Risks (LECRs) Estimated in the PRA for PFPeA and NDMA for the Resident Scenario[a]

Scenario	Aquifer	Percentile of Distribution				Deterministic HHRA Result for RME Resident
		50th	90th	95th	99th	
Noncancer HI for PFPeA						
Child	Shallow	0.11	0.96	1.4	2.1	1.3
Adult	Shallow	0.14	0.58	0.75	1.1	0.67
Child	Deep	0.11	0.95	1.3	2.1	1.3
Adult	Deep	0.14	0.58	0.75	1.1	0.66
LECR for NDMA						
Child/Adult	Shallow	9.3×10^{-8}	7.9×10^{-7}	1.3×10^{-6}	2.6×10^{-6}	2.9×10^{-6}
Child/Adult	Deep	9.2×10^{-8}	7.8×10^{-7}	1.2×10^{-6}	2.6×10^{-6}	2.9×10^{-6}

a Pathways evaluated were ingestion of tap water and dermal contact with tap water while showering/ bathing or handwashing. Exposure parameter distributions input into the Monte Carlo analysis are described in Appendix E and summarized in Table 6-1.

b EPCs used in the assessment were the same as in the deterministic HHRA (corresponding to values estimated by HDR (2021) for the shallow or deep aquifer at a location 200 feet downgradient from the reclaimed water basins), and are summarized in Table 6-2.

7.0 SUMMARY AND CONCLUSIONS

Overall, the results of the HHRA indicate the following.

With regard to estimated noncancer hazards under the baseline (current) treatment scenario in the deterministic HHRA, the following was found:

- Estimated upper bound noncancer HIs exceed the minimum threshold level of concern of 1.0 for only one chemical and scenario—PFPeA for the RME child resident scenario, with an estimated HI of 1.3 (or 1 if rounded to one significant figure). The RME scenario is intended to reflect a high end estimate of potential exposures. It is defined as the highest exposure that is reasonably expected to occur at a site, and is intended to estimate a conservative exposure case (i.e., well above the average case) that is still within the range of possible exposures, e.g., within approximately the 90th to 99.9th percentiles of the risk distribution for an exposure scenario.
- An HI >1 does not mean that adverse health effects are expected or will occur. In fact, if the noncancer HI is close to 1 (as is the case for the upper bound noncancer hazard estimate for the RME child resident scenario for PFPeA), adverse health effects are unlikely even if a person's exposure is at the estimated upper bound level. This is because multiple uncertainty factors are incorporated into the derived toxicity criterion (i.e., allowable daily dose) that is used to calculate the noncancer hazard for this chemical, to ensure it is at a level at which health effects are not expected.
- Estimated upper bound noncancer HIs for PFPeA for the shallow and deep aquifers are nearly the same because the estimated EPCs for these aquifers are nearly the same (with the EPCs for the deep aquifer slightly lower).
- Within the resident scenarios, estimated noncancer HIs for the child are approximately two-times those of the adult. This is because HIs are estimated based on an annualized average dose, and typically, average child intakes on a per-body-weight basis are greater than those of an average adult. The estimated upper bound noncancer HI for the RME adult resident scenario is below 1.0.
- Greater than 99% of the estimated noncancer HIs for the RME child or adult resident scenarios for PFPeA are contributed by the water ingestion pathway. This pathway assumes a child drinks approximately 1 liter of water per day or an adult drinks approximately 2.6 liters of water per day, nearly every day (350 days per year) in the home. The contribution of dermal contact with water to total daily dose is <1%.
- Estimated noncancer HIs for all other chemicals and all other scenarios, including the MLE resident scenario, are below 1.0. Under the MLE resident scenarios, the rate of ingestion of tap water in the home is assumed to be approximately one-half liter per day for a child and 1.3 liters per day for an adult for 234 days per year (approximately two-thirds of a year).
- People can also be exposed to PFPeA in the diet. Estimated daily exposures for the RME resident from tap water are estimated to be comparable to exposures from the diet unrelated to potential reclaimed water sources.

With regard to estimated cancer risks under the baseline (current) treatment scenario in the deterministic HHRA, the following was found:

- Estimated upper bound LECRs exceed U.S. EPA's *de minimis* cancer benchmark of 1 in 1,000,000, or 10^{-6} for only one chemical and scenario—NMDA for the RME resident scenario, which has an estimated LECR of 2.9×10^{-6} (or 3×10^{-6} if rounded to one significant figure).

- This LECR can be interpreted as a probability that, at the upper bound of the risk estimates, 2.9 persons in one million (10^6) people could develop cancer if they are exposed to this chemical at this rate over their lifetime.
- While the upper bound LECR estimate for the RME resident scenario slightly exceeds a *de minimis* one-in-a-million LECR, it falls within the range of risks considered to be allowable by U.S. EPA and others at different sites depending on specific site characteristics (1×10^{-4} to 1×10^{-6}, or 1 in 10,000 to 1 in 1,000,000).
- Estimated upper bound LECRs for NDMA for the shallow and deep aquifers are nearly the same because the estimated EPCs for these aquifers are nearly the same (with the EPCs for the deep aquifer slightly lower). More than 99% of this estimated risk is contributed by the water ingestion pathway.
- Estimated LECRs for all other chemicals and all other scenarios, including the MLE resident scenario, are below 1×10^{-6}.
- Other sources of exposure to NDMA, other than water, include food or beverages that contain nitrosamines, such as smoked or cured meats and fish, vegetables, dried milk or formula, and malt beverages ("exogenous" NDMA) and food that contains nitrates, such as cured meats or fish and vegetables, that can be converted to NDMA in the stomach ("endogenous" NDMA). Estimated upper bound daily exposures for the RME resident from tap water are estimated be about 1 to 3% of exposures to exogenous or endogenous NDMA from sources unrelated to potential reclaimed water sources.

With regard to potential noncancer hazards and cancer risks associated with consumption of fish from either McAllister Creek or Woodland Creek, the HHRA predicts that even at a high end fish consumption rate of 330.5 g/d (corresponding to the 95th percentile estimate of "total fish" consumption from the Puget Sound and elsewhere by Squaxin Tribe consumer only adults, as presented by U.S. EPA and supported by the Squaxin Tribe, or approximately 609 servings per year assuming an average 7-ounce serving size), estimated noncancer hazards and cancer risks for these scenarios are below threshold levels of concern.

Evaluation of hazards and risks assuming implementation of potential treatment options (Option 1: RO-AOP or Option 2: O3-BAC-GAC) indicates that these options would reduce all estimated noncancer HIs and LECRs to below threshold levels of concern.

Results of a PRA conducted for the two chemicals with upper bound hazard or risk estimates that slightly exceed allowable thresholds based on the deterministic risk assessment—PFPeA and NDMA, for the resident scenario—indicate that estimated HIs for PFPeA and LECRs for NDMA meet the human health protection goals set by the Florida Department of Environmental Protection and the Oregon Department of Environmental Quality (the only two regulatory agencies with PRA-based water quality goals corresponding to specific distribution percentiles for HIs and LECRs), and that even at the 99th percentile, the LECRs for NDMA are within U.S. EPA's allowable risk range (1×10^{-6} to 1×10^{-4}).

Two key sources of uncertainty in the PRA noncancer hazard and cancer risk estimates for PFPeA and NDMA are the assumed water concentrations and the applied toxicity criteria. Water concentrations applied in the PRA are point estimate values and are the same as values used in the deterministic HHRA. They are based on the 95 percent UCL of the arithmetic mean concentrations of these chemicals in reclaimed water applied to the infiltration basins, modeled to locations in the shallow or deep aquifers 200 feet downgradient of the basins. For these chemicals, no biodegradation

or sorption downgradient of the source was assumed to occur. Overall, these assumptions are assumed to result in conservative (health protective) estimates of potential EPCs for these chemicals. The toxicity criteria used to estimate noncancer hazards or cancer risk for these chemicals are the same as applied in the deterministic HHRA and are assumed to provide a conservative (health protective) estimate of potential hazards or risks at a given dose. Thus, even if exposures consistent with the upper bounds of the PRA output distributions were to occur, it does not mean that adverse health effects are expected or will occur.

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APPENDIX A

SUMMARY OF CHEMICAL PROPERTIES AND UPTAKE FACTORS FOR CHEMICALS OF INTEREST EVALUATED IN THE HUMAN HEALTH RISK ASSESSMENT

Table A-1. Summary of Chemical Properties and Chemical-Specific Uptake Factors for Chemicals of Interest in the Human Health Risk Assessment

Chemical	CAS No.	MW (g/mol)	Henry's Law Constant (atm-m^3/mol)	log K_{ow}	BCF (L/kg)	τevent (h/event)	K_p (cm/h)	log K_{ow} and Henry's Constant Reference	BCF Reference
1,4-Dioxane	123-91-1	88.11	4.8E-06	-0.27	0.6	3.3E-01	3.4E-04	ATSDR, 2012; Stepien et al., 2014; U.S. EPA, 2021a; U.S. EPA, 2021b	U.S. EPA, 2015
Carbamazepine	298-46-4	236.27	2.2E-10	2.45	0.52	2.2E+00	3.1E-03	U.S. EPA, 2021a	Netherton, 2011; Zhang et al., 2010
N-Nitroso dimethylamine (NDMA)	62-75-9	74.08	2.6E-07 to 5.3E-07	-0.57	3	2.7E-01	2.6E-04	ATSDR, 1989; U.S. EPA, 2021a; U.S. EPA, 2021b; Zhang, 2016	U.S. EPA, 2017
Perfluoro octanoic acid (PFOA)	15899-31-7	414.069	1.9E-10	3.10	894	2.2E+01	8.5E-04	U.S. EPA, 2021a	Zodrow et al., 2021
Perfluoro-n-hexanoic acid (PFHxA)	307-24-4	314.06	2.4E-10	2.85	317	6.0E+00	2.1E-03	U.S. EPA, 2021a	Zodrow et al., 2021
Perfluoropentanoic acid (PFPeA)	2706-90-3	264.05	3.0E-10	1.35	83.18	3.2E+00	4.1E-04	U.S. EPA, 2021a	Burkhard, 2021
Primidone	125-33-7	218.25	4.3E-10	0.91	NA	1.8E+00	3.8E-04	U.S. EPA, 2021a	NA
Quinoline	91-22-5	129.16	2.5E-07 to 8.7E-06	2.03	21	5.6E-01	6.6E-03	U.S. EPA, 2001; U.S. EPA, 2021a	U.S. EPA, 2001

BCF – Bioconcentration factor; K_{ow} – Octanol-water partition coefficient; K_p – Permeability constant; MW – Molecular weight; NA – Not available; τ – Lag time

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APPENDIX B

SUMMARY OF EXPOSURE PARAMETERS FOR POPULATIONS OF INTEREST EVALUATED IN THE HUMAN HEALTH RISK ASSESSMENT

Exposure parameters applied in the deterministic HHRA for each exposure scenario are summarized in Table B-1. Figures B-1 through B-5 show where several of the values applied for key exposure parameters in the RME resident scenario fall within the distributions of these parameters for the U.S. population. These illustrations show that the selected parameter values overestimate exposures for average members of a population such that when combined in the RME resident exposure calculations, yield upper bound estimates of exposure that are assumed to be conservative (i.e., health protective) when applied to estimates of noncancer hazard or cancer risk.

Specifically:

- Figures B-1 and B-2 show where the selected tap water ingestion rates for the child and adult RME resident, respectively, fall within the distributions of values for consumers only intake. As shown, the selected values lie near the upper end of the parameter distributions and so reflect conservative (health protective) assumptions.
- Figure B-3 shows where the selected value for total residence time in a person's current home (child and adult combined) for the child and adult RME resident scenario falls within the distribution of values for this parameter. As shown, the selected value lies near the upper end of the parameter distributions and so reflects a conservative (health protective) assumption.
- Figures B-4 and B-5 show where the selected body weights for the child and adult RME resident, respectively, fall within the distributions of values for this parameter. As shown, the selected value for a child lies near the lower end of the parameter distributions and so reflects a conservative (health protective) assumption, while the adult value reflects a more average estimate.

Table B-1. Summary of Exposure Parameters Applied in the HHRA

Symbol	Units	Description	RME Resident (Child)	RME Resident (Adult)	MLE Resident (Child)	MLE Resident (Adult)	Main-tenance Worker (Adult)	Recreator-Playfield or Water Feature (Child)	Recreator/ Fish Consumer -Creek (Child)	Recreator/ Fish Consumer -Creek (Adult)	Basis	Source
$IR_{water(tap)}$	L/d	Tap water ingestion rate	0.985	2.645	0.458	1.269	1.763	0.657	NA	NA	Child and adult resident RME and MLE: 90th and mean percentile consumer-only combined direct and indirect water ingestion rates for community water. For adult maintenance worker (ingestion while at work) and child recreator scenarios, assume 2/3 of resident RME values.	U.S. EPA, 2019; U.S. EPA, 2021; professional judgment
IR_{inc}	L/h	Surface or groundwater incidental ingestion rate	NA	NA	NA	NA	NA	0.12	0.12	0.11	U.S. EPA RSLs (recreator ingestion rate of surface water).	U.S. EPA, 2021
FI	unitless	Fraction of water ingested from a contaminated source	1	1	1	1	1	1	1	1	Assume 100%	Professional judgment
SA_{water}	cm^2/event	Skin surface area available for tap water contact during showering/ bathing or at water feature	11,484	18,090	9,363	10,968	NA	9,570	NA	NA	RME and MLE: Age-weighted whole body surface areas (90th %ile and mean, respectively), and assumption that 75% of exposure is to whole body and 25% to hands and lower arms. For child at water feature, assume 50% of time is equal to whole body SA for child (from RME resident) and 50% is equal to SA of hands, feet, lower legs, lower arms for child age 3 to 11 years.	U.S. EPA 2008, 2011; professional judgment

Symbol	Units	Description	RME Resident (Child)	RME Resident (Adult)	MLE Resident (Child)	MLE Resident (Adult)	Main-tenance Worker (Adult)	Recreator-Playfield or Water Feature (Child)	Recreator/ Fish Consumer -Creek (Child)	Recreator/ Fish Consumer -Creek (Adult)	Basis	Source
$SA_{water(rec)}$	cm^2/event	Skin surface area available for surface or groundwater contact during incidental contact, swimming or wading	NA	NA	NA	NA	3,527	NA	5,633	9,080	For adult maintenance worker, based on U.S. EPA RSLs for SA exposed for outdoor worker. For child and adult in creek, assume whole body SA (based on U.S. EPA RME resident) for 25% of events; hands, lower arms, feet, and lower legs for 25% of events; and hands and lower arms for 50% of events [based on percent body SA area by body part (child age 3-11 and adult) multiplied by whole body SA].	U.S.EPA 2008, 2011, 2021; professional judgment
EV	events/d	Exposure events/d for showering/ bathing with tap water	1	1	1	1	1	1	1	1	Default—assume one event per exposure day.	U.S. EPA, 2004
EF	d/yr	Exposure frequency to tap water for drinking, showering/ bathing, or on playfield	350	350	234	234	225	104 (playfield recreator only) 45 (water feature recreator)	NA	NA	For resident RME and maintenance worker, based on U.S. EPA RSLs (default). For resident MLE, based on average fraction of time annually spent at home (64%). For child playfield recreator, assume 3 d/wk in for 3 mth/yr + 2 d/mth for3 more months per years (professional judgment)	U.S. EPA, 1993; U.S. EPA, 2021; professional judgment
$EF_{(creek)}$	d/yr	Exposure frequency to creek water	NA	NA	NA	NA	NA	NA	27	27	For creek recreator, assume 4 d/mo in summer, 2 d/mo in spring and fall, and 1 d/mo in winter (professional judgment)	Professional judgment

Symbol	Units	Description	RME Resident (Child)	RME Resident (Adult)	MLE Resident (Child)	MLE Resident (Adult)	Main-tenance Worker (Adult)	Recreator-Playfield or Water Feature (Child)	Recreator/ Fish Consumer -Creek (Child)	Recreator/ Fish Consumer -Creek (Adult)	Basis	Source
ED	yr	Exposure duration	6	26	5	8	25	6	12	34	For resident RME, based on U.S. 90th %ile residence time and U.S. EPA RSLs (default), and for child and adult resident MLE, based on mean U.S. residence time distributed across child and adult. For maintenance worker, based on recommended upper bound for outdoor worker from U.S. EPA RSLs (default). For creek recreator/ fish consumer, based on 95th %ile time at one residence in U.S., distributed across a child and adult.	U.S. EPA, 2011; U.S. EPA, 2021
AT_{car}	d	Averaging time, carcinogens	25,550	25,550	25,550	25,550	25,550	25,550	25,550	25,550	Equal to 70 years (lifetime) for carcinogens (default)	U.S. EPA, 1989
BW	kg	Body weight	15	80	15	80	80	15	15	80	Based on U.S. EPA RSLs for a child and an adult (default)	U.S. EPA, 2021
t_{event}	h/event	Event time for contact with water	0.54	0.71	0.54	0.71	1.5	2.0	1.39	1.30	RME and MLE based on U.S. EPA RSLs (for resident exposure to tap water). For maintenance worker assume average of 1.5 hrs/workday (professional judgment). For child at water feature, assume 2 h/event (professional judgment). For creek recreators, annualized average based on events/year and assuming 2 h/event in summer, 1 h/event in spring/fall, and 30 min/event in winter (professional judgment).	U.S. EPA, 2021; professional judgment

Symbol	Units	Description	RME Resident (Child)	RME Resident (Adult)	MLE Resident (Child)	MLE Resident (Adult)	Main-tenance Worker (Adult)	Recreator-Playfield or Water Feature (Child)	Recreator/ Fish Consumer -Creek (Child)	Recreator/ Fish Consumer -Creek (Adult)	Basis	Source
InhR	m^3/d	Indoor inhalation rate	16.4	22.9	10.7	13.9	NA	NA	NA	NA	Default 95th %ile (RME) and mean (MLE) breathing rates for ages 2–9 and ages 16–70, OEHHA Air Toxic Hot Spots Program	OEHHA, 2014
IR_{fish}	g/d	Consumption rate of fish from local waters	NA	NA	NA	NA	NA	NA	Based on 10, 25, or 50 servings per year: 5.4, 13.6, or 27.1 g/d; Based on Squaxin survey: High end: 330.5. "Other-fish" estimate: 2.37	Based on 10, 25, or 50 servings per year: 5.4, 13.6, or 27.1 g/d; Based on Squaxin survey: High end: 330.5. "Other-fish" estimate: 9.84	Squaxin survey, high end estimate (child and adult): 330.5 g/d, based on 95th percentile "total, all fish" consumers-only consumption rate (including finfish and shellfish, from all areas including from inside and outside the Puget Sound and purchased at grocery stores, restaurants, or elsewhere) for adults reported in U.S. EPA (2013) and supported by the Squaxin Tribe (Whitener, 2018). Squaxin survey, moderate estimate: For children, 90th%ile all fish consumption rate for children of Squaxin Tribe age birth to 5 years (2.056 g/kg-d) *15 kg * assume 5% is other (i.e., freshwater) fish. For adults, 95th%ile "other fish" consumption rate for adult members of Squaxin Tribe (0.123 g/kg-d) * 80 kg.	Toy, 1996; U.S. EPA, 2013; Whitener, 2018
FI	unitless	Fraction of fish consumed from a contaminated source	NA	NA	NA	NA	NA	NA	1	1	Assume 100% since ingestion rate is based on sport fish consumption	Professional judgment

Symbol	Units	Description	RME Resident (Child)	RME Resident (Adult)	MLE Resident (Child)	MLE Resident (Adult)	Main-tenance Worker (Adult)	Recreator-Playfield or Water Feature (Child)	Recreator/ Fish Consumer -Creek (Child)	Recreator/ Fish Consumer -Creek (Adult)	Basis	Source
EF_{fish}	d/yr	Exposure frequency to locally caught fish	NA	NA	NA	NA	NA	NA	365	365	NA since consumption rates are based on an annual average.	NA

ED – Exposure duration; EF – Exposure frequency; EV – Event frequency; FI – Fraction ingested (from a contaminated source); InhR – Inhalation rate; IR – Ingestion rate; MLE – More likely exposure; NA – Not applicable; RME – Reasonable maximum exposure; RSL – Regional Screening Level; SA – Surface area

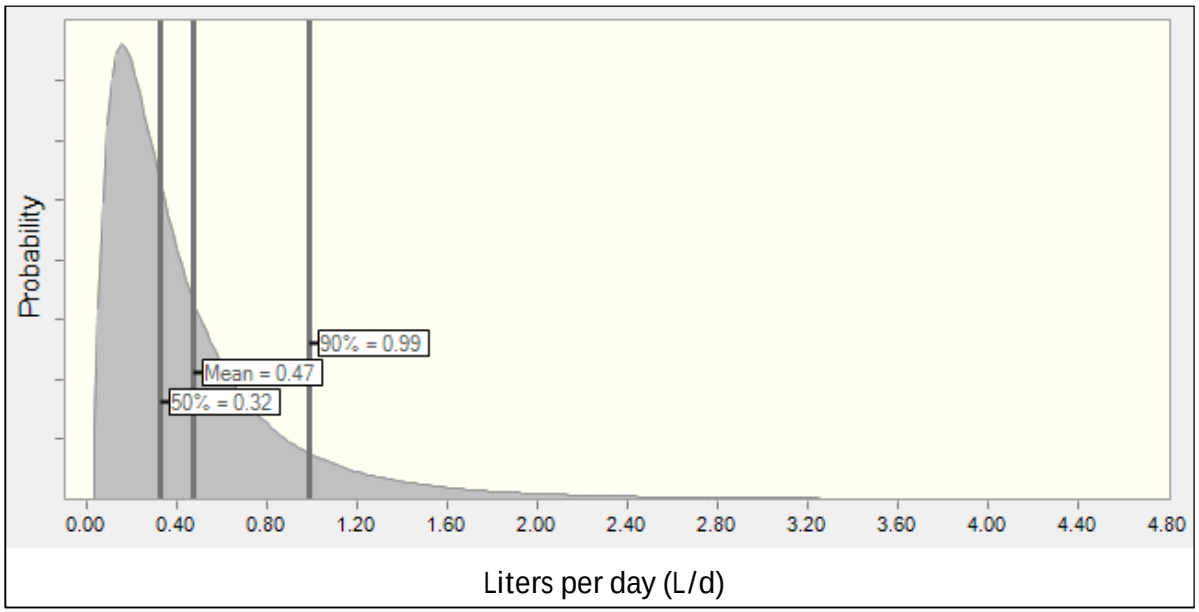

Figure B-1. Comparison of the Selected Child RME Resident Tap Water Ingestion Rate (IR_{water}) to Other Values in the Distribution of Consumer-Only Daily Water Intake Rates (ages 2 to 16 years, U.S. EPA, 2019). The selected value (0.985 L/d) falls at the 90th percentile of the distribution (assuming a lognormal distribution). Median (50th percentile) and mean estimates are 0.32 L/d and 0.47 L/d, respectively.

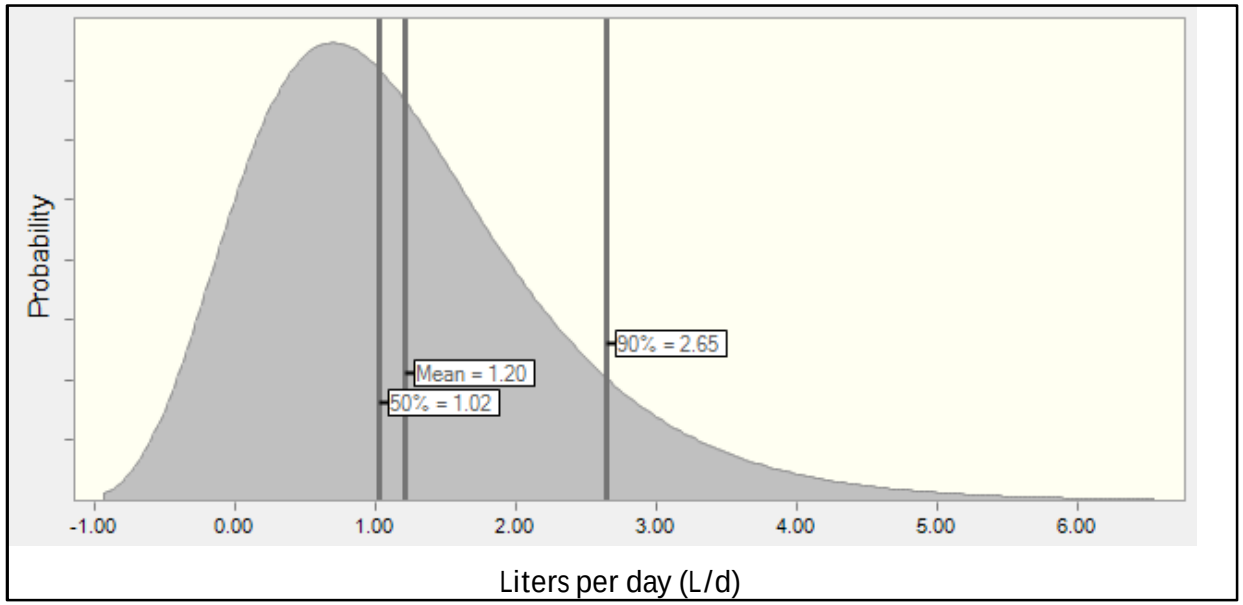

Figure B-2. Comparison of the Selected Adult RME Resident Tap Water Ingestion Rate (IRwater) to Other Values in the distribution (ages 16 to 70 years, U.S. EPA, 2019). The selected value (2.645 L/d) falls at the 90th percentile of the distribution (assuming a lognormal distribution). Median (50th percentile) and mean estimates are 1.02 L/d and 1.20 L/d, respectively.

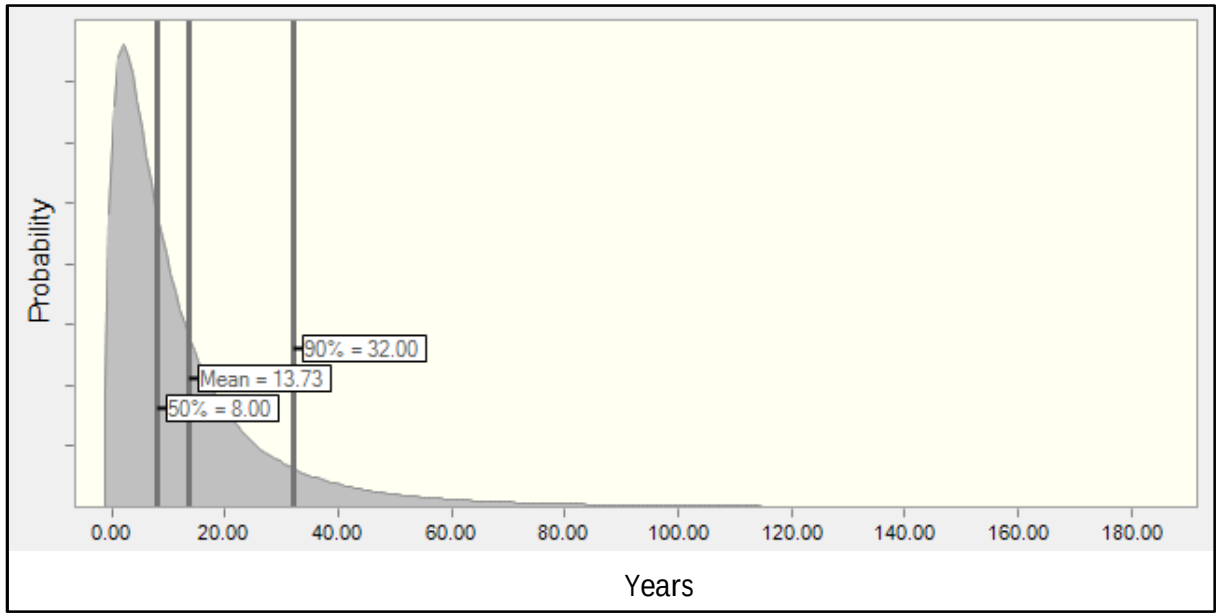

Figure B-3. Comparison of the Selected Total Residence Time in One's Current Home (Exposure Duration) for the Child and Adult RME Scenario (ED) to Other Values in the Distribution (U.S. EPA, 2011). The selected value (32 years) falls at the 90th percentile of the distribution (assuming a lognormal distribution). Median (50th percentile) and mean estimates are 8.0 years and 13.7 years, respectively.

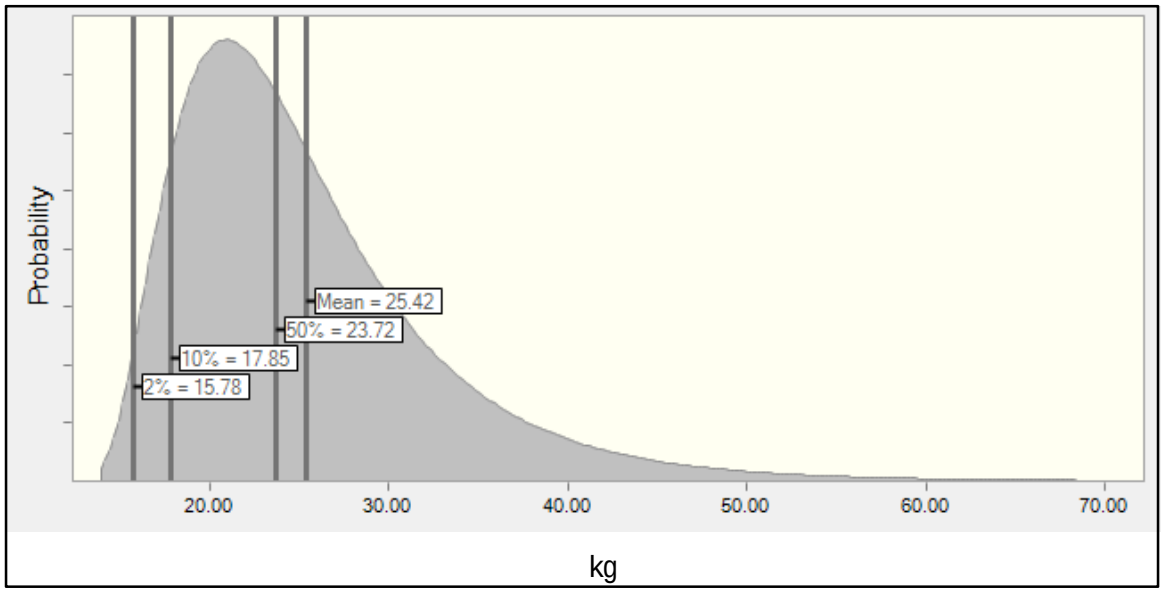

Figure B-4. Comparison of the Selected Child RME Resident Body Weight (BW) to Other Values in the Distribution (ages 2 to 11 years, U.S. EPA, 2011). The selected value (15 kg) falls at less than the 2nd percentile of the distribution (assuming a lognormal distribution). 10th Percentile, median (50th percentile), and mean estimates are 17.8, 23.7, and 25.4 kg, respectively.

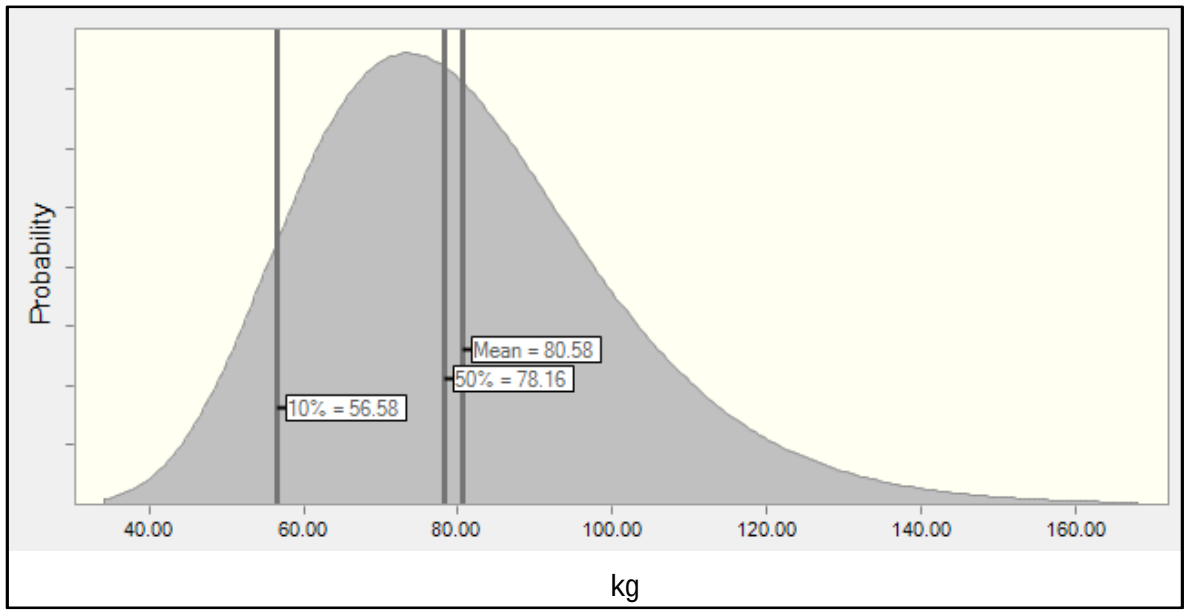

Figure B-5. Comparison of the Selected Adult RME Resident Body Weight (BW) to Other Values in the Distribution (ages 16 to <70 years, U.S. EPA, 2011). The selected value (80 kg) falls at approximately the mean of the distribution (assuming a lognormal distribution). 10th Percentile and median (50th percentile) estimates are 56.6 and 78.2 kg, respectively.

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APPENDIX C

SUMMARY OF PUBLISHED TOXICITY CRITERIA, CALCULATION OF NONCANCER ADIS FROM TOXICITY DATA AND THERAPEUTIC DOSES FOR PRIMIDONE, AND GENOTOXICITY/ CARCINOGENICITY DATA FOR CHEMICALS OF INTEREST EVALUATED IN THE HUMAN HEALTH RISK ASSESSMENT

Available published toxicity criteria for chronic noncancer or cancer effects from authoritative bodies for the chemicals of interest (COIs) considered in the HHRA are summarized in Table C-1.

For one of the COIs (primidone), a published and verified noncarcinogenicity assessment and acceptable daily intake (ADI) were not identified. Consequently, an ADI for this compound was derived based on review of data from animal toxicity studies and, since it is a pharmaceutical, information on therapeutic doses. The approach that yielded the lowest (most health-protective) value was selected as the basis of the noncancer ADI for use in the HHRA.

When establishing guidelines or standards for noncarcinogenic effects, including reference doses (RfDs; U.S. EPA, 2002), minimal risk levels (MRLs; ATSDR, 2007), and tolerable daily intakes (TDIs; WHO, 1994), agencies charged with developing guidance values typically review toxicity data to identify a threshold level of exposure below which adverse health effects have not been observed—typically the highest dose at which an effect is not seen (the no observed adverse effect level, NOAEL) or the lowest dose at which an effect is seen (the lowest observed adverse effect level, LOAEL)—and apply this as a point of departure upon which to base the guidance level. Below this dose, there is no evidence in animals or humans of a statistically or biologically significant increase in adverse effects, although some changes may occur that are not considered adverse (e.g., changes in certain enzyme levels). Study types considered to be most relevant for evaluating the significance of long-term low-level exposures are assumed to be subchronic, chronic, reproduction, and developmental toxicity studies. The majority of studies of this type are conducted in mice and rats, but studies may also assess effects in rabbits, dogs, primates, and other animals. For characterizing exposure to chemicals in water, exposures via the oral route are considered most relevant.

To calculate an ADI, the "point of departure" is divided by several uncertainty factors (UFs) to derive a value considered protective of exposure to broader population groups, including sensitive populations such as children or people with compromised immune systems. The calculation is as follows:

$$ADI_{NOAEL\ or\ LOAEL-based}\ (mg/kg-d) = \frac{NOAEL\ or\ LOAEL\ (mg/kg-d)}{UFs}$$

Generally, several multiplicative UFs are applied, individually ranging in value from 3 to 10 with each factor representing a specific area of uncertainty in the available data. Typical default values that are applied are as follows (U.S. EPA, 2008):

- UF1: 3 to 10, to account for extrapolation from an animal species to humans (or 1 if a human dose is used)
- UF2: 10 to account for intraspecies variability and sensitive subpopulations
- UF3: 3 to 10 to extrapolate from less-than-lifetime exposure (i.e., a subchronic study) to lifetime exposure (or 1 if a chronic study in used, or 1 for reproductive studies in which the whole period of organogenesis is covered [e.g., gestational day 5–15 in rodents and 6–18 in the rabbit (OECD, 2001))
- UF4: 3 to 10 to account for extrapolation from a LOAEL or lowest observed effect level (LOEL) to a NOAEL (or 1 if a NOAEL is used)

- UF5: 3 to 10 for database uncertainties including lack of certain study types or evidence of elevated toxicity at or near the point of departure dose (or 1 if a high quality, comprehensive database of studies is available).

Note that per U.S. EPA risk assessment guidance (U.S. EPA, 2008), a factor of 3 represents a "partial" uncertainty factor equal to the half-log (square root) of 10 (i.e., $10^{1/2}$) but is usually rounded to 3 for use in risk assessment. By convention, when two UFs with a value of 3 are multiplied together, the resulting combined UF is 10 (not 3 × 3 = 9). When high quality toxicity data are available, combined uncertainty factors applied in an ADI calculation typically range from 30 to 1,000.

Toxicological studies identified for primidone and corresponding ADIs calculated based on selected points of departure from those studies and study-specific UFs are summarized in Table C-2. Overall, the lowest identified ADI based on noncarcinogenic endpoints in toxicological studies was 0.0025 mg/kg-d, based on two separate studies: an oral gavage developmental study in mice showing an increase in the incidence of palatal defects in offspring (McElhatton et al., 1977) and a two-year feeding study in mice showing decreases in body weights as well as effects on the liver (hypertrophy, vacuolization) (NTP, 2000). In the two-year study, an increase in hepatocellular neoplasms (hepatocellular adenoma, hepatocellular carcinoma, and hepatoblastoma) was also observed; however, because the weight of evidence suggests primidone is not mutagenic (see Table C-4) and hyperplasia was observed, the increase in tumor incidence was considered to be a result of a non-genotoxic mechanism (IARC, 2016), that is, a mechanism that results in an increase in tumor incidence only after a relative high exposure threshold is exceeded. Still, because primidone shows evidence of being a nongenotoxic threshold carcinogen (evidence of "significant toxicity"), a UF of 10 was applied for UF5 in all of the ADI calculations for primidone.

