Northwest Pulp & Paper
ASSOCIATION

February 4, 2014

Kelly Susewind
Special Assistant for Water Quality
Department of Ecology
State of Washington
P.O. Box 47600
Olympia, WA 98504-7600

Dear Mr. Susewind:

On behalf of the members of the Northwest Pulp & Paper Association (NWPPA), we would like to propose for the Department of Ecology's consideration an alternative method for calculating surface water quality criteria.

This proposal is based on the best available science and guidance provided by the U.S. Environmental Protection Agency that is representative of both the general and tribal populations of Washington State. It utilizes total fish consumption rates as high as 291 grams per day at the 99th percentile of the tribal population, which is derived from Ecology's Fish Consumption Technical Support Document Version 2.0.

As you know, NWPPA and our members remain committed to working with the Department of Ecology, local governments, ports, businesses, tribes and sports fishermen to update Washington's surface water quality standards.

To help the Department identify balanced, effective and attainable standards, NWPPA commissioned a report by ARCADIS, an international company providing consultancy, design, engineering and management services in infrastructure, water, environment and buildings.

The task presented to ARCADIS was to identify water quality standards that protect all segments of the population at levels consistent with EPA guidelines.

The results of that report are submitted herein.

You will note that the ARCADIS report utilizes the probabilistic method to assess environmental risks, a method the Department has utilized elsewhere in the state. Also known as refined risk assessment, this approach is acknowledged to provide the most complete and accurate analysis of environmental risks.

Northwest Pulp & Paper Association • 212 Union Avenue SE, Suite 103 • Olympia, WA 98501-1302 • 360.529.8638 • Fax 360.529.8645
www.nwppa.net

As the EPA notes in its Technical Overview of Ecological Risk Assessment, *"Because the results of the refined risk assessment show the range of possible environmental impacts and which ones are most likely to occur, they provide a better basis for decision-making."* http://www.epa.gov/oppefed1/ecorisk_ders/toera_risk.htm

The EPA is utilizing this method to assess environmental risks in other jurisdictions around the nation, and we recommend the Department use it here to ensure the best possible basis for its decision-making on this vitally important issue.

As you are aware, the Department's initial proposal resulted in a possible range of surface water quality standards that would be virtually impossible to achieve because the technology to comply does not exist, and may not for decades. In some cases, the allowable levels could be too low to measure with existing technology and create uncertainties for measuring compliance.

A study by HDR Engineering, Inc. estimates that adopting those standards would cost local governments, ports and businesses billions of dollars in compliance costs with little or no environmental benefit. Similar water quality standards adopted in Oregon have created huge uncertainties for that state's water quality permit system. We must do better here in Washington.

We appreciate the opportunity to provide the ARCADIS report for the Department of Ecology's consideration, and we look forward to continuing our conversation with the Department and the other stakeholders to identify balanced water quality standards that are both protective and achievable.

Sincerely,

Christian M. McCabe
Executive Director
Northwest Pulp & Paper Association

cc: Melissa Gildersleeve

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Derivation of Alternative Human Health Risk-Based Ambient Water Quality Criteria Using Probabilistic Methods for the State of Washington

February 4, 2014

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Acronyms and Abbreviations

aAWQC	alternative ambient water quality criteria
AT_c	averaging time for carcinogenic effects
AT_{nc}	averaging time for noncarcinogenic effects
ATSDR	Agency for Toxic Substances and Disease Registry
AWQC	ambient water quality criteria
BCF_{lipid}	lipid-based bioconcentration factor
BCF_{tissue}	tissue-based bioconcentration factor
BW	body weight
C_w	concentration in water
CL	cooking loss
CLF	catch location factor
CSF	cancer slope factor
CSFII	Continuing Survey of Food Intakes by Individuals
DI	drinking water intake
ED	exposure duration
ELCR	excess lifetime cancer risk
FCR	fish consumption rate
FDEP	Florida Department of Environmental Protection
HEAST	Health Effects Assessment Summary Tables
HQ	hazard quotient
IRIS	Integrated Risk Information System
LHF	life history factor
NHANES	National Health and Nutrition Examination Survey

NWPPA	Northwest Pulp & Paper Association
PAWQCC	Probabilistic Ambient Water Quality Criteria Calculator
PCB	polychlorinated biphenyl
PPRTV	Provisional Peer Reviewed Toxicity Values
RBA_w	relative bioavailability, water
RBA_f	relative bioavailability, fish
RfD	reference dose
RSC	relative source contribution
TSD	Technical Support Document
USEPA	United States Environmental Protection Agency
WDOE	Washington Department of Ecology

1. Introduction

On behalf of the Northwest Pulp & Paper Association (NWPPA), ARCADIS used probabilistic risk assessment methods to derive alternative ambient water quality criteria (also referred to as aAWQC in the report) for 114 chemicals listed in the United States Environmental Protection Agency's (USEPA's) 2013 Human Health Criteria Table (USEPA 2013a). The input assumptions used to derive the alternative AWQC were developed to be representative of residents of the State of Washington and, thus, the alternative AWQC represent criteria that are protective of Washington residents.

When using the traditional deterministic approach to deriving AWQC, point estimates are selected to represent exposure parameters such as body weight, drinking water intake, and fish consumption rate. Typically, high-end or maximum values are chosen to represent most of these parameters, which, when combined, lead to unlikely exposure scenarios and overestimates of potential risk. The phenomenon of a combination of high-end assumptions leading to an overestimate of risk is known as "compounded conservatism."

In contrast to the deterministic approach, the probabilistic approach accounts for variability within populations by allowing one or more of the exposure parameters to be defined as distributions of potential values (i.e., probability density functions). The result is a distribution of potential risk representing a range of possible exposures. The probabilistic approach therefore provides explicit estimates of potential risk for different segments of the population, including both the general population (e.g., arithmetic mean or 50th percentile) and individuals with high-end exposures (e.g., the 90th, 95th or 99th percentiles). In this report, for example, fish consumption rates representative of both the general and tribal populations of Washington State are accounted for, with total fish consumption rates as high as 291 grams per day (g/day) at the 99th percentile of the tribal population included in the development of the fish consumption rate distribution. As long as one or more of the exposure parameters used to estimate risk are defined as distributions of values, the outcome will be a distribution of estimated risks. To derive AWQC using the information developed by the probabilistic approach, regulators must make risk management decisions to determine what level of protection will be afforded to a given segment of the population, recognizing that different segments of the population by definition will always have varying levels of potential risk.

The concept of probabilistic assessment is not a new one; USEPA has issued formal guidance for conducting probabilistic risk assessments (USEPA 2001). However, most agencies, including USEPA, have continued to use the traditional deterministic approach to deriving AWQC, despite criticism that the deterministic approach is overly conservative and can lead to unrealistic estimates of risk. Recently, the benefits of using the probabilistic approach to derive AWQC have been recognized. For example, the Florida Department of Environmental Protection (FDEP) is currently revising its state criteria using probabilistic methods that allow the State to demonstrate all segments of the population, including high end consumers, are protected, albeit at varying acceptable risk levels. While USEPA has not yet formally

accepted FDEP's revised criteria, they have reviewed the derivation methods and have indicated a probabilistic approach is acceptable.