For chemicals that are pharmaceuticals (e.g., primidone), the lower end of the drug's therapeutic dosing range can be considered an estimate of the threshold for appreciable biological activity in human populations, that is, a threshold for potential adverse effects in humans. Following an approach analogous to the NOAEL/LOAEL approach, ADIs for pharmaceutical compounds can be derived by dividing the lowest therapeutic dose (identified from the RxList database (www.rxlist.com), an online medical resource owned and operated by WebMD providing pharmaceutical information on brand and generic drugs, including drug dosing information) by a default composite UF of 1,000, as follows:

$$ADI_{LTD-based}\ (mg/kg-d) = \frac{Lowest\ Therapeutic\ Dose\ (mg/kg-d)}{UFs}$$

Application of a default composite UF of 1,000 is based on the above U.S. EPA (2008) uncertainty factor scheme, assuming a factor of 1 to account for use of human rather than animal dosing data, 10 to account for intraspecies variability and potential exposure to sensitive subpopulations, 10 to account for extrapolation from an assumed LOAEL to a NOAEL, and 10 to account for the assumption that therapeutic dosing typically anticipates a response after a relatively short exposure duration. As with the NOAEL/LOAEL approach, for primidone, an additional UF of 10 was also applied because the chemical was determined to be a nongenotoxic (threshold) carcinogen.

For primidone, the calculation of an ADI based on the lowest therapeutic dose is presented in Table C-3. As shown the lowest identified therapeutic dose is 100 mg/d (for treatment of seizures) (RxList.com, 2021a). Conservatively assuming an adult body weight of 80 kg, this corresponds to a

dose of 1.25 mg/kg-d. Applying a composite UF of 1,000 × 10 (using the additional factor of 10 because primidone shows evidence of being a nongenotoxic threshold carcinogen, as described above), the estimated ADI is 0.000125 mg/kg-d. Because this ADI is lower than that based on data from toxicological studies, it was applied in this assessment.

Two of the COIs (carbamazepine and primidone) do not have published carcinogenicity assessments from authoritative bodies. For chemicals that are genotoxic and data from chronic animal studies show evidence of carcinogenicity, a cancer slope factor (SF) can be derived using linear dose-response models. Models of this type assume that a linear relationship between cancer risk and dose exists, with no threshold exposure level below which the risk is zero (U.S. EPA, 2002; U.S. EPA, 2005; U.S. EPA, 2017b). Non-threshold models are conservative (health-protective) and are applied when there is an absence of sufficient information on modes of action to refute a non-threshold assumption or when the mode of action information indicates the dose-response curve at low doses is expected to be linear. The slope of the risk vs. dose line, known as the SF, is an upper-bound estimate of risk probability per increment of dose (e.g., per 1 mg/kg-d of exposure) that can be used to estimate risk probabilities for different exposure levels.

Data on the genotoxicity and carcinogenicity of carbamazepine and primidone (as well as the other COIs) are summarized in Table C-4. Both carbamazepine and primidone show some evidence of an increase in liver carcinomas in rodent studies, and primidone also shows an increase in thyroid gland follicular cell adenomas in mice (Novartis, 2010; Singh et al., 2005; NTP, 2000). However, neither of the chemicals is considered to be mutagenic, based on data from *in vitro* (including bacterial) and *in vivo* (including mammalian) test systems. As such, it is assumed that the mechanisms for carcinogenicity observed in these studies are non-DNA reactive mechanisms (e.g., liver enzyme induction, peroxisome proliferation, hormonal carcinogens) that require exposure to very large doses of a chemical resulting in a proliferative response, and ultimately tumor development if exposure is sufficient and prolonged; that is, tumors develop only after a certain threshold of exposure is reached. For chemicals of this type, development of a cancer SF based on the assumption of linear dose response (with no threshold) is inappropriate.

Therefore, for carbamazepine and primidone, a cancer SF was not derived but an additional UF of 10 was applied to the estimated ADIs for noncancer effects.

Table C-1. Published Toxicity Criteria from Authoritative Bodies for COIs Evaluated in the HHRA*

Chemical	U.S. EPA or Other RfD (noncancer) (mg/kg-d)	ATSDR MRL (noncancer, chronic) (mg/kg-d)	U.S. EPA or California Oral SF (cancer) $(mg/kg\text{-}d)^{-1}$	Other ADI or DWEL (units given)
1,4-Dioxane	**0.03 (U.S. EPA, 2013)**	0.1 (ATSDR, 2012)	**0.1 (U.S. EPA, 2013)**; 0.027 (OEHHA, 2021a)	1.0 µg/L (NL (cancer); CalEPA, 2019); 1 µg/L (HBV (cancer); MDH, 2021); 0.2 µg/L (Lifetime HA; U.S. EPA, 2017a); 30 µg/d (Cal NSRL; OEHHA, 2021a)
Carbamazepine	**0.0057 (chronic RfD; MDH, 2013)**	---	---	40 µg/L (chronic HBV (noncancer); MDH, 2021)
N-Nitroso dimethylamine (NDMA)	---	---	**51 (U.S. EPA, 1987)**; 15 (OEHHA, 2021b); 21 (MDH, 2017)	0.005 µg/L (HBV (cancer); MDH, 2021); 0.010 µg/L (NL (cancer); CalEPA, 2018); 0.30 µg/L (RL (cancer); CalEPA, 2018); 0.003 µg/L (PHG (cancer), OEHHA, 2021b)
Perfluoro octanoic acid (PFOA)	---	**0.0000030 (MRL (intermediate duration); ATSDR, 2021; WDOH, 2019);** 0.000018 mg/kg-d (RfD; MDH, 2020a)	**0.07 (U.S. EPA, 2016a**)	0.010 µg/L (DRAFT SAL, WDOH, 2019); 0.035 µg/L (HBV; MDH, 2021); 0.29 µg/L (PCL; TCEQ, 2021)
Perfluoro-n-hexanoic acid (PFHxA)	---	---	---	**3.8×10^{-6} mg/kg-d (Chronic RfD, equated to PCL of 0.093 µg/L; TCEQ, 2016, 2021);** 4×10^{-6} mg/kg-d (recommended chronic RfD; NHDES, 2019); 0.047 µg/L (equiv to 9.7×10^{-6} mg/kg-d; subchronic and chronic nHBV; MDH, 2020b); 5×10^{-6} mg/kg-d (RfD for PFOA, PFOS, PFNA, PFHxS, PFHpA and PFDA as a group; MaDEP, 2019)
Perfluoropentanoic acid (PFPeA)	---	---	---	**0.093 µg/L (PCL; equiv to RfD of 3.8×10^{-6} mg/kg-d; TCEQ, 2016, 2021)**
Primidone	---	---	---	---
Quinoline	**0.00079 (RfD, MDH, 2020c)**	---	**3 (U.S. EPA, 2001)**	0.03 µg/L (HBV (cancer); MDH, 2021)

ADI –Acceptable Daily Intake; ATSDR – Agency for Toxic Substances and Disease Registry; DWEL – Drinking Water Equivalent Level; HA –Health Advisory; HBV – Health Based Value; MDH – Minnesota Department of Health; MRL – Minimum Risk Level from Agency for Toxic Substances and Disease Registry (ATSDR); NL – Notification Level (California); NSRL – No Significant Risk Level for Proposition 65 (California EPA; OEHHA – Office of Environmental Health Hazard Assessment (California EPA); PCL – Protective Concentration Level; RfD – Reference Dose (U.S. EPA); RL – Response Level (California); SAL – State Action Level; SF – cancer slope factor estimated by the U.S. EPA or California EPA; TCEQ Texas – Commission on Environmental Quality; WDOH – Washington Department of Health; WHO –World Health Organization

*Values selected for use in the HHRA (for estimation of noncancer hazard or cancer risk) are shown in bold. For chemicals without available values, further examination of toxicity data or therapeutic dose information followed by derivation of ADIs was conducted.

Table C-2. Summary of Calculation of Noncancer Acceptable Daily Intakes (ADIs) from Toxicity Study Data for Primidone

Compound	Species/ Gender/ Study duration/ Route/ Doses	NOAEL/ LOAEL (mg/kg-d)	Effect	Reference	UFs* and ADI (mg/kg-d)
Primidone	Mouse/ F/ GD 6–16/ Oral gavage/ 0, 25, 50, 100, or 150 mg/kg-d	NOAEL: none LOAEL: 25 mg/kg-d (lowest dose)	Developmental (no increase in embryolethality at 25 mg/kg-d, but increased incidence of palatal defects)	McElhatton et al., 1977	10 × 10 × 1 × 10 × 10 0.0025 mg/kg-d
	Mouse/ F/ GD 6–16/ Oral gavage/ 0, 30, 90, or 180 mg/kg-d	NOAEL: none LOAEL: 30 mg/kg-d (lowest dose)	Developmental (no increase in embryolethality at 30 mg/kg-d, but increased incidence of palatal defects)	Sullivan and McElhatton, 1975	10 × 10 × 1 × 10 × 10 0.0030 mg/kg-d
	Rat/ F/ GD 8–17/ Oral gavage/ 0, 40, or 80 mg/kg-d	NOAEL: none LOAEL: 40 mg/kg-d (lowest dose)	Developmental (no effect on embryolethality at 40 mg/kg-d but decreased male pup body weight at PND 50; at 80 mg/kg-d, behavioral effects in males when tested as adults (deficits in performance of eight-arm radial maze task and reduction in open field activity))	Pizzi et al., 1996	10 × 10 × 1 × 10 × 10 0.0040 mg/kg-d
	Rat/ F/ GD 8–20/ Oral gavage/ 0 or 120 mg/kg-d	NOAEL: none LOAEL: 120 mg/kg-d (lowest dose)	Developmental (increase in embryolethality, increase in acquisition of a DRL-20 (differential reinforcement of low rates) operant schedule in surviving male offspring (a behavioral effect thought indicative of learning))	Pizzi et al., 1998	10 × 10 × 1 × 10 × 10 0.012 mg/kg-d
	Mouse/ F/ GD 6–16/ Oral gavage/ 0, 500, 1250, 2000, or 2500 mg/kg-d	NOAEL: none LOAEL: 500 mg/kg-d (lowest dose)	Developmental (increased incidence of palatal defects)	McElhatton and Sullivan, 1975	10 × 10 × 1 × 10 × 10 0.050 mg/kg-d
	Rat/ F, M/ 14-d/ Oral feed/ 0, 120, 240, 500, 970, or 1,100 mg/kg-d to males and 0, 120, 240, 500, or 900 mg/kg-d to females	NOAEL: 500 mg/kg-d LOAEL: 900 mg/kg-d	Systemic (decreased body weight in males and females at high dose)	NTP, 2000	10 × 10 × 10 × 1 × 10 0.050 mg/kg-d
	Mouse/ F, M/ 14-d/ Oral feed/ 0, 100, 200, 400, or 800 mg/kg-d to males and 0, 100, 250, 500, or 900 mg/kg-d to females	NOAEL: 400 mg/kg-d LOAEL: 800 mg/kg-d	Systemic (decreased body weight in males and females at high dose)	NTP, 2000	10 × 10 × 10 × 1 × 10 0.040 mg/kg-d

Compound	Species/ Gender/ Study duration/ Route/ Doses	NOAEL/ LOAEL (mg/kg-d)	Effect	Reference	UFs* and ADI (mg/kg-d)
	Rat/ F, M/ 14-wk/ Oral feed/ 0, 20, 40, 100, 200, or 400 mg/kg-d	NOAEL: 20 mg/kg-d LOAEL: 40 mg/kg-d	Liver (increased incidence of centrilobular hepatocyte hyper-trophy in males)	NTP, 2000	10 × 10 × 5 × 1 × 10 0.0040 mg/kg-d
	Mouse/ F, M/ 14-wk/ Oral feed/ 0, 50, 100, 200, 400, or 1,000 mg/kg-d to males and 0, 60, 120, 220, 440, or 1,100 mg/kg-d to females	NOAEL: 50 mg/kg-d LOAEL: 100 mg/kg-d	Liver (increased liver weights and incidence of centrilobular hepatocyte hypertrophy at 100 mg/kg-d in males and 120 mg/kg-d in females)	NTP, 2000	10 × 10 × 5 × 1 × 10 0.010 mg/kg-d
	Rat/ F, M/ 2-yr/ Oral feed/ 0, 25, 50, or 100 mg/kg-d	NOAEL: 25 mg/kg-d LOAEL: 50 mg/kg-d	Systemic/kidney (decreased survival in males and decreased body weight in males and females, increased kidney cysts in males)	NTP, 2000	10 × 10 × 1 × 1 × 10 0.025 mg/kg-d
	Mouse/ F, M/ 2-yr/ Oral feed/ 0, 30, 65, or 150 mg/kg to males and 25, 50, or 100 mg/kg to females	NOAEL: none LOAEL: 25 mg/kg-d (lowest dose)	Systemic/kidney (in males and females, decreased final mean body weights, and increased incidences of centrilobular hepatocyte hypertrophy, cytoplasmic vacuolization, eosinophilic focus). Note also an increase in hepatocellular neoplasms (hepatocellular adenoma, hepatocellular carcinoma, and hepatoblastoma) in all exposed groups.	NTP, 2000	10 × 10 × 1 × 10 × 10 0.0025 mg/kg-d

ADI – Acceptable Daily Intake; F – female; GD – gestation day; LOAEL – lowest observed adverse effect level; LOEL – lowest observed effect level; M – male; NOAEL – no observed adverse effect level; UF – uncertainty factor

*Uncertainty factors are as shown, in the following order: UF1 – Interspecies extrapolation (10 to extrapolate from a mouse or rat to a human, 1 if a human study is used); UF2 – Interspecies uncertainty (10 to account for potentially sensitive subpopulations or variations in response among exposed individuals); UF3 – Study duration (1 for chronic studies, 3 to 10 for subchronic or shorter duration studies; 1 for reproductive studies in which the whole period of organogenesis is covered [e.g., GD 5–15 in rodents and 6–18 in the rabbit (OECD, 2001)]); UF4 – Extrapolation from a LOAEL or LOEL to a NOAEL (3 to 10, 1 if a NOAEL is used); UF5 – Database uncertainties or deficiencies or relative severity of effect (e.g., 3 to 10 if database is deficient in some study types, 10 if shows evidence of being a nongenotoxic carcinogen (see Table C-4))

Table C-3. Summary of Calculation of a Noncancer Acceptable Daily Intake (ADI) from the Lowest Therapeutic Dose for Primidone*

Compound	Lowest therapeutic dose (mg/d)	Treatment endpoint	Age group and assumed body weight (kg)	Minimum therapeutic dose (mg/kg-d)	Pregnancy category & adverse effects	UF† and ADI (mg/kg-d)
Primidone	100	Anticonvulsant	Adult, 80	1.25	D (safety during pregnancy not established)	1,000 × 10‡ 0 .000125 mg/kg-d

ADI – Acceptable daily intake; UF – Uncertainty factor

*Data source RxList.com, 2021a.

†A factor of 1,000 was applied based on the assumption of application of the following UFs: UF1 – Interspecies extrapolation (1 because data are in humans); UF2 – Interspecies uncertainty (10 to account for potentially sensitive subpopulations or variations in response among exposed individuals); UF3 – Study duration (3 because pharmaceutical dosing is assumed to be of subchronic duration); UF4 – Extrapolation from a LOAEL to a NOAEL (10); UF5 – Database uncertainties or deficiencies or relative severity of effect (3 because it is assumed the pharmaceutical is well studied)

‡An additional UF of 10 for database uncertainty was applied because the compound shows evidence of being a nongenotoxic carcinogen (see Table C-4).

Table C-4. Summary of Carcinogenicity and Genotoxicity Data for COIs

Compound	Evidence	Genotoxicity assumption	Availability of tumor incidence data	Cancer SF $(mg/kg\text{-}d)^{-1}$
1,4-Dioxane	Classified as a B2, probable human carcinogen by U.S. EPA (2013), based on inadequate evidence of carcinogenicity in humans, and sufficient evidence in animals (i.e., hepatic tumors in multiple species [three strains of rats, two strains of mouse, and in guinea pigs]; mesotheliomas of the peritoneum, mammary, and nasal tumors have also been observed in rats following 2 years of oral exposure to 1,4-dioxane). Classified as 2B, possibly carcinogenic to humans, by IARC (1999). Classified as reasonably anticipated to be a human carcinogen by NTP (2016).	Mixed [Most tests for genotoxic activity have produced negative results including *in vitro* tests for reverse bacterial mutagenicity in *Salmonella typhimurium* and in *E. coli* and mouse lymphoma cell forward mutation assays, but positive results were obtained in a cell transformation assay and conflicting results were obtained in mouse bone-marrow cell tests for micronucleus induction (IARC, 1999; CCRIS, 2008).]	U.S. EPA cancer SF available, based on increased incidence of hepatocellular adenomas and carcinomas in female mice exposed to 1,4-dioxane in drinking water for 2 years (U.S. EPA, 2013).	0.1 $(mg/kg\text{-}d)^{-1}$ (U.S. EPA, 2013)
Carbamazepine	Increase in liver carcinomas in female rats administered 25, 75, or 250 mg/kg-d orally in the diet for 2-years (Novartis, 2010; Singh et al., 2005).	Negative [Negative findings in bacterial (*in vitro*) and mammalian (*in vivo*) mutagenicity studies (RxList.com, 2021b).]	Not applicable (data not located; based on negative mutagenicity data, mechanism for development of cancers in rodents likely to be nongenotoxic).	NA
N-Nitroso dimethylamine (NDMA)	Identified by U.S. EPA as a probable (B2) human carcinogen, based on induction of tumors at multiple sites in both rodents and nonrodent mammals exposed by various routes (U.S. EPA, 1987). It is identified as reasonably anticipated to be a human carcinogen by NTP based on sufficient evidence of carcinogenicity from studies in experimental animals (NTP, 2016). Classified by IARC (1978) as Group 2A, sufficient evidence of a carcinogenic effect in humans.	Positive [Positive for mutagenicity in *in vitro* systems including bacterial reverse mutagenicity in *S. typhimurium* and *E. coli*, in Chinese hamster V79 cells, in mouse lymphoma L5178Y (TK+/TK-) cells, and in *in vivo* systems including a UDS assay in mouse hepatocytes and a micronucleus assay in rats (CCRIS, 2010)].	U.S. EPA cancer SF available, based on increased incidence of liver tumors in female rats exposed to NDMA in drinking water for 2 years (U.S. EPA, 1987).	51 $(mg/kg\text{-}d)^{-1}$ (U.S. EPA, 1987)

Compound	Evidence	Genotoxicity assumption	Availability of tumor incidence data	Cancer SF $(mg/kg\text{-}d)^{-1}$
Perfluorinated compounds	IARC (2018) classified PFOA as possibly carcinogenic to humans (Group 2B) based on limited evidence for carcinogenicity in animals and in humans. For PFOA, in 2-year diet studies, male but not female rats showed a dose-response relationship with exposure for one tumor type (Leydig cell in testes) (U.S. EPA, 2016a). Per U.S. EPA (2016a), evidence for the carcinogenicity of PFOA is considered suggestive because only one species has been evaluated for lifetime exposures and the tumor responses occurred primarily in males. In a single chronic bioassay for PFOS in rats (2-year study with exposure in diet), liver adenomas were increased in males and females at the highest dose (U.S. EPA, 2016b). However, per U.S. EPA (2016b), the existing evidence for PFOS does not support a strong correlation between the tumor incidence and dose to justify a quantitative assessment.	Predominantly negative [Both PFOA and PFOS were negative in *in vitro* bacterial reverse mutagenicity assays in *S. typhimurium* w/ and w/o metabolic activation and in *E. coli* WP2 uvrA (U.S. EPA, 2016a,b). For PFOA, clastogenicity studies in CHO cells were positive for chromosomal abnormalities and polyploidy with activation and equivocal in the absence of activation. Micronucleus assays were negative (U.S. EPA, 2016a). For PFOS, an *in vitro* assay for chromosomal aberrations in human whole blood lymphocytes with and without metabolic activation was negative, as was a mouse *in vivo* micronucleus assay (U.S. EPA, 2016b).]	Data for PFOA and PFOS were judged to be inadequate by U.S. EPA (2016a,b) for quantitative assessments of cancer risk. However, for PFOA, U.S. EPA modeled cancer risk from dose-response data for Leydig cell tumors in rats and derived a cancer SF of $0.07\ (mg/kg\text{-}d)^{-1}$ (U.S. EPA, 2016a).	$0.07\ (mg/kg\text{-}d)^{-1}$ (PFOA; U.S. EPA, 2016a)
Primidone	Increased incidence of hepatocellular neoplasms in males and females and thyroid gland follicular cell adenomas in 2-year oral study in mice (NTP, 2000). Per IARC, "The reported carcinogenicity of primidone in mice is likely to be mediated through a non-genotoxic mechanism resulting from the metabolism of primidone to phenobarbital." IARC (2016) classified primidone as Group 2B, possibly carcinogenic to humans based on sufficient evidence of carcinogenicity in animals.	Negative [Positive *in vitro* in *S. typhimurium* strain TA1535 in the absence of S9 activation only; not mutagenic in strain TA98, TA100, or TA1537, with or without activation. Negative in *in vitro* mouse lymphoma cell assay. Negative *in vitro* for sister chromatid exchanges or chromosomal aberrations in cultured CHO cells, with or without activation. Negative in *in vivo* mouse bone marrow micronucleus test (NTP, 2000; CCRIS, 2009a).]	Not applicable (mechanism for induction of tumors in mice thought to be non-genotoxic).	NA

Compound	Evidence	Genotoxicity assumption	Availability of tumor incidence data	Cancer SF $(mg/kg\text{-}d)^{-1}$
Quinoline	Identified by U.S. EPA as a Group B2 probable human carcinogen, based on inadequate evidence in humans and sufficient evidence in animals, including hepatocellular carcinomas and hemangioendotheliomas or hemangiosarcomas (a vascular tumor) in rats and mice (U.S. EPA, 2001). Not classified by NTP. Classified as Group 2B, possibly carcinogenic to humans based on sufficient evidence of carcinogenicity in animals, by IARC (2019).	Positive [Positive for mutagenicity in *in vitro* systems including bacterial reverse mutagenicity in *S. typhimurium* and in *E. coli* and a UDS assay in rat hepatocytes, and in *in vivo* systems including a micronucleus assay in rats. It was negative in a chromosomal aberration assay *in vitro* in Chinese hamster lung cells (CCRIS, 2009b)].	U.S. EPA cancer SF available, based on increased incidence of hepatic hemangio-endotheliomas or hemangiosarcomas in male rats exposed to quinoline in diet (U.S. EPA, 2001)	3 $(mg/kg\text{-}d)^{-1}$ (U.S. EPA, 2001)

CCRIS – Chemical Carcinogenesis Research Information System; CHO – Chinese hamster ovary; F – female; IARC – International Agency for Research on Cancer; M – male; NA – Not available; NLM – National Library of Medicine; NTP – National Toxicology Program; SF – slope factor; UDS – unscheduled DNA synthesis

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APPENDIX D

RISK CALCULATION RESULTS FOR THE BASELINE TREATMENT SCENARIO

Table D-1. Summary of Estimated Chemical- and Pathway- Specific Noncancer Hazards for the RME and MLE Resident Scenarios, Assuming Exposure to Water from the Shallow Aquifer (Baseline Treatment Scenario)*

		Reasonable maximum exposure (RME)				More likely exposure (MLE)			
Chemical of Interest	**Population**	**Ingestion of Tap Water**	**Dermal Contact with Tap Water**	**Inhalation of Volatiles**	**TOTAL**	**Ingestion of Tap Water**	**Dermal Contact with Tap Water**	**Inhalation of Volatiles**	**TOTAL**
1,4-Dioxane	Child	1.1E-03	5.2E-06	--- (a)	1.1E-03	3.6E-04	2.8E-06	--- (a)	3.6E-04
	Adult	5.8E-04	1.8E-06	--- (a)	5.8E-04	1.8E-04	7.2E-07	--- (a)	1.9E-04
Carbamazepine	Child	3.1E-02	3.4E-03	--- (a)	3.4E-02	9.6E-03	1.9E-03	--- (a)	1.1E-02
	Adult	1.6E-02	1.2E-03	--- (a)	1.7E-02	5.0E-03	4.7E-04	--- (a)	5.5E-03
N-Nitroso dimethylamine (NDMA)	Child	--- (b)	--- (b)	--- (a, b)	---	--- (b)	--- (b)	--- (a, b)	---
	Adult	--- (b)	--- (b)	--- (a, b)	---	--- (b)	--- (b)	--- (a, b)	---
Perfluoro octanoic acid (PFOA)	Child	3.1E-01	2.9E-02	--- (a)	3.4E-01	9.7E-02	1.6E-02	--- (a)	1.1E-01
	Adult	1.6E-01	9.9E-03	--- (a)	1.7E-01	5.1E-02	4.0E-03	--- (a)	5.5E-02
Perfluoro-n-hexanoic acid (PFHxA)	Child	7.6E-01	9.3E-02	--- (a)	8.5E-01	2.4E-01	5.0E-02	--- (a)	2.9E-01
	Adult	3.8E-01	3.1E-02	--- (a)	4.1E-01	1.2E-01	1.3E-02	--- (a)	1.4E-01
Perfluoropentanoic acid (PFPeA)	Child	1.3E+00	2.3E-02	--- (a)	1.3E+00	4.1E-01	1.2E-02	--- (a)	4.2E-01
	Adult	6.6E-01	7.7E-03	--- (a)	6.7E-01	2.1E-01	3.1E-03	--- (a)	2.2E-01
Primidone	Child	9.3E-02	1.1E-03	--- (a)	9.5E-02	2.9E-02	6.0E-04	--- (a)	3.0E-02
	Adult	4.7E-02	3.8E-04	--- (a)	4.7E-02	1.5E-02	1.5E-04	--- (a)	1.5E-02
Quinoline	Child	7.8E-04	9.0E-05	--- (a)	8.7E-04	2.4E-04	4.9E-05	--- (a)	2.9E-04
	Adult	3.9E-04	3.0E-05	--- (a)	4.2E-04	1.3E-04	1.2E-05	--- (a)	1.4E-04

*Exposures estimated using EPCs for the closest modeled point (200-ft down gradient of the infiltration basins), assuming no additional treatment options are implemented (baseline scenario).

--- Chemical and/or pathway not evaluated for the following reason(s): (a) Pathway not evaluated because molecular weight and/or Henry's Law constant for the chemical do not meet volatility criteria for evaluation of inhalation risk; (b) Chemical not evaluated because it is regulated as a carcinogen (not a noncarcinogen) by U.S. EPA and a toxicity criterion is not available.

Table D-2. Summary of Estimated Chemical- and Pathway- Specific Noncancer Hazards for the RME and MLE Resident Scenarios, Assuming Exposure to Water from the Deep Aquifer (Baseline Treatment Scenario)*

		Reasonable maximum exposure (RME)				More likely exposure (MLE)			
Chemical of Interest	**Population**	**Ingestion of Tap Water**	**Dermal Contact with Tap Water**	**Inhalation of Volatiles**	**TOTAL**	**Ingestion of Tap Water**	**Dermal Contact with Tap Water**	**Inhalation of Volatiles**	**TOTAL**
1,4-Dioxane	Child	--- (a)	--- (a)	--- (a, c)	---	--- (a)	--- (a)	--- (a, c)	---
	Adult	--- (a)	--- (a)	--- (a, c)	---	--- (a)	--- (a)	--- (a, c)	---
Carbamazepine	Child	--- (a)	--- (a)	--- (a, c)	---	--- (a)	--- (a)	--- (a, c)	---
	Adult	--- (a)	--- (a)	--- (a, c)	---	--- (a)	--- (a)	--- (a, c)	---
N-Nitroso dimethylamine (NDMA)	Child	--- (b)	--- (b)	--- (b, c)	---	--- (b)	--- (b)	--- (b, c)	---
	Adult	--- (b)	--- (b)	--- (b, c)	---	--- (b)	--- (b)	--- (b, c)	---
Perfluoro octanoic acid (PFOA)	Child	3.1E-01	2.9E-02	--- (c)	3.4E-01	9.6E-02	1.6E-02	--- (c)	1.1E-01
	Adult	1.6E-01	9.8E-03	--- (c)	1.7E-01	5.0E-02	4.0E-03	--- (c)	5.4E-02
Perfluoro-n-hexanoic acid (PFHxA)	Child	7.5E-01	9.2E-02	--- (c)	8.4E-01	2.3E-01	5.0E-02	--- (c)	2.8E-01
	Adult	3.8E-01	3.1E-02	--- (c)	4.1E-01	1.2E-01	1.3E-02	--- (c)	1.3E-01
Perfluoropentanoic acid (PFPeA)	Child	1.3E+00	2.2E-02	--- (c)	1.3E+00	4.0E-01	1.2E-02	--- (c)	4.2E-01
	Adult	6.5E-01	7.6E-03	--- (c)	6.6E-01	2.1E-01	3.1E-03	--- (c)	2.1E-01
Primidone	Child	--- (a)	--- (a)	--- (a, c)	---	--- (a)	--- (a)	--- (a, c)	---
	Adult	--- (a)	--- (a)	--- (a, c)	---	--- (a)	--- (a)	--- (a, c)	---
Quinoline	Child	--- (a)	--- (a)	--- (a, c)	---	--- (a)	--- (a)	--- (a, c)	---
	Adult	--- (a)	--- (a)	--- (a, c)	---	--- (a)	--- (a)	--- (a, c)	---

*Exposures estimated using EPCs for the closest modeled point (200-ft down gradient of the infiltration basins), assuming no additional treatment options are implemented (baseline scenario).

--- Chemical and/or pathway not evaluated for the following reason(s): (a) Chemical not evaluated because fate and transport modelling predicts the chemical would not be present in the deep aquifer; (b) Chemical not evaluated because it is regulated as a carcinogen (not a noncarcinogen) by U.S. EPA and a toxicity criterion is not available; (c) Pathway not evaluated because molecular weight and/or Henry's Law constant for the chemical do not meet volatility criteria for evaluation of inhalation risk.

Table D-3. Summary of Estimated Chemical- and Pathway- Specific Noncancer Hazards for the Adult Maintenance Worker Scenario, Assuming Exposure to Water from the Shallow or Deep Aquifers (Baseline Treatment Scenario)*

	Shallow Aquifer			Deep Aquifer		
Chemical of Interest	**Ingestion of Tap/ Well Water**	**Dermal Contact with Tap/ Well Water**	**TOTAL**	**Ingestion of Tap/ Well Water**	**Dermal Contact with Tap/ Well Water**	**TOTAL**
1,4-Dioxane	2.5E-04	3.2E-07	2.5E-04	--- (a)	--- (a)	---
Carbamazepine	6.7E-03	2.1E-04	6.9E-03	--- (a)	--- (a)	---
N-Nitroso dimethylamine (NDMA)	--- (b)	--- (b)	---	--- (b)	--- (b)	---
Perfluoro octanoic acid (PFOA)	6.7E-02	1.8E-03	6.9E-02	6.7E-02	1.8E-03	6.9E-02
Perfluoro-n-hexanoic acid (PFHxA)	1.6E-01	5.7E-03	1.7E-01	1.6E-01	5.7E-03	1.7E-01
Perfluoropentanoic acid (PFPeA)	2.8E-01	1.4E-03	2.8E-01	2.8E-01	1.4E-03	2.8E-01
Primidone	2.0E-02	6.8E-05	2.0E-02	--- (a)	--- (a)	---
Quinoline	1.7E-04	5.5E-06	1.7E-04	--- (a)	--- (a)	---

*Exposures estimated using EPCs for the closest modeled point (200-ft down gradient of the infiltration basins), assuming no additional treatment options are implemented (baseline scenario).

--- Chemical and/or pathway not evaluated for the following reason(s): (a) Chemical not evaluated because fate and transport modelling predicts the chemical would not be present in the deep aquifer; (b) Chemical not evaluated because it is regulated as a carcinogen (not a noncarcinogen) by U.S. EPA and a toxicity criterion is not available.

Table D-4. Summary of Estimated Chemical- and Pathway- Specific Noncancer Hazards for the Child Playfield and Water Feature Recreator Scenario, Assuming Exposure to Water from the Shallow or Deep Aquifers (Baseline Treatment Scenario)*

	Shallow Aquifer				Deep Aquifer			
Chemical of Interest	**Ingestion of Tap/ Well Water on Playfield**	**Incidental Ingestion of Tap/ Well Water at Water Feature**	**Dermal Contact with Tap/ Well Water at Water Feature**	**TOTAL**	**Ingestion of Tap/ Well Water on Playfield**	**Incidental Ingestion of Tap/ Well Water at Water Feature**	**Dermal Contact with Tap/ Well Water at Water Feature**	**TOTAL**
1,4-Dioxane	2.3E-04	3.6E-05	1.1E-06	2.6E-04	--- (a)	--- (a)	--- (a)	---
Carbamazepine	6.1E-03	9.7E-04	7.0E-04	7.8E-03	--- (a)	--- (a)	--- (a)	---
N-Nitroso dimethylamine (NDMA)	--- (b)	--- (b)	--- (b)	---	--- (b)	--- (b)	--- (b)	---
Perfluoro octanoic acid (PFOA)	6.2E-02	9.8E-03	6.0E-03	7.8E-02	6.1E-02	9.7E-03	6.0E-03	7.7E-02
Perfluoro-n-hexanoic acid (PFHxA)	1.5E-01	2.4E-02	1.9E-02	1.9E-01	1.5E-01	2.4E-02	1.9E-02	1.9E-01
Perfluoropentanoic acid (PFPeA)	2.6E-01	4.1E-02	4.7E-03	3.1E-01	2.6E-01	4.1E-02	4.6E-03	3.0E-01
Primidone	1.9E-02	2.9E-03	2.3E-04	2.2E-02	--- (a)	--- (a)	--- (a)	---
Quinoline	1.5E-04	2.4E-05	1.9E-05	2.0E-04	--- (a)	--- (a)	--- (a)	---

*Exposures estimated using EPCs for the closest modeled point (200-ft down gradient of the infiltration basins), assuming no additional treatment options are implemented (baseline scenario).

--- Chemical and/or pathway not evaluated for the following reason(s): (a) Chemical not evaluated because fate and transport modelling predicts the chemical would not be present in the deep aquifer; (b) Chemical not evaluated because it is regulated as a carcinogen (not a noncarcinogen) by U.S. EPA and a toxicity criterion is not available.

Table D-5. Summary of Estimated Chemical- and Pathway- Specific Noncancer Hazards for the Creek Recreator/ High End Fish Consumer Scenarios, Assuming Exposure to Water in McAllister or Woodland Creeks (Baseline Treatment Scenario)*

		Woodland Creek				McAllister Creek			
Chemical of Interest	Population	Incidental Ingestion of Surface Water	Dermal Contact with Surface Water	Consumption of Fish (High end consumer)†	TOTAL	Incidental Ingestion of Surface Water	Dermal Contact with Surface Water	Consumption of Fish (High end consumer)†	TOTAL
1,4-Dioxane	Child	--- (a)	--- (a)	--- (a)	---	--- (a)	--- (a)	--- (a)	---
	Adult	--- (a)	--- (a)	--- (a)	---	--- (a)	--- (a)	--- (a)	---
Carbamazepine	Child	--- (a)	--- (a)	--- (a)	---	--- (a)	--- (a)	--- (a)	---
	Adult	--- (a)	--- (a)	--- (a)	---	--- (a)	--- (a)	--- (a)	---
N-Nitroso dimethylamine (NDMA)	Child	--- (b)	--- (b)	--- (b)	---	--- (b)	--- (b)	--- (b)	---
	Adult	--- (b)	--- (b)	--- (b)	---	--- (b)	--- (b)	--- (b)	---
Perfluoro octanoic acid (PFOA)	Child	1.7E-05	7.3E-06	4.0E-01	4.0E-01	3.3E-07	1.5E-07	8.0E-03	8.0E-03
	Adult	2.9E-06	2.2E-06	7.5E-02	7.5E-02	5.7E-08	4.4E-08	1.5E-03	1.5E-03
Perfluoro-n-hexanoic acid (PFHxA)	Child	4.1E-05	2.3E-05	3.4E-01	3.4E-01	8.1E-07	4.6E-07	6.9E-03	6.9E-03
	Adult	7.0E-06	6.9E-06	6.5E-02	6.5E-02	1.4E-07	1.4E-07	1.3E-03	1.3E-03
Perfluoropentanoic acid (PFPeA)	Child	7.0E-05	5.6E-06	1.6E-01	1.6E-01	1.4E-06	1.1E-07	3.1E-03	3.1E-03
	Adult	1.2E-05	1.7E-06	2.9E-02	2.9E-02	2.4E-07	3.4E-08	5.9E-04	5.9E-04
Primidone	Child	--- (a)	--- (a)	--- (a, c)	---	--- (a)	--- (a)	--- (a, c)	---
	Adult	--- (a)	--- (a)	--- (a, c)	---	--- (a)	--- (a)	--- (a, c)	---
Quinoline	Child	--- (a)	--- (a)	--- (a)	---	--- (a)	--- (a)	--- (a)	---
	Adult	--- (a)	--- (a)	--- (a)	---	--- (a)	--- (a)	--- (a)	---

*Exposures estimated using EPCs for the closest modeled point (200-ft down gradient of the infiltration basins), assuming no additional treatment options are implemented (baseline scenario).

†Estimates assume consumption of 330.5 g/d of fish, by both child and adult, based on 95th percentile estimate of consumers only "total fish" consumption from the Puget Sound and elsewhere by Squaxin Tribe adults, as presented by U.S. EPA (2013) and supported by the Squaxin Tribe (Whitener, 2018).

--- Chemical and/or pathway not evaluated for the following reason(s): (a) Chemical not evaluated because fate and transport modelling predicts the chemical would not be present in the creek; (b) Chemical not evaluated because it is regulated as a carcinogen (not a noncarcinogen) by U.S. EPA and a toxicity criterion is not available; (c) A bioconcentration factor (BCF) for this chemical is not available.