2. Methods

The general AWQC derivation process uses equations that account for the key exposure pathways (i.e., consumption of water and fish). Deterministic AWQC are derived using equations that include both exposure and toxicity parameters combined with a risk management threshold (i.e., an acceptable risk level). Probabilistic AWQC are derived by using these same equations, combined with distributions for one or more parameters representing the inherent variability in a population's physical characteristics and behaviors, to generate a distribution of risk. The AWQC derived using probabilistic methods is the water concentration that has associated with it a distribution of potential risk that meets (i.e., does not exceed) the risk management threshold(s) selected by the regulatory agency. In some cases, a regulatory agency may select a single risk management threshold. For example, a regulatory agency might require that the Hazard Quotient (HQ) for the 90th percentile of the population be equal to or less than 1.0. Alternatively, a regulatory agency may select multiple risk management thresholds that need to be met by an AWQC. For example, that the 50th percentile of the population (the median) must have an excess lifetime cancer risk (ELCR) equal to or less than $1x10^{-5}$ and that the 99th percentile of the population must have an ELCR equal to or less than $1x10^{-4}$. Both of these risk management thresholds must be met by the AWQC and are used in this report to derive alternate AWQC.

2.1 Risk Characterization

Risks were estimated using the fundamental equations employed by USEPA to derive AWQC (USEPA 2000). The USEPA equation for chemicals with noncarcinogenic endpoints is:

$$HQ = \frac{C_w \; x \; [DI + (FCR \; x \; BCF_{tissue})]}{BW \; x \; RSC \; x \; RfD} \qquad \textbf{(Equation 1)}$$

The USEPA equation for chemicals with noncarcinogenic endpoints is:

$$ELCR = \frac{C_w \; x \; [DI + (FCR \; x \; BCF_{tissue})] \; x \; CSF}{BW} \qquad \textbf{(Equation 2)}$$

Where:

HQ = hazard quotient (unitless);
ELCR = excess lifetime cancer risk (unitless);
C_w = concentration in water (mg/L);
DI = drinking water intake (L/day);

FCR = fish consumption rate (kg/day);
BCF_{tissue} = tissue-based bioconcentration factor (L/kg tissue);
BW = body weight (kg);
RSC = relative source contribution (unitless);
RfD = reference dose (mg/kg-day); and
CSF = cancer slope factor $(mg/kg\text{-}day)^{-1}$.

In addition to the parameters explicitly listed in the USEPA equations, additional implicit parameters (e.g., cooking loss, relative bioavailability, life history factor) also affect the characterization of risk and can be included in the risk characterization equations. The expanded equation for chemicals with noncarcinogenic health endpoints is:

$$HQ = \frac{C_w \; x \left[(RBA_w \; x \; DI) + \left(RBA_f \; x \; FCR \; x \; CLF \; x \; LHF \; x \; BCF_{lipid} \; x \; lipid \; x \; (1-CL) \right) \right] x \; ED}{BW \; x \; AT_{nc} \; x \; RSC \; x \; RfD}$$ **(Equation 3)**

The expanded equation for chemicals with carcinogenic health endpoints is:

$$ELCR = \frac{C_w \; x \left[(RBA_w \; x \; DI) + \left(RBA_f \; x \; FCR \; x \; CLF \; x \; LHF \; x \; BCF_{tissue} \; x \; lipid \; x \; (1-CL) \right) \right] x \; ED \; x \; CSF}{BW \; x \; AT_c}$$ **(Equation 4)**

Where the additional implicit parameters include:

RBA_w = relative bioavailability, water (unitless);
RBA_f = relative bioavailability, fish (unitless);
CLF = catch location factor (unitless);
LHF = life history factor (unitless);
BCF_{lipid} = bioconcentration factor (L/kg lipid)
Lipid = proportion of lipid in fish tissue (kg lipid/kg tissue);
CL = cooking loss (unitless);
ED = exposure duration (years);
AT_{nc} = averaging time for noncarcinogenic effects (years); and
AT_c = averaging time for carcinogenic effects (years).

2.2 Probabilistic Approach

The equations presented in Section 2.1 are referred to as “forward” risk equations; that is, the equations estimate risk from a chemical concentration, exposure dose, and toxicity. When deriving AWQC using a deterministic approach, USEPA rearranges the equations such that they predict an allowable water concentration (i.e., the AWQC) based on an allowable risk and the same exposure and toxicity factors

used by the forward equation to estimate risk. These rearranged equations are sometimes referred to as "backward" equations and are typically used for deterministic calculation of risk-based acceptable media concentrations (e.g., AWQC or preliminary remediation goals at waste sites).

Deriving AWQC using probabilistic methods requires forward equations. The reasons for using the forward equations for probabilistic assessments are mathematically complex and are described in greater detail elsewhere (e.g., Burmaster et al. 1995, Ferson 1996). In essence, the forward equation will yield a distribution of risks dependent on several inputs that are also distributions. If the equation is "flipped" to solve for one of the inputs, the resulting distribution and the original input distribution may have similar means, but the spread of the distributions will be different. Because it is the tails of a distribution that are typically of interest when setting acceptable risk or acceptable media concentrations, this disparity has marked effects on the outcome of the calculation. Therefore, USEPA recommends using forward equations when conducting probabilistic assessments to avoid the mathematical limitations associated with backcalculation (USEPA 2001).

For probabilistic derivation of AWQC, the process of estimating risk by selecting from the input point estimates or distributions is repeated until the number of desired iterations (e.g., 100,000 iterations in the case of the alternative AWQC presented herein) is complete. One complete set of iterations is called a simulation. As long as one or more of the input parameters are distributions, the final output of a simulation will be a distribution of risks associated with a particular concentration of a chemical in water. If the estimate of risk at a specific percentile meets the risk management requirements selected by the regulatory agency, the chemical concentration that was used to generate the output is the AWQC.

Typically, multiple simulations are required to derive probabilistic AWQC. Two methods can be used to develop the AWQC.

- **Trial and Error** – Select a water concentration, run a simulation, and compare the resulting risk distribution to risk management thresholds. If one or more thresholds is not met, repeat the process inserting alternative chemical concentrations until a concentration is identified that results in a risk distribution that meets risk management thresholds. That concentration is the AWQC.
- **Systematic Linear Derivation** – Run simulations at three or more alternative chemical concentrations. Plot the estimated risk at the percentile of the risk distribution corresponding to the risk management threshold versus the chemical concentration used for each simulation. Generate a least-squares linear regression line based on the plot of paired ELCRs and concentrations. Use that equation to solve for the chemical concentration that corresponds to the allowable risk level for the percentile of the population specified by the risk management threshold. That concentration is the AWQC. This process is recommended by USEPA (2001) as a "shortcut" for the trial-and-error method when using probabilistic methods to calculate risk-based acceptable media concentrations.

The systematic linear derivation method was used to derive the alternative AWQC presented in this report. Simulations using 100,000 iterations each were run using the Probabilistic Ambient Water Quality Criteria Calculator (PAWQCC) developed by ARCADIS. PAWQCC is an Excel-based calculator tool that employs @Risk software (Palisade Corporation 2013) to develop probabilistically based estimates of risk. The calculator, along with the inputs used to derive the AWQC presented in this report, will be provided under separate cover.

2.3 Risk Management Thresholds

For chemicals with noncarcinogenic health endpoints, the alternative AWQC are based on a target HQ of 1.0 at the 90th percentile of the risk distribution. For chemicals with carcinogenic health endpoints, the alternative AWQC are based on a target ELCR of one in one hundred thousand ($1x10^{-5}$) at the 50th percentile (i.e., median) of the risk distribution and one in ten thousand ($1x10^{-4}$) at the 99th percentile of the risk distribution. This is consistent with USEPA methodology, which states “EPA believes that both 10^{-6} and 10^{-5} may be acceptable for the general population and that highly exposed populations should not exceed a 10^{-4} risk level” (USEPA 2000).

2.4 Input Assumptions

To derive alternative AWQC using a probabilistic approach, distributions were selected to represent a number of the input parameters. Washington-specific data were used to incorporate information about fish consumption rate and the life history factor into the fish consumption rate distribution. The other distributions were based on data representing the general United States population.