Table D-6. Summary of Estimated Chemical- and Pathway- Specific LECRs for the RME and MLE Resident Scenarios, Assuming Exposure to Water from the Shallow Aquifer (Baseline Treatment Scenario)*

	Reasonable maximum exposure (RME)				More likely exposure (MLE)			
Chemical of Interest	**Ingestion of Tap Water**	**Dermal Contact with Tap Water**	**Inhalation of Volatiles from Tap Water**	**TOTAL**	**Ingestion of Tap Water**	**Dermal Contact with Tap Water**	**Inhalation of Volatiles from Tap Water**	**TOTAL**
1,4-Dioxane	9.3E-07	3.3E-09	--- (a)	9.4E-07	1.2E-07	7.3E-10	--- (a)	1.2E-07
Carbamazepine	--- (b)	--- (b)	--- (a, b)	---	--- (b)	--- (b)	--- (a, b)	---
N-Nitroso dimethylamine (NDMA)	2.9E-06	7.1E-09	--- (a)	2.9E-06	3.8E-07	1.6E-09	--- (a)	3.8E-07
Perfluoro octanoic acid (PFOA)	1.8E-08	1.3E-09	--- (a)	1.9E-08	2.4E-09	2.9E-10	--- (a)	2.7E-09
Perfluoro-n-hexanoic acid (PFHxA)	5.5E-08	5.2E-09	--- (a)	6.0E-08	7.3E-09	1.2E-09	--- (a)	8.5E-09
Perfluoropentanoic acid (PFPeA)	9.5E-08	1.3E-09	--- (a)	9.7E-08	1.3E-08	2.8E-10	--- (a)	1.3E-08
Primidone	--- (b)	--- (b)	--- (a, b)	---	--- (b)	--- (b)	--- (a, b)	---
Quinoline	5.0E-07	4.5E-08	--- (a)	5.5E-07	6.7E-08	1.0E-08	--- (a)	7.7E-08

*Exposures estimated using EPCs for the closest modeled point (200-ft down gradient of the infiltration basins), assuming no additional treatment options are implemented (baseline scenario). The notation "E-…" is equivalent to "× 10-…", for example 1.2E-07 is equivalent to 1.2×10^{-7}, which is equivalent to a probability that 1.2 persons in 10 million will develop the particular form of cancer due to exposure to this chemical in their lifetime.

--- Chemical and/or pathway not evaluated for the following reason(s): (a) Pathway not evaluated because molecular weight and/or Henry's Law constant for the chemical do not meet volatility criteria for evaluation of inhalation risk; (b) Chemical not evaluated because it is not classified as a carcinogen.

Table D-7. Summary of Estimated Chemical- and Pathway- Specific LECRs for the RME and MLE Resident Scenarios, Assuming Exposure to Water from the Deep Aquifer (Baseline Treatment Scenario)*

	Reasonable maximum exposure (RME)				More likely exposure (MLE)			
Chemical of Interest	**Ingestion of Tap Water**	**Dermal Contact with Tap Water**	**Inhalation of Volatiles**	**TOTAL**	**Ingestion of Tap Water**	**Dermal Contact with Tap Water**	**Inhalation of Volatiles**	**TOTAL**
1,4-Dioxane	--- (a)	--- (a)	--- (a, c)	---	--- (a)	--- (a)	--- (a, c)	---
Carbamazepine	--- (b)	--- (b)	--- (b, c)	---	--- (b)	--- (b)	--- (b, c)	---
N-Nitroso dimethylamine (NDMA)	2.8E-06	7.0E-09	--- (c)	2.9E-06	3.8E-07	1.5E-09	--- (c)	3.8E-07
Perfluoro octanoic acid (PFOA)	1.8E-08	1.3E-09	--- (c)	1.9E-08	2.4E-09	2.9E-10	--- (c)	2.6E-09
Perfluoro-n-hexanoic acid (PFHxA)	5.5E-08	5.2E-09	--- (c)	6.0E-08	7.2E-09	1.1E-09	--- (c)	8.4E-09
Perfluoropentanoic acid (PFPeA)	9.4E-08	1.3E-09	--- (c)	9.6E-08	1.3E-08	2.8E-10	--- (c)	1.3E-08
Primidone	--- (b)	--- (b)	--- (b, c)	---	--- (b)	--- (b)	--- (b, c)	---
Quinoline	--- (a)	--- (a)	--- (a, c)	---	--- (a)	--- (a)	--- (a, c)	---

*Exposures estimated using EPCs for the closest modeled point (200-ft down gradient of the infiltration basins), assuming no additional treatment options are implemented (baseline scenario). The notation "E-…" is equivalent to "× 10-…", for example 3.8E-07 is equivalent to 3.8×10^{-7}, which is equivalent to a probability that 3.8 persons in 10 million will develop the particular form of cancer due to exposure to this chemical in their lifetime.

--- Chemical and/or pathway not evaluated for the following reason(s): (a) Chemical not evaluated because fate and transport modelling predicts the chemical would not be present in the deep aquifer; (b) Chemical not evaluated because it is not classified as a carcinogen; (c) Pathway not evaluated because molecular weight and/or Henry's Law constant for the chemical do not meet volatility criteria for evaluation of inhalation risk.

Table D-8: Summary of Estimated Chemical- and Pathway- Specific LECRs for the Adult Maintenance Worker Scenario, Assuming Exposure to Water from the Shallow or Deep Aquifer (Baseline Treatment Scenario)*

	Shallow Aquifer			Deep Aquifer		
Chemical of Interest	**Ingestion of Tap/ Well Water**	**Dermal Contact with Tap/ Well Water**	**TOTAL**	**Ingestion of Tap/ Well Water**	**Dermal Contact with Tap/ Well Water**	**TOTAL**
1,4-Dioxane	2.6E-07	3.5E-10	2.6E-07	--- (a)	--- (a)	---
Carbamazepine	--- (b)	--- (b)	---	--- (b)	--- (b)	---
N-Nitroso dimethylamine (NDMA)	8.1E-07	7.4E-10	8.1E-07	8.0E-07	7.3E-10	8.0E-07
Perfluoro octanoic acid (PFOA)	5.1E-09	1.4E-10	5.2E-09	5.0E-09	1.3E-10	5.1E-09
Perfluoro-n-hexanoic acid (PFHxA)	1.6E-08	5.4E-10	1.6E-08	1.5E-08	5.4E-10	1.6E-08
Perfluoropentanoic acid (PFPeA)	2.7E-08	1.3E-10	2.7E-08	2.7E-08	1.3E-10	2.7E-08
Primidone	--- (b)	--- (b)	---	--- (b)	--- (b)	---
Quinoline	1.4E-07	4.7E-09	1.5E-07	--- (a)	--- (a)	---

*Exposures estimated using EPCs for the closest modeled point (200-ft down gradient of the infiltration basins), assuming no additional treatment options are implemented (baseline scenario). The notation "E-…" is equivalent to "× 10-…", for example 1.2E-07 is equivalent to 1.2×10^{-7}, which is equivalent to a probability that 1.2 persons in 10 million will develop the particular form of cancer due to exposure to this chemical in their lifetime.

--- Chemical and/or pathway not evaluated for the following reason(s): (a) Chemical not evaluated because fate and transport modelling predicts the chemical would not be present in the deep aquifer; (b) Chemical not evaluated because it is not classified as a carcinogen.

Table D-9. Summary of Estimated Chemical- and Pathway- Specific LECRs for the Child Playfield and Water Feature Recreator Scenario, Assuming Exposure to Water from the Shallow or Deep Aquifer (Baseline Treatment Scenario)*

	Shallow Aquifer				Deep Aquifer			
Chemical of Interest	**Ingestion of Tap/ Well Water on Playfield**	**Incidental Ingestion of Tap/ Well Water at Water Feature**	**Dermal Contact with Tap/ Well Water at Water Feature**	**TOTAL**	**Ingestion of Tap/ Well Water on Playfield**	**Incidental Ingestion of Tap/ Well Water at Water Feature**	**Dermal Contact with Tap/ Well Water at Water Feature**	**TOTAL**
1,4-Dioxane	5.8E-08	9.2E-09	2.8E-10	6.8E-08	--- (a)	--- (a)	--- (a)	---
Carbamazepine	--- (b)	--- (b)	--- (b)	---	--- (b)	--- (b)	--- (b)	---
N-Nitroso dimethylamine (NDMA)	1.8E-07	2.8E-08	5.9E-10	2.1E-07	1.8E-07	2.8E-08	5.8E-10	2.1E-07
Perfluoro octanoic acid (PFOA)	1.1E-09	1.8E-10	1.1E-10	1.4E-09	1.1E-09	1.7E-10	1.1E-10	1.4E-09
Perfluoro-n-hexanoic acid (PFHxA)	3.4E-09	5.4E-10	4.4E-10	4.4E-09	3.4E-09	5.4E-10	4.3E-10	4.4E-09
Perfluoropentanoic acid (PFPeA)	5.9E-09	9.4E-10	1.1E-10	7.0E-09	5.9E-09	9.3E-10	1.1E-10	6.9E-09
Primidone	--- (b)	--- (b)	--- (b)	---	--- (b)	--- (b)	--- (b)	---
Quinoline	3.1E-08	4.9E-09	3.8E-09	4.0E-08	--- (a)	--- (a)	--- (a)	---

*Exposures estimated using EPCs for the closest modeled point (200-ft down gradient of the infiltration basins), assuming no additional treatment options are implemented (baseline scenario). The notation "E-…" is equivalent to "× 10-…", for example 1.2E-07 is equivalent to 1.2×10^{-7}, which is equivalent to a probability that 1.2 persons in 10 million will develop the particular form of cancer due to exposure to this chemical in their lifetime.

--- Chemical and/or pathway not evaluated for the following reason(s): (a) Chemical not evaluated because fate and transport modelling predicts the chemical would not be present in the deep aquifer; (b) Chemical not evaluated because it is not classified as a carcinogen.

Table D-10. Summary of Estimated Chemical- and Pathway- Specific LECRs for the Creek Recreator/High End Fish Consumer Scenarios, Assuming Exposure to Water in McAllister or Woodland Creeks (Baseline Treatment Scenario)*

	Woodland Creek				McAllister Creek			
Chemical of Interest	**Incidental Ingestion of Surface Water**	**Dermal Contact with Surface Water**	**Consumption of Fish (High end consumer) †**	**TOTAL**	**Incidental Ingestion of Surface Water**	**Dermal Contact with Surface Water**	**Consumption of Fish (High end consumer) †**	**TOTAL**
1,4-Dioxane	--- (a)	--- (a)	--- (a)	---	--- (a)	--- (a)	--- (a)	---
Carbamazepine	--- (a)	--- (a)	--- (a)	---	--- (a)	--- (a)	--- (a)	---
N-Nitroso dimethylamine (NDMA)	1.4E-10	2.6E-12	1.2E-08	1.2E-08	2.9E-12	5.3E-14	2.4E-10	2.4E-10
Perfluoro octanoic acid (PFOA)	8.9E-13	4.9E-13	2.2E-08	2.2E-08	1.8E-14	9.7E-15	4.4E-10	4.4E-10
Perfluoro-n-hexanoic acid (PFHxA)	2.7E-12	1.9E-12	2.4E-08	2.4E-08	5.5E-14	3.9E-14	4.8E-10	4.8E-10
Perfluoropentanoic acid (PFPeA)	4.8E-12	4.8E-13	1.1E-08	1.1E-08	9.5E-14	9.5E-15	2.2E-10	2.2E-10
Primidone	--- (a)	--- (a)	--- (a, c)	---	--- (a)	--- (a)	--- (a, c)	---
Quinoline	--- (a)	--- (a)	--- (a)	---	--- (a)	--- (a)	--- (a)	---

*Exposures estimated using EPCs for the closest modeled point (200-ft down gradient of the infiltration basins), assuming no additional treatment options are implemented (baseline scenario). The notation "E-…" is equivalent to "× 10-…", for example 1.2E-07 is equivalent to 1.2×10^{-7}, which is equivalent to a probability that 1.2 persons in 10 million will develop the particular form of cancer due to exposure to this chemical in their lifetime.

†Estimates assume consumption of 330.5 g/d of fish, by both child and adult, based on 95th percentile estimate of consumers only "total fish" consumption from the Puget Sound and elsewhere by Squaxin Tribe adults, as presented by U.S. EPA (2013) and supported by the Squaxin Tribe (Whitener, 2018).

--- Chemical and/or pathway not evaluated for the following reason(s): (a) Chemical not evaluated because fate and transport modelling predicts the chemical would not be present in the creek; (b) Chemical not evaluated because it is not classified as a carcinogen; (c) A bioconcentration factor (BCF) for this chemical is not available.

APPENDIX E

PROBABILISTIC RISK ASSESSMENT FOR THE RESIDENT SCENARIO

Introduction

Results of the deterministic Human Health Risk Assessment (HHRA) conducted for the LOTT Clean Water Alliance Reclaimed Water Infiltration Study show that for one scenario (the Reasonable Maximum Exposure (RME) resident), noncancer Hazard Indices (HIs) calculated in the HHRA slightly exceed 1.0 for one chemical (PFPeA, with an estimated HI of 1.3 for the RME child resident) and Lifetime Excess Cancer Risks (LECRs) slightly exceed the *de minimis* cancer risk benchmark of 1 in 1,000,000 (1×10^{-6}) for one chemical (NMDA, with an estimated LECR of 2.9×10^{-6} for the RME resident). In both cases, the estimated hazards or risks are dominated by contribution from the water ingestion pathway (>99%), with dermal contact with water while showering/bathing or washing contributing minimally to estimated hazards and risks.

As noted in Section 5.3, the RME scenario is intended to estimate a conservative exposure case that is still within the range of possible exposures, i.e., well above the average case and within approximately the 90^{th} to 99.9^{th} percentiles of the exposure distribution for an exposure scenario (U.S. EPA, 1989). Application of a deterministic HHRA approach is consistent with U.S. EPA's recommendations to implement a tiered approach when conducting risk assessments (U.S. EPA, 2001). Per this approach, after first conducting a screening assessment to identify chemicals, scenarios, and exposure pathways of interest, one conducts a conservative point estimate risk assessment intended to overestimate exposures and risks for most members of a population. However, a limitation of the deterministic approach is that the output does not reflect the range of possible exposures or risks within a population or characterize the relative likelihood of these outcomes. In particular, the use of multiple conservative inputs in a deterministic HHRA for an RME scenario can lead to an estimate of exposure that is outside the range of values that can actually occur in a population.

Alternatively, inputs into the HHRA can be represented by distributions of possible parameter values rather than single point estimates. Per the tiered approach, if the results of the deterministic HHRA show that some scenarios and pathways exceed allowable risk thresholds, more refined evaluations can be conducted as part of a probabilistic risk assessment (PRA) to characterize the variability of potential exposures and risks and the uncertainty in the risk estimates.

In a PRA, exposure parameters are represented by a range of values represented as distributions, or probability density functions (PDFs), that characterize the uncertainty and/or variability of values in a population. PDFs are quantitative expressions of existing knowledge about the occurrence of values within a population, characterized as frequency distributions that describe the range of possible values for a given parameter and provide information on the likelihood each value will occur. For instance, a PDF might reflect the likelihood that members of a population have a particular body weight based on the range of measurements of body weights in a larger but representative population group (variability). Alternatively, the true value of a parameter, such as the exposure concentration, may be uncertain, and so a PDF could be selected that reflects that reflects the uncertainty about the true exposure concentration to exposed individuals (uncertainty). However, note that in this assessment, a point estimate (the 95 percent UCL) was applied as an estimate of the EPC in the PRA, as discussed in the section, *Inputs for Exposure Parameters and Chemical-Specific Values for the PRA for the Resident Scenario*, below.

When inputs to a dose equation are defined by distributions, each equation has many possible outcomes. Using a process known as Monte Carlo simulation, which is best done using computer software programs to perform the calculations, the equation can be solved repeatedly using, in each

trial, different values selected from the PDFs for each uncertain or variable parameter with selected values more likely to be drawn from the areas of the PDF that have higher probabilities of occurrence. The output of a Monte Carlo PRA simulation is itself a PDF, describing not only the best (i.e., most likely) estimate of the overall result but also the range of estimated results and the likelihood of each.

Approach for PRA for the Resident Scenario

Consistent with U.S. EPA's recommended tiered approach for conducting HHRAs, to provide perspective on where estimated doses of PFPeA and NDMA, and corresponding noncancer hazards and cancer risks for the RME resident fall within the range of possible exposures and risks, a PRA was conducted for these chemicals for the resident scenario.

For the two chemicals, potential doses to a resident associated with ingestion of or contact with tap water in the home were estimated by identifying PDFs characterizing the ranges of possible values for each exposure parameter in the dose calculations, and then repeatedly recalculating doses by Monte Carlo simulation using values selected from these distributions. In the PRA, Monte Carlo simulations were conducted using the Crystal Ball software package (Oracle Corporation, Redwood Shores, CA, 2020, version 11.1.2.4.850 (64-bit), https://www.oracle.com/applications/crystalball/).

Specifically, for each dose equation developed to quantify exposure to a specific population via a specific pathway (such as the average daily dose of a chemical to adults ingesting drinking water), a Monte Carlo simulation was run using a sample size of 100,000 trials. Results from the Monte Carlo simulations were then presented as graphs and as values at the 5th, 50th, 90th, 95th, and 99th percentiles of the output distributions. Output includes estimate of dose, noncancer hazard (for PFPeA only), and cancer risk (for NDMA only) for each scenario (residential exposure to water in the shallow and deep aquifer), chemical, and pathway (ingestion of or contact with tap water). Note that consistent with U.S. EPA principles (see U.S. EPA, 1997b), probabilistic methods were applied in this PRA only to the exposure assessment (not the toxicity assessment). That is, point estimate values were used in the PRA for benchmarks of toxicity (a reference dose for potential noncancer effects of PFPeA and a cancer slope factor for potential carcinogenicity of NDMA—these were the same values applied in the deterministic HHRA).

The resulting distributions of dose and noncancer hazard or cancer risk are intended to reflect the range of exposure and risk across an exposed population. That is, they reflect exposures to average or typical individuals within the population, as well as less and more highly exposed individuals.

In conducting the PRA, principles and policies described in the following guidance were applied:

- U.S. EPA, 1997a. *Guiding Principles for Monte Carlo Analysis*. United States Environmental Protection Agency. Washington, D.C. EPA/630/R-97/001. March.
- U.S. EPA, 1997b. *Policy for Use of Probabilistic Models in Risk Assessment*. United States Environmental Protection Agency. Washington, D.C. May 15.
- U.S. EPA, 2001. *Risk Assessment Guidance for Superfund: Volume III - Part A, Process for Conducting Probabilistic Risk Assessment*. United States Environmental Protection Agency. Washington, D.C. EPA 540-R-02-002. December.
- U.S. EPA, 2014a. *Risk Assessment Forum White Paper: Probabilistic Risk Assessment Methods and Case Studies*. United States Environmental Protection Agency. Washington,

D.C. EPA/100/R-14/004. July.

- U.S. EPA, 2014b. *Risk Assessment to Inform Decision Making: Frequently Asked Questions*. United States Environmental Protection Agency. Washington, D.C. EPA/100/R-14/003. July.

Dose Equations

Ingestion of Tap Water by the Child and Adult Resident

In the deterministic risk assessment, for the child and adult resident, exposures to PFPeA and NDMA via ingestion of tap water were estimated using the general equation shown below.

$$Dose_{ing-water}\ (mg/kg-d) = \frac{C_{water} \times CF \times IR_{water} \times FI \times EF \times ED}{BW \times AT}$$

Where:

$Dose_{ing\text{-}water}$	=	Average daily dose (ADD) for noncarcinogens (PFPeA) or lifetime average daily dose (LADD) for carcinogens (NDMA), from direct ingestion of tap water as drinking water by a child or adult resident, mg/kg-d
C_{water}	=	EPC of chemical in water from the shallow or deep aquifer, ng/L
CF	=	Conversion factor, mg/ng (10^{-6} mg/ng)
IR_{water}	=	Water ingestion rate, L/d
FI	=	Fraction ingested from a contaminated source, unitless
EF	=	Exposure frequency, d/yr
ED	=	Exposure duration, yr
BW	=	Body weight, kg
AT	=	Averaging time, d (equal to ED × 365 d/yr for noncarcinogens and 70 yr × 365 d/yr for carcinogens)

For assessment of noncarcinogens, the average daily dose (ADD) is calculated assuming that the averaging time (AT; in days) is equal to the exposure duration (ED; in years) multiplied by the number of days in a year (365 d/yr) such that ED effectively cancels out of the exposure equation.

In the PRA, given that calculation of an ADD for noncancer effects implicitly calculates doses averaged over a relatively shorter exposure (typically a year is assumed) and relative intake rates (such as via ingestion) are relatively greater on a per bodyweight basis for a young child compared to an adult, separate distributions of ADDs were calculated for a child and an adult. In addition, since intake rates (e.g., the amount of drinking water consumed per day) are typically positively correlated to body weight (i.e., water ingestion rates generally increase with increasing body weight), in the PRA, intake rates applied in the dose calculations were input on a per kilogram of body weight basis (i.e., liters of water per kilogram body weight per day (L/kg-d)).

Thus, in the PRA, modified dose equations applied to calculate the ADD for ingestion of tap water by a child (assumed to have an age from 0 to <6 years old) and an adult (age 16 to <70 years) were as follows:

$$ADD_{ing-water-child}\ (mg/kg-d) = \frac{C_{water} \times CF \times IR_{water-age\ 0\ to<6\ by\ bw} \times FI \times EF \times ED}{AT}$$

Where:

$ADD_{ing\text{-}water\text{-}child}$	=	Average daily dose (ADD) for noncarcinogens (PFPeA) from direct ingestion of tap water as drinking water by a child resident, mg/kg-d
C_{water}	=	EPC of chemical in water from the shallow or deep aquifer, ng/L
CF	=	Conversion factor, mg/ng (10^{-6} mg/ng)
$IR_{water\text{-}child\ by\ bw}$	=	Water ingestion rate for a child (age 0 to <6 years) on a per kilogram body weight basis, L/kg-d
FI	=	Fraction ingested from a contaminated source, unitless
EF	=	Exposure frequency, d/yr
ED	=	Exposure duration, yr (1 yr is assumed)
AT	=	Averaging time, d (equal to ED × 365 d/yr for noncarcinogens)

and,

$$ADD_{ing-water-adult}\ (mg/kg-d) = \frac{C_{water} \times CF \times IR_{water-age\ 16\ to<70\ by\ bw} \times FI \times EF \times ED}{AT}$$

Where:

$ADD_{ing\text{-}water\text{-}adult}$	=	Average daily dose (ADD) for noncarcinogens (PFPeA) from direct ingestion of tap water as drinking water by an adult resident, mg/kg-d
C_{water}	=	EPC of chemical in water from the shallow or deep aquifer, ng/L
CF	=	Conversion factor (10^{-6} mg/ng)
$IR_{water\text{-}child}$	=	Water ingestion rate for an adult (age 16 to <70 years) on a per kilogram body weight basis, L/kg-d
FI	=	Fraction ingested from a contaminated source, unitless
EF	=	Exposure frequency, d/yr
ED	=	Exposure duration, yr (1 yr is assumed)
AT	=	Averaging time, d (equal to ED × 365 d/yr for noncarcinogens)

For carcinogens, a lifetime average daily dose (LADD) is calculated as a "lifetime" exposure that could occur as a child and as an adult and the AT is assumed to be 70 years (25,550 days), while ED is assumed to be equal to the number of years one resides in one's home during a lifetime. However, the data available to support a PDF for ED for the resident scenario are based on lifetime exposure and are not readily apportioned between a child and adult. But, in the PRA, since intake rates are typically positively correlated to body weight, intake rates applied in the dose calculations were input on a per kilogram of body weight basis (i.e., liters of water per kilogram body weight per day (L/kg-d)).

In the PRA, the modified dose equation applied to calculate the LADD for exposure to NDMA via ingestion of tap water was as follows:

$$LADD_{ing-water}\ (mg/kg-d) = \frac{C_{water} \times CF \times IR_{water-age\ 0\ to\ 70\ by\ bw} \times FI \times EF \times ED}{AT}$$

Where:

$LADD_{ing\text{-}water}$	=	Lifetime average daily dose (LADD) for carcinogens (NDMA) from direct ingestion of tap water as drinking water by a resident, mg/kg-d
C_{water}	=	EPC of chemical in water from the shallow or deep aquifer, ng/L
CF	=	Conversion factor (10^{-6} mg/ng)
$IR_{water\text{-}age\ 0\ to\ 70\ by\ bw}$	=	Water ingestion rate for a person from birth (age 0) to 70 years on a per kilogram body weight basis, L/kg-d
FI	=	Fraction ingested from a contaminated source, unitless
EF	=	Exposure frequency, d/yr
ED	=	Exposure duration, yr
AT	=	Averaging time, d (equal to 70 yr × 365 d/yr for carcinogens)

Dermal Contact with Tap Water by the Child and Adult Resident

In the deterministic risk assessment, for the child and adult resident, exposures to NDMA and PFePA via dermal contact with tap water are estimated using the general equation shown below.

$$Dose_{derm-water}\,(mg/kg-d) = \frac{DA_{event} \times SA_{water} \times EV \times EF \times ED}{BW \times AT}$$

and:

$$DA_{event}\,(mg/cm^2-event) = 2 \times C_{water} \times CF_1 \times K_p \times CF_2 \times \sqrt{\frac{6 \times \tau_{event} \times t_{event}}{\pi}}$$

Where:

$Dose_{derm\text{-}water}$	=	Average daily dose (ADD) for noncarcinogens (PFPeA) or lifetime average daily dose (LADD) for carcinogens (NDMA), from dermal contact with tap water by a child or adult resident while bathing, mg/kg-d
DA_{event}	=	Dermally absorbed dose per event, mg/cm^2-event
SA_{water}	=	Skin surface area available for contact with tap water while bathing, cm^2
EV	=	Event frequency, event/d
EF	=	Exposure frequency, d/yr
ED	=	Exposure duration, yr
BW	=	Body weight, kg
AT	=	Averaging time, d (equal to ED × 365 d/yr for noncarcinogens and 70 yr × 365 d/yr for carcinogens)
C_{water}	=	EPC of chemical in water from the shallow or deep aquifer, ng/L
CF_1	=	Conversion factor, mg/ng (10^{-6} mg/ng)
K_p	=	Chemical-specific dermal permeability constant, cm/h
CF_2	=	Conversion factor, L/cm^3 (0.001 L/cm^3)
τ_{event}	=	Chemical-specific lag time per event, h/event
t_{event}	=	Event duration, h/event

Consistent with U.S. EPA (2004), DA_{event} is estimated as the total dose in the stratum corneum of the skin that is available for absorption after exposure on the skin surface has ended, and lag time (τ_{event}) is a chemical-specific value that describes the time it takes for the chemical to penetrate through skin (see Section 3.3.3.6).

As discussed above, for assessment of noncarcinogens, the ADD is calculated assuming that the averaging time (AT; in days) is equal to the exposure duration (ED; in years) multiplied by the number of days in a year (365 d/yr) such that ED effectively cancels out of the exposure equation. In addition, in the PRA, given that calculation of an ADD for noncancer effects implicitly calculates doses averaged over a relatively shorter exposure (typically a year is assumed) and relative intake rates (such as via ingestion) are relatively greater on a per bodyweight basis for a young child compared to an adult, separate distributions of ADDs were calculated for a child and an adult. Further, since intake rates (e.g., the surface area of the body that contacts water during bathing) are typically positively correlated to body weight (i.e., Phillips et al., 1993 as cited in U.S. EPA, 2011 observed a strong correlation of 0.986 between body surface area and body weight), in the PRA, intake rates applied in the dose calculations were input on a per kilogram of body weight basis (i.e., square centimeters of skin surface area per kilogram body weight per day (cm^2/kg-d)).

Thus, in the PRA, the modified dose equations applied to calculate the ADD for dermal contact with tap water while bathing or washing for a child (assumed to have an age from 0 to <6 years old) and an adult (age 16 to <70 years) were as follows (DA_{event} was assumed to be the same for a child and an adult, and was calculated using the equation shown above):

$$ADD_{derm-water-child}\,(mg/kg-d) = \frac{DA_{event} \times SA/BW_{water-child} \times EV \times EF \times ED}{AT}$$

Where:

$ADD_{derm\text{-}water\text{-}child}$	=	Average daily dose (ADD) for noncarcinogens (PFPeA) from dermal contact with tap water by a child resident while bathing, mg/kg-d
DA_{event}	=	Dermally absorbed dose per event, mg/cm^2-event
$SA/BW_{water\text{-}child}$	=	Skin surface area available for contact with tap water while bathing for a child on a per kilogram body weight basis, cm^2/kg
EV	=	Event frequency, event/d
EF	=	Exposure frequency, d/yr
ED	=	Exposure duration, yr (1 yr is assumed)
AT	=	Averaging time, d (equal to ED × 365 d/yr for noncarcinogens)

$$ADD_{derm-water-adult}\,(mg/kg-d) = \frac{DA_{event} \times SA/BW_{water-adult} \times EV \times EF \times ED}{AT}$$

Where:

$ADD_{derm\text{-}water\text{-}adult}$	=	Average daily dose (ADD) for noncarcinogens (PFPeA) from dermal contact with tap water by an adult resident while bathing, mg/kg-d
DA_{event}	=	Dermally absorbed dose per event, mg/cm^2-event

$SA/BW_{water\text{-}adult}$	=	Skin surface area available for contact with tap water while bathing for an adult on a per kilogram body weight basis, cm^2/kg
EV	=	Event frequency, event/d
EF	=	Exposure frequency, d/yr
ED	=	Exposure duration, yr (1 yr is assumed)
AT	=	Averaging time, d (equal to ED × 365 d/yr for noncarcinogens)

For carcinogens, a LADD is calculated as a "lifetime" exposure that could occur as a child and as an adult and the AT is assumed to be 70 years (25,550 days), while ED is assumed to be equal to the number of years one resides in one's home during a lifetime. However, the data available to support a PDF for ED for the resident scenario are based on lifetime exposure and are not apportioned between a child and adult. But, in the PRA, since intake rates are typically positively correlated to body weight, intake rates applied in the dose calculations were input on a per kilogram of body weight basis (i.e., skin surface area available for contact on a per kilogram body weight per day (cm^2/kg)).

In the PRA, the modified dose equation applied to calculate the LADD for exposure to NDMA via dermal contact with tap water was as follows:

$$LADD_{derm-water}\,(mg/kg-d) = \frac{DA_{event} \times SA/BW_{water-all\ ages} \times EV \times EF \times ED}{AT}$$

and:

$$DA_{event}\,(mg/cm^2-event) = 2 \times C_{water} \times CF_1 \times K_p \times CF_2 \times \sqrt{\frac{6 \times \tau_{event} \times t_{event}}{\pi}}$$

Where:

$LADD_{ing\text{-}water}$	=	Lifetime average daily dose (LADD) for carcinogens (NDMA), from dermal contact with tap water while bathing by a resident, mg/kg-d
DA_{event}	=	Dermally absorbed dose per event, mg/cm^2-event
EV	=	Event frequency, event/d
EF	=	Exposure frequency, d/yr
ED	=	Exposure duration, yr
AT	=	Averaging time, d (equal to 70 yr × 365 d/yr for carcinogens)
$SA/BW_{water\text{-}all\ ages}$	=	Skin surface area available for contact with tap water while bathing for a resident, all ages, on a per kilogram body weight basis, cm^2/kg
C_{water}	=	EPC of chemical in tap or well water, ng/L
CF_1	=	Conversion factor, mg/ng (10^{-6} mg/ng)
K_p	=	Chemical-specific dermal permeability constant, cm/h
CF_2	=	Conversion factor, L/cm^3 ($0.001\ L/cm^3$)
τ_{event}	=	Lag time per event, h/event
t_{event}	=	Event duration, h/event

Inputs for Exposure Parameters and Chemical-Specific Values for the PRA for the Resident Scenario

Table 6-1 summarizes the values applied in the PRA for each exposure parameter for the resident scenarios. For most parameters, a PDF was applied. However, point estimates were applied for fraction ingested from a contaminated source (FI, which was assumed to be 1.0) and for exposure duration (ED) and averaging time (AT) for the noncancer assessment, as these essentially cancel out of the calculation. Table 6-1 also lists the value for each parameter that was applied in the deterministic HHRA.

Table 6-2 summarizes chemical-specific parameter values (C_{water}, K_p, $\tau_{event,,}$ and cancer slope factor (SF) or noncancer reference dose (RfD))—for these, point estimates were used because data were insufficient to support derivation of a PDF. The same values were used in the deterministic HHRA for each of these parameters.

The basis for the water concentration values and the exposure parameter values applied in the PRA are described below.

Water concentration (C_{water})

The water concentrations (C_{water}) applied in the PRA calculations were the EPCs for PFPeA and NDMA estimated for the shallow and deep aquifers at the closest residential exposure location (200 feet downgradient from the recharge basins), based on values derived in the groundwater fate and transport analysis (HDR, 2021). These values are point estimates and are assumed to reflect conservative (health protective) estimates of potential EPCs for these chemicals. The same values were used in the deterministic HHRA for the RME resident scenario.

Two key factors applied in the calculation of the C_{water} values that reflect conservative (health protective) assumptions are:

- *Reclaimed water concentration*. This is the "starting point" for deriving an estimate of the EPC, as it is the concentration of residual chemical in reclaimed water that is applied to the infiltration basins. Typically, in a risk assessment, an estimate of the average concentration is used to characterize potential long-term exposures. However, since the measured reclaimed water concentrations of many of the residual chemicals of interest in this study, including PFPeA and NDMA, fluctuated over time, a 95 percent upper confidence limit (UCL) of the arithmetic mean, rather than the arithmetic mean, reclaimed water concentration of each chemical (using data obtained over multiple sampling events) was used as an estimate of the average reclaimed water concentration. Use of the 95 percent UCL provides reasonable confidence that the true average concentration is not being underestimated, thereby providing an element of conservatism in the estimated water concentration.
- *Attenuation factor*. As discussed in HDR (2021), the fate and transport analysis considered the effects of advection and dispersion on down-gradient concentrations of all residual chemicals as the reclaimed water moves through the groundwater system. Additional attenuation, accounting for other processes such as biodegradation and sorption, was considered only for those chemicals where empirical data, from the 2018 tracer test, confidently indicated such processes were at work. To be conservative and not potentially overestimate the extent of additional attenuation, this "attenuation factor" was assumed to be zero (i.e., no biodegradation or sorption is assumed to occur) for those chemicals where

empirical data were either sparse (and therefore no definitive attenuation relationship could be established) or did not reflect a decrease in concentration with travel time away from the infiltration basins (thereby suggesting minimal to no degradation or sorption). NDMA is an example of a chemical that falls in the first subset. Only sporadic observations of NDMA in groundwater were observed and those observed concentrations were within the range of detected reclaimed water concentrations. PFPeA was more routinely observed in groundwater monitoring wells, but at concentrations that suggest no attenuation beyond the physical processes of advection and dispersion. Consequently, in both cases, no biodegradation or sorption was assumed to occur, although it is possible that such processes may be occurring to some extent, particularly with increased travel time away from the infiltration site. This is assumed to result in conservative (health protective) estimates of potential EPCs for these chemicals.

Note that using a 95 percent UCL in the PRA is consistent with U.S. EPA guidance for a 1-dimensional (1-D) PRA (U.S. EPA, 2001), that is, in a PRA where probability distributions for input parameters primarily reflect parameter variability (e.g., across a population) as opposed to uncertainty, which was conducted here. For clarity, U.S. EPA recommends that a 1-D PRA be conducted as the first tier of a PRA process. If further refinement to the 1-D PRA is desired (e.g., if risk estimates exceed allowable risk ranges and one desires greater understanding of the parameter inputs that result in this exceedance), a 2-dimensional (2-D) PRA can be conducted wherein uncertainty and variability in parameter inputs are assessed separately. Because a 2-D PRA is more resource intensive than a 1-D PRA, it is recommended that a 2-D PRA be conducted after a 1-D PRA has been completed.

In discussing how to characterize the EPC term in a PRA, U.S. EPA (2001) states, “In PRA, either a point estimate (e.g., 95% UCL) or a probability distribution may be used to characterize uncertainty in the concentration term…The decision to use a point estimate, PDFv [probability distribution function for variability only], or PDFu [probability distribution function for uncertainty only], as the input for the concentration term in a Monte Carlo model will depend on the goals of the Monte Carlo simulation, as determined by the tiered process…If the goal is to characterize variability in risk, in general, a one-dimensional Monte Carlo analysis (1-D MCA) will be used and the appropriate input for the concentration term will be a point estimate that characterizes uncertainty in the mean concentration within the EU [exposure unit].” Elsewhere, U.S. EPA (2001) states, “In a 1-D MCA, a point estimate for the EPC is combined with PDFv’s for other variables to yield a probability distribution for risk.” They also note regarding this term that “The most appropriate expression of the exposure point concentration term for chronic exposure will characterize the long-term average concentration experienced by a receptor within the exposure unit” and, regarding the use of a 95% UCL, “Because an EPC is calculated from a sample [i.e., it is based on a finite set of sampling data], there is uncertainty that the sample mean equals the true mean concentration within the EU [exposure unit]; therefore, to account for associated uncertainty, the 95% upper confidence limit for the mean (95% UCL) is generally used for Superfund risk assessments.”

Given these recommendations, the relatively limited number of reclaimed water samples, and the fact that available data sets reflect both spatial (different sample locations) and temporal (different sample times) variability, as well as uncertainty about the true distribution of sample concentrations over space and time, it was judged that a PDF comprised from these data would not sufficiently capture the uncertainty and variability about the true mean of the data sets over time. Consequently, use of a

95 present UCL as a value representative of the long-term average concentration potentially experienced by a receptor in this PRA is judged to be appropriate.

Ingestion of tap water (IR_{water})

PDFs characterizing the rate of tap water ingestion by a resident were established based on ingestion rates of community water reported as part of U.S. EPA's analysis of the 2005−2010 National Health and Nutrition Examination Surveys (NHANES; U.S. EPA, 2019). The NHANES surveys collect data on population behaviors and were designed to obtain a statistically valid sample of the civilian noninstitutionalized U.S. population. Data are assumed to reflect a sufficient sample size to adequately reflect respondent variability.

Daily water consumption volumes reported by NHANES reflect the average of two nonconsecutive days of direct and indirect community water consumption reported by each NHANES respondent (U.S. EPA, 2019). Community water consists of tap water from a community or municipal water supply. Direct consumption is water ingested directly as a beverage, and indirect consumption reflects water added in the preparation of food or beverages. Values used to derive the PDFs applied in the PRA reflect per capita intake rates, that is, intake that has been averaged over the entire population (including those individuals who reported no intake). Per U.S. EPA (2019), "In general, per capita intake rates are appropriate for use in exposure assessments for which average daily dose estimates are of interest because they represent both individuals who drank water during the survey period and individuals who may drink water at some time but did not consume it during the survey period."

On average, the rate of water ingestion per day is assumed to be correlated to a person's relative size (i.e., on average, larger persons drink a larger volume of water per day than smaller persons). Consequently, community indirect and direct water ingestion rates presented by U.S. EPA, based on the 2005−2010 NHANES survey, in units of liters per kilogram of body weight per day (L/kg-d) were applied in the PRA. Because very young children drink more water on a per kilogram body weight basis than older children and adults and ADDs are calculated on an annual basis, separate ADDs were calculated for a child (age 0 to <6) and an adult for the noncancer assessment (for PFPeA), using drinking water ingestion rate distributions specific to these age groups. For calculation of a LADD for the cancer assessment (for NDMA), a drinking water ingestion rate distribution was derived representing body weight-based rates of ingestion (in L/kg-d) for persons age 0 to <70 years.

PDFs applied for the water ingestion rate parameter (IR_{water}) for the resident scenarios are as follows:

- For the child resident ADD (noncancer) calculation, the PDF ($IR_{water\text{-}age\ 0\ to\ <6\ by\ bw}$) is based on two-day average per capita estimates of combined direct and indirect community water ingestion from NHANES 2005−2010 (mL/kg-day) reported for infants and children ages 0 to <6 years (males and females combined) (U.S. EPA, 2019; Table 3-21). For this distribution, age-weighted statistics based on values presented by U.S. EPA (2019) were determined, including the mean, standard deviation, minimum, maximum, and 5^{th}, 10^{th}, 25^{th} 50^{th}, 75^{th}, 90^{th}, 95^{th}, and 99^{th} percentiles. In Crystal Ball, a beta distribution using the following distribution values (in mL/kg-day) was found to best fit these data and produce a forecast distribution that closely fits this dataset: minimum = 0, 50^{th} percentile = 0.0049, 90^{th} percentile = 0.0474, and maximum = 0.1818. A comparison of the selected statistics for the reported and fitted distributions is shown in Table E-1.

- For the adult resident ADD (noncancer) calculation, the PDF ($IR_{water\text{-}age\ 16\ to\ <70\ by\ bw}$) is based on two-day average per capita estimates of combined direct and indirect community water ingestion based on NHANES 2005−2010 (mL/kg-day) reported for adults age 16 to <70 years (males and females combined) (U.S. EPA, 2019; Table 3-21). For this distribution, age-weighted statistics based on values presented by U.S. EPA (2019) were determined, including the mean, standard deviation, minimum, maximum, and 5th, 10th, 25th 50th, 75th, 90th, 95th, and 99th percentiles. In Crystal Ball, a beta distribution using the following reported distribution values (in mL/kg-day) was found to best fit these data and produce a forecast distribution that closely fit this dataset: minimum = 0, 50th percentile = 0.0069, 90th percentile = 0.0287, and maximum = 0.1032. A comparison of the selected statistics for the reported and fitted distributions is shown in Table E-1.
- For the resident LADD (cancer) calculation, the PDF ($IR_{water\text{-}age\ 0\ to\ 70\ by\ bw}$) is based on two-day average per capita estimates of combined direct and indirect community water ingestion based on NHANES 2005−2010 (mL/kg-day) reported for age 0 to <70 years (males and females combined) (U.S. EPA, 2019; Table 3-21). For this distribution, age-weighted statistics based on values presented by U.S. EPA (2019) were determined, including the mean, standard deviation, minimum, maximum, and 5th, 10th, 25th 50th, 75th, 90th, 95th, and 99th percentiles. In Crystal Ball, a beta distribution using the following reported distribution values (in mL/kg-day) was found to best fit these data and produce a forecast distribution that closely fit this dataset: minimum = 0, 50th percentile = 0.0058, 90th percentile = 0.0286, and maximum = 0.2675. A comparison of the selected statistics for the reported and fitted distributions is shown in Table E-1.

Exposure frequency (EF)

In the dose equations for ingestion of tap water or dermal contact with tap water, exposure frequency (EF) describes the number of days per year that a person drinks or contacts water from the subject aquifer (shallow or deep), at a rate consistent with the water ingestion rate (IR_{water}) or the skin surface area contact rate (SA_{water}). In theory, the IR_{water} and EF parameters could apply to consumption of water both inside and outside the home (e.g., at school or work), as long as the consumed water is from the subject aquifer, although the EPCs applied (C_{water}) are consistent with the closest potential residential contact point (200 feet downgradient from the recharge basins).

Statistics for the range of possible values for EF for populations in the U.S. were not located. However, the maximum possible value is every day (365 d/year), and the default value typically applied for EF for residential exposure (e.g., in the U.S. EPA Regional Screening Level (RSL) calculations; U.S. EPA, 2021) is 350 d/yr, which assumes that a person, on average, spends a total of 15 days per year away from their residence (e.g., for work, travel, weekend trips, and vacations); this value is assumed by U.S. EPA to provide a conservative (health protective) estimate of potential annual days of exposure in a home.

Given these considerations, the PDF applied for EF for the resident scenarios was established based on professional judgment. Given the lack of knowledge about the likelihood of values less than the most-likely estimate and about the shape of the distribution, a triangular distribution was assumed with minimum and maximum values 15 days less than and 15 days more than the most-likely value of 350 d/yr, respectively. The PDF applied for this parameter was therefore as follows:

- For the resident (child or adult, or lifetime exposure), the PDF (EF) is assumed to be represented by a triangular distribution with a maximum value of 365 d/yr, a most-likely estimate of 350 d/yr

(15 days per year away from the residence), and a minimum value of 335 d/yr (30 days per year away from the residence).

Exposure duration (ED)

For the resident scenario, exposure duration (ED) applied in the calculation of LADD (for the cancer assessment for NDMA) was based on the total time spent in one's residence in a lifetime (also known as the residential occupancy period—specifically the number of years between the date one moves into a new residence and the date one moves out of the residence or dies). Values applied were computed by Johnson and Capel (1992) using a Monte Carlo approach to simulate a distribution of residential occupancy period for 500,000 persons using data for the U.S. on population, mobility, and mortality for 1987, and including data for both rental and owned residences. Distribution parameters tabulated by Johnson and Capel (1992) and by U.S. EPA (2011) include the following: mean = 11.7 years, median = 9 years, 90th percentile = 26 years, and 95th percentile value = 33 years.

For the ADD calculations (for the noncancer assessment for PFPeA), an ED of 1 year was assumed since the averaging time (AT) in the denominator of the equation is assumed to be equal to ED multiplied by 365 days per year, such that ED regardless of its value cancels out of the equation.

The PDF applied for the exposure duration parameter (ED) for the resident LADD calculations is as follows:

For the resident LADD (cancer) calculation, a beta distribution was found to best fit the data reported by Johnson and Capel (1992). The PDF (ED) was derived using the following reported values (in years): minimum = 0, 50th percentile = 9, 90th percentile = 26, and maximum = 87. Based on these inputs, the forecast distribution predicted a mean of 11.7, and 75th, 95th, 99th, and 99.9th percentiles of 16.9, 32.1, 44.0, and 56.6, respectively. By comparison, values for these statistics reported by Johnson and Capel (1992) are: mean = 11.7, 75th percentile = 16, 95th percentile = 33, and 99th percentile = 46, 99.9th percentile = 59. Thus, the input parameters yield an output distribution with good fit to the supporting data.

Body surface area for contact with tap water (SA_{water})

PDFs for body surface areas of residents that come in contact with tap water during bathing were established based on surface area to body weight ratios (cm^2/kg) reported by Phillips et al. (1993; as cited in U.S. EPA, 2011 (Table 7-15)). The authors suggested that given the strong correlation (0.986) between body surface area and body weight, the use of body surface area-to-body weight (SA/BW) ratios in human exposure assessments may be more appropriate than treating these factors as independent variables. Reported ratios were based on data for 401 individuals summarized by U.S. EPA. Per Phillips et al. (1993; as reported in U.S. EPA, 2011), the distributions based on data for adults and for all ages were lognormally distributed, whereas those for children were neither normally nor lognormally distributed.

Because SA/BW ratios were found to decrease with age, and since the noncarcinogen assessment (for PFPeA) is based on an annualized estimate of exposure, ADDs were calculated using PDFs for this parameter specific to a child (age 0 to 2; data for ages ranging from infant to an older child were not available—this is a conservative assumption) and to an adult. For the carcinogen assessment (for NDMA), LADDs were calculated using PDFs corresponding to the full population age range ("all ages").

To estimate dermal exposure through contact with surface water, doses were calculated separately for time spent showering or in a bath (for which whole body exposure was assumed) and for handwashing (for which it was assumed that 95% of the time, exposure is to the hands only, and for 5% of the time, exposure is to the hands plus lower arms).

PDFs applied for the surface area to body weight ratio parameters (SA/BW_{water}) for dermal contact with tap water for the resident scenarios are:

- For the child resident ADD (noncancer) calculation, the PDF for the whole body surface area to body weight ratio ($SA/BW_{water\text{-}whole\ body\text{-}age\ 0\ to\ 2}$) is based on values reported for persons ages 0 to 2 years (males and females combined) (U.S. EPA, 2011; Table 7-15). When input into Crystal Ball (assuming the data are lognormally distributed), the arithmetic mean (640 cm^2/kg) and the 95th percentile (850 cm^2/kg) were found to produce a distribution that provided a close fit to all other percentile values described for this dataset, and so were applied as the input parameters for this distribution.

  For the child resident ADD (noncancer) calculation, the PDF for the handwashing surface area to body weight ratio ($SA/BW_{water\text{-}handwash\text{-}age\ 0\ to\ 2}$) is based on values reported for persons ages 0 to 2 years (males and females combined), and is calculated by multiplying the whole body surface area value for this group (see above) by the assumed percentage of the whole body that is comprised of hands for children ages 0 to 2 years (5.5%) (for 95% of contact events) plus the assumed percentage of the whole body that is comprised of hands plus the lower arms for this age group (6.7%%) (for 5% of events) (U.S. EPA, 2011; Table 7-15 and Table 7-2). When input into Crystal Ball (assuming the data are lognormally distributed), the arithmetic mean (37 cm^2/kg) and the 95th percentile (50 cm^2/kg) were found to produce a distribution that provides a close fit to all other percentile values described for this dataset, and so were applied as the input parameters for this distribution.
- For the adult resident ADD (noncancer) calculation, the PDF for the whole body surface area to body weight ratio ($SA/BW_{water\text{-}whole\ body\text{-}age\ \geq 18}$) is based on values reported for persons ages 18 years and older (males and females combined) (U.S. EPA, 2011; Table 7-15). When input into Crystal Ball (assuming the data are lognormally distributed), the arithmetic mean (280 cm^2/kg) and the 95th percentile (330 cm^2/kg) were found to produce a distribution that provided a close fit to all other percentile values described for this dataset, and so were applied as the input parameters for this distribution.

  For the adult resident ADD (noncancer) calculation, the PDF for the handwashing surface area to body weight ratio ($SA/BW_{water\text{-}handwash\text{-}\ age\ \geq 18}$) is based on values reported for persons ages 18 years and older (males and females combined), and is calculated by multiplying the whole body surface area value for this group (see above) by the assumed percentage of the whole body that is comprised of hands for adults ages 18 years and older (5.2%) (for 95% of contact events) plus the assumed percentage of the whole body that is comprised of hands plus the lower arms for this age group (7.0%%) (for 5% of events) (U.S. EPA, 2011; Table 7-15 and Table 7-6). When input into Crystal Ball (assuming the data are lognormally distributed), the arithmetic mean (15 cm^2/kg) and the 95th percentile (18 cm^2/kg) were found to produce a distribution that provided a close fit to all other percentile values described for this dataset, and so were applied as the input parameters for this distribution.
- For the resident LADD (cancer) calculation, the PDF for the whole body surface area to body weight ratio ($SA/BW_{water\text{-}whole\ body\text{-}all\ ages}$) is based on values reported for persons of all ages (males

and females combined) (U.S. EPA, 2011; Table 7-15). When input into Crystal Ball (assuming the data are lognormally distributed), the arithmetic mean (490 cm^2/kg) and the 95th percentile (790 cm^2/kg) were found to produce a distribution that provided a close fit to all other percentile values described for this dataset, and so were applied as the input parameters for this distribution.

For the resident LADD (cancer) calculation, the PDF for the handwashing surface area to body weight ratio ($SA/BW_{water\text{-}handwash\text{-}\ all\ ages}$) is based on values reported for persons of all ages (males and females combined), and is calculated by multiplying the whole body surface area value for this group (see above) by the assumed percentage of the whole body that is comprised of hands for persons of all ages (5.3%) (for 95% of contact events) plus the assumed percentage of the whole body that is comprised of hands plus the lower arms for this age group (6.5%%) (for 5% of events) (U.S. EPA, 2011; Table 7-15 and Table 7-2). When input into Crystal Ball (assuming the data are lognormally distributed), the arithmetic mean (28 cm^2/kg) and the 95th percentile (45 cm^2/kg) were found to produce a distribution that provided a close fit to all other percentile values described for this dataset, and so were applied as the input parameters for this distribution.

Exposure events per day for dermal contact with tap water while bathing or handwashing (EV)

PDFs for the number of exposure events per day for dermal contact with tap water while bathing or handwashing (EV) were based on data describing the number of times a person showers or bathes (whole body) per day, or the number of times that they wash their hands per day.

PDFs describing the number of times a person showers or bathes per day or the number of times a person washes their hands per day were based on data gathered as part of the National Human Activities Pattern Survey (NHAPS) presented by U.S. EPA (1996) and U.S. EPA (2011). The NHAPS database was compiled based on the results of an U.S. EPA-supported survey, conducted between October 1992 and September 1994, with the goal of collecting a rich set of exposure-related behavioral data from over 9,000 U.S. residents who were queried over the telephone. NHAPS respondents recalled the previous day's shower and bath frequencies and durations and provided demographic information, such as data on housing type, gender, age, race, education level, and employment status (Wilkes et al., 2005).

PDFs applied for the event frequency parameters (EV_{bath}) for dermal contact with tap water while showering or bathing (whole body) for the resident scenarios are:

- For the child resident ADD (noncancer) calculation, the PDF for the number of times bathing per day ($EV_{bath\text{-}child}$) is based on values reported for persons ages 1 to 17 years (males and females combined) (U.S. EPA, 1996; p. 3-157). The PDF was defined based on the age-weighted arithmetic mean and standard deviation (1.26 ± 0.51 events/d), assuming a lognormal distribution. These values provide a reasonable fit to the observed dataset (which reported a 95th percentile estimate of 2 showers or baths per day).
- For the adult resident ADD (noncancer) calculation, the PDF for the number of times bathing per day ($EV_{bath\text{-}adult}$) is based on values reported for persons ages 18 to 64 years (males and females combined) (U.S. EPA, 1996; p. 3-157). The PDF was defined based on the arithmetic mean and standard deviation (1.36 ± 0.62 events/d), assuming a lognormal distribution. These values provide a reasonable fit to the observed dataset (which reported a 95th percentile estimate of 3 showers or baths per day).
- For the resident LADD (cancer) calculation, the PDF for the number of times bathing per day ($EV_{bath\text{-}all\ ages}$) is based on values reported for all ages (males and females combined) (U.S. EPA,

1996; p. 3-157). The PDF was defined based on the arithmetic mean and standard deviation (1.34 ± 0.60 events/d), assuming a lognormal distribution. These values provide a reasonable fit to the observed dataset (which reported a 95th percentile estimate of 3 showers or baths per day).

PDFs applied for the event frequency parameters ($EV_{handwash}$) for dermal contact with tap water while hand washing for the resident scenarios are:

- For the child resident ADD (noncancer) calculation, the PDF for the number of times washing hands per day ($EV_{handwash\text{-}child}$) is based on values reported for persons ages 2 to <16 years (males and females combined) (U.S. EPA, 2011; Table 16-37). The PDF was defined based on the age-weighted arithmetic mean and standard deviation (5.2 ± 4.0 events/d), assuming a lognormal distribution. These values provide a reasonable fit to the observed dataset (which reported a 95th percentile estimate of 12.5 handwashing events per day).
- For the adult resident ADD (noncancer) calculation, the PDF for the number of times washing hands per day ($EV_{handwash\text{-}adult}$) is based on values reported for persons ages 18 to 64 years (males and females combined) (U.S. EPA, 2011; Table 16-37). The PDF was defined based on the arithmetic mean and standard deviation (9.7 ± 8.2 events/d), assuming a lognormal distribution. These values provide a reasonable fit to the observed dataset (which reported a 95th percentile estimate of 24.8 handwashing events per day).
- For the resident LADD (cancer) calculation, the PDF for the number of times washing hands per day ($EV_{handwash\text{-}all\ ages}$) is based on values reported for all ages 2 years and up (males and females combined) (U.S. EPA, 2011; Table 16-37). The PDF was defined based on the age-weighted arithmetic mean and standard deviation (8.6 ± 7.1 events/d), assuming a lognormal distribution. These values provide a reasonable fit to the observed dataset (which reported a 95th percentile estimate of 21.7 handwashing events per day).

Event duration for dermal contact with tap water while bathing or handwashing (t_{event})

PDFs for the duration of dermal contact with tap water while bathing or handwashing (t_{event}) reflect the average duration of an individual shower/bath or handwashing event. Data on this parameter are somewhat limited. The PDF for time spent showering or bathing is based on probability distributions reported by Wilkes et al. (2005) based on the Residential End Uses of Water Study (REUWS) database. The REUWS database was compiled through an American Water Works Association Research Foundation project conducted between May 1996 and March 1998 with the goal of understanding how water is used and to identify potential for water conservation. It contains a continuous water-use record for each of the 1,188 households in the study, recorded via a magnetic sensor and data-logger device placed on the household water meter during two approximately two-week periods in the spring and in the fall.

Robust statistics for the average duration of a handwashing event were not located; consequently, the PDF for this parameter was based on a best-estimate value for this parameter consistent with a Centers for Disease Control (CDC) recommendation on how long a person should wash their hands, with upper and lower bounds estimated based on professional judgment.

PDFs applied for the duration of dermal contact with tap water while bathing or handwashing (t_{event}) parameter for the resident scenarios are:

- For the resident ADD (noncancer) calculations (both child and adult) and the resident LADD (cancer) calculations, the PDF for the duration of a shower or bath ($t_{event\text{-}bath}$) is based on statistics

for duration of a shower reported for all age based on REUWS data (Wilkes et al., 2005). The PDF was defined based on the reported age-weighted geometric mean and geometric standard deviation (6.8 ± 0.49 minutes/event, or 0.11 ± 0.0082 h/event), assuming a lognormal distribution.

- For the resident ADD (noncancer) calculations (both child and adult) and the resident LADD (cancer) calculations, the PDF for the duration of a handwashing event ($t_{event\text{-}handwash}$) is based on a best-estimate of 20 seconds (0.00556 hour) corresponding to CDC's recommendation for how long one should wash their hands (CDC, 2021). Given the lack of robust data, a triangular distribution was assumed, with a minimum value of 5 seconds (0.00139 hour) and a maximum value of 2 minutes (0.0333 hour), based on professional judgment.

PRA Results

Using the above described inputs, Monte Carlo simulations were run using Crystal Ball and a sample size of 100,000 trials. Outputs include forecast distributions of dose, noncancer hazard, and cancer risk for each chemical and pathway for exposure of a resident to tap water from the shallow or deep aquifer.

Results from repeated sample runs of 100,000 iterations were stable (i.e., results varied minimally, by <1% at the 99th percentile of the distributions).

Results of the simulations for the resident scenario for PFPeA and NDMA are summarized in Tables E-2 and E-3 and Figures E-1 through E-6. For the noncancer hazard and cancer risk forecast distributions, statistics shown include the mean and standard deviation, and the central tendency (50th), 75th, 90th, 95th, 99th, and 99.9th percentiles of the output distributions. Detailed tabulated results and the full output report from the Crystal Ball Monte Carlo simulation (which includes statistics and charts for input and output distributions), are provided in an Attachment to Appendix E.

For PFPeA, estimated noncancer hazard indices (HIs) (all pathways) for the child resident scenario for both the shallow and deep aquifer range from 0.11 at the 50th percentile to 0.95 to 0.96 at the 90th percentile and 1.3 to 1.4 at the 95th percentile. For the adult resident scenario for both the shallow and deep aquifer, estimated total HIs (all pathways) range from 0.14 at the 50th percentile to 0.58 at the 90th percentile and 0.75 at the 95th percentile. By comparison, the upper bound total HIs for PFPeA estimated in the deterministic HHRA for the resident RME scenario were 1.3 and 0.67 for the child and adult resident, respectively, for contact with water from the shallow aquifer, and 1.3 and 0.66 for the child and adult resident, respectively, for contact with water from the deep aquifer (see Table 5-1 in the main document). These values fall between the 90th and 95th percentiles of the output distributions from the PRA.

For NDMA, estimated lifetime excess cancer risks (LECRs) for the resident scenario for both the shallow and deep aquifer range from 9.2×10^{-7} to 9.3×10^{-7} at the 50th percentile to 7.8×10^{-7} to 7.9×10^{-7} at the 90th percentile and 1.2×10^{-6} to 1.3×10^{-6} at the 95th percentile. By comparison, the upper bound LECRs for NDMA estimated in the deterministic HHRA for the resident RME scenario were 2.9×10^{-6} for contact with water from either the shallow or deep aquifers (see Table 5-2 in the main document). These values fall at greater than the 99th percentile of the output distributions from the PRA.

For both the noncancer assessment for PFPeA and the cancer assessment for NDMA, the ingestion pathway dominates the estimated hazard or risk, contributing about 90% of the estimated noncancer

hazard for the child and about 99% of the LECR at the 50th percentile, and about 99% of the estimated noncancer hazard or LECR at the 95th percentile. Estimated hazards and risks for both chemicals for a hypothetical resident exposed to tap water from either the shallow or deep aquifers are comparable, because estimated EPCs for these chemicals at the location 200 feet downgradient of the recharge basins are nearly identical for both aquifers.

Discussion

In a PRA, the upper percentiles of the risk estimates (e.g., 90th percentile and above) are of most interest in decision making. However, some parameters in the dose and risk calculations have a much greater influence on variability and uncertainty in dose and risk estimates than others. To determine which parameters in the PRA contribute most to variability and uncertainty in outputs, sensitivity analysis was conducted to assess the relative contribution of the model inputs to model output variability, and determine which inputs "drive" the variability in the dose and risk estimates for the chemicals and scenarios evaluated in the PRA.

The results of sensitivity analysis show that in the calculation of ADD for PFPeA, the ingestion rate of tap water (IR_{water}) parameter contributes more than 99% of the variability in the output forecast (see Figure E-7, for the child resident exposure to shallow aquifer scenario). All other parameters contribute 0.4% or less to the total variance. For the estimation of LADD for NDMA, the ingestion rate of tap water (IR_{water}) and the exposure duration (ED) parameters contribute approximately 68.6% and 31.3% of the variance, respectively, in the output forecast (see Figure E-8, for the resident exposure to shallow aquifer scenario). Other parameters combined contribute minimally to the total variance (<0.1%).

Because the IR_{water} and ED parameters contribute most to variability in output distributions of hazard or risk in the PRA, the basis of the applied PDFs for these parameters, including uncertainties regarding their applicability to the LOTT Clean Water Alliance Reclaimed Water Infiltration Study area of interest, is explored further below.

As described above, the PDFs applied to the IR_{water} parameters were based on combined direct and indirect per capita ingestion rates of community water (which is assumed to consist of tap water from a community or municipal water supply) reported as part of U.S. EPA's analysis of the 2005−2010 NHANES database, which reflects data on population behaviors and was designed to obtain a statistically valid sample of the civilian noninstitutionalized U.S. population, including individuals from all 50 states and Washington, D.C. (U.S. EPA, 2019). In the NHANES survey, water ingestion estimates were collected from each respondent in two interviews: the first conducted in-person and the second by telephone. Data are assumed to reflect a sufficient sample size to adequately reflect respondent variability—sample size is approximately 24,673 for persons of all ages, 4,087 for persons ages 0 to <6 years, and 13,250 for persons ages 16 to <70 years—and were weighted by demographic data in order to ensure that the resulting water intakes were representative of the entire U.S. population.

The applied water ingestion rates reflect direct consumption of water as a beverage as well as indirect consumption of water added in the preparation of food or beverages. Estimates reflect per capita intake, which represents intake that has been averaged over the entire population (including those individuals that reported no intake). Per U.S. EPA (2019), "In general, per capita intake rates are appropriate for use in exposure assessments for which average daily dose estimates are of interest because they represent both individuals who drank water during the survey period and individuals who may drink water at some time but did not consume it during the survey period." By comparison,

in the deterministic HHRA, the applied drinking water ingestion rates were based on "consumers only" ingestion rates, which exclude individuals who reported drinking zero water on the given survey day and so tend to be somewhat higher and likely overestimate average drinking water ingestion rates over time.

Potential sources of bias in the applied ingestion rate data include the use of short-term intake data to estimate long-term intake rates, and the use of recall data, which is subject to error as well as potential bias (e.g., subjects may overstate water intake to appear healthier) (MDEQ, 2015). A comparable assessment of drinking water ingestion rates specific to Washington State or a more localized area relevant to the LOTT Clean Water Alliance Reclaimed Water Infiltration Study area of interest (e.g., south Puget Sound) was not located, and it is unlikely that local drinking water ingestion rates would vary substantially from the national sample. As such, despite the potential limitations in the dataset, it is assumed that the NHANES-based dataset is appropriate for analysis of the study population of interest in the current assessment.

The PDF for ED was based on estimates of residential occupancy period for the U.S. general population, which reflects the time (years) between a person moving into a residence and the time the person moves out or dies. These estimates were computed by Johnson and Capel (1992) using a Monte Carlo approach to simulate a distribution for this parameter for 500,000 persons using data on population, mobility, and mortality for 1987. The mean and median values are 11.7 and 9 years, respectively, and the 90th and 95th percentile values are 26 and 33 years, respectively. No data on this parameter specific to Washington State or a more localized area relevant to the LOTT Clean Water Alliance Reclaimed Water Infiltration Study area of interest were located, and it is unknown to what extent a more localized estimate would vary from an estimate based on national data. In addition, data on which this PDF is based were collected in 1987, and it is unknown how these values might compare to current population mobility estimates.

It is noted that the mean and upper percentile values for the residential occupancy period distribution are lower than estimates presented elsewhere for "current residence time", which reflects the time since moving into a residence by any member of a household. Instead, residential occupancy period reflects the residence time of individual members of a household, which is expected to be smaller and reflect more frequent moves by some individuals. For example, as estimated by U.S. EPA (2011; Table 16-111) from U.S. Census Bureau (2008) data, the mean current residence time in the U.S. is 13 years and the 95th percentile value is 46 years. However, residential occupancy period is assumed to better reflect the residential exposure duration of individuals. As such, despite the potential limitations in the dataset, it is assumed that the applied residential occupancy period distribution is appropriate for analysis of the study population of interest in the current assessment.

Two other key sources of uncertainty in the PRA dose and risk estimates for PFPeA and NDMA are noted. First, water concentrations applied in the PRA are point estimate values and are the same as values used in the deterministic HHRA. For assessment of the resident scenario, values used were estimated based on groundwater fate and transport modeling (HDR, 2021) using the 95 percent UCL of the arithmetic mean concentrations of these chemicals in reclaimed water applied to the infiltration basins, modeled to locations in the shallow or deep aquifers 200 feet downgradient of the basins. Because empirical data demonstrating biodegradation and sorption were sparse for NDMA and data from groundwater monitoring for PFPeA showed concentrations were within the range of detected reclaimed water concentrations, no biodegradation or sorption downgradient of the source was assumed to occur for these chemicals. Further, while no domestic or municipal water supply wells are currently located as close as 200 feet to the infiltration basins, it is assumed that 200 feet

represents the minimum buffer potentially required in future permitting to install a new groundwater supply well in proximity to an infiltration basin. Overall, these assumptions are assumed to result in conservative (health protective) estimates of potential EPCs for these chemicals.

Second, the toxicity criteria used to estimate hazards or risk for these chemicals are assumed to provide a conservative (health protective) estimate of potential hazards or risks. For PFPeA, the estimated allowable daily dose for noncarcinogenic effects applied in this assessment is a "chronic reference dose" (RfD) set by the TCEQ. No other regulatory agency has established a toxicity threshold for PFPeA, including the U.S. EPA, ATSDR, or the State of California. Because no toxicological studies of sufficient quality have been conducted for PFPeA, the TCEQ set its RfD equal to that for PFHxS, a structurally similar compound. TCEQ noted that toxicological data for PFHxS are also limited, and the RfD was based on findings of effects on the liver of male rats administered large doses of this compound. To derive the RfD, the lowest dose of PFHxS that caused an effect in rats was divided by a factor to account for the assumed difference in the half-life of this compound in the bodies of humans compared to rodents, as well as multiple other uncertainty factors, to yield an assumed allowable dose that is nearly 80,000-fold lower than the dose that caused an effect in rats. Thus, the HIs for PFPeA estimated in the PRA are based on conservative estimate of the potential toxicity of PFPeA. As such, given that HIs for PFPeA only slightly exceed 1.0 even at the upper end of the output distributions for the resident scenarios (for the child resident, estimated HIs for the shallow aquifer are approximately 0.96, 1.4, and 2.1 at the 90^{th}, 95^{th}, and 99^{th} percentiles, respectively), it is unlikely that adverse effects would occur even at estimated upper bound exposure levels.

For NDMA, cancer risk estimates are based on linear extrapolation of cancer risk from relatively higher dose animal studies to an estimated lower dose human exposures using methods and assumptions intended to err on the side of safety. Given that estimated LECRs are below *de minimis* cancer risk levels (1×10^{-6}) even at the 90^{th} percentile of the risk distributions for the resident scenarios and only slightly exceed *de minimis* cancer risk levels even at the highest end of the output distributions (for the resident, estimated LECRs for the shallow aquifer are approximately 7.9×10^{-7}, 1.3×10^{-6}, and 2.6×10^{-6} at the 90^{th}, 95^{th}, and 99^{th} percentiles, respectively) (and all are within U.S. EPA's allowable risk range of 1×10^{-6} (1 in one million) to 1×10^{-4} (1 in 10,000)), the PRA suggests that cancer risks in excess of U.S. EPA's allowable risk range are unlikely.

Results the PRA indicate that estimated noncancer HIs for PFPeA meet the human health protection goals set by Florida and Oregon (the only two regulatory agencies with PRA-based water quality goals corresponding to specific distribution percentiles for HIs and LECRs). Specifically, for noncancer:

- Florida has set a noncancer health protection goal equal to an HI $\leq$1 at the 90^{th} percentile (Florida Department of Environmental Protection, 2016).
- Oregon has set a noncancer health protection goal equal to an HI $\leq$1 at the 90^{th} percentile and <10 at the 95^{th} percentile (Oregon Department of Environmental Quality, 1999).

For PFPeA, the estimated HIs at the 90^{th} percentile for the child (HI=0.96 for the shallow aquifer and 0.95 for the deep aquifer) and adult (HI=0.58 for both the shallow and deep aquifer) meet both Florida's and Oregon's health protection targets for the 90^{th} percentile ($\leq$1). The estimated HIs at the 95^{th} percentile for the child (HI=1.4 for the shallow aquifer and 1.3 for the deep aquifer) and adult (HI=0.75 for both the shallow and deep aquifer) also meet Oregon's target for the 95^{th} percentile (<10).

For cancer:

- Florida has set a cancer health protection goal equal to an LECR $\leq 1\times10^{-6}$ at the 50th percentile, $\leq 1\times10^{-5}$ at the 90th percentile, and $\leq 1\times10^{-4}$ at the 99th percentile (Florida Department of Environmental Protection, 2016).
- Oregon has set a cancer health protection goal equal to an LECR $\leq 1\times10^{-6}$ at the 90th percentile and $\leq 1\times10^{-5}$ at the 99th percentile (Oregon Department of Environmental Quality, 1999).

For NDMA, the estimated LECRs at all percentiles meet Florida's and Oregon's health protection goals, including at the 90th percentile (7.9×10^{-7} for the shallow aquifer and 7.8×10^{-7} for the deep aquifer), the 95th percentile (1.3×10^{-6} for the shallow aquifer and 1.2×10^{-6} for the deep aquifer) and the 99th percentile (2.6×10^{-6} for both aquifers).

Overall, results of the PRA conducted for the two chemicals with upper-bound hazard or risk estimates that slightly exceed allowable thresholds based on the deterministic risk assessment—PFPeA and NDMA, for the resident scenario—indicate that estimated HIs for PFPeA and the LECRs for NDMA meet the human health protection goals set by the Florida Department of Environmental Protection and the Oregon Department of Environmental Quality (the only two regulatory agencies with PRA-based water quality goals corresponding to specific distribution percentiles for HIs and LECRs), and that even at the 99th percentile, the LECRs for NDMA are within U.S. EPA's allowable risk range (10^{-6} to 10^{-4}).

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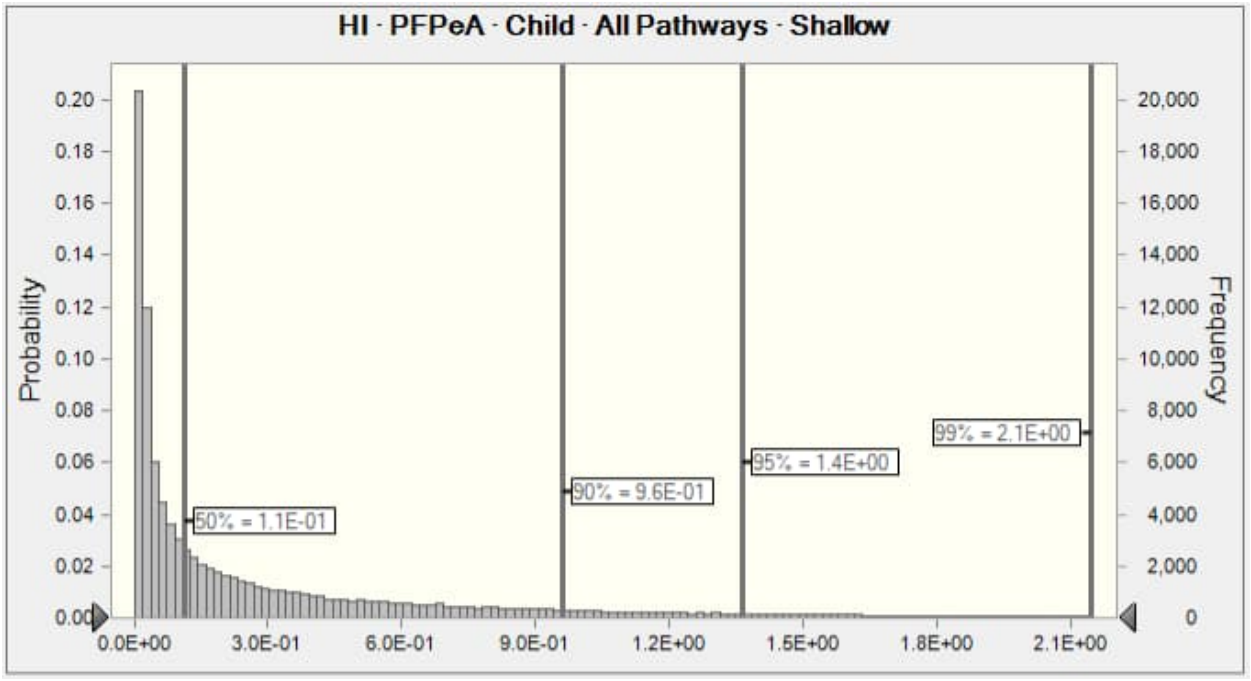


Figure E-1. PRA Output Distribution for Estimated Hazard Index for PFPeA, Child Resident, Shallow Aquifer Scenario. Central tendency (50th percentile) and upper bound (90th, 95th, and 99th percentile) estimates are shown.

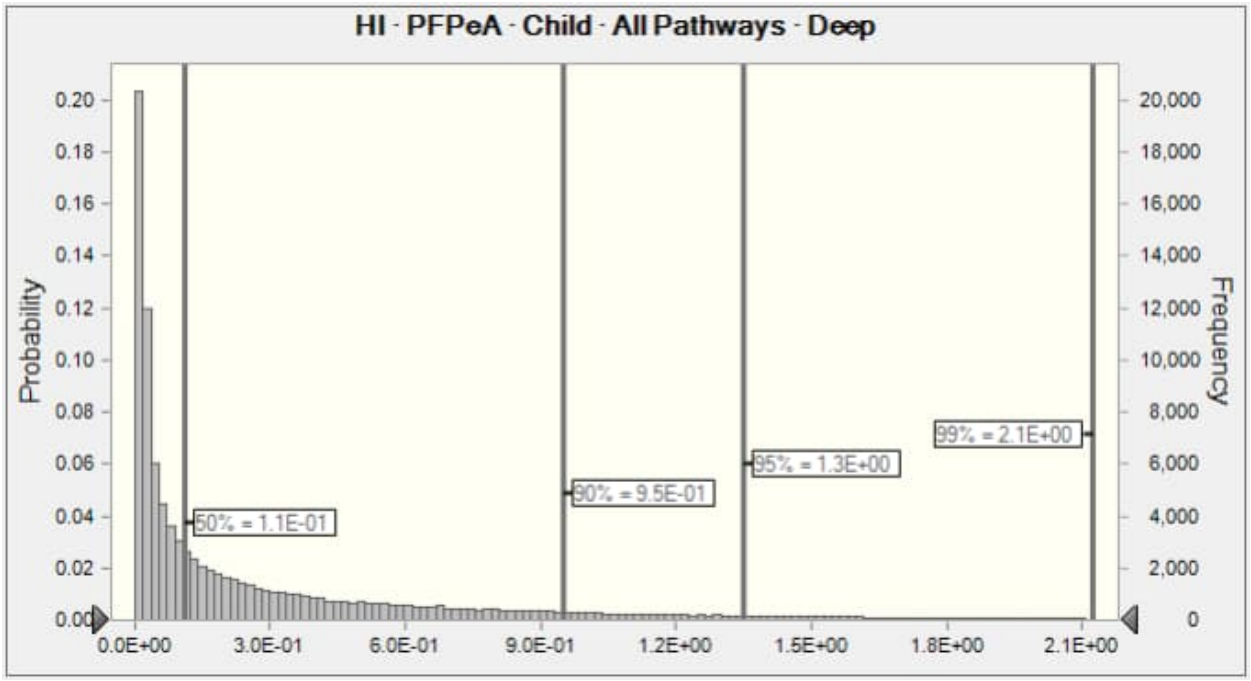


Figure E-2. PRA Output Distribution for Estimated Hazard Index for PFPeA, Child Resident, Deep Aquifer Scenario. Central tendency (50th percentile) and upper bound (90th, 95th, and 99th percentile) estimates are shown.