2.4.1 Toxicity

The toxicity values used to derive AWQC were obtained from the USEPA National Recommended Water Quality Criteria: 2002 Human Health Criteria Calculation Matrix (USEPA 2002a). To determine whether the toxicity values listed in USEPA (2002a) still reflect the current understanding of each chemical’s health effects, the following sources were consulted, in accordance with the recommended hierarchy presented in USEPA guidance (2003), in order of priority:

- USEPA's Integrated Risk Information System (IRIS) (USEPA 2014a);
- USEPA’s Provisional Peer Reviewed Toxicity Values (PPRTVs) (USEPA 2014b);
- Additional USEPA and non-USEPA sources of toxicity information, including but not limited to the California Environmental Protection Agency toxicity values, the Agency for Toxic Substances and Disease Registry (ATSDR) minimum risk levels, and toxicity values published in the USEPA Health Effects Assessment Summary Tables (HEAST) (USEPA 1997).

In cases where the toxicity values listed in USEPA (2002a) have been superseded by newer data (e.g., a toxicity value had been withdrawn or updated in IRIS), the current toxicity values were used, in accordance with the hierarchy listed above.

In some cases, USEPA (2002a) was not able to identify toxicity values for a given chemical. In these cases, USEPA (2002a) chose surrogate toxicity values from a chemical that is considered structurally and toxicologically similar to the chemical that did not have toxicity values from the above sources (e.g., the toxicity value for endosulfan was selected to represent both alpha- and beta-endosulfan, for which toxicity values are not available). The same chemical surrogates used by USEPA (2002a) were used in this report. A summary of toxicity values used to derive alternative AWQC is presented in **Table 1**.

The derivation of probabilistic alternative AWQC presented in this report treats all toxicity values as point estimates.

2.4.2 Relative Source Contribution

Relative source contribution (RSC) refers to the portion of an individual's daily exposure to a chemical that is allocated to exposure from the regulated surface water (i.e., the consumption of water and fish). The RSC accounts for the possibility that individuals can be exposed to a chemical through sources other than surface water (e.g., food or air). The RSC applies only to AWQC with noncarcinogenc health endpoints.

USEPA (2000) describes a decision process to select an RSC. That process leads to RSCs of no greater than 0.8 and as low as 0.2. However, for the majority of chemicals, national AWQC are based on an RSC of 1.0, though USEPA has indicated that in the future, the decision process described in USEPA (2000) for selecting an RSC will need to be followed when revising AWQC. In response to comments from USEPA regarding Florida's proposed AWQC, Florida is currently deriving RSCs for several chemicals.

Because RSCs can have a substantial effect on AWQC (a five-fold difference between AWQC based on an RSC of 1.0 versus an RSC of 0.2), alternative AWQC protective of noncarcinogenic endpoints were derived in two ways.

- First, AWQC were derived assuming an RSC of 1.0 for all chemicals (i.e., all of a person's exposure to a chemical is assumed to come from the regulated surface water). This approach is consistent with most of the existing national AWQC derived by USEPA.
- Second, USEPA has derived RSCs of less than 1.0 for 19 of the 114 chemicals addressed in this report (USEPA 2013b). Alternative AWQC were also derived for these 19 chemicals using the RSCs recommended by USEPA (**Table 2**).

The derivation of probabilistic alternative AWQC presented in this report treats all RSCs as point estimates.

2.4.3 Bioconcentration and Percent Lipid

Bioconcentration refers to the process by which a chemical present in ambient water accumulates in fish tissue. The lipid-based bioconcentration factor (BCF) used in Equations 1 and 2, expressed in units of liters per kilogram lipid, is defined as the ratio of the concentration of the chemical in fish lipid to its concentration in the surrounding water. The lipid-based BCF is multiplied by the proportion of lipid in fish tissue to ultimately express bioconcentration on a fish tissue basis (i.e., units of liters per kilogram tissue). USEPA (2002a) provides default BCFs expressed on a fish tissue basis and normalized to a default lipid content of 3%. The default USEPA BCFs and 3% lipid were used to derive the alternative AWQC presented in this report. Where a default BCF was unavailable, AWQC were derived based on the consumption of water only. A summary of bioconcentration factors used to derive AWQC for the State of Washington is presented in **Table 3**.

The derivation of probabilistic alternative AWQC presented in this report treats all BCFs and lipid content as point estimates.

2.4.4 Cooking Loss

Cooking loss refers to the proportion of the chemical present in fish tissue that is lost as part of the cooking process. The AWQC presented in this report conservatively assume no cooking loss and that all of the chemical in raw fish remains in cooked fish. This assumption is consistent with the approach USEPA has used to derive national AWQC. For lipophilic chemicals (e.g., polychlorinated biphenyls [PCBs]) this is likely to lead to conservative AWQC because concentrations of such chemicals tend to be reduced by cooking. The amount of loss depends upon cooking method and the frequency at which various methods are used. Sufficient data are available for some chemicals (e.g., PCBs) to develop an input distribution for cooking loss. Thus, cooking loss could be incorporated in AWQC in the future.

2.4.5 Exposure Duration

As a matter of default and to be consistent with USEPA's approach to derivation of AWQC, exposure duration was assumed to occur over an entire lifetime (equal to 70 years). This conservative approach assumes that every member of the population lives in the same place and is exposed to the same chemical concentration in water and/or fish tissue each day over the duration of their 70-year lifetime. In reality, this is unlikely to be the case; the mean residential occupancy period according to USEPA is 12 years, and the 95th percentile is only 33 years (USEPA 2011). Even if an individual lives in the same state

their entire life, it is highly unlikely that they will live only near (and thus be exposed only to) contaminated waters over the course of their lifetime.

2.4.6 Body Weight

The 2011 Exposure Factors Handbook (USEPA 2011) provides age-specific distributions of body weight computed by Portier et al. (2007) using National Health and Nutrition Examination Survey (NHANES) II, III, and IV data. USEPA recommends using the Portier et al. (2007) data when body weight distributions are required, because the data are based on a large sample size and are representative of the general United States population. The body weight distribution derived from the NHANES IV survey for ages 18-65, males and females combined, was used to develop the alternative AWQC presented in this report (USEPA 2011; Table 8-25). Body weight was truncated at a lower limit of 44 kilograms (97 pounds), corresponding to the 1st percentile of the distribution. This approach is consistent with the approach used by the State of Florida to derive AWQC (FDEP 2013). Summary statistics for the body weight distribution are provided in **Table 4**.

2.4.7 Drinking Water Intake

In 2010, USEPA analyzed the 2003-2006 NHANES survey data to assess water ingestion rates across the general United States population. The results of the USEPA analysis are presented in the 2011 Exposure Factors Handbook (USEPA 2011). The consumer-only direct and indirect water intake distribution for ages 21 and above was used to derive the alternative AWQC presented in this report (USEPA 2011; Table 3-36). Using @Risk, a distribution was fit to the data using the range of reported percentiles as fit parameters. The resulting distribution was truncated at a lower limit of 0 liters per day. Summary statistics for the drinking water intake distribution are provided in **Table 4**.

2.4.8 Catch Location Factor

Catch location factor refers to the proportion of fish consumed that are caught in state or local waters. The alternative AWQC presented in this report assume that all fish consumed are caught locally (i.e., catch location factor [CLF] equals 1.0). This approach leads to conservative AWQC because it assumes that no one consumes either fresh or pre-packaged fish products that may have been produced in other states or outside of the United States.