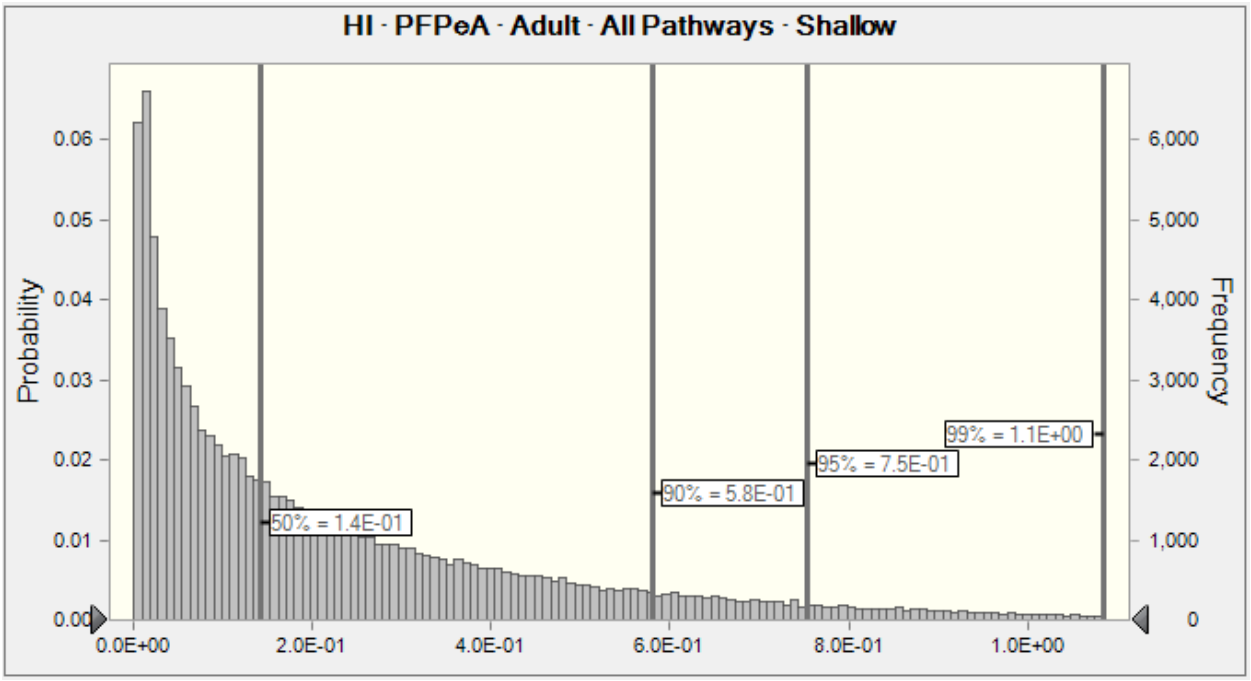


Figure E-3. PRA Output Distribution for Estimated Hazard Index for PFPeA, Adult Resident, Shallow Aquifer Scenario. Central tendency (50th percentile) and upper bound (90th, 95th, and 99th percentile) estimates are shown.

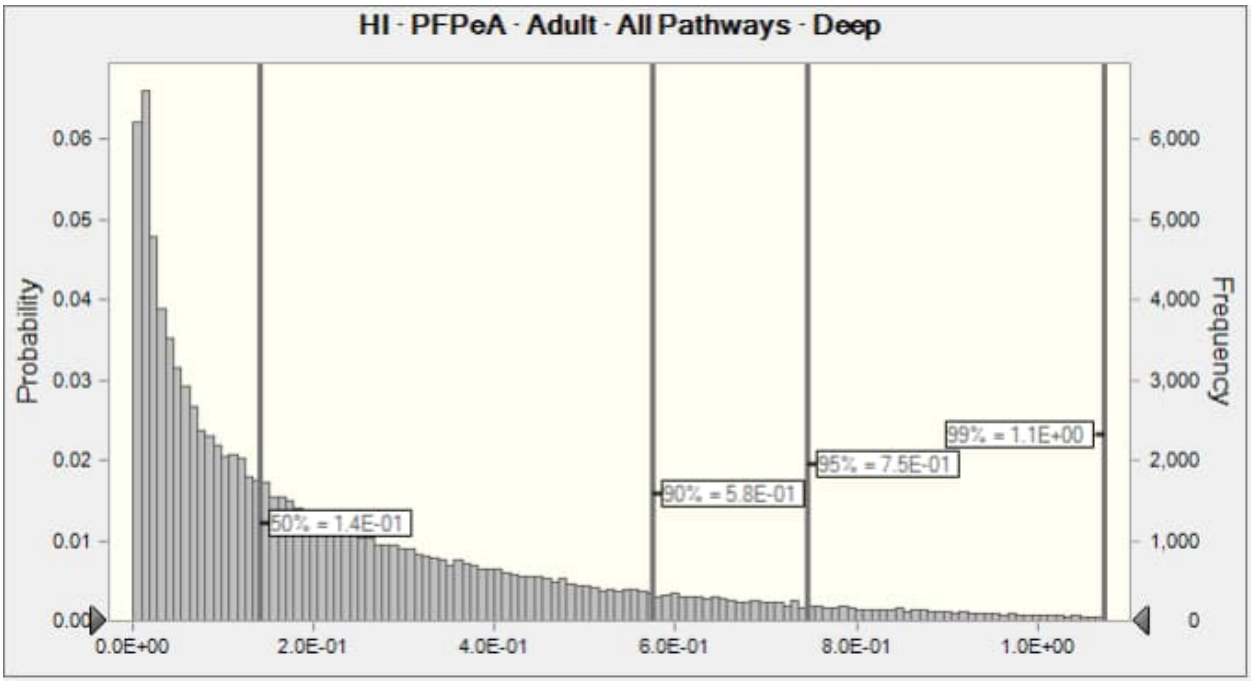


Figure E-4. PRA Output Distribution for Estimated Hazard Index for PFPeA, Adult Resident, Deep Aquifer Scenario. Central tendency (50th percentile) and upper bound (90th, 95th, and 99th percentile) estimates are shown.

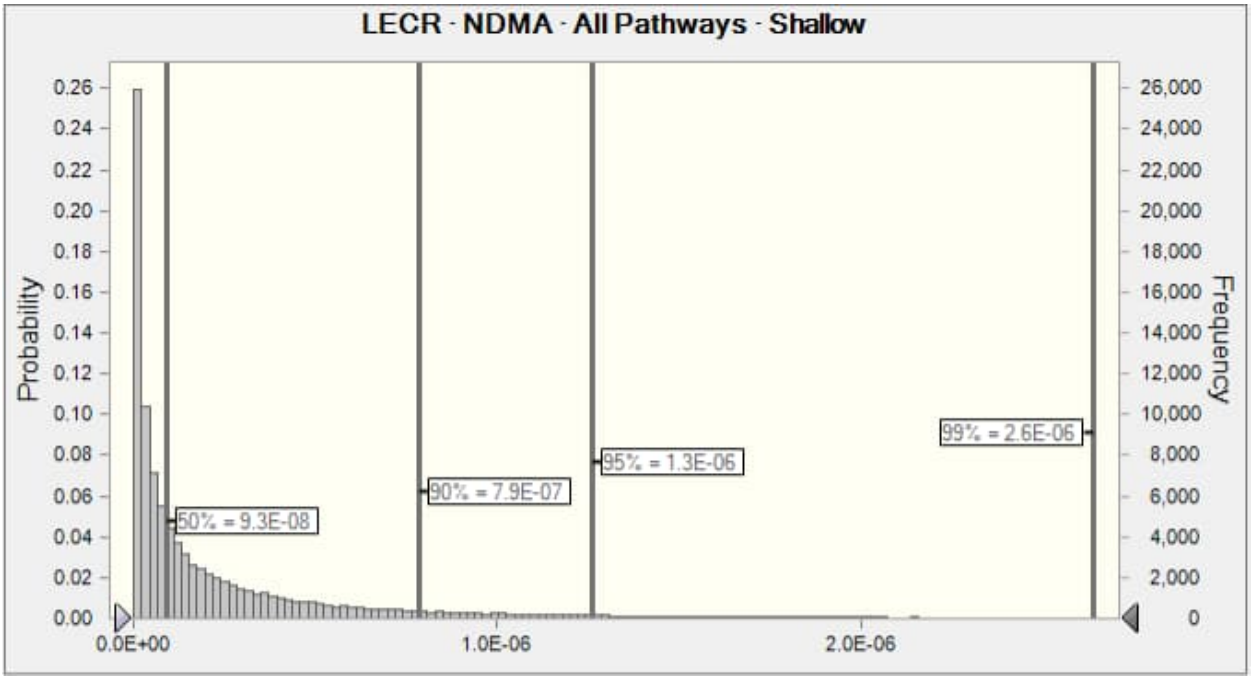


Figure E-5. PRA Output Distribution for Estimated LECR for NDMA, Resident, Shallow Aquifer Scenario. Central tendency (50th percentile) and upper bound (90th, 95th, and 99th percentile) estimates are shown.

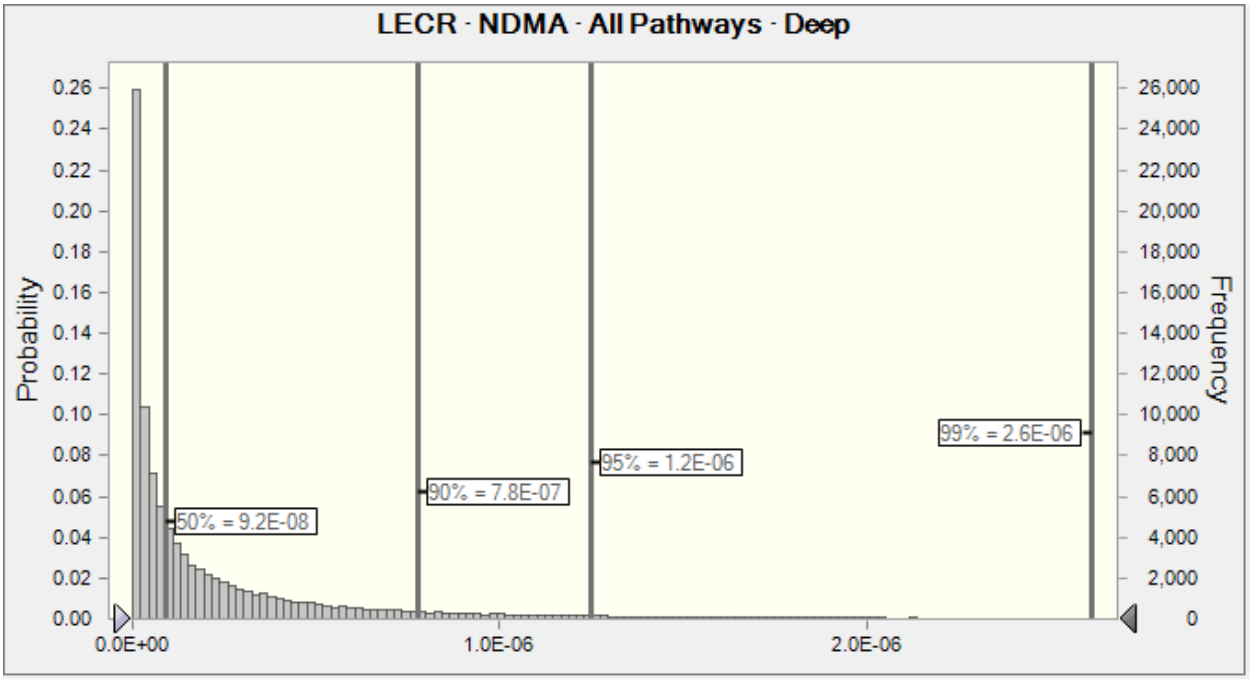


Figure E-6. PRA Output Distribution for Estimated LECR for NDMA, Resident, Deep Aquifer Scenario. Central tendency (50th percentile) and upper bound (90th, 95th, and 99th percentile) estimates are shown.

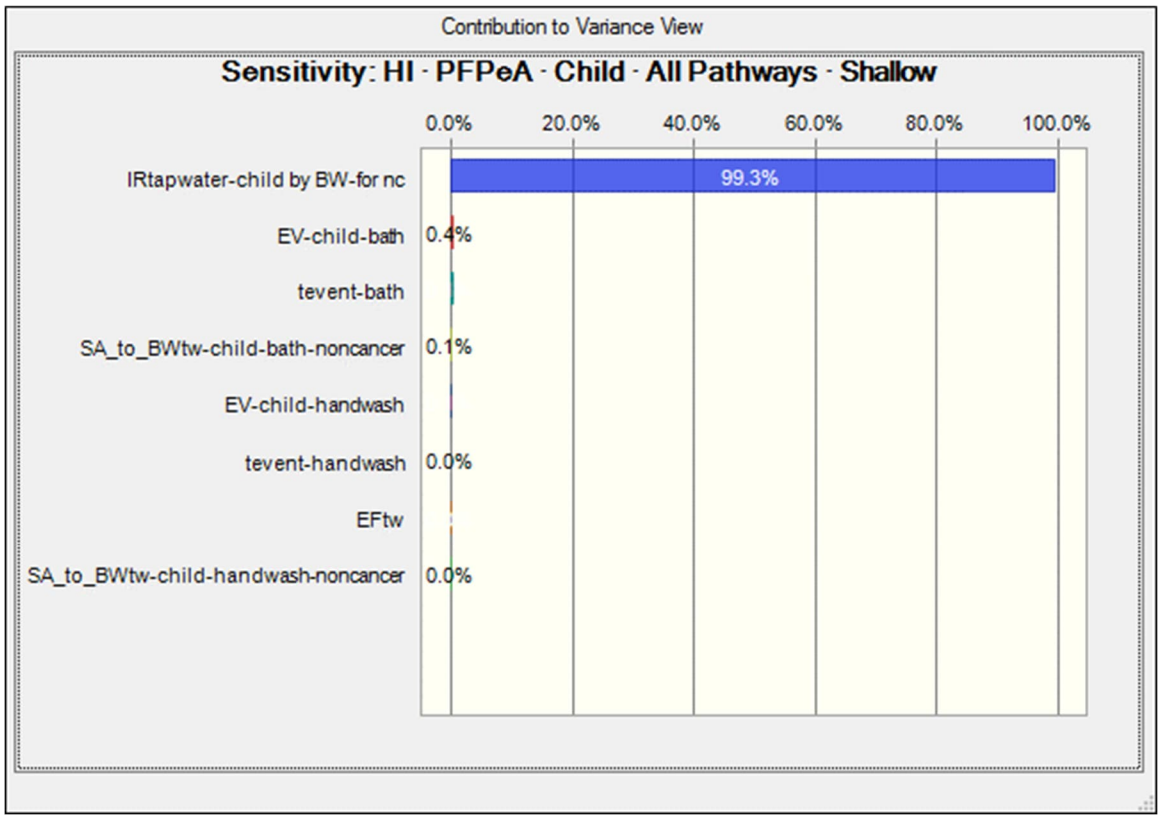


Figure E-7. Results of PRA Sensitivity Analysis for Estimation of the Hazard Index (HI) for PFPeA, Child Resident Exposure to Shallow Aquifer Scenario

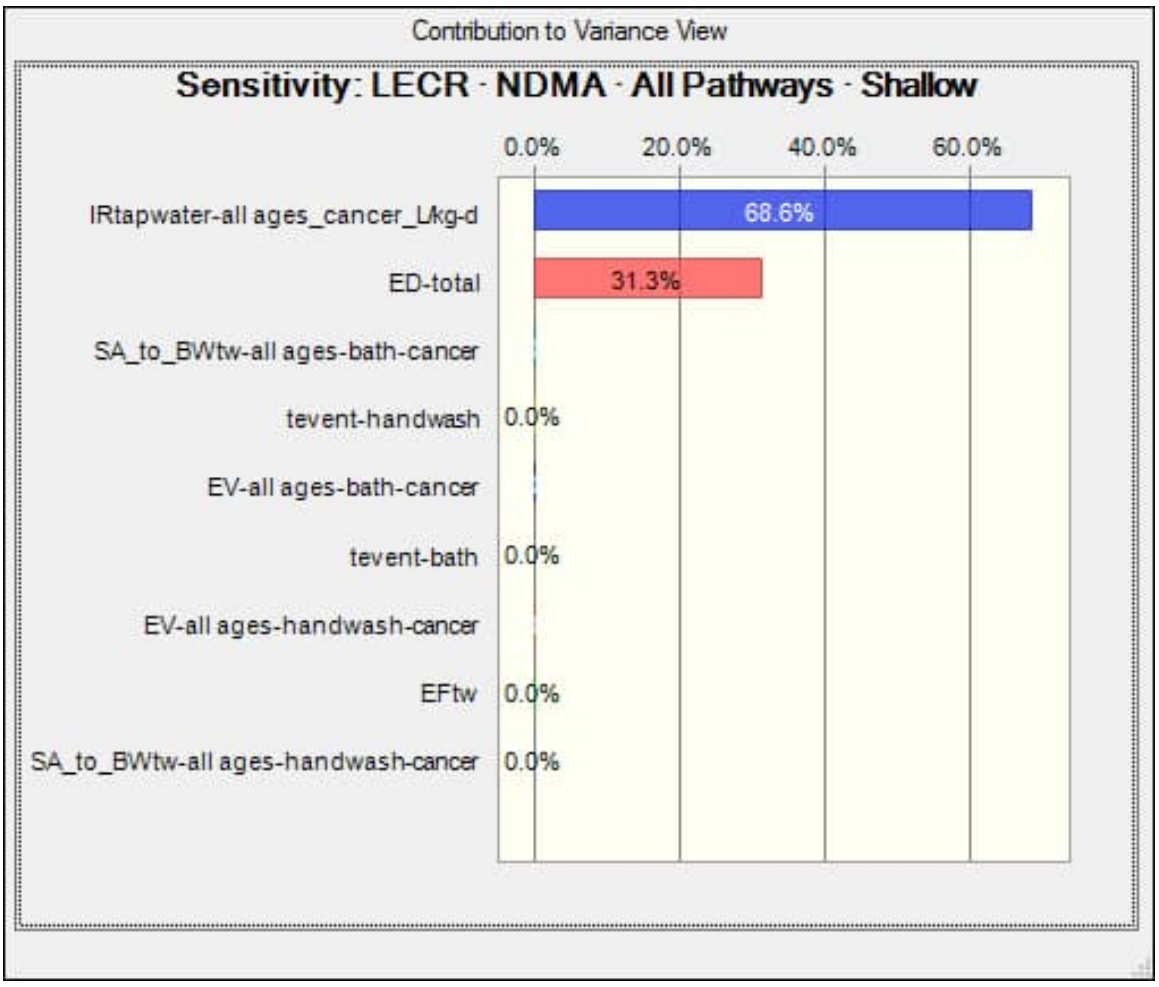


Figure E-8. Results of PRA Sensitivity Analysis for Estimation of the Lifetime Excess Cancer Risk (LECR) for NDMA, Resident Exposure to Shallow Aquifer Scenario

Table E-1. Selected Statistics for Reported and Fitted Distributions for Ingestion of Tap Water (L/kg-d)

	Child (0 to < 6 yrs)		Adult (16 to <70 yrs)		All ages (0 to <70 yrs)	
Summary Statistic	**Reported Values[a]**	**Beta Distribution**	**Reported Values[a]**	**Beta Distribution**	**Reported Values[a]**	**Beta Distribution**
Mean	0.0153	0.0155	0.0108	0.0112	0.0107	0.0109
Minimum	**0**	0	**0**	0	**0**	0
50th	**0.0049**	0.0049	**0.0069**	0.069	**0.0058**	0.0058
75th	0.0244	0.0207	0.0168	0.0164	0.0163	0.0151
90th	**0.0474**	0.0474	**0.0287**	0.0287	**0.0286**	0.0286
95th	0.0620	0.0674	0.0365	0.0373	0.0371	0.0390
99th	0.0855	0.1061	0.0567	0.0541	0.0641	0.0623
Maximum	**0.1818**	0.1818	**0.1032**	0.1032	**0.2675**	0.2675

a Source: NHANES 2005–2010, per capita estimates of combined direct and indirect community water ingestion (U.S. EPA, 2019). Values input into Crystal Ball to establish the beta distribution are bolded.

Table E-2. Results of PRA for PFPeA (Noncancer Hazard Index (HI)) for the Resident Scenario

Scenario	Aquifer	Pathway	PRA HI for Resident								Deterministic HI for RME Resident
			Mean	SD	50th	75th	90th	95th	99th	99.9th	
Child	**Shallow**	Dermal contact with tap water while showering, bathing, or handwashing	0.012	0.0060	0.011	0.015	0.02	0.024	0.032	0.046	0.023
		Ingestion of tap water	0.30	0.47	0.10	0.41	0.95	1.3	2.1	2.8	1.3
		Total	**0.32**	**0.47**	**0.11**	**0.43**	**0.96**	**1.4**	**2.1**	**2.8**	**1.3**
Adult	**Shallow**	Dermal contact with tap water while showering, bathing, or handwashing	0.0060	0.0030	0.0054	0.0073	0.0097	0.012	0.016	0.024	0.0077
		Ingestion of tap water	0.22	0.25	0.14	0.33	0.58	0.75	1.1	1.4	0.66
		Total	**0.23**	**0.25**	**0.14**	**0.33**	**0.58**	**0.75**	**1.1**	**1.4**	**0.67**
Child	**Deep**	Dermal contact with tap water while showering, bathing, or handwashing	0.012	0.0059	0.011	0.015	0.02	0.023	0.032	0.045	0.022
		Ingestion of tap water	0.30	0.46	0.099	0.41	0.94	1.3	2.1	2.8	1.3
		Total	**0.31**	**0.46**	**0.11**	**0.42**	**0.95**	**1.3**	**2.1**	**2.8**	**1.3**
Adult	**Deep**	Dermal contact with tap water while showering, bathing, or handwashing	0.0059	0.0029	0.0053	0.0072	0.0096	0.011	0.016	0.024	0.0076
		Ingestion of tap water	0.22	0.25	0.14	0.32	0.57	0.74	1.1	1.4	0.65
		Total	**0.23**	**0.25**	**0.14**	**0.33**	**0.58**	**0.75**	**1.1**	**1.4**	**0.66**

Table E-3. Results of PRA for NDMA (Lifetime Excess Cancer Risk (LECR)) for the Resident Scenario

Scenario	Aquifer	Pathway	PRA LECR for Resident								Deterministic LECR for RME Resident
			Mean	SD	50th	75th	90th	95th	99th	99.9th	
Child/ Adult	**Shallow**	Dermal contact with tap water while showering, bathing, or handwashing	2.6×10^{-9}	3.0×10^{-9}	1.7×10^{-9}	3.5×10^{-9}	6.1×10^{-9}	8.3×10^{-9}	1.4×10^{-8}	2.4×10^{-8}	7.1×10^{-9}
		Ingestion of tap water	2.9×10^{-7}	5.4×10^{-7}	9.0×10^{-8}	3.2×10^{-7}	7.8×10^{-7}	1.3×10^{-6}	2.6×10^{-6}	5.3×10^{-6}	2.9×10^{-6}
		Total	**2.9×10^{-7}**	**5.4×10^{-7}**	**9.3×10^{-8}**	**3.2×10^{-7}**	**7.9×10^{-7}**	**1.3×10^{-6}**	**2.6×10^{-6}**	**5.3×10^{-6}**	**2.9×10^{-6}**
Child/ Adult	**Deep**	Dermal contact with tap water while showering, bathing, or handwashing	2.6×10^{-9}	2.9×10^{-9}	1.7×10^{-9}	3.5×10^{-9}	6.1×10^{-9}	8.2×10^{-9}	1.4×10^{-8}	2.4×10^{-8}	7.0×10^{-9}
		Ingestion of tap water	2.9×10^{-7}	5.4×10^{-7}	8.9×10^{-8}	3.1×10^{-7}	7.7×10^{-7}	1.2×10^{-6}	2.6×10^{-6}	5.3×10^{-6}	2.8×10^{-6}
		Total	**2.9×10^{-7}**	**5.4×10^{-7}**	**9.2×10^{-8}**	**3.2×10^{-7}**	**7.8×10^{-7}**	**1.2×10^{-6}**	**2.6×10^{-6}**	**5.3×10^{-6}**	**2.9×10^{-6}**

ATTACHMENT TO APPENDIX E

DETAILED PROBABILISTIC RISK ASSESSMENT OUTPUT SUMMARY AND CRYSTAL BALL ASSUMPTIONS AND OUTPUT REPORT

Statistics	Trials	Mean	Standard D	Minimum	Maximum	2.5%	5%	10%	25%	50%	75%	90%	95%	97.5%	99%	99.9%
HI · PFPeA · Child · Dermal contact with water, total · Shallow	100000	0.012	0.0060	0.0018	0.082	0.0044	0.0051	0.0061	0.0080	0.011	0.015	0.02	0.024	0.027	0.032	0.046
HI · PFPeA · Child · Water Ingestion · Shallow	100000	0.31	0.47	6E-17	3.5	8.6E-06	0.000071	0.00063	0.011	0.10	0.41	0.95	1.3	1.7	2.1	2.8
HI · PFPeA · Child · All Pathways · Shallow	100000	0.32	0.47	0.0019	3.5	0.0074	0.0092	0.012	0.025	0.11	0.43	0.96	1.4	1.7	2.1	2.8
HI · PFPeA · Adult · Dermal contact with water, total · Shallow	100000	0.0060	0.0030	0.00059	0.036	0.0022	0.0025	0.0030	0.0039	0.0054	0.0073	0.0097	0.012	0.013	0.016	0.024
HI · PFPeA · Adult · Water Ingestion · Shallow	100000	0.22	0.25	4.2E-10	1.8	0.00094	0.0028	0.0085	0.040	0.14	0.33	0.58	0.75	0.90	1.1	1.4
HI · PFPeA · Adult · All Pathways · Shallow	100000	0.23	0.25	0.0012	1.8	0.0063	0.0089	0.015	0.046	0.14	0.33	0.58	0.75	0.91	1.1	1.4
HI · PFPeA · Child · Dermal contact with water, total · Deep	100000	0.012	0.0059	0.0018	0.081	0.0044	0.0051	0.0060	0.0079	0.011	0.015	0.02	0.023	0.027	0.032	0.045
HI · PFPeA · Child · Water Ingestion · Deep	100000	0.31	0.46	5.9E-17	3.5	8.5E-06	0.000070	0.00063	0.011	0.099	0.41	0.94	1.3	1.7	2.1	2.8
HI · PFPeA · Child · All Pathways · Deep	100000	0.32	0.46	0.0019	3.5	0.0074	0.0091	0.012	0.024	0.11	0.42	0.95	1.3	1.7	2.1	2.8
HI · PFPeA · Adult · Dermal contact with water, total · Deep	100000	0.0059	0.0029	0.00058	0.036	0.0022	0.0025	0.0030	0.0039	0.0053	0.0072	0.0096	0.011	0.013	0.016	0.024
HI · PFPeA · Adult · Water Ingestion · Deep	100000	0.22	0.25	4.2E-10	1.8	0.00093	0.0028	0.0085	0.039	0.14	0.32	0.57	0.74	0.89	1.1	1.4
HI · PFPeA · Adult · All Pathways · Deep	100000	0.23	0.25	0.0012	1.8	0.0062	0.0088	0.015	0.045	0.14	0.33	0.58	0.75	0.90	1.1	1.4
LECR · NDMA · Dermal contact with water, total · Shallow	100000	2.6E-09	3.0E-09	3.9E-16	6.4E-08	6.5E-11	1.3E-10	2.7E-10	7.1E-10	1.7E-09	3.5E-09	6.1E-09	8.3E-09	1.1E-08	1.4E-08	2.4E-08
LECR · NDMA · Water ingestion · Shallow	100000	2.9E-07	5.4E-07	9.6E-18	8.9E-06	2.2E-10	8.2E-10	3.0E-09	1.8E-08	9.0E-08	3.2E-07	7.8E-07	1.3E-06	1.8E-06	2.6E-06	5.3E-06
LECR · NDMA · All Pathways · Shallow	100000	2.9E-07	5.4E-07	1.4E-14	8.9E-06	8.7E-10	1.9E-09	4.6E-09	2.0E-08	9.3E-08	3.2E-07	7.9E-07	1.3E-06	1.8E-06	2.6E-06	5.3E-06
LECR · NDMA · Dermal contact with water, total · Deep	100000	2.6E-09	2.9E-09	3.9E-16	6.4E-08	6.4E-11	1.3E-10	2.6E-10	7.0E-10	1.7E-09	3.5E-09	6.1E-09	8.2E-09	1.1E-08	1.4E-08	2.4E-08
LECR · NDMA · Water ingestion · Deep	100000	2.9E-07	5.4E-07	9.5E-18	8.9E-06	2.2E-10	8.1E-10	3.0E-09	1.8E-08	8.9E-08	3.1E-07	7.7E-07	1.2E-06	1.8E-06	2.6E-06	5.3E-06
LECR · NDMA · All Pathways · Deep	100000	2.9E-07	5.4E-07	1.4E-14	8.9E-06	8.6E-10	1.9E-09	4.6E-09	2.0E-08	9.2E-08	3.2E-07	7.8E-07	1.2E-06	1.8E-06	2.6E-06	5.3E-06

Crystal Ball Report - Custom

Simulation started on 2/18/2022 at 6:07 PM

Simulation stopped on 2/18/2022 at 6:12 PM

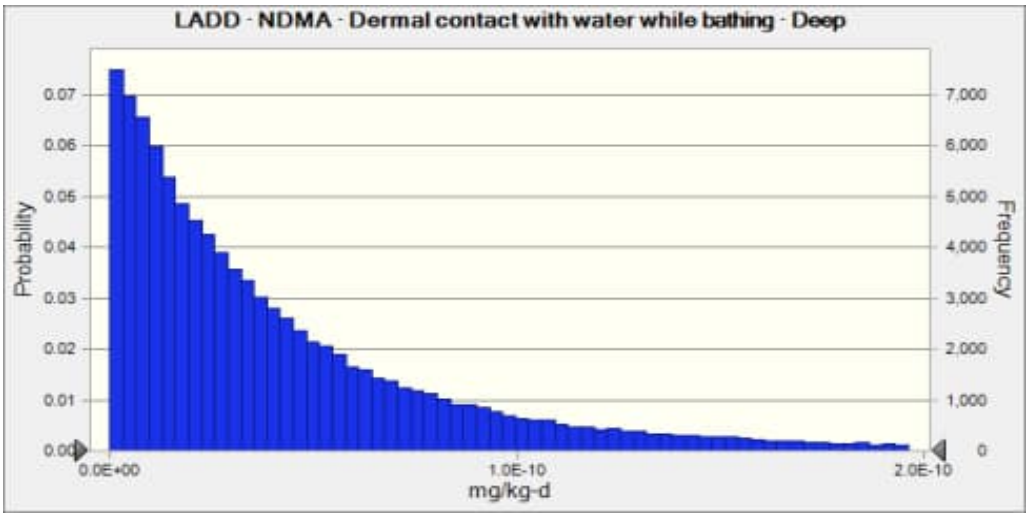
Run preferences:	
Number of trials run	100,000
Monte Carlo	
Random seed	
Precision control on	
Confidence level	95.00%
Run statistics:	
Total running time (sec)	340.07
Trials/second (average)	294
Random numbers per sec	6,763
Crystal Ball data:	
Assumptions	23
Correlations	0
Correlation matrices	0
Decision variables	0
Forecasts	158

Forecasts

Forecast: LADD · NDMA · Dermal contact with water while bathing · Deep

Summary:

Entire range is from 6.6E-18 to 1.2E-09
Base case is 4.3E-11
After 100,000 trials, the std. error of the mean is 1.7E-13



Statistics:	Forecast values
Trials	100,000
Base Case	4.3E-11
Mean	4.6E-11
Median	2.9E-11
Mode	---
Standard Deviation	5.4E-11
Variance	2.9E-21
Skewness	3.07
Kurtosis	20.78
Coeff. of Variation	1.16
Minimum	6.6E-18
Maximum	1.2E-09
Range Width	1.2E-09
Mean Std. Error	1.7E-13

Forecast: LADD · NDMA · Dermal contact with water while bathing · Deep (cont'd)

Percentiles:	Forecast values
0%	6.6E-18
10%	4.4E-12
20%	9.1E-12
30%	1.5E-11
40%	2.1E-11
50%	2.9E-11
60%	3.9E-11
70%	5.2E-11
80%	7.1E-11
90%	1.1E-10
100%	1.2E-09

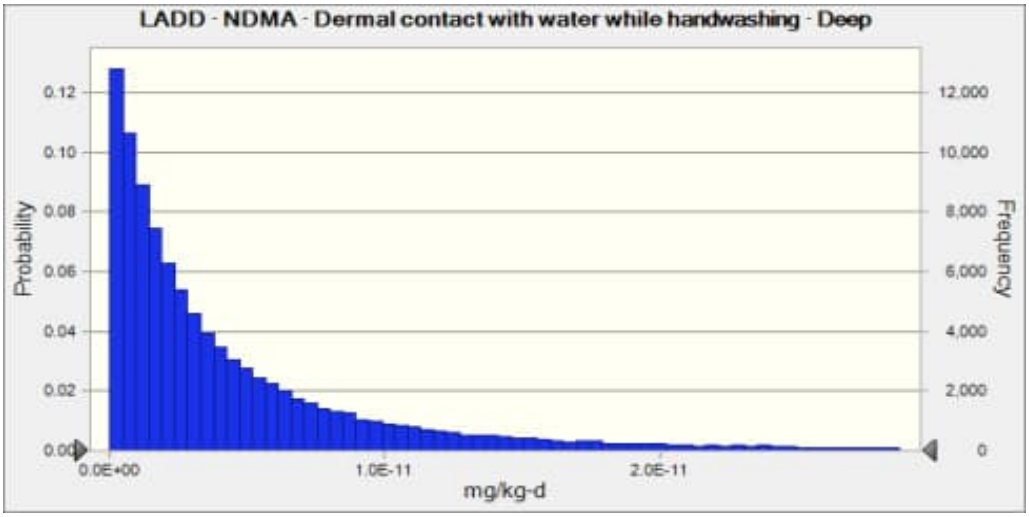
Forecast: LADD · NDMA · Dermal contact with water while handwashing · Deep

Summary:

Entire range is from 1.0E-18 to 2.9E-10

Base case is 3.5E-12

After 100,000 trials, the std. error of the mean is 2.6E-14



Statistics:	Forecast values
Trials	100,000
Base Case	3.5E-12
Mean	5.4E-12
Median	2.7E-12
Mode	---
Standard Deviation	8.3E-12
Variance	7.0E-23
Skewness	5.81
Kurtosis	78.01
Coeff. of Variation	1.55
Minimum	1.0E-18
Maximum	2.9E-10
Range Width	2.9E-10
Mean Std. Error	2.6E-14

Forecast: LADD · NDMA · Dermal contact with water while handwashing · Deep (cont'd)

Percentiles:	Forecast values
0%	1.0E-18
10%	3.6E-13
20%	7.8E-13
30%	1.3E-12
40%	1.9E-12
50%	2.7E-12
60%	3.8E-12
70%	5.3E-12
80%	7.8E-12
90%	1.3E-11
100%	2.9E-10

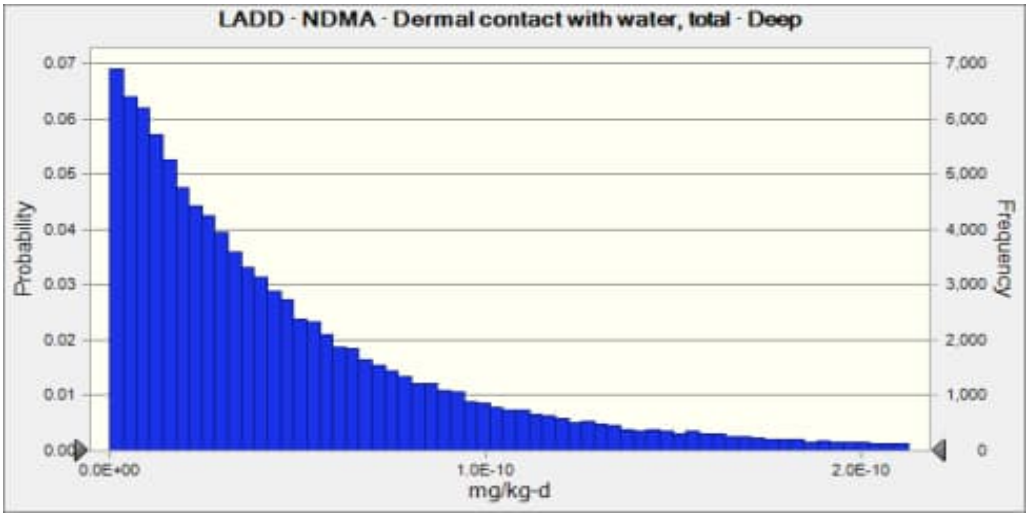
Forecast: LADD · NDMA · Dermal contact with water, total · Deep

Summary:

Entire range is from 7.6E-18 to 1.2E-09

Base case is 4.6E-11

After 100,000 trials, the std. error of the mean is 1.8E-13



Statistics:	Forecast values
Trials	100,000
Base Case	4.6E-11
Mean	5.1E-11
Median	3.3E-11
Mode	---
Standard Deviation	5.8E-11
Variance	3.3E-21
Skewness	2.87
Kurtosis	18.50
Coeff. of Variation	1.12
Minimum	7.6E-18
Maximum	1.2E-09
Range Width	1.2E-09
Mean Std. Error	1.8E-13

Forecast: LADD · NDMA · Dermal contact with water, total · Deep (cont'd)

Percentiles:	Forecast values
0%	7.6E-18
10%	5.1E-12
20%	1.1E-11
30%	1.7E-11
40%	2.5E-11
50%	3.3E-11
60%	4.4E-11
70%	5.9E-11
80%	8.0E-11
90%	1.2E-10
100%	1.2E-09

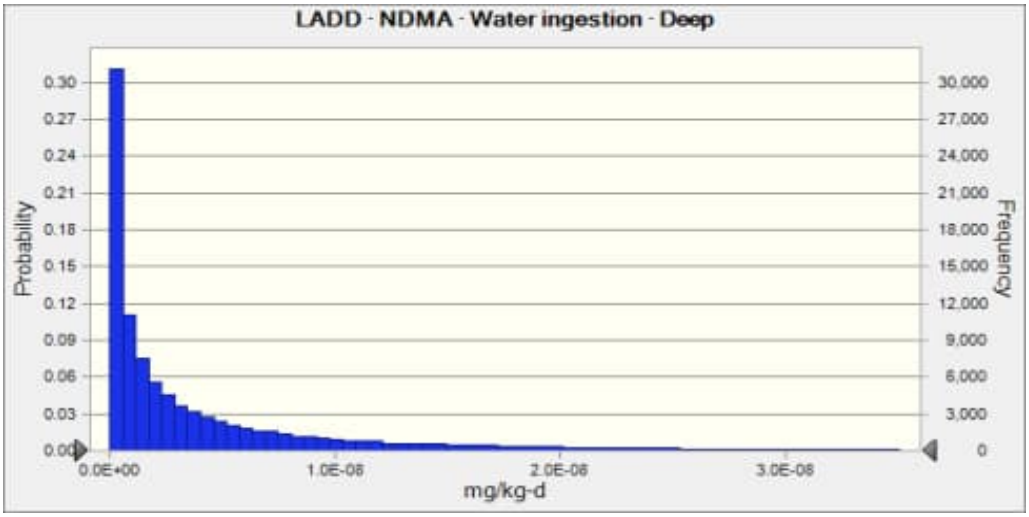
Forecast: LADD · NDMA · Water ingestion · Deep

Summary:

Entire range is from 1.9E-19 to 1.7E-07

Base case is 5.6E-09

After 100,000 trials, the std. error of the mean is 3.3E-11



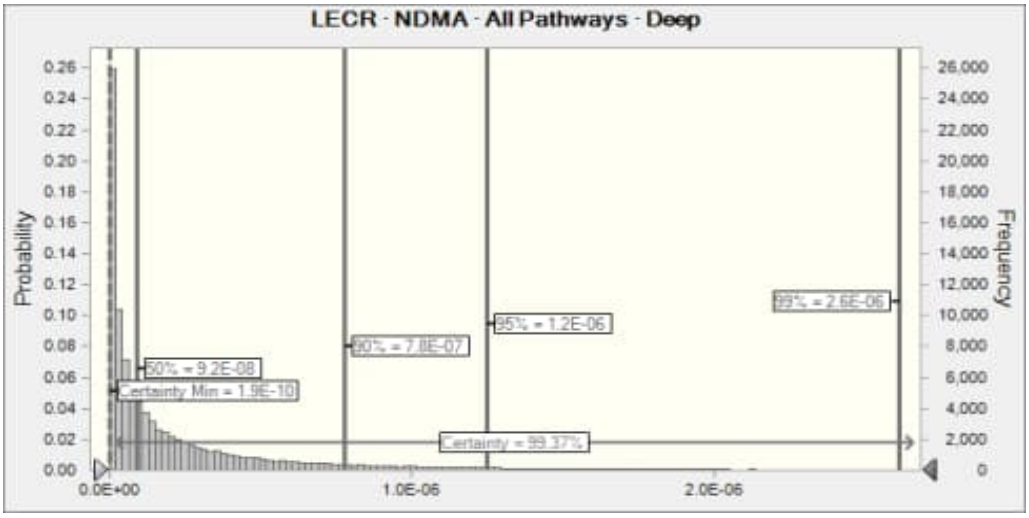
Statistics:	Forecast values
Trials	100,000
Base Case	5.6E-09
Mean	5.6E-09
Median	1.8E-09
Mode	---
Standard Deviation	1.1E-08
Variance	1.1E-16
Skewness	4.49
Kurtosis	33.89
Coeff. of Variation	1.87
Minimum	1.9E-19
Maximum	1.7E-07
Range Width	1.7E-07
Mean Std. Error	3.3E-11

Forecast: LADD · NDMA · Water ingestion · Deep (cont'd)

Percentiles:	Forecast values
0%	1.9E-19
10%	5.9E-11
20%	2.3E-10
30%	5.3E-10
40%	1.0E-09
50%	1.8E-09
60%	2.9E-09
70%	4.7E-09
80%	8.0E-09
90%	1.5E-08
100%	1.7E-07

Forecast: LECR · NDMA · All Pathways · Deep

Summary:
Certainty level is 99.371%
Certainty range is from 1.9E-10 to ∞
Entire range is from 1.4E-14 to 8.9E-06
Base case is 2.9E-07
After 100,000 trials, the std. error of the mean is 1.7E-09



Statistics:	Forecast values
Trials	100,000
Base Case	2.9E-07
Mean	2.9E-07
Median	9.2E-08
Mode	---
Standard Deviation	5.4E-07
Variance	2.9E-13
Skewness	4.48
Kurtosis	33.78
Coeff. of Variation	1.86
Minimum	1.4E-14
Maximum	8.9E-06
Range Width	8.9E-06
Mean Std. Error	1.7E-09

Forecast: LECR · NDMA · All Pathways · Deep (cont'd)

Percentiles:	Forecast values
0%	1.4E-14
10%	4.6E-09
20%	1.3E-08
30%	2.9E-08
40%	5.4E-08
50%	9.2E-08
60%	1.5E-07
70%	2.5E-07
80%	4.1E-07
90%	7.8E-07
100%	8.9E-06

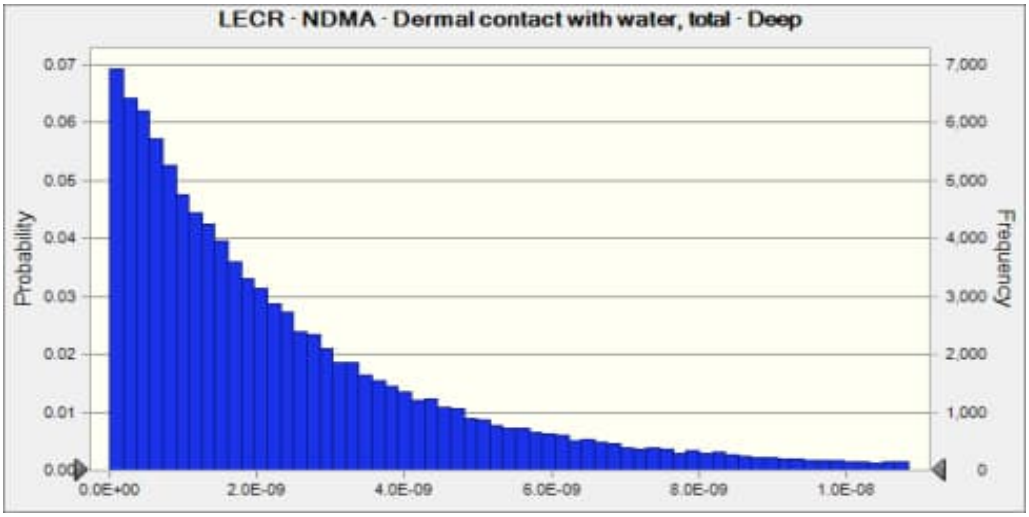
Forecast: LECR · NDMA · Dermal contact with water, total · Deep

Summary:

Entire range is from 3.9E-16 to 6.4E-08

Base case is 2.3E-09

After 100,000 trials, the std. error of the mean is 9.3E-12



Statistics:	Forecast values
Trials	100,000
Base Case	2.3E-09
Mean	2.6E-09
Median	1.7E-09
Mode	---
Standard Deviation	2.9E-09
Variance	8.6E-18
Skewness	2.87
Kurtosis	18.50
Coeff. of Variation	1.12
Minimum	3.9E-16
Maximum	6.4E-08
Range Width	6.4E-08
Mean Std. Error	9.3E-12

Forecast: LECR · NDMA · Dermal contact with water, total · Deep (cont'd)

Percentiles:	Forecast values
0%	3.9E-16
10%	2.6E-10
20%	5.5E-10
30%	8.7E-10
40%	1.3E-09
50%	1.7E-09
60%	2.3E-09
70%	3.0E-09
80%	4.1E-09
90%	6.1E-09
100%	6.4E-08

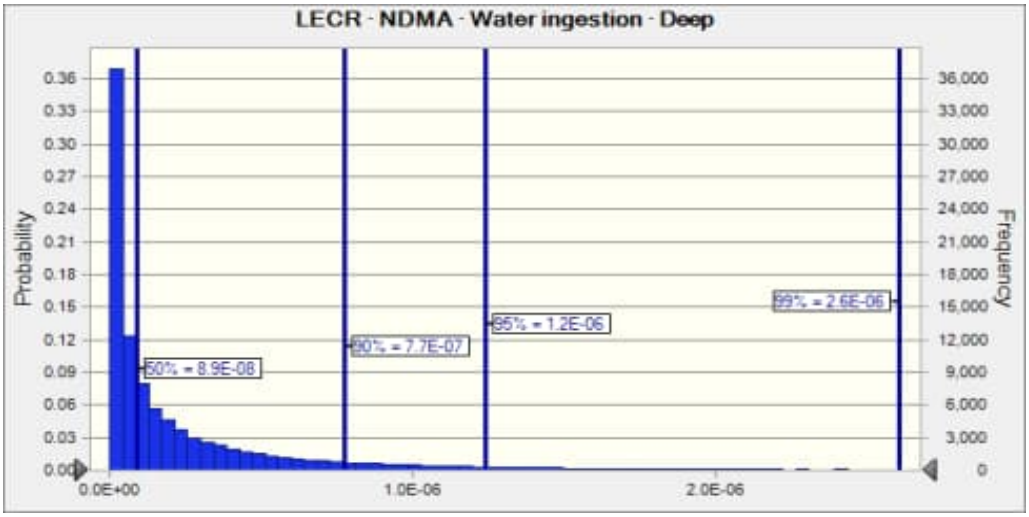
Forecast: LECR · NDMA · Water ingestion · Deep

Summary:

Entire range is from 9.5E-18 to 8.9E-06

Base case is 2.8E-07

After 100,000 trials, the std. error of the mean is 1.7E-09



Statistics:	Forecast values
Trials	100,000
Base Case	2.8E-07
Mean	2.9E-07
Median	8.9E-08
Mode	---
Standard Deviation	5.4E-07
Variance	2.9E-13
Skewness	4.49
Kurtosis	33.89
Coeff. of Variation	1.87
Minimum	9.5E-18
Maximum	8.9E-06
Range Width	8.9E-06
Mean Std. Error	1.7E-09

Forecast: LECR · NDMA · Water ingestion · Deep (cont'd)

Percentiles:	Forecast values
0%	9.5E-18
10%	3.0E-09
20%	1.2E-08
30%	2.7E-08
40%	5.2E-08
50%	8.9E-08
60%	1.5E-07
70%	2.4E-07
80%	4.1E-07
90%	7.7E-07
100%	8.9E-06

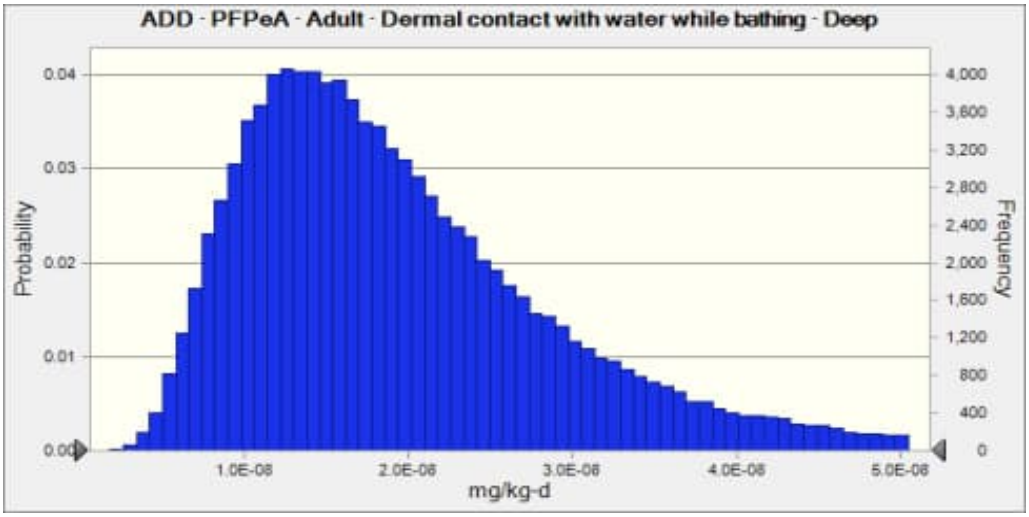
Forecast: ADD · PFPeA · Adult · Dermal contact with water while bathing · Deep

Summary:

Entire range is from 1.8E-09 to 1.4E-07

Base case is 1.9E-08

After 100,000 trials, the std. error of the mean is 3.4E-11



Statistics:	Forecast values
Trials	100,000
Base Case	1.9E-08
Mean	2.0E-08
Median	1.8E-08
Mode	---
Standard Deviation	1.1E-08
Variance	1.2E-16
Skewness	1.79
Kurtosis	8.93
Coeff. of Variation	0.5436
Minimum	1.8E-09
Maximum	1.4E-07
Range Width	1.3E-07
Mean Std. Error	3.4E-11

Forecast: ADD · PFPeA · Adult · Dermal contact with water while bathing · Deep (cont'd)

Percentiles:	Forecast values
0%	1.8E-09
10%	9.2E-09
20%	1.1E-08
30%	1.3E-08
40%	1.5E-08
50%	1.8E-08
60%	2.0E-08
70%	2.3E-08
80%	2.7E-08
90%	3.4E-08
100%	1.4E-07

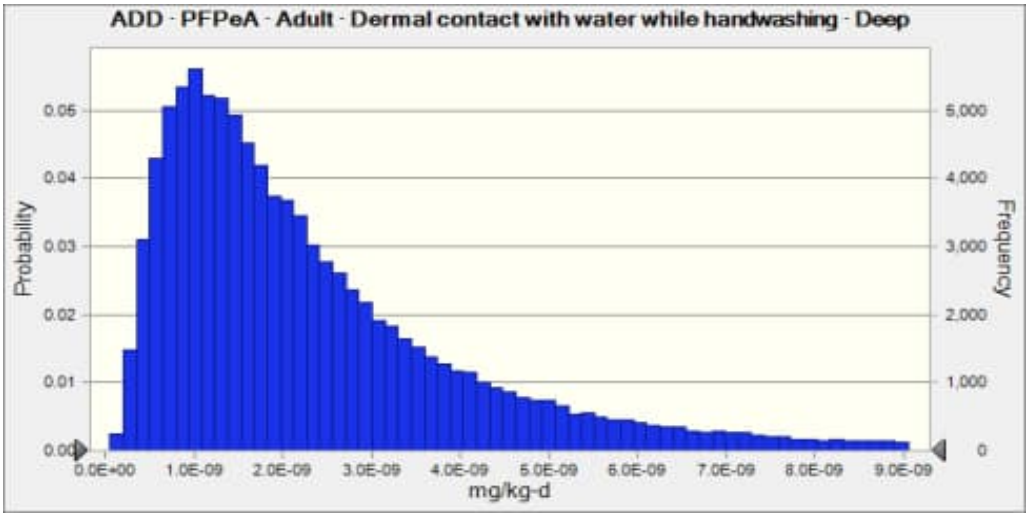
Forecast: ADD · PFPeA · Adult · Dermal contact with water while handwashing · Deep

Summary:

Entire range is from 4.6E-11 to 5.0E-08

Base case is 1.6E-09

After 100,000 trials, the std. error of the mean is 7.4E-12



Statistics:	Forecast values
Trials	100,000
Base Case	1.6E-09
Mean	2.5E-09
Median	1.9E-09
Mode	---
Standard Deviation	2.3E-09
Variance	5.4E-18
Skewness	3.32
Kurtosis	24.95
Coeff. of Variation	0.9243
Minimum	4.6E-11
Maximum	5.0E-08
Range Width	5.0E-08
Mean Std. Error	7.4E-12

Forecast: ADD · PFPeA · Adult · Dermal contact with water while handwashing · Deep (cont'd)

Percentiles:	Forecast values
0%	4.6E-11
10%	6.6E-10
20%	9.5E-10
30%	1.2E-09
40%	1.5E-09
50%	1.9E-09
60%	2.3E-09
70%	2.8E-09
80%	3.6E-09
90%	5.1E-09
100%	5.0E-08

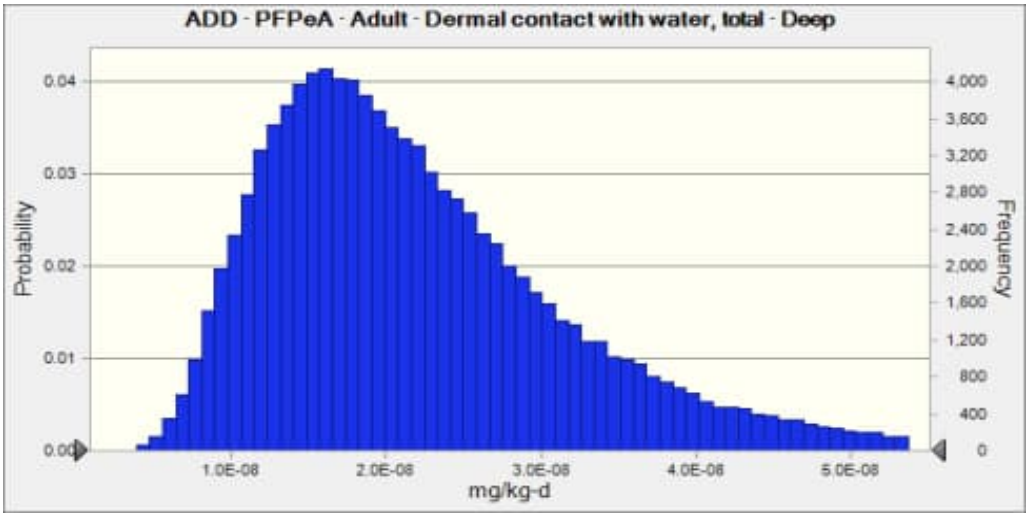
Forecast: ADD · PFPeA · Adult · Dermal contact with water, total · Deep

Summary:

Entire range is from 2.2E-09 to 1.4E-07

Base case is 2.1E-08

After 100,000 trials, the std. error of the mean is 3.5E-11



Statistics:	Forecast values
Trials	100,000
Base Case	2.1E-08
Mean	2.3E-08
Median	2.0E-08
Mode	---
Standard Deviation	1.1E-08
Variance	1.2E-16
Skewness	1.71
Kurtosis	8.47
Coeff. of Variation	0.4939
Minimum	2.2E-09
Maximum	1.4E-07
Range Width	1.3E-07
Mean Std. Error	3.5E-11

Forecast: ADD · PFPeA · Adult · Dermal contact with water, total · Deep (cont'd)

Percentiles:	Forecast values
0%	2.2E-09
10%	1.1E-08
20%	1.4E-08
30%	1.6E-08
40%	1.8E-08
50%	2.0E-08
60%	2.3E-08
70%	2.6E-08
80%	3.0E-08
90%	3.7E-08
100%	1.4E-07

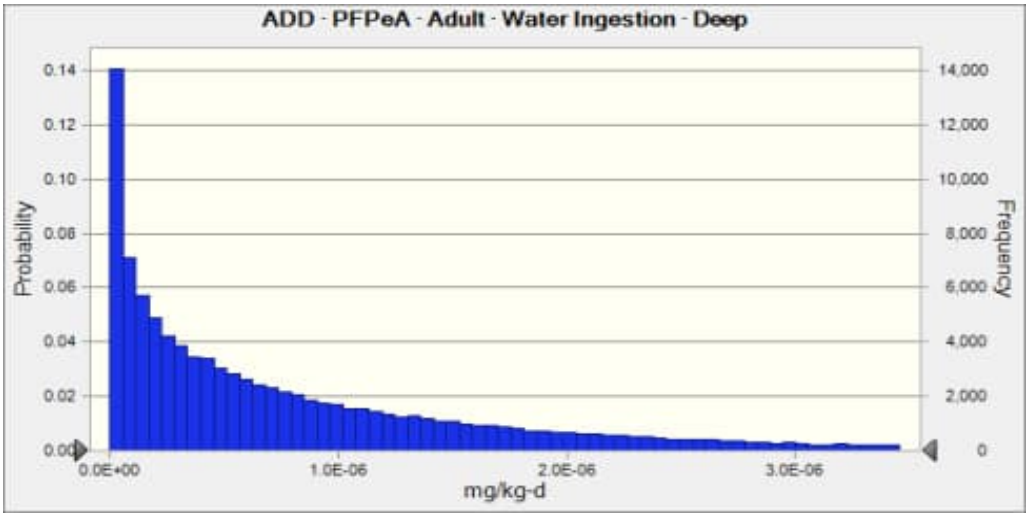
Forecast: ADD · PFPeA · Adult · Water Ingestion · Deep

Summary:

Entire range is from 1.6E-15 to 6.8E-06

Base case is 8.1E-07

After 100,000 trials, the std. error of the mean is 2.9E-09



Statistics:	Forecast values
Trials	100,000
Base Case	8.1E-07
Mean	8.5E-07
Median	5.1E-07
Mode	---
Standard Deviation	9.3E-07
Variance	8.7E-13
Skewness	1.68
Kurtosis	6.06
Coeff. of Variation	1.10
Minimum	1.6E-15
Maximum	6.8E-06
Range Width	6.8E-06
Mean Std. Error	2.9E-09

Forecast: ADD · PFPeA · Adult · Water Ingestion · Deep (cont'd)

Percentiles:	Forecast values
0%	1.6E-15
10%	3.2E-08
20%	1.0E-07
30%	2.1E-07
40%	3.4E-07
50%	5.1E-07
60%	7.4E-07
70%	1.0E-06
80%	1.5E-06
90%	2.2E-06
100%	6.8E-06

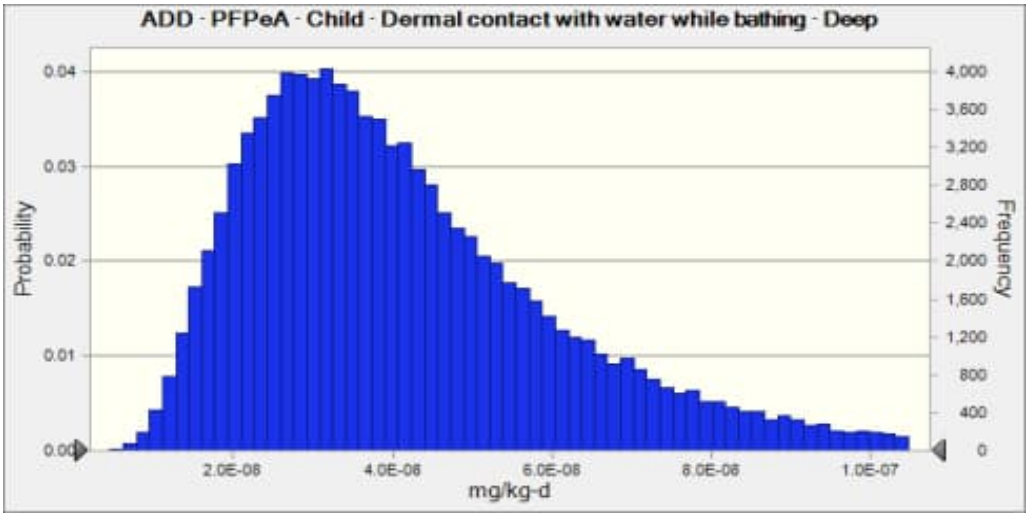
Forecast: ADD · PFPeA · Child · Dermal contact with water while bathing · Deep

Summary:

Entire range is from 4.5E-09 to 3.1E-07

Base case is 4.1E-08

After 100,000 trials, the std. error of the mean is 7.0E-11



Statistics:	Forecast values
Trials	100,000
Base Case	4.1E-08
Mean	4.2E-08
Median	3.8E-08
Mode	---
Standard Deviation	2.2E-08
Variance	5.0E-16
Skewness	1.65
Kurtosis	8.02
Coeff. of Variation	0.5252
Minimum	4.5E-09
Maximum	3.1E-07
Range Width	3.0E-07
Mean Std. Error	7.0E-11

Forecast: ADD · PFPeA · Child · Dermal contact with water while bathing · Deep (cont'd)

Percentiles:	Forecast values
0%	4.5E-09
10%	2.0E-08
20%	2.5E-08
30%	2.9E-08
40%	3.3E-08
50%	3.8E-08
60%	4.2E-08
70%	4.9E-08
80%	5.7E-08
90%	7.1E-08
100%	3.1E-07

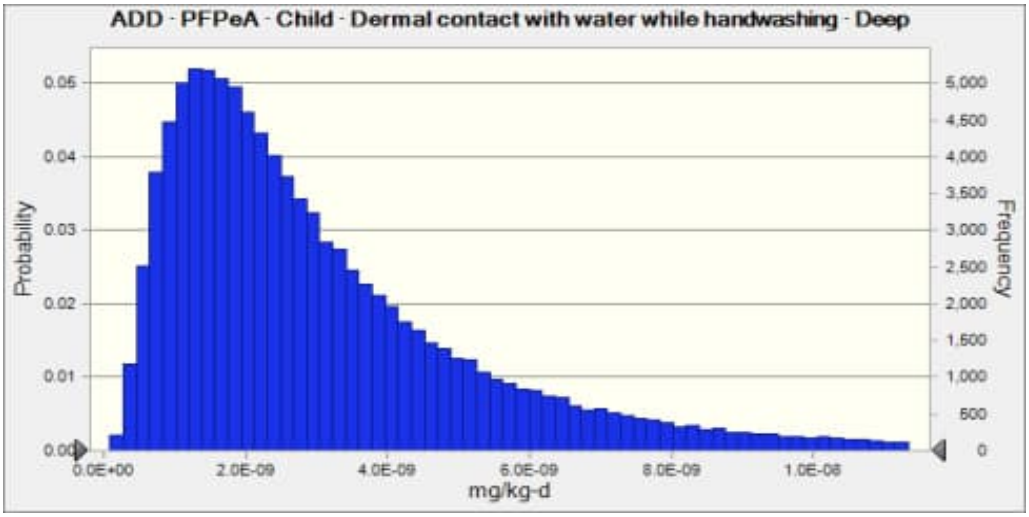
Forecast: ADD · PFPeA · Child · Dermal contact with water while handwashing · Deep

Summary:

Entire range is from 8.8E-11 to 7.4E-08

Base case is 2.2E-09

After 100,000 trials, the std. error of the mean is 9.1E-12



Statistics:	Forecast values
Trials	100,000
Base Case	2.2E-09
Mean	3.3E-09
Median	2.5E-09
Mode	---
Standard Deviation	2.9E-09
Variance	8.3E-18
Skewness	3.22
Kurtosis	26.06
Coeff. of Variation	0.8769
Minimum	8.8E-11
Maximum	7.4E-08
Range Width	7.4E-08
Mean Std. Error	9.1E-12

Forecast: ADD · PFPeA · Child · Dermal contact with water while handwashing · Deep (cont'd)

Percentiles:	Forecast values
0%	8.8E-11
10%	9.2E-10
20%	1.3E-09
30%	1.7E-09
40%	2.0E-09
50%	2.5E-09
60%	3.0E-09
70%	3.7E-09
80%	4.7E-09
90%	6.5E-09
100%	7.4E-08

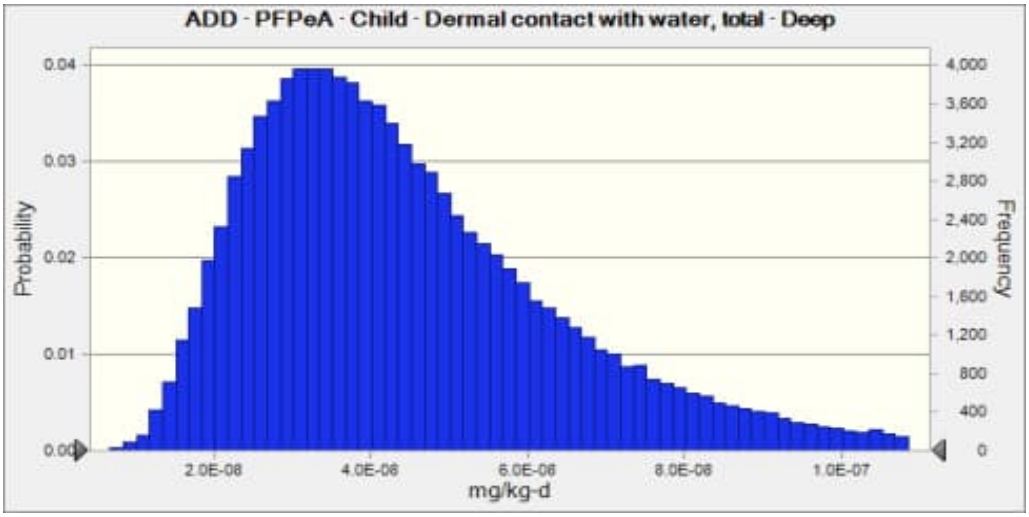
Forecast: ADD · PFPeA · Child · Dermal contact with water, total · Deep

Summary:

Entire range is from 6.8E-09 to 3.1E-07

Base case is 4.3E-08

After 100,000 trials, the std. error of the mean is 7.1E-11



Statistics:	Forecast values
Trials	100,000
Base Case	4.3E-08
Mean	4.6E-08
Median	4.1E-08
Mode	---
Standard Deviation	2.2E-08
Variance	5.0E-16
Skewness	1.62
Kurtosis	7.85
Coeff. of Variation	0.4916
Minimum	6.8E-09
Maximum	3.1E-07
Range Width	3.0E-07
Mean Std. Error	7.1E-11

Forecast: ADD · PFPeA · Child · Dermal contact with water, total · Deep (cont'd)

Percentiles:	Forecast values
0%	6.8E-09
10%	2.3E-08
20%	2.8E-08
30%	3.2E-08
40%	3.6E-08
50%	4.1E-08
60%	4.6E-08
70%	5.2E-08
80%	6.0E-08
90%	7.4E-08
100%	3.1E-07

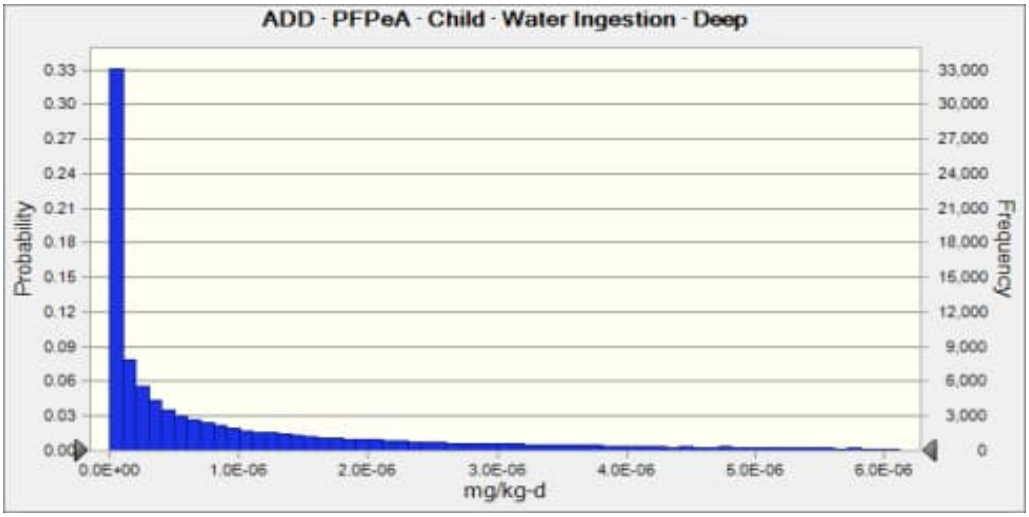
Forecast: ADD · PFPeA · Child · Water Ingestion · Deep

Summary:

Entire range is from 2.2E-22 to 1.3E-05

Base case is 1.1E-06

After 100,000 trials, the std. error of the mean is 5.6E-09



Statistics:	Forecast values
Trials	100,000
Base Case	1.1E-06
Mean	1.2E-06
Median	3.8E-07
Mode	---
Standard Deviation	1.8E-06
Variance	3.1E-12
Skewness	2.25
Kurtosis	8.53
Coeff. of Variation	1.50
Minimum	2.2E-22
Maximum	1.3E-05
Range Width	1.3E-05
Mean Std. Error	5.6E-09

Forecast: ADD · PFPeA · Child · Water Ingestion · Deep (cont'd)

Percentiles:	Forecast values
0%	2.2E-22
10%	2.4E-09
20%	2.1E-08
30%	7.3E-08
40%	1.8E-07
50%	3.8E-07
60%	7.0E-07
70%	1.2E-06
80%	2.0E-06
90%	3.6E-06
100%	1.3E-05

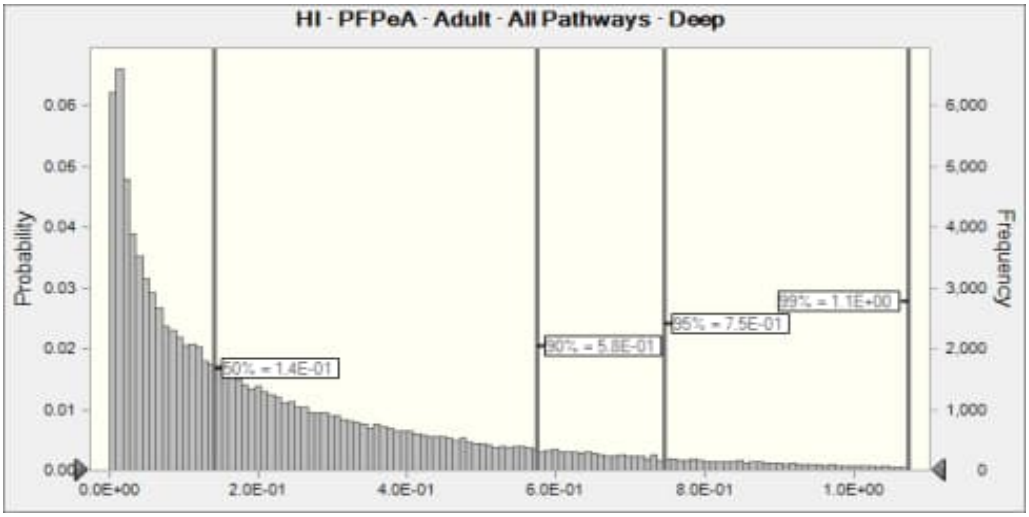
Forecast: HI · PFPeA · Adult · All Pathways · Deep

Summary:

Entire range is from 1.2E-03 to 1.8E+00

Base case is 2.2E-01

After 100,000 trials, the std. error of the mean is 7.8E-04



Statistics:	Forecast values
Trials	100,000
Base Case	2.2E-01
Mean	2.3E-01
Median	1.4E-01
Mode	---
Standard Deviation	2.5E-01
Variance	6.0E-02
Skewness	1.68
Kurtosis	6.06
Coeff. of Variation	1.07
Minimum	1.2E-03
Maximum	1.8E+00
Range Width	1.8E+00
Mean Std. Error	7.8E-04

Forecast: HI · PFPeA · Adult · All Pathways · Deep (cont'd)

Percentiles:	Forecast values
0%	1.2E-03
10%	1.5E-02
20%	3.3E-02
30%	6.0E-02
40%	9.6E-02
50%	1.4E-01
60%	2.0E-01
70%	2.8E-01
80%	3.9E-01
90%	5.8E-01
100%	1.8E+00

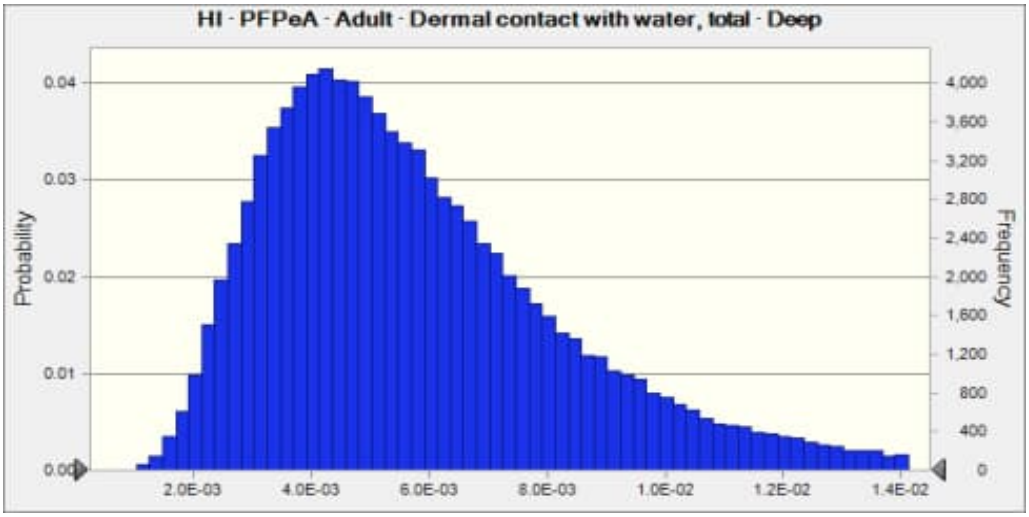
Forecast: HI · PFPeA · Adult · Dermal contact with water, total · Deep

Summary:

Entire range is from 5.8E-04 to 3.6E-02

Base case is 5.5E-03

After 100,000 trials, the std. error of the mean is 9.3E-06



Statistics:	Forecast values
Trials	100,000
Base Case	5.5E-03
Mean	5.9E-03
Median	5.3E-03
Mode	---
Standard Deviation	2.9E-03
Variance	8.6E-06
Skewness	1.71
Kurtosis	8.47
Coeff. of Variation	0.4939
Minimum	5.8E-04
Maximum	3.6E-02
Range Width	3.5E-02
Mean Std. Error	9.3E-06

Forecast: HI · PFPeA · Adult · Dermal contact with water, total · Deep (cont'd)

Percentiles:	Forecast values
0%	5.8E-04
10%	3.0E-03
20%	3.6E-03
30%	4.2E-03
40%	4.7E-03
50%	5.3E-03
60%	6.0E-03
70%	6.8E-03
80%	7.8E-03
90%	9.6E-03
100%	3.6E-02

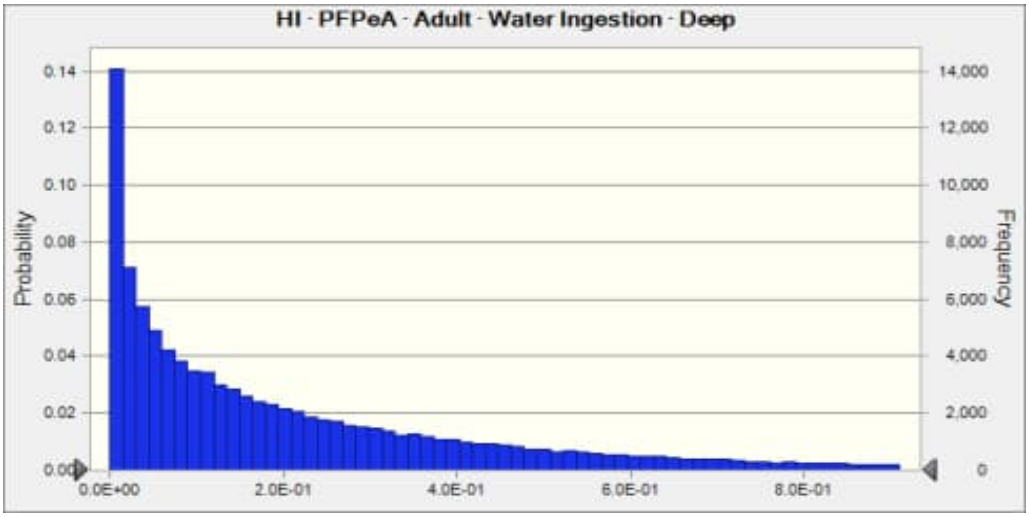
Forecast: HI · PFPeA · Adult · Water Ingestion · Deep