2.4.9 Life History Factor

In this report, life history factor (LHF) refers to the portion of the fish life cycle that is spent in state or local waters. For true freshwater fish, the LHF will be 1. For anadromous species that spend the majority of their life cycle in marine waters, including many species and populations of salmon, the LHF will be some value less than 1. If it is assumed that bioaccumulation of chemicals by aquatic organisms is a linear function of

time, a life history factor reflecting time spent in waters of the state is equivalent to the fraction of the chemical body burden in adult salmon acquired in waters of the state. Thus, life history factors based on residence time were developed for five species of Pacific Northwest salmon to account for the fraction of salmon chemical body burden acquired in state or local waters (**Appendix A in Attachment A**). An alternative and perhaps more accurate approach would consider when and where chemical body burden is accumulated as a function of relative growth. Deriving life history factors based on residence time is a simplifying assumption and one that is likely to overstate the importance of bioaccumulation during early life stages, when salmon are not accruing a significant portion of their body mass. In other words, the residence time-based life history factors derived for salmon are believed to serve as a conservative approximation. Ultimately, a composite life history factor for all Pacific Northwest salmon species was derived using weighting factors reflecting the species-specific consumption patterns of the Suquamish Tribe. The final composite life history factor (i.e., 0.318) was then incorporated directly into the derivation of a Washington State fish consumption rate, as summarized below in Section 2.4.10 and detailed in **Appendix A in Attachment A**.

2.4.10 Fish Consumption Rate

The Washington Department of Ecology (WDOE) released two Technical Support Documents (TSDs) reviewing fish consumption rates for both the general and tribal populations of Washington State (WDOE 2011, 2013). Using the data presented in these WDOE TSDs, a composite fish consumption rate distribution was developed to represent both general population and tribal consumption of freshwater species, estuarine species, and salmon (**Attachment A**).

The general population distribution provided in the WDOE TSD (2013) for consumption of all fish species has a mean of 19 g/day, ranging up to 91 g/day at the 99th percentile. Several steps were taken to refine the fish consumption rate distribution to make sure it is representative of Washington residents. First, the general population distribution was adjusted to reflect only freshwater and estuarine species (i.e., off-shore marine species were removed from the distribution) using data from USEPA's Continuing Survey of Food Intakes by Individuals (CSFII) survey (USEPA 2002b). Next, the distribution was adjusted upward to add back the portion of overall fish consumption that is salmon (because USEPA's CSFII survey classifies salmon as a marine species and marine species were excluded in the first step of the fish consumption rate [FCR] distribution derivation process). This salmon component was multiplied by the composite salmon life history factor before being added to the final distribution; thus, only the consumption of salmon associated with waters of the State based on salmon life history was included in the distribution.

The tribal population distribution provided in the WDOE TSD (2011; Appendix C) for consumption of all fish species has a mean of 71 g/day, ranging up to 291 g/day at the 99th percentile. It was assumed that the only marine species consumed by the tribal population is salmon. Therefore, the only adjustment made to the tribal fish consumption rate distribution was to incorporate the salmon life history factor. It was

assumed that 46% of tribal fish consumption is comprised of salmon, based on data provided in the WDOE TSD. The salmon life history factor was applied to this portion of the overall tribal fish consumption rate.

Once the general and tribal fish consumption rate distributions were adjusted to reflect only freshwater species, estuarine species, and salmon associated with waters of the State, the two distributions were combined to reflect the entire population of Washington State. A single, composite fish consumption rate distribution was derived using weighting factors based on relative population size. Using data provided in the WDOE TSD, weighting factors of 98% and 2% were used for the general and tribal portions of the population, respectively. Using @Risk, a distribution was fit to the data using the range of percentiles as fit parameters. The resulting distribution was truncated at a lower limit of 0 g/day. An upper truncation limit for the fish consumption rate distribution was not defined, meaning that the fitted distribution can theoretically extend to any positive value. The actual maximum values achieved by the distribution ranged from 135 to 250 g/day, with a mean of 150 g/day, after 500 simulations of 100,000 iterations each. Summary statistics for the fish consumption rate distribution are provided in **Table 4**, and a detailed description of the complete derivation process is provided in **Attachment A**.

3. Results and Discussion

ARCADIS developed alternative AWQC (abbreviated aAWQC in the supporting tables) for 114 chemicals using a probabilistic approach. Alternative AWQC were developed for the consumption of water and organisms as well as for the consumption of organisms only (**Table 5**). All alternative AWQC were developed using an RSC of 1.0. Alternate AWQC were also derived for the 19 chemicals having USEPA-recommended RSCs lower than 1.0, (**Table 6**).

All alternative AWQC were compared to the corresponding national AWQC listed in USEPA's 2013 Human Health Criteria Table (USEPA 2013a) (**Table 7**). Differences between existing national AWQC and the probabilistically derived alternative AWQC arise due to the fundamental differences in derivation approach; the current national criteria were derived using deterministic methods assuming single point estimates for all inputs, while the alternative criteria were derived using a probabilistic approach that incorporates distributions for several of the inputs that determine exposure. Differences also arise due to changes in the understanding of the health effects associated with select chemicals (i.e., changes in the USEPA toxicity factors).

The alternative AWQC presented in this report were derived using probabilistic methods to be protective of Washington residents. The exposure assumptions used to derive these alternate criteria were developed to represent the full range of potential exposures as they are understood today, including both the general population as well as highly exposed individuals, such as tribal members who consume large amounts of fish (i.e., greater than 200 g/day).

National data were used to develop distributions for drinking water intake and body weight. Both national and Washington-specific data were used to develop a distribution of fish consumption rates representative of the entire population of Washington State. The national data were used to represent general fish consumption rates and tribal rate data published by Washington State Department of Ecology (WDOE 2011, 2013) were used to represent tribal consumption rates.

Even with the inclusion of probabilistic methods to better represent the range of fish consumption expected among residents of Washington State as well as distributions for body weight and drinking water consumption, the alternative AWQC retain several conservative elements and are more protective than implied by the risk management thresholds employed in this report. For example, point estimates equal to the maximum value were used for several implicit parameters (e.g., cooking loss, catch location factor, relative bioavailability) leading to an overestimate of potential risk and alternative AWQC that are more stringent than necessary to meet the specified level of protection. Additionally, point estimates were used for toxicity factors and those too are upper bounds (in the case of cancer slope factors) or are derived using several uncertainty factors (in the case of reference doses) as well as other conservative assumptions designed to overstate the potential toxicity of a chemical to protect public health.

Combined the assumptions and approach used in this report lead to alternative AWQC that are protective of public health but are based on a more complete representation of the range of risks associated with consumption of fish and drinking water than is possible with a deterministic approach, leading to improved risk management decision-making.

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Tables

Table 1. Toxicity Values

CAS Number	Chemical	Noncarcinogenic Effects Reference Dose (RfD)		Carcinogenic Effects Cancer Slope Factor (CSF)	
		mg/kg-day	source	$(mg/kg\text{-}day)^{-1}$	source
71-55-6	1,1,1-Trichloroethane	2.0E+00	IRIS	NA	
79-34-5	1,1,2,2-Tetrachloroethane	2.0E-02	IRIS	2.0E-01	IRIS
79-00-5	1,1,2-Trichloroethane	4.0E-03	IRIS	5.7E-02	IRIS
75-35-4	1,1-Dichloroethene	5.0E-02	IRIS	NA	
95-94-3	1,2,4,5-Tetrachlorobenzene	3.0E-04	IRIS	NA	
120-82-1	1,2,4-Trichlorobenzene	1.0E-02	IRIS	2.9E-02	PPRTV
95-50-1	1,2-Dichlorobenzene	9.0E-02	IRIS	NA	
107-06-2	1,2-Dichloroethane	NA		9.1E-02	IRIS
78-87-5	1,2-Dichloropropane	9.0E-02	ATSDR	3.6E-02	CalEPA
122-66-7	1,2-Diphenylhydrazine	NA		8.0E-01	IRIS
541-73-1	1,3-Dichlorobenzene	9.0E-02	IRIS [1]	NA	
542-75-6	1,3-Dichloropropene	3.0E-02	IRIS	1.0E-01	IRIS
106-46-7	1,4-Dichlorobenzene	7.0E-02	ATSDR	5.4E-03	CalEPA
1746-01-6	2,3,7,8-TCDD	7.0E-10	IRIS	1.3E+05	CalEPA
95-95-4	2,4,5-Trichlorophenol	1.0E-01	IRIS	NA	
88-06-2	2,4,6-Trichlorophenol	1.0E-03	PPRTV	1.1E-02	IRIS
120-83-2	2,4-Dichlorophenol	3.0E-03	IRIS	NA	
105-67-9	2,4-Dimethylphenol	2.0E-02	IRIS	NA	
51-28-5	2,4-Dinitrophenol	2.0E-03	IRIS	NA	
121-14-2	2,4-Dinitrotoluene	2.0E-03	IRIS	3.1E-01	CalEPA
91-58-7	2-Chloronaphthalene	8.0E-02	IRIS	NA	
95-57-8	2-Chlorophenol	5.0E-03	IRIS	NA	
534-52-1	2-Methyl-4,6-Dinitrophenol	8.0E-05	PPRTV	NA	
91-94-1	3,3-Dichlorobenzidine	NA		4.5E-01	IRIS
72-54-8	4,4-DDD	NA		2.4E-01	IRIS
72-55-9	4,4-DDE	NA		3.4E-01	IRIS
50-29-3	4,4-DDT	5.0E-04	IRIS	3.4E-01	IRIS
83-32-9	Acenaphthene	6.0E-02	IRIS	NA	
107-02-8	Acrolein	5.0E-04	IRIS	NA	
107-13-1	Acrylonitrile	4.0E-02	ATSDR	5.4E-01	IRIS
309-00-2	Aldrin	3.0E-05	IRIS	1.7E+01	IRIS
319-84-6	alpha-BHC	8.0E-03	ATSDR	6.3E+00	IRIS
959-98-8	alpha-Endosulfan	6.0E-03	IRIS [2]	NA	
120-12-7	Anthracene	3.0E-01	IRIS	NA	
7440-36-0	Antimony	4.0E-04	IRIS	NA	
7440-38-2	Arsenic (Inorganic)	3.0E-04	IRIS	1.5E+00	IRIS
7440-39-3	Barium	2.0E-01	IRIS	NA	
56-55-3	Benz[a]anthracene	NA		7.3E-01	ECAO
71-43-2	Benzene	4.0E-03	IRIS	1.5E-02	IRIS [3]
92-87-5	Benzidine	3.0E-03	IRIS	2.3E+02	IRIS
50-32-8	Benzo[a]pyrene	NA		7.3E+00	IRIS
205-99-2	Benzo[b]fluoranthene	NA		7.3E-01	ECAO
207-08-9	Benzo[k]fluoranthene	NA		7.3E-02	ECAO
7440-41-7	Beryllium	2.0E-03	IRIS	NA	
319-85-7	beta-BHC	NA		1.8E+00	IRIS
33213-65-9	beta-Endosulfan	6.0E-03	IRIS [2]	NA	
111-44-4	Bis(2-Chloroethyl)ether	NA		1.1E+00	IRIS
108-60-1	Bis(2-Chloroisopropyl)ether	4.0E-02	IRIS	7.0E-02	HEAST
117-81-7	Bis(2-Ethylhexyl) Phthalate	2.0E-02	IRIS	1.4E-02	IRIS
542-88-1	Bis(Chloromethyl)ether	NA		2.2E+02	IRIS
75-25-2	Bromoform	2.0E-02	IRIS	7.9E-03	IRIS
85-68-7	Butylbenzyl phthalate	2.0E-01	IRIS	1.9E-03	PPRTV
7440-43-9	Cadmium	5.0E-04	IRIS [4]	NA	
56-23-5	Carbon Tetrachloride	4.0E-03	IRIS	7.0E-02	IRIS
12789-03-6	Chlordane	5.0E-04	IRIS	3.5E-01	IRIS
108-90-7	Chlorobenzene	2.0E-02	IRIS	NA	
124-48-1	Chlorodibromomethane	2.0E-02	IRIS	8.4E-02	IRIS

Table 1. Toxicity Values

CAS Number	Chemical	Noncarcinogenic Effects Reference Dose (RfD)		Carcinogenic Effects Cancer Slope Factor (CSF)	
		mg/kg-day	source	$(mg/kg\text{-}day)^{-1}$	source
67-66-3	Chloroform	1.0E-02	IRIS	3.1E-02	CalEPA
94-75-7	Chlorophenoxy Herbicide (2,4-D)	1.0E-02	IRIS	NA	
16065-83-1	Chromium III	1.5E+00	IRIS	NA	
18540-29-9	Chromium VI	3.0E-03	IRIS	5.0E-01	NJDEP
218-01-9	Chrysene	NA		7.3E-03	ECAO
7440-50-8	Copper	4.0E-02	HEAST	NA	
57-12-5	Cyanide	6.0E-04	IRIS	NA	
53-70-3	Dibenz[a,h]anthracene	NA		7.3E+00	ECAO
75-27-4	Dichlorobromomethane	2.0E-02	IRIS	6.2E-02	IRIS
75-09-2	Dichloromethane	6.0E-03	IRIS	2.0E-03	IRIS
60-57-1	Dieldrin	5.0E-05	IRIS	1.6E+01	IRIS
84-66-2	Diethyl phthalate	8.0E-01	IRIS	NA	
131-11-3	Dimethyl Phthalate	1.0E+01	[5]	NA	
25550-58-7	Dinitrophenols	2.0E-03	IRIS [6]	NA	
84-74-2	Di-n-Butyl phthalate	1.0E-01	IRIS	NA	
1031-07-8	Endosulfan Sulfate	6.0E-03	IRIS [2]	NA	
72-20-8	Endrin	3.0E-04	IRIS	NA	
7421-93-4	Endrin Aldehyde	3.0E-04	IRIS [7]	NA	
100-41-4	Ethylbenzene	1.0E-01	IRIS	1.1E-02	CalEPA
206-44-0	Fluoranthene	4.0E-02	IRIS	NA	
86-73-7	Fluorene	4.0E-02	IRIS	NA	
76-44-8	Heptachlor	5.0E-04	IRIS	4.5E+00	IRIS
1024-57-3	Heptachlor Epoxide	1.3E-05	IRIS	9.1E+00	IRIS
118-74-1	Hexachlorobenzene	8.0E-04	IRIS	1.6E+00	IRIS
87-68-3	Hexachlorobutadiene	1.0E-03	PPRTV	7.8E-02	IRIS
608-73-1	Hexachlorocyclohexane (Technical)	NA		1.8E+00	IRIS
77-47-4	Hexachlorocyclopentadiene	6.0E-03	IRIS	NA	
67-72-1	Hexachloroethane	7.0E-04	IRIS	4.0E-02	IRIS
193-39-5	Indeno[1,2,3-cd]pyrene	NA		7.3E-01	ECAO
78-59-1	Isophorone	2.0E-01	IRIS	9.5E-04	IRIS
58-89-9	Lindane (gamma-BHC)	3.0E-04	IRIS	1.1E+00	CalEPA
7439-96-5	Manganese	1.4E-01	IRIS	NA	
72-43-5	Methoxychlor	5.0E-02	IRIS	NA	
74-83-9	Methyl bromide	1.4E-03	IRIS	NA	
7440-02-0	Nickel	2.0E-02	IRIS	NA	
14797-55-8	Nitrates	1.6E+00	IRIS	NA	
98-95-3	Nitrobenzene	2.0E-03	IRIS	NA	
—	Nitrosamines	NA		1.5E+02	IRIS [8]
924-16-3	N-Nitrosodibutylamine	NA		5.4E+00	IRIS
55-18-5	N-Nitrosodiethylamine	NA		1.5E+02	IRIS
62-75-9	N-Nitrosodimethylamine	8.0E-06	PPRTV	5.1E+01	IRIS
621-64-7	N-Nitrosodi-n-propylamine	NA		7.0E+00	IRIS
86-30-6	N-Nitrosodiphenylamine	NA		4.9E-03	IRIS
930-55-2	N-Nitrosopyrrolidine	NA		2.1E+00	IRIS
1336-36-3	PCBs	NA		2.0E+00	IRIS
608-93-5	Pentachlorobenzene	8.0E-04	IRIS	NA	
87-86-5	Pentachlorophenol	5.0E-03	IRIS	4.0E-01	IRIS
108-95-2	Phenol	3.0E-01	IRIS	NA	
129-00-0	Pyrene	3.0E-02	IRIS	NA	
7782-49-2	Selenium	5.0E-03	IRIS	NA	
127-18-4	Tetrachloroethene	6.0E-03	IRIS	2.1E-03	IRIS
7440-28-0	Thallium	6.8E-05	IRIS [9]	NA	
108-88-3	Toluene	8.0E-02	IRIS	NA	
8001-35-2	Toxaphene	NA		1.1E+00	IRIS
156-60-5	trans-1,2-Dichloroethylene	2.0E-02	IRIS	NA	
79-01-6	Trichloroethene	5.0E-04	IRIS	4.6E-02	IRIS