Summary:

Entire range is from 4.2E-10 to 1.8E+00

Base case is 2.1E-01

After 100,000 trials, the std. error of the mean is 7.8E-04



Statistics:	Forecast values
Trials	100,000
Base Case	2.1E-01
Mean	2.2E-01
Median	1.4E-01
Mode	---
Standard Deviation	2.5E-01
Variance	6.0E-02
Skewness	1.68
Kurtosis	6.06
Coeff. of Variation	1.10
Minimum	4.2E-10
Maximum	1.8E+00
Range Width	1.8E+00
Mean Std. Error	7.8E-04

Forecast: HI · PFPeA · Adult · Water Ingestion · Deep (cont'd)

Percentiles:	Forecast values
0%	4.2E-10
10%	8.5E-03
20%	2.7E-02
30%	5.4E-02
40%	9.0E-02
50%	1.4E-01
60%	1.9E-01
70%	2.7E-01
80%	3.8E-01
90%	5.7E-01
100%	1.8E+00

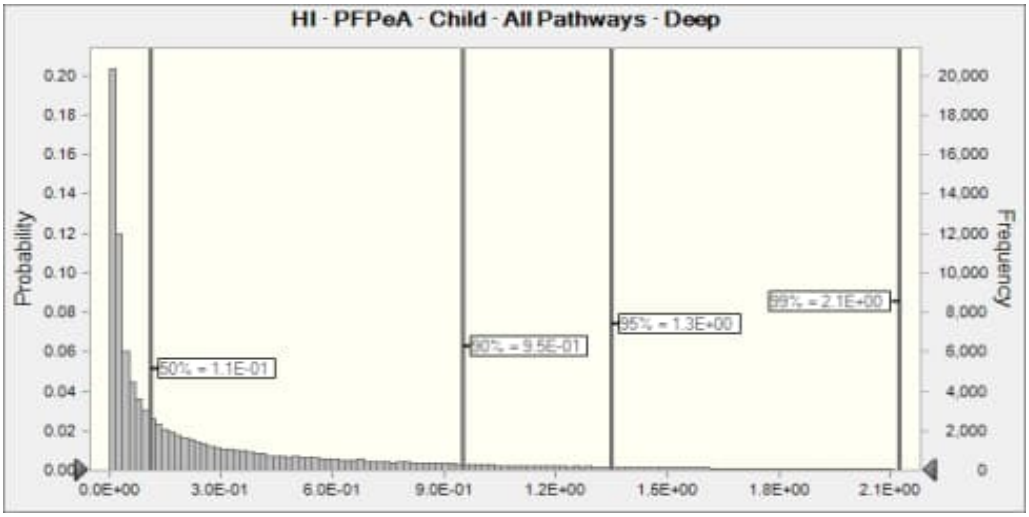
Forecast: HI · PFPeA · Child · All Pathways · Deep

Summary:

Entire range is from 1.9E-03 to 3.5E+00

Base case is 3.1E-01

After 100,000 trials, the std. error of the mean is 1.5E-03



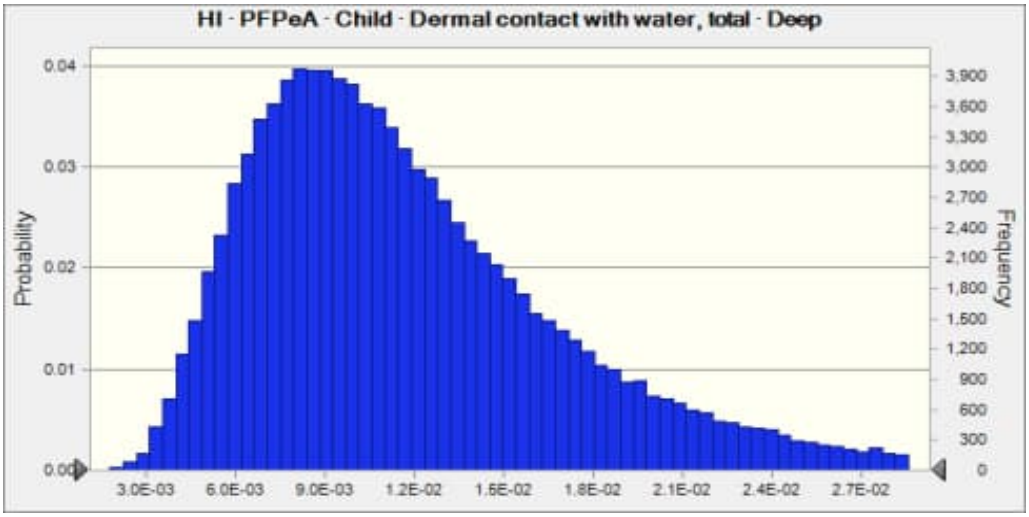
Statistics:	Forecast values
Trials	100,000
Base Case	3.1E-01
Mean	3.2E-01
Median	1.1E-01
Mode	---
Standard Deviation	4.6E-01
Variance	2.2E-01
Skewness	2.25
Kurtosis	8.53
Coeff. of Variation	1.45
Minimum	1.9E-03
Maximum	3.5E+00
Range Width	3.5E+00
Mean Std. Error	1.5E-03

Forecast: HI · PFPeA · Child · All Pathways · Deep (cont'd)

Percentiles:	Forecast values
0%	1.9E-03
10%	1.2E-02
20%	1.9E-02
30%	3.2E-02
40%	6.1E-02
50%	1.1E-01
60%	1.9E-01
70%	3.3E-01
80%	5.5E-01
90%	9.5E-01
100%	3.5E+00

Forecast: HI · PFPeA · Child · Dermal contact with water, total · Deep

Summary:
Entire range is from 1.8E-03 to 8.1E-02
Base case is 1.1E-02
After 100,000 trials, the std. error of the mean is 1.9E-05



Statistics:	Forecast values
Trials	100,000
Base Case	1.1E-02
Mean	1.2E-02
Median	1.1E-02
Mode	---
Standard Deviation	5.9E-03
Variance	3.5E-05
Skewness	1.62
Kurtosis	7.85
Coeff. of Variation	0.4916
Minimum	1.8E-03
Maximum	8.1E-02
Range Width	8.0E-02
Mean Std. Error	1.9E-05

Forecast: HI · PFPeA · Child · Dermal contact with water, total · Deep (cont'd)

Percentiles:	Forecast values
0%	1.8E-03
10%	6.0E-03
20%	7.3E-03
30%	8.5E-03
40%	9.6E-03
50%	1.1E-02
60%	1.2E-02
70%	1.4E-02
80%	1.6E-02
90%	2.0E-02
100%	8.1E-02

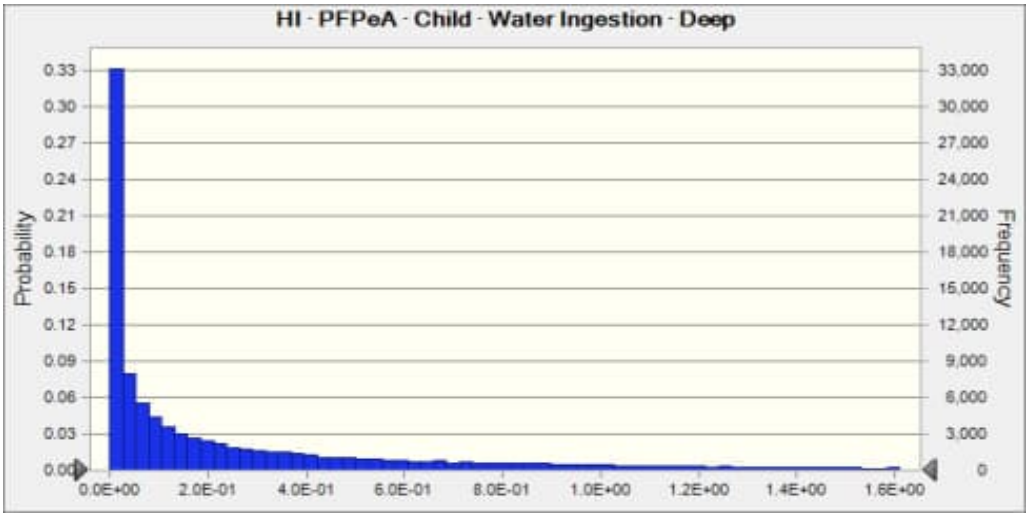
Forecast: HI · PFPeA · Child · Water Ingestion · Deep

Summary:

Entire range is from 5.9E-17 to 3.5E+00

Base case is 3.0E-01

After 100,000 trials, the std. error of the mean is 1.5E-03



Statistics:	Forecast values
Trials	100,000
Base Case	3.0E-01
Mean	3.1E-01
Median	9.9E-02
Mode	---
Standard Deviation	4.6E-01
Variance	2.2E-01
Skewness	2.25
Kurtosis	8.53
Coeff. of Variation	1.50
Minimum	5.9E-17
Maximum	3.5E+00
Range Width	3.5E+00
Mean Std. Error	1.5E-03

Forecast: HI · PFPeA · Child · Water Ingestion · Deep (cont'd)

Percentiles:	Forecast values
0%	5.9E-17
10%	6.3E-04
20%	5.4E-03
30%	1.9E-02
40%	4.9E-02
50%	9.9E-02
60%	1.8E-01
70%	3.2E-01
80%	5.4E-01
90%	9.4E-01
100%	3.5E+00

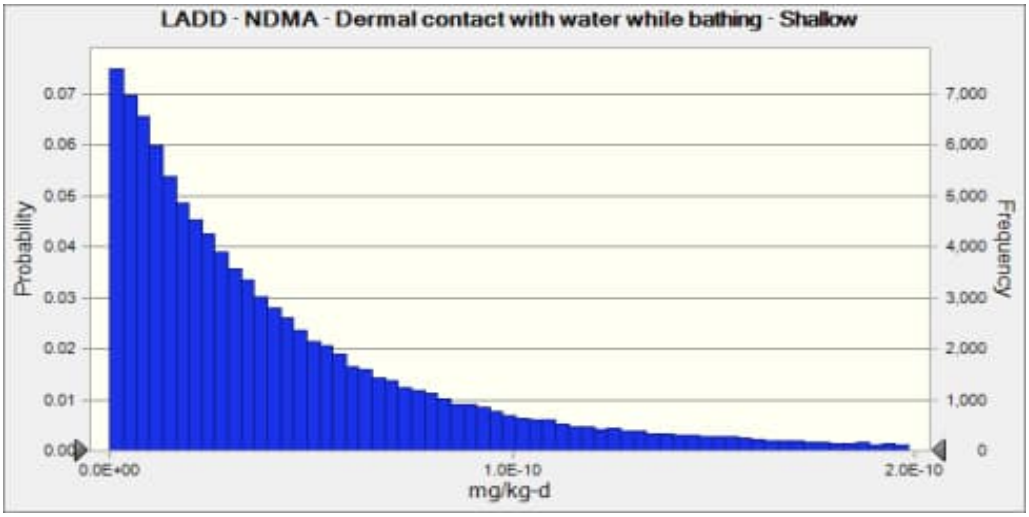
Forecast: LADD · NDMA · Dermal contact with water while bathing · Shallow

Summary:

Entire range is from 6.7E-18 to 1.2E-09

Base case is 4.3E-11

After 100,000 trials, the std. error of the mean is 1.7E-13



Statistics:	Forecast values
Trials	100,000
Base Case	4.3E-11
Mean	4.7E-11
Median	2.9E-11
Mode	---
Standard Deviation	5.4E-11
Variance	2.9E-21
Skewness	3.07
Kurtosis	20.78
Coeff. of Variation	1.16
Minimum	6.7E-18
Maximum	1.2E-09
Range Width	1.2E-09
Mean Std. Error	1.7E-13

Forecast: LADD · NDMA · Dermal contact with water while bathing · Shallow (cont'd)

Percentiles:	Forecast values
0%	6.7E-18
10%	4.4E-12
20%	9.2E-12
30%	1.5E-11
40%	2.1E-11
50%	2.9E-11
60%	3.9E-11
70%	5.2E-11
80%	7.2E-11
90%	1.1E-10
100%	1.2E-09

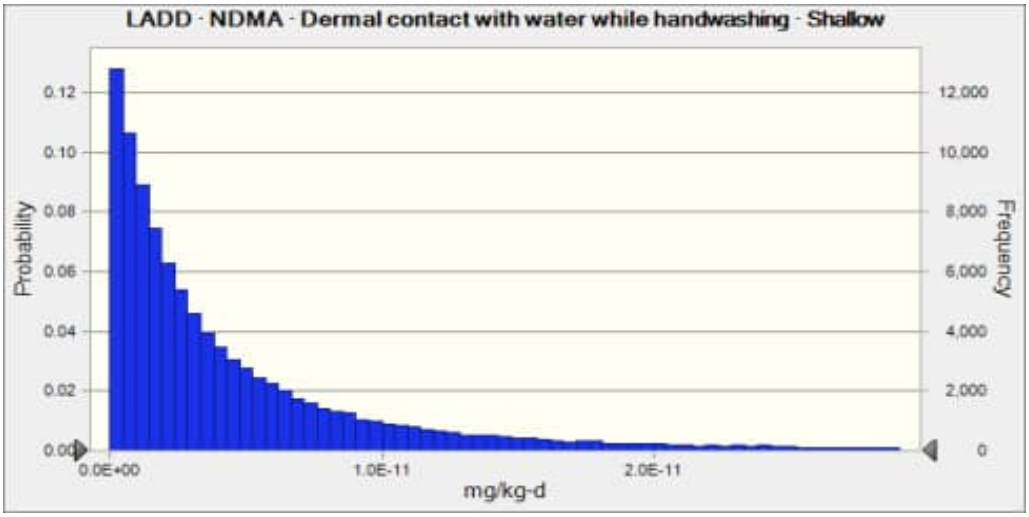
Forecast: LADD · NDMA · Dermal contact with water while handwashing · Shallow

Summary:

Entire range is from 1.0E-18 to 2.9E-10

Base case is 3.5E-12

After 100,000 trials, the std. error of the mean is 2.7E-14



Statistics:	Forecast values
Trials	100,000
Base Case	3.5E-12
Mean	5.4E-12
Median	2.7E-12
Mode	---
Standard Deviation	8.4E-12
Variance	7.1E-23
Skewness	5.81
Kurtosis	78.01
Coeff. of Variation	1.55
Minimum	1.0E-18
Maximum	2.9E-10
Range Width	2.9E-10
Mean Std. Error	2.7E-14

Forecast: LADD · NDMA · Dermal contact with water while handwashing · Shallow (cont'd)

Percentiles:	Forecast values
0%	1.0E-18
10%	3.6E-13
20%	7.9E-13
30%	1.3E-12
40%	1.9E-12
50%	2.7E-12
60%	3.8E-12
70%	5.4E-12
80%	7.9E-12
90%	1.3E-11
100%	2.9E-10

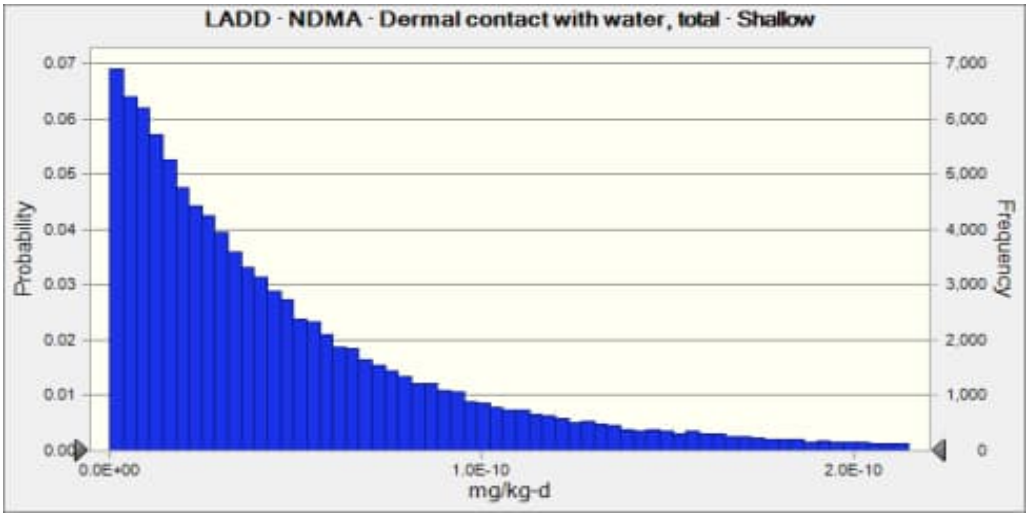
Forecast: LADD · NDMA · Dermal contact with water, total · Shallow

Summary:

Entire range is from 7.7E-18 to 1.3E-09

Base case is 4.7E-11

After 100,000 trials, the std. error of the mean is 1.8E-13



Statistics:	Forecast values
Trials	100,000
Base Case	4.7E-11
Mean	5.2E-11
Median	3.4E-11
Mode	---
Standard Deviation	5.8E-11
Variance	3.4E-21
Skewness	2.87
Kurtosis	18.50
Coeff. of Variation	1.12
Minimum	7.7E-18
Maximum	1.3E-09
Range Width	1.3E-09
Mean Std. Error	1.8E-13

Forecast: LADD · NDMA · Dermal contact with water, total · Shallow (cont'd)

Percentiles:	Forecast values
0%	7.7E-18
10%	5.2E-12
20%	1.1E-11
30%	1.7E-11
40%	2.5E-11
50%	3.4E-11
60%	4.5E-11
70%	5.9E-11
80%	8.1E-11
90%	1.2E-10
100%	1.3E-09

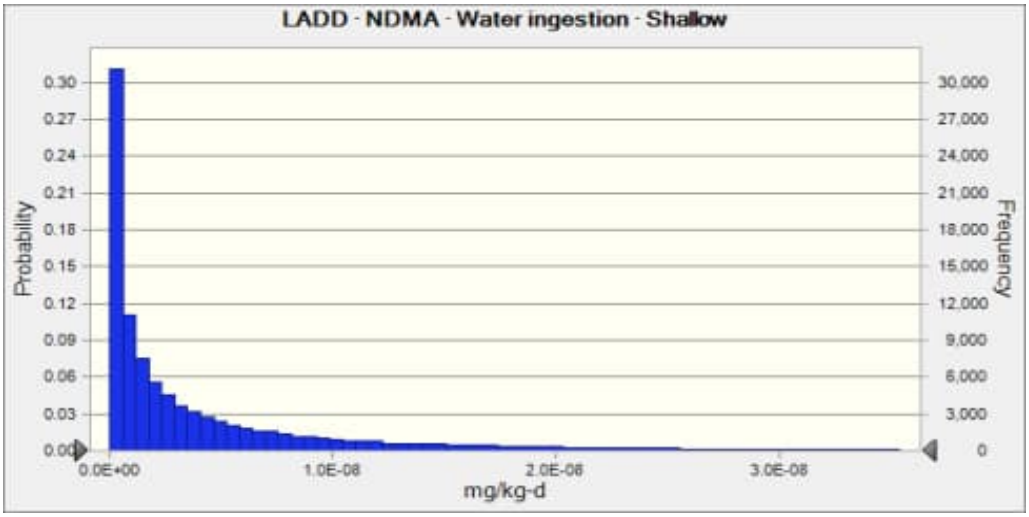
Forecast: LADD · NDMA · Water ingestion · Shallow

Summary:

Entire range is from 1.9E-19 to 1.8E-07

Base case is 5.6E-09

After 100,000 trials, the std. error of the mean is 3.4E-11



Statistics:	Forecast values
Trials	100,000
Base Case	5.6E-09
Mean	5.7E-09
Median	1.8E-09
Mode	---
Standard Deviation	1.1E-08
Variance	1.1E-16
Skewness	4.49
Kurtosis	33.89
Coeff. of Variation	1.87
Minimum	1.9E-19
Maximum	1.8E-07
Range Width	1.8E-07
Mean Std. Error	3.4E-11

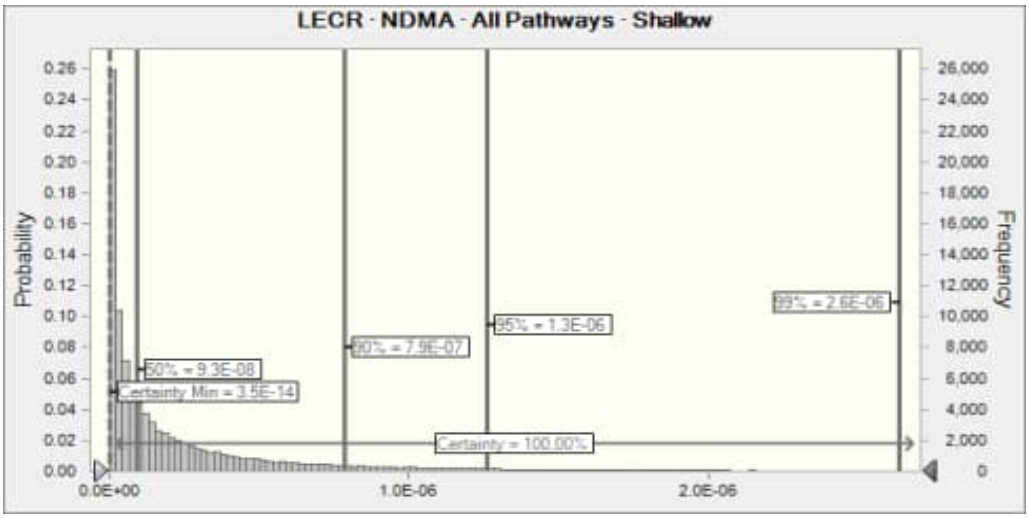
Forecast: LADD · NDMA · Water ingestion · Shallow (cont'd)

Percentiles:	Forecast values
0%	1.9E-19
10%	6.0E-11
20%	2.3E-10
30%	5.3E-10
40%	1.0E-09
50%	1.8E-09
60%	2.9E-09
70%	4.8E-09
80%	8.1E-09
90%	1.5E-08
100%	1.8E-07

Forecast: LECR · NDMA · All Pathways · Shallow

Summary:

Certainty level is 99.999%
Certainty range is from 3.5E-14 to ∞
Entire range is from 1.4E-14 to 8.9E-06
Base case is 2.9E-07
After 100,000 trials, the std. error of the mean is 1.7E-09



Statistics:	Forecast values
Trials	100,000
Base Case	2.9E-07
Mean	2.9E-07
Median	9.3E-08
Mode	---
Standard Deviation	5.4E-07
Variance	2.9E-13
Skewness	4.48
Kurtosis	33.78
Coeff. of Variation	1.86
Minimum	1.4E-14
Maximum	8.9E-06
Range Width	8.9E-06
Mean Std. Error	1.7E-09

Forecast: LECR · NDMA · All Pathways · Shallow (cont'd)

Percentiles:	Forecast values
0%	1.4E-14
10%	4.6E-09
20%	1.4E-08
30%	2.9E-08
40%	5.4E-08
50%	9.3E-08
60%	1.5E-07
70%	2.5E-07
80%	4.1E-07
90%	7.9E-07
100%	8.9E-06

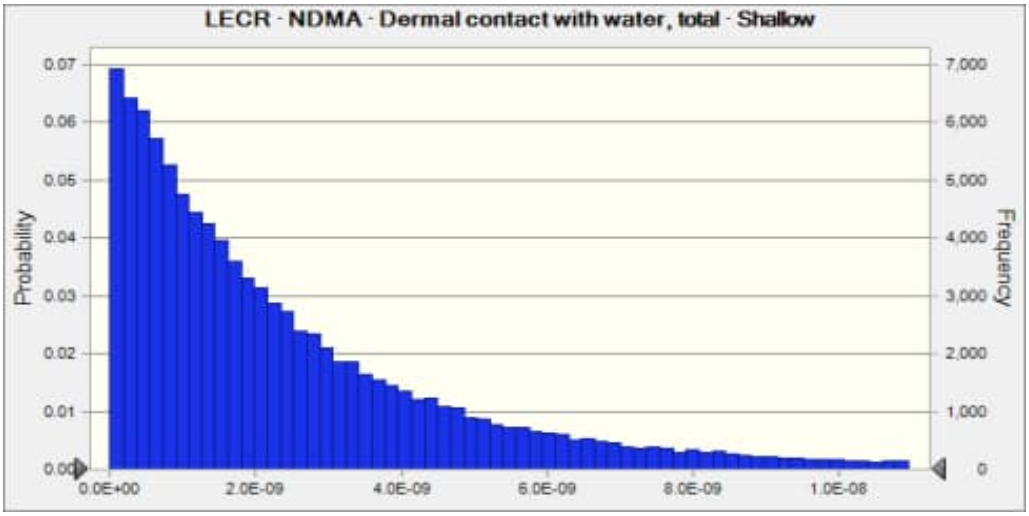
Forecast: LECR · NDMA · Dermal contact with water, total · Shallow

Summary:

Entire range is from 3.9E-16 to 6.4E-08

Base case is 2.4E-09

After 100,000 trials, the std. error of the mean is 9.4E-12



Statistics:	Forecast values
Trials	100,000
Base Case	2.4E-09
Mean	2.6E-09
Median	1.7E-09
Mode	---
Standard Deviation	3.0E-09
Variance	8.8E-18
Skewness	2.87
Kurtosis	18.50
Coeff. of Variation	1.12
Minimum	3.9E-16
Maximum	6.4E-08
Range Width	6.4E-08
Mean Std. Error	9.4E-12

Forecast: LECR · NDMA · Dermal contact with water, total · Shallow (cont'd)

Percentiles:	Forecast values
0%	3.9E-16
10%	2.7E-10
20%	5.5E-10
30%	8.8E-10
40%	1.3E-09
50%	1.7E-09
60%	2.3E-09
70%	3.0E-09
80%	4.1E-09
90%	6.1E-09
100%	6.4E-08

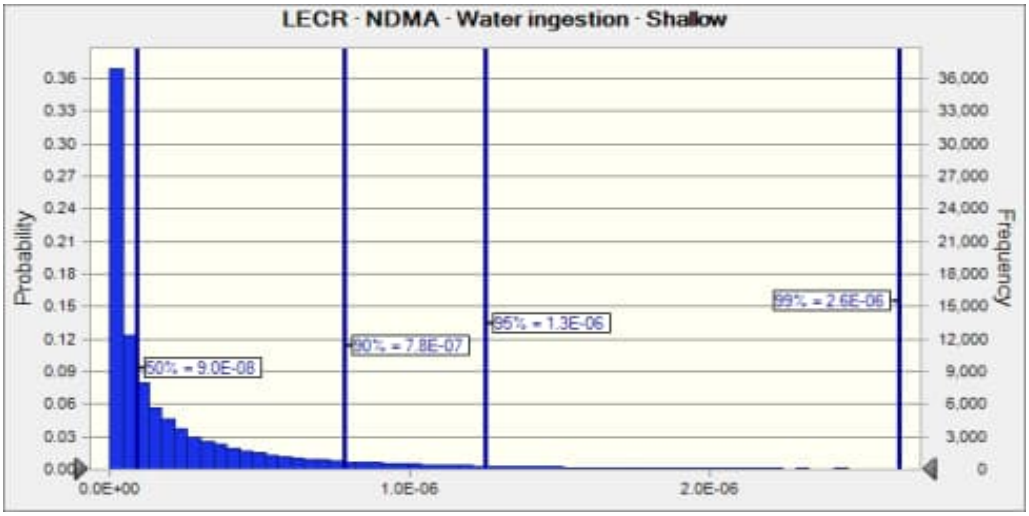
Forecast: LECR · NDMA · Water ingestion · Shallow

Summary:

Entire range is from 9.6E-18 to 8.9E-06

Base case is 2.9E-07

After 100,000 trials, the std. error of the mean is 1.7E-09



Statistics:	Forecast values
Trials	100,000
Base Case	2.9E-07
Mean	2.9E-07
Median	9.0E-08
Mode	---
Standard Deviation	5.4E-07
Variance	2.9E-13
Skewness	4.49
Kurtosis	33.89
Coeff. of Variation	1.87
Minimum	9.6E-18
Maximum	8.9E-06
Range Width	8.9E-06
Mean Std. Error	1.7E-09

Forecast: LECR · NDMA · Water ingestion · Shallow (cont'd)

Percentiles:	Forecast values
0%	9.6E-18
10%	3.0E-09
20%	1.2E-08
30%	2.7E-08
40%	5.2E-08
50%	9.0E-08
60%	1.5E-07
70%	2.4E-07
80%	4.1E-07
90%	7.8E-07
100%	8.9E-06

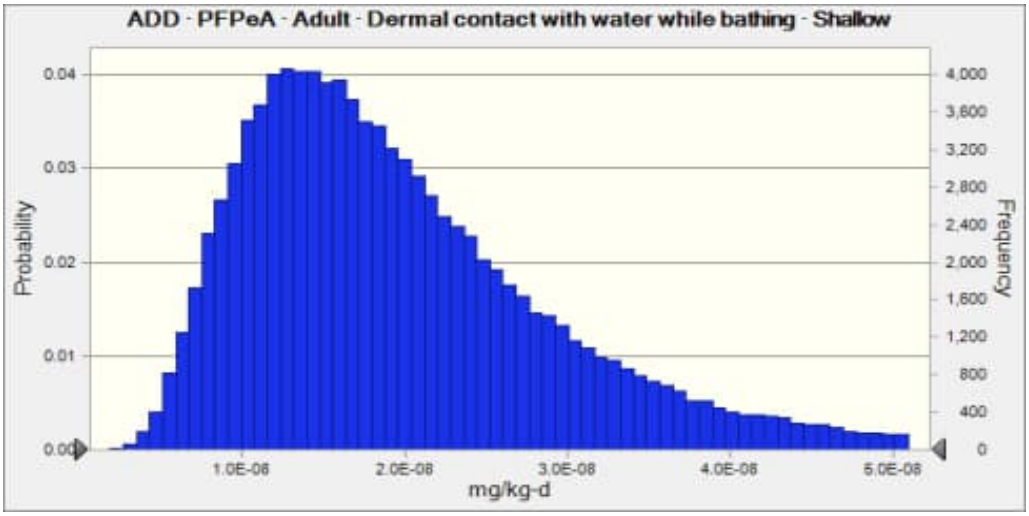
Forecast: ADD · PFPeA · Adult · Dermal contact with water while bathing · Shallow

Summary:

Entire range is from 1.9E-09 to 1.4E-07

Base case is 2.0E-08

After 100,000 trials, the std. error of the mean is 3.5E-11



Statistics:	Forecast values
Trials	100,000
Base Case	2.0E-08
Mean	2.0E-08
Median	1.8E-08
Mode	---
Standard Deviation	1.1E-08
Variance	1.2E-16
Skewness	1.79
Kurtosis	8.93
Coeff. of Variation	0.5436
Minimum	1.9E-09
Maximum	1.4E-07
Range Width	1.4E-07
Mean Std. Error	3.5E-11

Forecast: ADD · PFPeA · Adult · Dermal contact with water while bathing · Shallow (cont'd)

Percentiles:	Forecast values
0%	1.9E-09
10%	9.3E-09
20%	1.2E-08
30%	1.4E-08
40%	1.6E-08
50%	1.8E-08
60%	2.0E-08
70%	2.3E-08
80%	2.7E-08
90%	3.4E-08
100%	1.4E-07

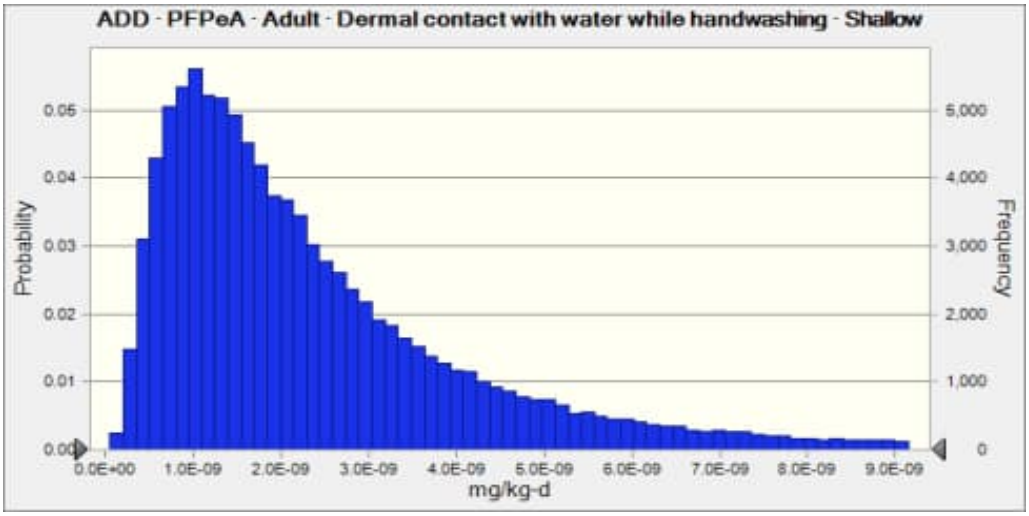
Forecast: ADD · PFPeA · Adult · Dermal contact with water while handwashing · Shallow

Summary:

Entire range is from 4.7E-11 to 5.0E-08

Base case is 1.7E-09

After 100,000 trials, the std. error of the mean is 7.5E-12



Statistics:	Forecast values
Trials	100,000
Base Case	1.7E-09
Mean	2.5E-09
Median	1.9E-09
Mode	---
Standard Deviation	2.4E-09
Variance	5.6E-18
Skewness	3.32
Kurtosis	24.95
Coeff. of Variation	0.9243
Minimum	4.7E-11
Maximum	5.0E-08
Range Width	5.0E-08
Mean Std. Error	7.5E-12

Forecast: ADD · PFPeA · Adult · Dermal contact with water while handwashing · Shallow (cont'd)

Percentiles:	Forecast values
0%	4.7E-11
10%	6.7E-10
20%	9.5E-10
30%	1.2E-09
40%	1.5E-09
50%	1.9E-09
60%	2.3E-09
70%	2.8E-09
80%	3.6E-09
90%	5.1E-09
100%	5.0E-08

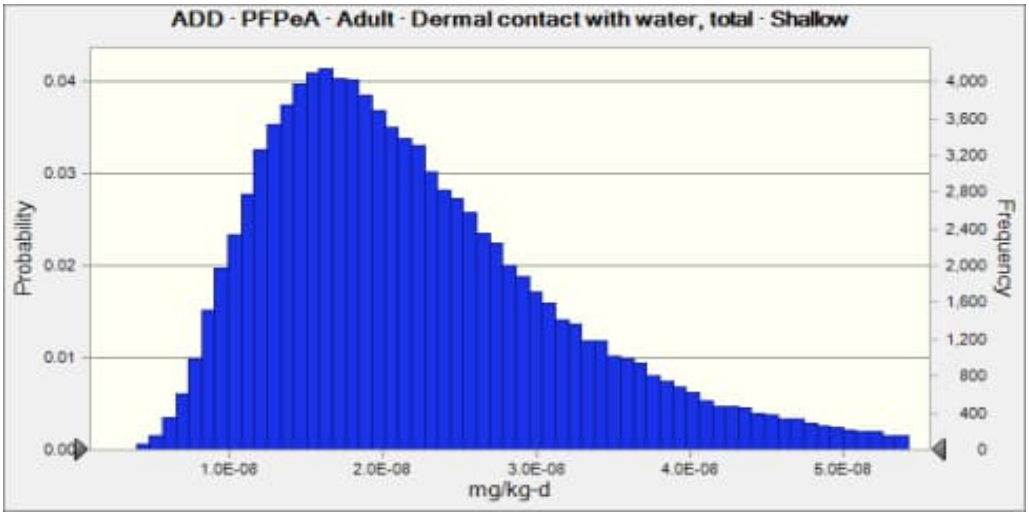
Forecast: ADD · PFPeA · Adult · Dermal contact with water, total · Shallow

Summary:

Entire range is from 2.2E-09 to 1.4E-07

Base case is 2.1E-08

After 100,000 trials, the std. error of the mean is 3.6E-11



Statistics:	Forecast values
Trials	100,000
Base Case	2.1E-08
Mean	2.3E-08
Median	2.0E-08
Mode	---
Standard Deviation	1.1E-08
Variance	1.3E-16
Skewness	1.71
Kurtosis	8.47
Coeff. of Variation	0.4939
Minimum	2.2E-09
Maximum	1.4E-07
Range Width	1.4E-07
Mean Std. Error	3.6E-11

Forecast: ADD · PFPeA · Adult · Dermal contact with water, total · Shallow (cont'd)

Percentiles:	Forecast values
0%	2.2E-09
10%	1.1E-08
20%	1.4E-08
30%	1.6E-08
40%	1.8E-08
50%	2.0E-08
60%	2.3E-08
70%	2.6E-08
80%	3.0E-08
90%	3.7E-08
100%	1.4E-07

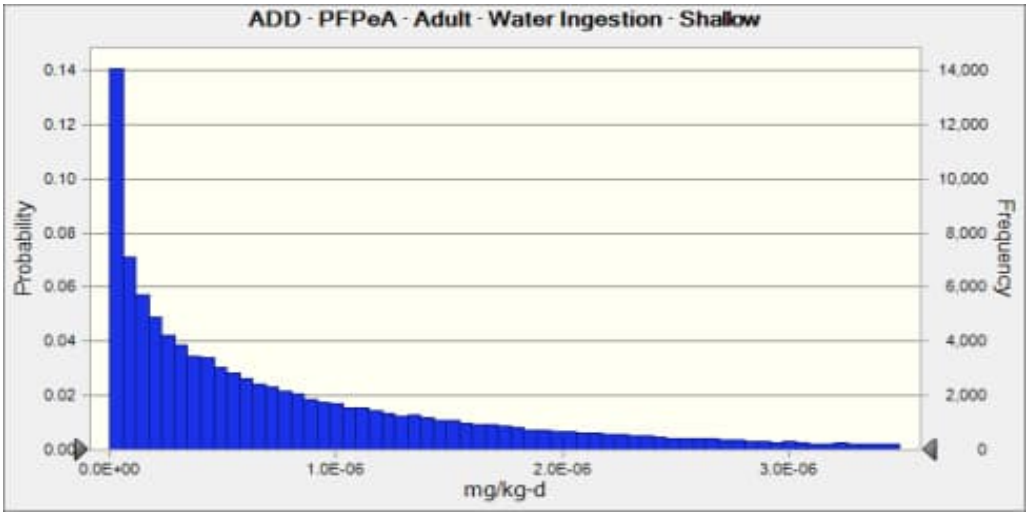
Forecast: ADD · PFPeA · Adult · Water Ingestion · Shallow