Table 1. Toxicity Values

CAS Number	Chemical	Noncarcinogenic Effects Reference Dose (RfD)		Carcinogenic Effects Cancer Slope Factor (CSF)	
		mg/kg-day	source	$(mg/kg\text{-}day)^{-1}$	source
75-01-4	Vinyl Chloride	3.0E-03	IRIS	1.4E+00	IRIS [10]
7440-66-6	Zinc	3.0E-01	IRIS	NA	

Sources:

IRIS = USEPA Integrated Risk Information System
PPRTV = Provisional Peer-Reviewed Toxicity Values
HEAST = Health Effects Assessment Summary Tables
CalEPA = California Environmental Protection Agency
ECAO = Environmental Criteria and Assessment Office
NJDEP = New Jersey Department of Environmental Protection
ATSDR = Agency for Toxic Substances and Disease Registry

USEPA. 2002a. National Recommended Water Quality Criteria: 2002 Human Health Criteria Calculation Matrix. EPA-822-R-02-012. Washington, DC: United States Environmental Protection Agency Office of Water Office of Science and Technology.

USEPA. 2013a. National Recommended Water Quality Criteria: Human Health Criteria Table. Accessible via: http://water.epa.gov/scitech/swguidance/standards/criteria/current/index.cfm. Last updated: August 22.

Notes:

CAS = Chemical Abstracts Service
mg/kg-day = milligrams per kilogram per day
NA = not available
USEPA = United States Environmental Protection Agency

[1] 1,2-Dichlorobenzene was used as a surrogate, consistent with the USEPA (2002a) approach.
[2] Endosulfan was used as a surrogate, consistent with the USEPA (2002a) approach.
[3] The CSF for benzene ranges from $1.5x10^{-2}$ to $5.5x10^{-2}$ per mg/kg-day. The lower value was used ($1.5x10^{-2}$), consistent with the USEPA (2013a) approach.
[4] Reference dose for cadmium in water.
[5] An average daily intake (ADI) of 10 mg/kg-day was used by USEPA (2002a) to derive the national criterion for dimethyl phthalate.
[6] 2,4-Dinitrophenol was used as a surrogate, consistent with the USEPA (2002a) approach.
[7] Endrin was used as a surrogate, consistent with the USEPA (2002a) approach.
[8] N-Nitrosodiethylamine was used as a surrogate, consistent with the USEPA (2002a) approach.
[9] In 2009, USEPA withdrew the oral RfD for thallium noting the available toxicity database contains studies that are generally of poor quality.
[10] The CSF for vinyl chloride assumes continuous lifetime exposure from birth.

Table 2. USEPA-Recommended Relative Source Contribution Factors (RSCs)

Chemical	USEPA-Recommended RSC
1,1-Dichloroethene	0.2
1,2,4-Trichlorobenzene	0.2
1,2-Dichlorobenzene	0.2
1,4-Dichlorobenzene	0.2
Antimony	0.4
Cadmium	0.25 [1]
Chlorobenzene	0.2
Chromium III	0.2
Chromium VI	0.2
Copper	0.2
Cyanide	0.2
Endrin	0.2
Ethylbenzene	0.2
Hexachlorocyclopentadiene	0.2
Lindane (gamma-BHC)	0.2 – 0.8
Methoxychlor	0.2
Thallium	0.2
Toluene	0.2
trans-1,2-Dichloroethylene	0.2

Source:

USEPA. 2013b. Technical Support Document for Action on the Revised Surface Water Quality Standards of the Spokane Tribe of Indians Submitted April 2010. U.S. Environmental Protection Agency, Region 10, Seattle, Washington. December.

Notes:

RSC = relative source contribution

USEPA = United Stated Environmental Protection Agency

[1] Based on the RSC used to develop the cadmium drinking water Maximum Contaminant Level Goal (MCLG).

Table 3. Default USEPA Bioconcentration Factors

CAS Number	Chemical	Tissue-Based Bioconcentration Factor (BCF_{tissue}) L/kg tissue
71-55-6	1,1,1-Trichloroethane	5.6
79-34-5	1,1,2,2-Tetrachloroethane	5
79-00-5	1,1,2-Trichloroethane	4.5
75-35-4	1,1-Dichloroethene	5.6
95-94-3	1,2,4,5-Tetrachlorobenzene	1125
120-82-1	1,2,4-Trichlorobenzene	114
95-50-1	1,2-Dichlorobenzene	55.6
107-06-2	1,2-Dichloroethane	1.2
78-87-5	1,2-Dichloropropane	4.1
122-66-7	1,2-Diphenylhydrazine	24.9
541-73-1	1,3-Dichlorobenzene	55.6
542-75-6	1,3-Dichloropropene	1.9
106-46-7	1,4-Dichlorobenzene	55.6
1746-01-6	2,3,7,8-TCDD	5000
95-95-4	2,4,5-Trichlorophenol	110
88-06-2	2,4,6-Trichlorophenol	150
120-83-2	2,4-Dichlorophenol	40.7
105-67-9	2,4-Dimethylphenol	93.8
51-28-5	2,4-Dinitrophenol	1.5
121-14-2	2,4-Dinitrotoluene	3.8
91-58-7	2-Chloronaphthalene	202
95-57-8	2-Chlorophenol	134
534-52-1	2-Methyl-4,6-Dinitrophenol	5.5
91-94-1	3,3-Dichlorobenzidine	312
72-54-8	4,4-DDD	53600
72-55-9	4,4-DDE	53600
50-29-3	4,4-DDT	53600
83-32-9	Acenaphthene	242
107-02-8	Acrolein	215
107-13-1	Acrylonitrile	30
309-00-2	Aldrin	4670
319-84-6	alpha-BHC	130
959-98-8	alpha-Endosulfan	270
120-12-7	Anthracene	30
7440-36-0	Antimony	1
7440-38-2	Arsenic (Inorganic)	44
7440-39-3	Barium	NA [1]
56-55-3	Benz[a]anthracene	30
71-43-2	Benzene	5.2
92-87-5	Benzidine	87.5
50-32-8	Benzo[a]pyrene	30
205-99-2	Benzo[b]fluoranthene	30
207-08-9	Benzo[k]fluoranthene	30
7440-41-7	Beryllium	19
319-85-7	beta-BHC	130
33213-65-9	beta-Endosulfan	270
111-44-4	Bis(2-Chloroethyl)ether	6.9
108-60-1	Bis(2-Chloroisopropyl)ether	2.47
117-81-7	Bis(2-Ethylhexyl) Phthalate	130
542-88-1	Bis(Chloromethyl)ether	63
75-25-2	Bromoform	3.75
85-68-7	Butylbenzyl phthalate	414
7440-43-9	Cadmium	NA [2]
56-23-5	Carbon Tetrachloride	18.75

Table 3. Default USEPA Bioconcentration Factors

CAS Number	Chemical	Tissue-Based Bioconcentration Factor (BCF_{tissue}) L/kg tissue
12789-03-6	Chlordane	14100
108-90-7	Chlorobenzene	10.3
124-48-1	Chlorodibromomethane	3.75
67-66-3	Chloroform	3.75
94-75-7	Chlorophenoxy Herbicide (2,4-D)	NA [1]
16065-83-1	Chromium III	16
18540-29-9	Chromium VI	16
218-01-9	Chrysene	30
7440-50-8	Copper	36
57-12-5	Cyanide	1
53-70-3	Dibenz[a,h]anthracene	30
75-27-4	Dichlorobromomethane	3.75
75-09-2	Dichloromethane	0.9
60-57-1	Dieldrin	4670
84-66-2	Diethyl phthalate	73
131-11-3	Dimethyl Phthalate	36
84-74-2	Di-n-Butyl phthalate	89
25550-58-7	Dinitrophenols	1.51
1031-07-8	Endosulfan Sulfate	270
72-20-8	Endrin	3970
7421-93-4	Endrin Aldehyde	3970
100-41-4	Ethylbenzene	37.5
206-44-0	Fluoranthene	1150
86-73-7	Fluorene	30
76-44-8	Heptachlor	11200
1024-57-3	Heptachlor Epoxide	11200
118-74-1	Hexachlorobenzene	8690
87-68-3	Hexachlorobutadiene	2.78
608-73-1	Hexachlorocyclohexane (Technical)	130
77-47-4	Hexachlorocyclopentadiene	4.34
67-72-1	Hexachloroethane	86.9
193-39-5	Indeno[1,2,3-cd]pyrene	30
78-59-1	Isophorone	4.38
58-89-9	Lindane (gamma-BHC)	130
7439-96-5	Manganese	NA [1]
72-43-5	Methoxychlor	NA [1]
74-83-9	Methyl bromide	3.75
7440-02-0	Nickel	47
14797-55-8	Nitrates	NA [1]
98-95-3	Nitrobenzene	2.89
—	Nitrosamines	0.2
924-16-3	N-Nitrosodibutylamine	3.38
55-18-5	N-Nitrosodiethylamine	0.2
62-75-9	N-Nitrosodimethylamine	0.026
621-64-7	N-Nitrosodi-n-propylamine	1.13
86-30-6	N-Nitrosodiphenylamine	136
930-55-2	N-Nitrosopyrrolidine	0.055
1336-36-3	PCBs	31200
608-93-5	Pentachlorobenzene	2125
87-86-5	Pentachlorophenol	11
108-95-2	Phenol	1.4
129-00-0	Pyrene	30
7782-49-2	Selenium	4.8
127-18-4	Tetrachloroethene	30.6

Table 3. Default USEPA Bioconcentration Factors

CAS Number	Chemical	Tissue-Based Bioconcentration Factor (BCF_{tissue}) L/kg tissue
7440-28-0	Thallium	116
108-88-3	Toluene	10.7
8001-35-2	Toxaphene	13100
156-60-5	trans-1,2-Dichloroethylene	1.58
79-01-6	Trichloroethene	10.6
75-01-4	Vinyl Chloride	1.17
7440-66-6	Zinc	47

Source:

USEPA. 2002a. National Recommended Water Quality Criteria: 2002 Human Health Criteria Calculation Matrix. EPA-822-R-02-012. Washington, DC: United States Environmental Protection Agency Office of Water Office of Science and Technology.

Notes:

CAS = Chemical Abstracts Service

L/kg tissue = liters per kilogram tissue

NA = not available

USEPA = United States Environmental Protection Agency

[1] The national criterion for this chemical was originally published in the 1976 USEPA Red Book, which did not utilize the fish ingestion BCF approach. No default USEPA BCF is provided.

[2] The national criterion for cadmium is based on the Maximum Contaminant Level (MCL) issued by USEPA. No default USEPA BCF is provided.

Table 4. Input Distribution Summary Statistics

Input Parameter	Drinking Water Intake	Body Weight	Fish Consumption Rate
Units	liters per day (L/day)	kilograms (g)	grams per day (g/day)
Distribution Type	Pearson Type V	Lognormal	Inverse Gaussian
Minimum	0	44	0
Maximum	∞	∞	∞
Mean	1.72	80.5	8.59
Mode	1.20	72.5	2.29
Median	1.53	77.7	5.79
Std Dev	1.07	20.3	8.86
1%	0.110	46.6	0.385
5%	0.358	52.4	1.02
10%	0.552	56.8	1.56
15%	0.703	60.1	2.03
20%	0.835	63.1	2.49
25%	0.957	65.7	2.96
30%	1.07	68.2	3.44
35%	1.19	70.6	3.96
40%	1.30	72.9	4.51
45%	1.41	75.3	5.12
50%	1.53	77.7	5.79
55%	1.66	80.2	6.54
60%	1.79	82.9	7.39
65%	1.93	85.7	8.39
70%	2.09	88.7	9.56
75%	2.27	92.2	11.0
80%	2.48	96.2	12.8
85%	2.75	101	15.3
90%	3.12	108	19.0
95%	3.73	118	25.7
99%	5.15	140	43.3

Table 5. Alternate AWQC for the State of Washington (Assuming Relative Source Contribution = 1.0)