Summary:

Entire range is from 1.6E-15 to 6.9E-06

Base case is 8.2E-07

After 100,000 trials, the std. error of the mean is 3.0E-09



Statistics:	Forecast values
Trials	100,000
Base Case	8.2E-07
Mean	8.5E-07
Median	5.2E-07
Mode	---
Standard Deviation	9.4E-07
Variance	8.9E-13
Skewness	1.68
Kurtosis	6.06
Coeff. of Variation	1.10
Minimum	1.6E-15
Maximum	6.9E-06
Range Width	6.9E-06
Mean Std. Error	3.0E-09

Forecast: ADD · PFPeA · Adult · Water Ingestion · Shallow (cont'd)

Percentiles:	Forecast values
0%	1.6E-15
10%	3.2E-08
20%	1.0E-07
30%	2.1E-07
40%	3.5E-07
50%	5.2E-07
60%	7.5E-07
70%	1.0E-06
80%	1.5E-06
90%	2.2E-06
100%	6.9E-06

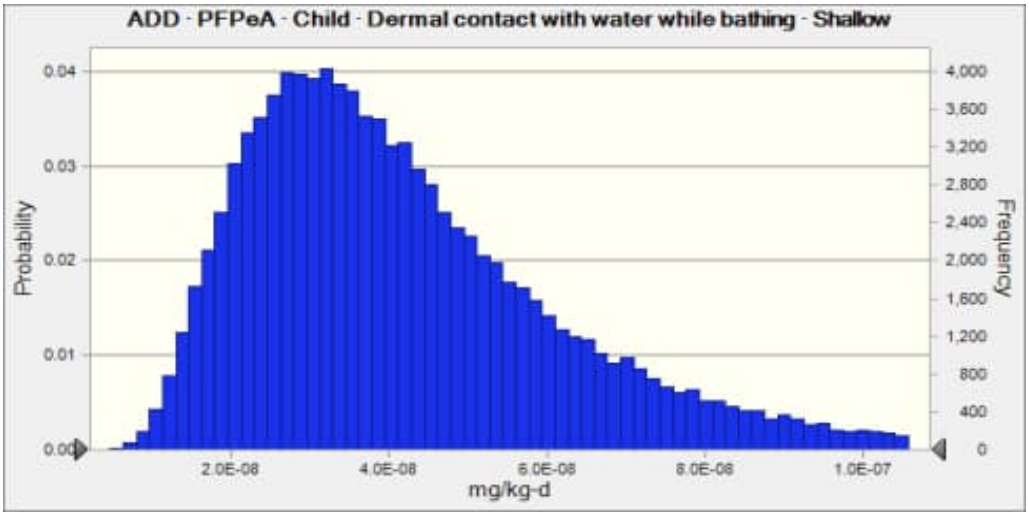
Forecast: ADD · PFPeA · Child · Dermal contact with water while bathing · Shallow

Summary:

Entire range is from 4.6E-09 to 3.1E-07

Base case is 4.2E-08

After 100,000 trials, the std. error of the mean is 7.1E-11



Statistics:	Forecast values
Trials	100,000
Base Case	4.2E-08
Mean	4.3E-08
Median	3.8E-08
Mode	---
Standard Deviation	2.2E-08
Variance	5.1E-16
Skewness	1.65
Kurtosis	8.02
Coeff. of Variation	0.5252
Minimum	4.6E-09
Maximum	3.1E-07
Range Width	3.0E-07
Mean Std. Error	7.1E-11

Forecast: ADD · PFPeA · Child · Dermal contact with water while bathing · Shallow (cont'd)

Percentiles:	Forecast values
0%	4.6E-09
10%	2.0E-08
20%	2.5E-08
30%	2.9E-08
40%	3.3E-08
50%	3.8E-08
60%	4.3E-08
70%	4.9E-08
80%	5.8E-08
90%	7.2E-08
100%	3.1E-07

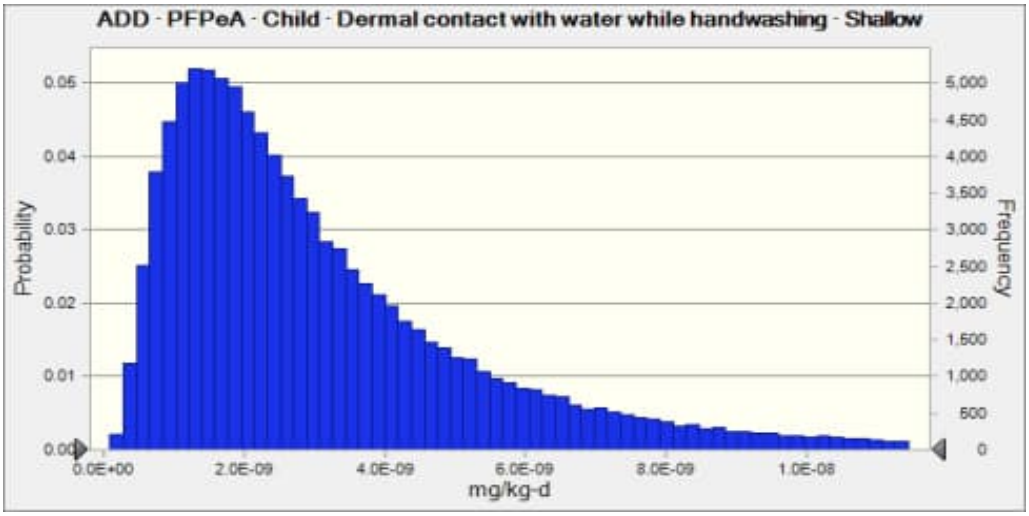
Forecast: ADD · PFPeA · Child · Dermal contact with water while handwashing · Shallow

Summary:

Entire range is from 8.9E-11 to 7.5E-08

Base case is 2.2E-09

After 100,000 trials, the std. error of the mean is 9.2E-12



Statistics:	Forecast values
Trials	100,000
Base Case	2.2E-09
Mean	3.3E-09
Median	2.5E-09
Mode	---
Standard Deviation	2.9E-09
Variance	8.4E-18
Skewness	3.22
Kurtosis	26.06
Coeff. of Variation	0.8769
Minimum	8.9E-11
Maximum	7.5E-08
Range Width	7.5E-08
Mean Std. Error	9.2E-12

Forecast: ADD · PFPeA · Child · Dermal contact with water while handwashing · Shallow (cont'd)

Percentiles:	Forecast values
0%	8.9E-11
10%	9.3E-10
20%	1.3E-09
30%	1.7E-09
40%	2.0E-09
50%	2.5E-09
60%	3.0E-09
70%	3.7E-09
80%	4.7E-09
90%	6.6E-09
100%	7.5E-08

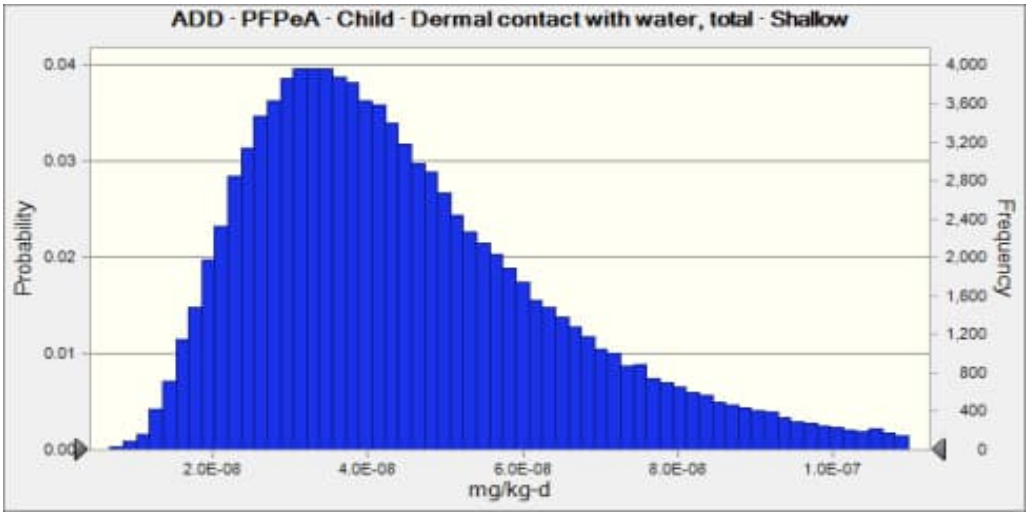
Forecast: ADD · PFPeA · Child · Dermal contact with water, total · Shallow

Summary:

Entire range is from 6.8E-09 to 3.1E-07

Base case is 4.4E-08

After 100,000 trials, the std. error of the mean is 7.2E-11



Statistics:	Forecast values
Trials	100,000
Base Case	4.4E-08
Mean	4.6E-08
Median	4.1E-08
Mode	---
Standard Deviation	2.3E-08
Variance	5.1E-16
Skewness	1.62
Kurtosis	7.85
Coeff. of Variation	0.4916
Minimum	6.8E-09
Maximum	3.1E-07
Range Width	3.1E-07
Mean Std. Error	7.2E-11

Forecast: ADD · PFPeA · Child · Dermal contact with water, total · Shallow (cont'd)

Percentiles:	Forecast values
0%	6.8E-09
10%	2.3E-08
20%	2.8E-08
30%	3.2E-08
40%	3.7E-08
50%	4.1E-08
60%	4.6E-08
70%	5.3E-08
80%	6.1E-08
90%	7.5E-08
100%	3.1E-07

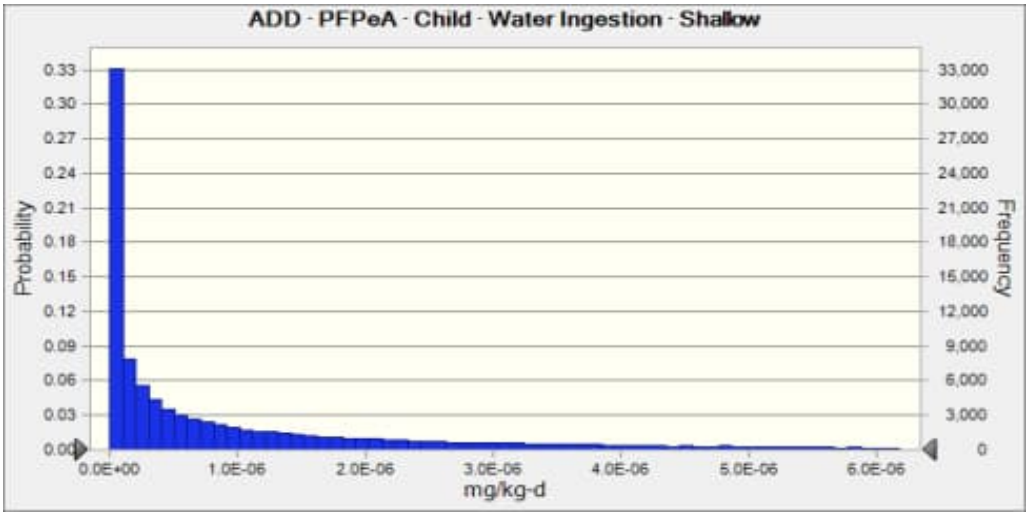
Forecast: ADD · PFPeA · Child · Water Ingestion · Shallow

Summary:

Entire range is from 2.3E-22 to 1.3E-05

Base case is 1.2E-06

After 100,000 trials, the std. error of the mean is 5.6E-09



Statistics:	Forecast values
Trials	100,000
Base Case	1.2E-06
Mean	1.2E-06
Median	3.8E-07
Mode	---
Standard Deviation	1.8E-06
Variance	3.2E-12
Skewness	2.25
Kurtosis	8.53
Coeff. of Variation	1.50
Minimum	2.3E-22
Maximum	1.3E-05
Range Width	1.3E-05
Mean Std. Error	5.6E-09

Forecast: ADD · PFPeA · Child · Water Ingestion · Shallow (cont'd)

Percentiles:	Forecast values
0%	2.3E-22
10%	2.4E-09
20%	2.1E-08
30%	7.4E-08
40%	1.9E-07
50%	3.8E-07
60%	7.0E-07
70%	1.2E-06
80%	2.1E-06
90%	3.6E-06
100%	1.3E-05

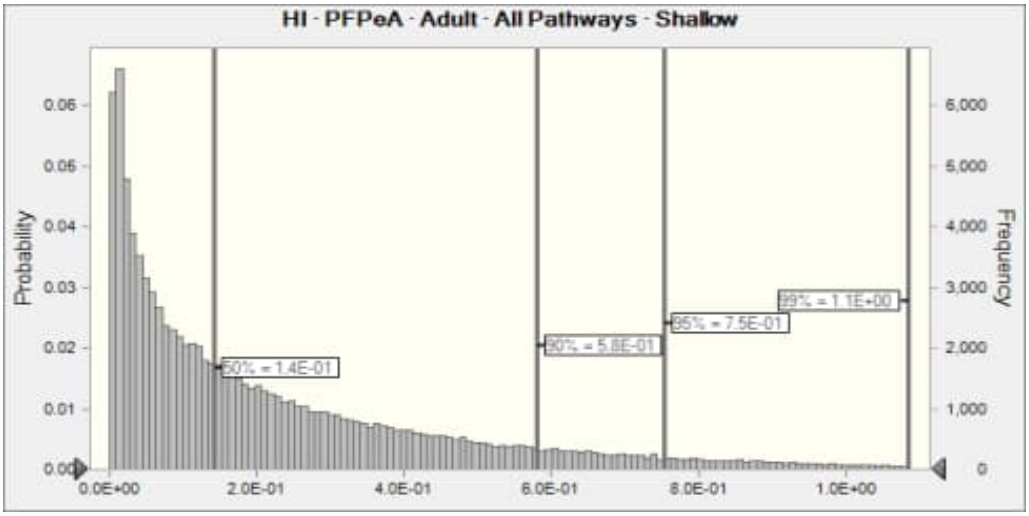
Forecast: HI · PFPeA · Adult · All Pathways · Shallow

Summary:

Entire range is from 1.2E-03 to 1.8E+00

Base case is 2.2E-01

After 100,000 trials, the std. error of the mean is 7.8E-04



Statistics:	Forecast values
Trials	100,000
Base Case	2.2E-01
Mean	2.3E-01
Median	1.4E-01
Mode	---
Standard Deviation	2.5E-01
Variance	6.1E-02
Skewness	1.68
Kurtosis	6.06
Coeff. of Variation	1.07
Minimum	1.2E-03
Maximum	1.8E+00
Range Width	1.8E+00
Mean Std. Error	7.8E-04

Forecast: HI · PFPeA · Adult · All Pathways · Shallow (cont'd)

Percentiles:	Forecast values
0%	1.2E-03
10%	1.5E-02
20%	3.3E-02
30%	6.1E-02
40%	9.7E-02
50%	1.4E-01
60%	2.0E-01
70%	2.8E-01
80%	3.9E-01
90%	5.8E-01
100%	1.8E+00

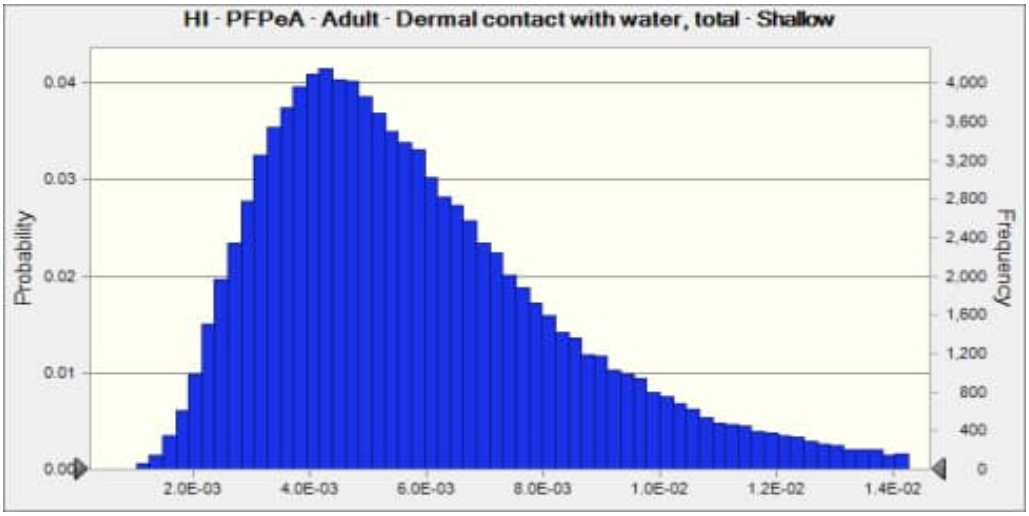
Forecast: HI · PFPeA · Adult · Dermal contact with water, total · Shallow

Summary:

Entire range is from 5.9E-04 to 3.6E-02

Base case is 5.6E-03

After 100,000 trials, the std. error of the mean is 9.3E-06



Statistics:	Forecast values
Trials	100,000
Base Case	5.6E-03
Mean	6.0E-03
Median	5.4E-03
Mode	---
Standard Deviation	3.0E-03
Variance	8.7E-06
Skewness	1.71
Kurtosis	8.47
Coeff. of Variation	0.4939
Minimum	5.9E-04
Maximum	3.6E-02
Range Width	3.6E-02
Mean Std. Error	9.3E-06

Forecast: HI · PFPeA · Adult · Dermal contact with water, total · Shallow (cont'd)

Percentiles:	Forecast values
0%	5.9E-04
10%	3.0E-03
20%	3.6E-03
30%	4.2E-03
40%	4.8E-03
50%	5.4E-03
60%	6.0E-03
70%	6.8E-03
80%	7.9E-03
90%	9.7E-03
100%	3.6E-02

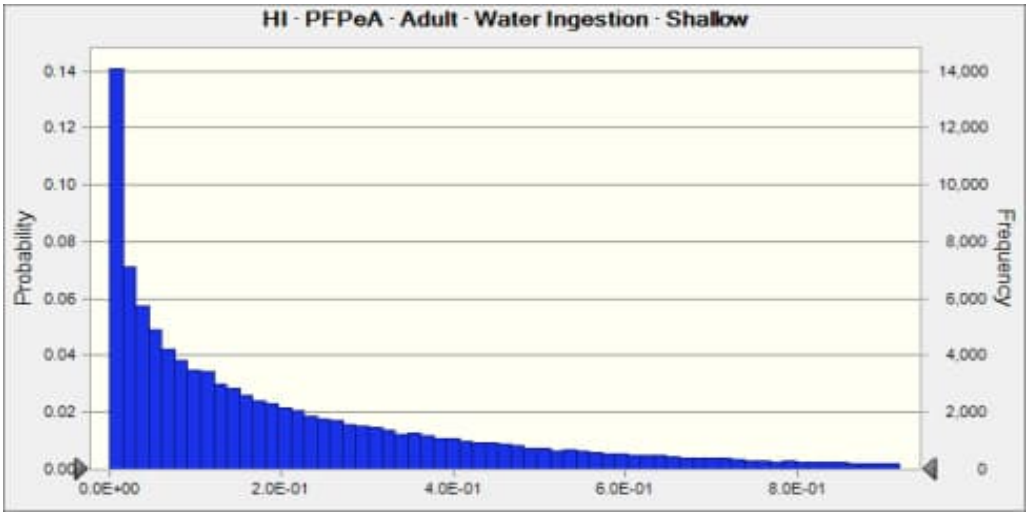
Forecast: HI · PFPeA · Adult · Water Ingestion · Shallow

Summary:

Entire range is from 4.2E-10 to 1.8E+00

Base case is 2.2E-01

After 100,000 trials, the std. error of the mean is 7.8E-04



Statistics:	Forecast values
Trials	100,000
Base Case	2.2E-01
Mean	2.2E-01
Median	1.4E-01
Mode	---
Standard Deviation	2.5E-01
Variance	6.1E-02
Skewness	1.68
Kurtosis	6.06
Coeff. of Variation	1.10
Minimum	4.2E-10
Maximum	1.8E+00
Range Width	1.8E+00
Mean Std. Error	7.8E-04

Forecast: HI · PFPeA · Adult · Water Ingestion · Shallow (cont'd)

Percentiles:	Forecast values
0%	4.2E-10
10%	8.5E-03
20%	2.7E-02
30%	5.5E-02
40%	9.1E-02
50%	1.4E-01
60%	2.0E-01
70%	2.8E-01
80%	3.9E-01
90%	5.8E-01
100%	1.8E+00

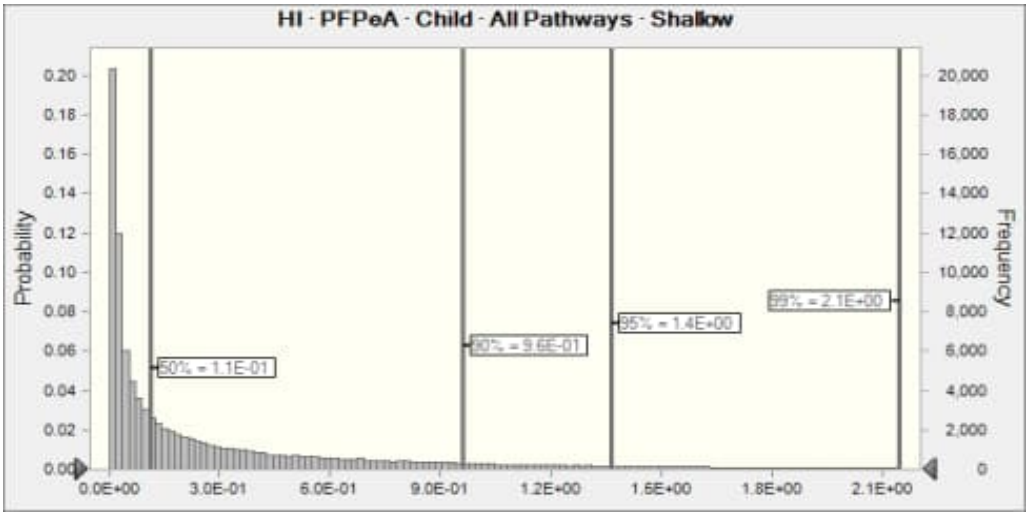
Forecast: HI · PFPeA · Child · All Pathways · Shallow

Summary:

Entire range is from 1.9E-03 to 3.5E+00

Base case is 3.2E-01

After 100,000 trials, the std. error of the mean is 1.5E-03



Statistics:	Forecast values
Trials	100,000
Base Case	3.2E-01
Mean	3.2E-01
Median	1.1E-01
Mode	---
Standard Deviation	4.7E-01
Variance	2.2E-01
Skewness	2.25
Kurtosis	8.53
Coeff. of Variation	1.45
Minimum	1.9E-03
Maximum	3.5E+00
Range Width	3.5E+00
Mean Std. Error	1.5E-03

Forecast: HI · PFPeA · Child · All Pathways · Shallow (cont'd)

Percentiles:	Forecast values
0%	1.9E-03
10%	1.2E-02
20%	1.9E-02
30%	3.3E-02
40%	6.1E-02
50%	1.1E-01
60%	2.0E-01
70%	3.3E-01
80%	5.5E-01
90%	9.6E-01
100%	3.5E+00

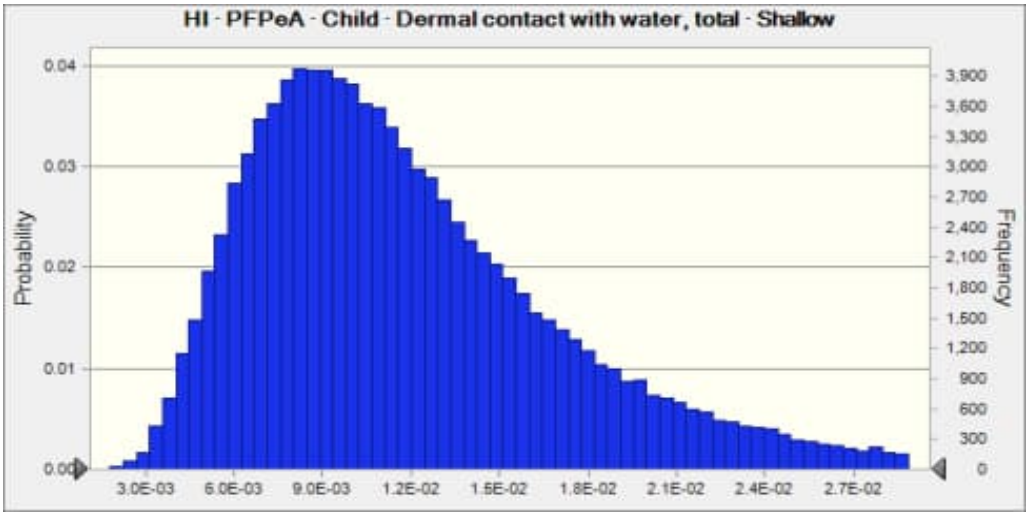
Forecast: HI · PFPeA · Child · Dermal contact with water, total · Shallow

Summary:

Entire range is from 1.8E-03 to 8.2E-02

Base case is 1.2E-02

After 100,000 trials, the std. error of the mean is 1.9E-05



Statistics:	Forecast values
Trials	100,000
Base Case	1.2E-02
Mean	1.2E-02
Median	1.1E-02
Mode	---
Standard Deviation	6.0E-03
Variance	3.6E-05
Skewness	1.62
Kurtosis	7.85
Coeff. of Variation	0.4916
Minimum	1.8E-03
Maximum	8.2E-02
Range Width	8.0E-02
Mean Std. Error	1.9E-05

Forecast: HI · PFPeA · Child · Dermal contact with water, total · Shallow (cont'd)

Percentiles:	Forecast values
0%	1.8E-03
10%	6.1E-03
20%	7.4E-03
30%	8.5E-03
40%	9.7E-03
50%	1.1E-02
60%	1.2E-02
70%	1.4E-02
80%	1.6E-02
90%	2.0E-02
100%	8.2E-02

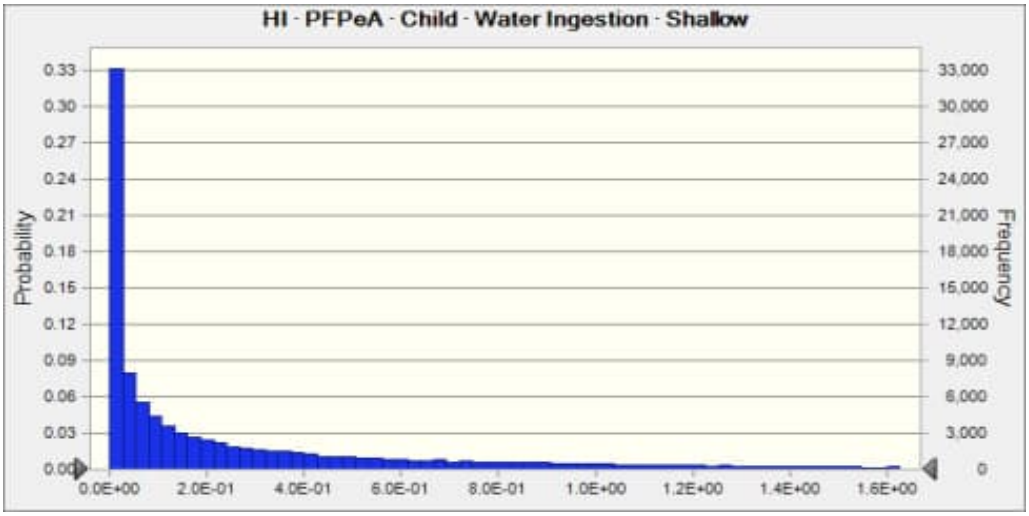
Forecast: HI · PFPeA · Child · Water Ingestion · Shallow

Summary:

Entire range is from 6.0E-17 to 3.5E+00

Base case is 3.1E-01

After 100,000 trials, the std. error of the mean is 1.5E-03



Statistics:	Forecast values
Trials	100,000
Base Case	3.1E-01
Mean	3.1E-01
Median	1.0E-01
Mode	---
Standard Deviation	4.7E-01
Variance	2.2E-01
Skewness	2.25
Kurtosis	8.53
Coeff. of Variation	1.50
Minimum	6.0E-17
Maximum	3.5E+00
Range Width	3.5E+00
Mean Std. Error	1.5E-03

Forecast: HI · PFPeA · Child · Water Ingestion · Shallow (cont'd)

Percentiles:	Forecast values
0%	6.0E-17
10%	6.3E-04
20%	5.5E-03
30%	2.0E-02
40%	4.9E-02
50%	1.0E-01
60%	1.8E-01
70%	3.2E-01
80%	5.4E-01
90%	9.5E-01
100%	3.5E+00

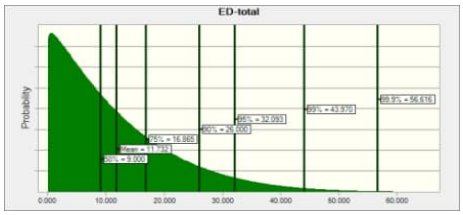
End of Forecasts

Assumptions

Assumption: ED-total

Beta distribution with parameters:

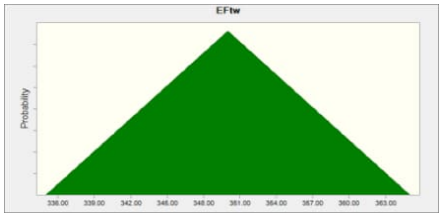
Minimum	0.000
Maximum	87.000
50%	9.000
90%	26.000



Assumption: EFtw

Triangular distribution with parameters:

Minimum	335.00
Likeliest	350.00
Maximum	365.00

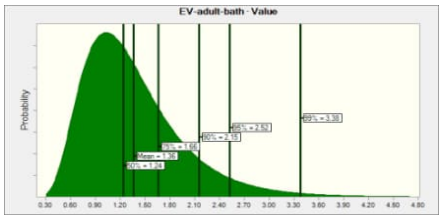


Assumption: EV-adult-bath · Value

Lognormal distribution with parameters:

Location	0.00
Mean	1.36
Std. Dev.	0.62

Selected range is from 0.00 to ∞

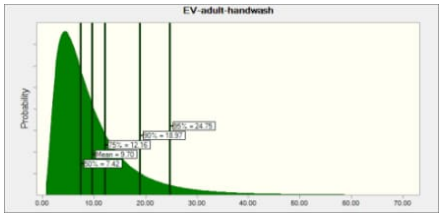


Assumption: EV-adult-handwash

Lognormal distribution with parameters:

Location	0.00
Mean	9.70
Std. Dev.	8.17

Selected range is from 0.00 to ∞

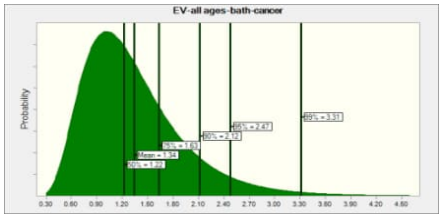


Assumption: EV-all ages-bath-cancer

Lognormal distribution with parameters:

Location	0.00
Mean	1.34
Std. Dev.	0.60

Selected range is from 0.00 to ∞

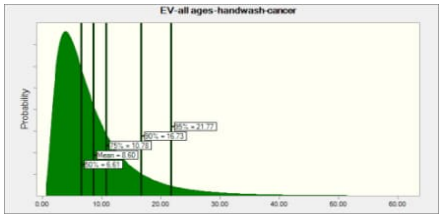


Assumption: EV-all ages-handwash-cancer

Lognormal distribution with parameters:

Location	0.00
Mean	8.60
Std. Dev.	7.14

Selected range is from 0.00 to ∞

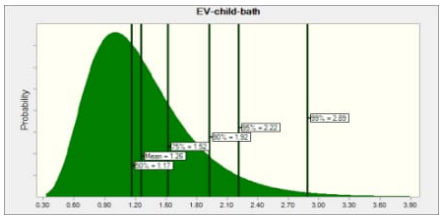


Assumption: EV-child-bath

Lognormal distribution with parameters:

Location	0.00
Mean	1.26
Std. Dev.	0.51

Selected range is from 0.00 to ∞

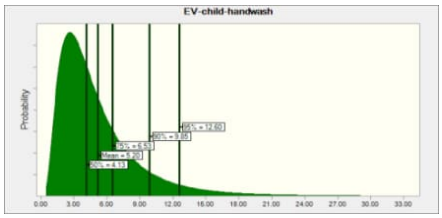


Assumption: EV-child-handwash

Lognormal distribution with parameters:

Location	0.00
Mean	5.20
Std. Dev.	3.97

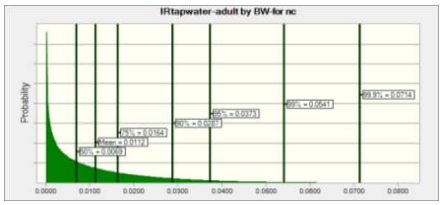
Selected range is from 0.00 to ∞



Assumption: IRtapwater-adult by BW-for nc

Beta distribution with parameters:

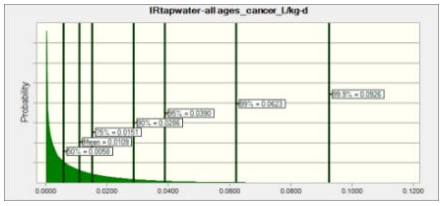
Minimum	0.0000
Maximum	0.1032
50%	0.0069
90%	0.0287



Assumption: IRtapwater-all ages_cancer_L/kg-d

Beta distribution with parameters:

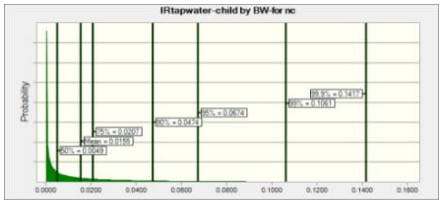
Minimum	0.0000
Maximum	0.2675
50%	0.0058
90%	0.0286



Assumption: IRtapwater-child by BW-for nc

Beta distribution with parameters:

Minimum	0.0000
Maximum	0.1818
50%	0.0049
90%	0.0474

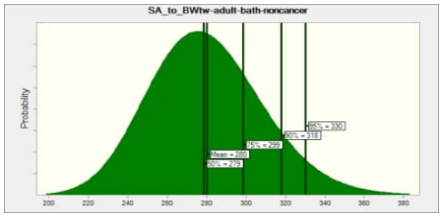


Assumption: SA_to_BWtw-adult-bath-noncancer

Lognormal distribution with parameters:

Location	0
Mean	280
95%	330

Selected range is from 0 to ∞

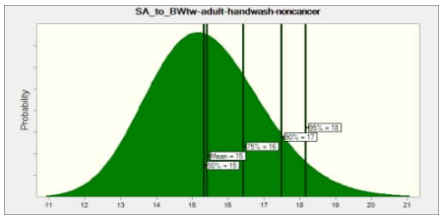


Assumption: SA_to_BWtw-adult-handwash-noncancer

Lognormal distribution with parameters:

Location	0
Mean	15
95%	18

Selected range is from 0 to ∞

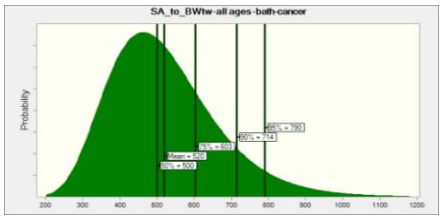


Assumption: SA_to_BWtw-all ages-bath-cancer

Lognormal distribution with parameters:

Location	0
50%	500
95%	790

Selected range is from 0 to ∞

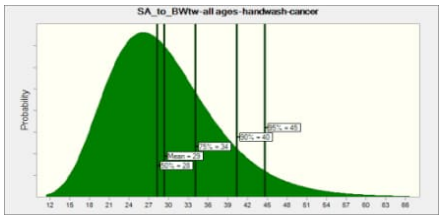


Assumption: SA_to_BWtw-all ages-handwash-cancer

Lognormal distribution with parameters:

Location	0
50%	28
95%	45

Selected range is from 0 to ∞

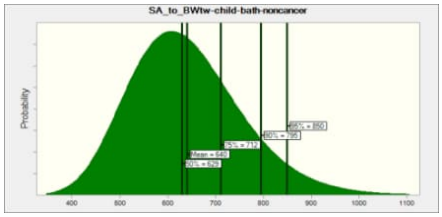


Assumption: SA_to_BWtw-child-bath-noncancer

Lognormal distribution with parameters:

Location	0
Mean	640
95%	850

Selected range is from 0 to ∞

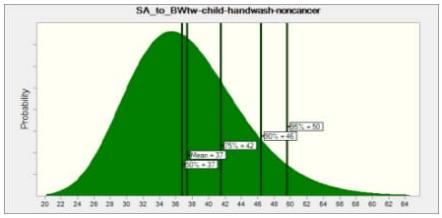


Assumption: SA_to_BWtw-child-handwash-noncancer

Lognormal distribution with parameters:

Location	0
Mean	37
95%	50

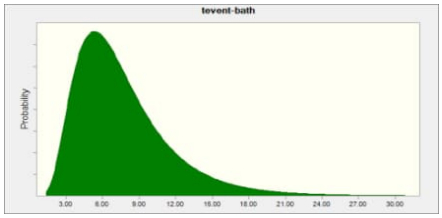
Selected range is from 0 to ∞



Assumption: tevent-bath

Lognormal distribution with parameters:

Location	0.00
Geo. Mean	6.80
Geo. Std. Dev.	1.64

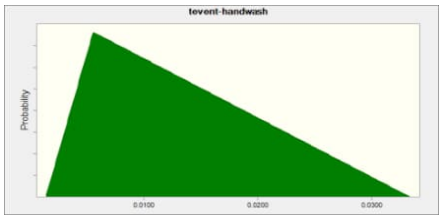


Assumption: tevent-handwash

Triangular distribution with parameters:

Minimum	0.0014
Likeliest	0.0056
Maximum	0.0333

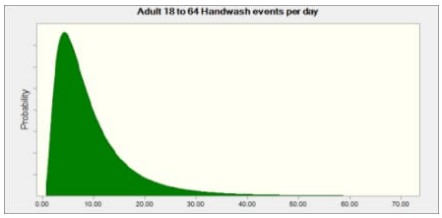
Selected range is from 0.0000 to ∞



Assumption: Adult 18 to 64 Handwash events per day

Lognormal distribution with parameters:

Location	0.00
Mean	9.64
90%	18.89



Assumption: Child 0 to <6 Handwash events per day

Lognormal distribution with parameters:

Location	0.00
Mean	5.23
90%	10.06