Chemical	Water + Organism				Organism Only			
	aAWQC (ug/L)	HQ at 90th Percentile [1]	ELCR at 50th Percentile [2]	ELCR at 99th Percentile [2]	aAWQC (ug/L)	HQ at 90th Percentile [1]	ELCR at 50th Percentile [2]	ELCR at 99th Percentile [2]
1,1,1-Trichloroethane	4.61E+04	1.0	NA	NA	1.42E+06	1.0	NA	NA
1,1,2,2-Tetrachloroethane	2.50E+00	0.0054	1.0E-05	3.8E-05	1.35E+02	0.0085	1.0E-05	8.2E-05
1,1,2-Trichloroethane	8.78E+00	0.095	1.0E-05	3.8E-05	5.29E+02	0.15	1.0E-05	8.1E-05
1,1-Dichloroethene	1.16E+03	1.0	NA	NA	3.54E+04	1.0	NA	NA
1,2,4,5-Tetrachlorobenzene	9.71E-01	1.0	NA	NA	1.06E+00	1.0	NA	NA
1,2,4-Trichlorobenzene	1.11E+01	0.070	1.0E-05	3.5E-05	4.09E+01	0.12	1.0E-05	8.2E-05
1,2-Dichlorobenzene	1.74E+03	1.0	NA	NA	6.39E+03	1.0	NA	NA
1,2-Dichloroethane	5.62E+00	NA	1.0E-05	3.8E-05	1.24E+03	NA	1.0E-05	8.2E-05
1,2-Dichloropropane	1.40E+01	0.0067	1.0E-05	3.8E-05	9.17E+02	0.011	1.0E-05	8.2E-05
1,2-Diphenylhydrazine	5.63E-01	NA	1.0E-05	3.6E-05	6.80E+00	NA	1.0E-05	8.1E-05
1,3-Dichlorobenzene	1.74E+03	1.0	NA	NA	6.39E+03	1.0	NA	NA
1,3-Dichloropropene	5.11E+00	0.0073	1.0E-05	3.9E-05	7.11E+02	0.011	1.0E-05	8.1E-05
1,4-Dichlorobenzene	7.29E+01	0.054	1.0E-05	3.4E-05	4.50E+02	0.090	1.0E-05	8.1E-05
2,3,7,8-TCDD	1.96E-07	0.36	1.0E-05	7.8E-05	2.09E-07	0.38	1.0E-05	8.2E-05
2,4,5-Trichlorophenol	1.61E+03	1.0	NA	NA	3.59E+03	1.0	NA	NA
2,4,6-Trichlorophenol	1.41E+01	1.0	5.3E-06	2.0E-05	2.64E+01	1.0	3.2E-06	2.6E-05
2,4-Dichlorophenol	6.13E+01	1.0	NA	NA	2.92E+02	1.0	NA	NA
2,4-Dimethylphenol	3.39E+02	1.0	NA	NA	8.45E+02	1.0	NA	NA
2,4-Dinitrophenol	4.67E+01	1.0	NA	NA	5.26E+03	0.99	NA	NA
2,4-Dinitrotoluene	1.63E+00	0.035	1.0E-05	3.8E-05	1.15E+02	0.055	1.0E-05	8.2E-05
2-Chloronaphthalene	9.71E+02	1.0	NA	NA	1.57E+03	1.0	NA	NA
2-Chlorophenol	7.40E+01	1.0	NA	NA	1.47E+02	1.0	NA	NA
2-Methyl-4,6-Dinitrophenol	1.85E+00	1.0	NA	NA	5.78E+01	1.0	NA	NA
3,3-Dichlorobenzidine	4.73E-01	NA	1.0E-05	4.6E-05	9.61E-01	NA	1.0E-05	8.2E-05
4,4-DDD	1.04E-02	NA	9.9E-06	8.1E-05	1.05E-02	NA	1.0E-05	8.2E-05
4,4-DDE	7.39E-03	NA	1.0E-05	8.1E-05	7.43E-03	NA	1.0E-05	8.2E-05
4,4-DDT	7.38E-03	0.2	1.0E-05	8.2E-05	7.44E-03	0.20	1.0E-05	8.2E-05
Acenaphthene	6.56E+02	1.0	NA	NA	9.84E+02	1.0	NA	NA
Acrolein	5.89E+00	1.0	NA	NA	9.21E+00	1.0	NA	NA
Acrylonitrile	8.13E-01	0.00096	1.0E-05	3.5E-05	8.36E+00	0.0016	1.0E-05	8.2E-05
Aldrin	1.59E-03	0.064	1.0E-05	7.7E-05	1.70E-03	0.067	1.0E-05	8.2E-05
alpha-BHC	4.90E-02	0.00041	1.0E-05	3.6E-05	1.65E-01	0.00068	1.0E-05	8.2E-05
alpha-Endosulfan	6.10E+01	1.0	NA	NA	8.79E+01	1.0	NA	NA
Anthracene	6.37E+03	1.0	NA	NA	3.97E+04	1.0	NA	NA
Antimony	9.35E+00	1.0	NA	NA	1.58E+03	0.99	NA	NA
Arsenic (Inorganic) [3]	NA	NA	NA	NA	NA	NA	NA	NA
Barium [4]	4.70E+03	1.0	NA	NA	NA	NA	NA	NA
Benz[a]anthracene	6.02E-01	NA	1.0E-05	3.5E-05	6.18E+00	NA	1.0E-05	8.1E-05
Benzene	3.34E+01	0.36	1.0E-05	3.8E-05	1.73E+03	0.57	1.0E-05	8.1E-05
Benzidine	1.52E-03	0.000029	1.0E-05	3.5E-05	6.72E-03	0.000049	1.0E-05	8.2E-05
Benzo[a]pyrene	6.02E-02	NA	1.0E-05	3.5E-05	6.17E-01	NA	1.0E-05	8.2E-05
Benzo[b]fluoranthene	6.02E-01	NA	1.0E-05	3.5E-05	6.19E+00	NA	1.0E-05	8.2E-05
Benzo[k]fluoranthene	6.01E+00	NA	1.0E-05	3.5E-05	6.17E+01	NA	1.0E-05	8.1E-05

Table 5. Alternate AWQC for the State of Washington (Assuming Relative Source Contribution = 1.0)

Chemical	Water + Organism				Organism Only			
	aAWQC (ug/L)	HQ at 90th Percentile [1]	ELCR at 50th Percentile [2]	ELCR at 99th Percentile [2]	aAWQC (ug/L)	HQ at 90th Percentile [1]	ELCR at 50th Percentile [2]	ELCR at 99th Percentile [2]
Beryllium	4.42E+01	1.0	NA	NA	4.16E+02	1.0	NA	NA
beta-BHC	1.72E-01	NA	1.0E-05	3.6E-05	5.80E-01	NA	1.0E-05	8.2E-05
beta-Endosulfan	6.13E+01	1.0	NA	NA	8.78E+01	0.99	NA	NA
Bis(2-Chloroethyl)ether	4.50E-01	NA	1.0E-05	3.8E-05	1.78E+01	NA	1.0E-05	8.1E-05
Bis(2-Chloroisopropyl)ether	7.24E+00	0.0078	1.0E-05	3.8E-05	7.82E+02	0.012	1.0E-05	8.1E-05
Bis(2-Ethylhexyl) Phthalate	2.21E+01	0.074	1.0E-05	3.6E-05	7.44E+01	0.12	1.0E-05	8.2E-05
Bis(Chloromethyl)ether	1.74E-03	NA	1.0E-05	3.4E-05	9.74E-03	NA	1.0E-05	8.2E-05
Bromoform	6.38E+01	0.14	1.0E-05	3.8E-05	4.55E+03	0.22	1.0E-05	8.1E-05
Butylbenzyl phthalate	9.62E+01	0.064	1.0E-05	5.1E-05	1.72E+02	0.090	1.0E-05	8.1E-05
Cadmium [4]	1.17E+01	1.0	NA	NA	NA	NA	NA	NA
Carbon Tetrachloride	6.63E+00	0.075	1.0E-05	3.6E-05	1.03E+02	0.12	1.0E-05	8.1E-05
Chlordane	2.68E-02	0.19	1.0E-05	8.0E-05	2.75E-02	0.20	1.0E-05	8.0E-05
Chlorobenzene	4.55E+02	1.0	NA	NA	7.70E+03	1.0	NA	NA
Chlorodibromomethane	5.99E+00	0.013	1.0E-05	3.8E-05	4.30E+02	0.020	1.0E-05	8.2E-05
Chloroform	1.62E+01	0.070	1.0E-05	3.8E-05	1.16E+03	0.11	1.0E-05	8.1E-05
Chlorophenoxy Herbicide (2,4-D) [4]	2.34E+02	1.0	NA	NA	NA	NA	NA	NA
Chromium III	3.34E+04	1.0	NA	NA	3.72E+05	1.0	NA	NA
Chromium VI	9.41E-01	0.014	1.0E-05	3.6E-05	1.69E+01	0.023	1.0E-05	8.1E-05
Chrysene	6.02E+01	NA	1.0E-05	3.5E-05	6.16E+02	NA	1.0E-05	8.1E-05
Copper	8.34E+02	1.0	NA	NA	4.40E+03	1.0	NA	NA
Cyanide	1.40E+01	1.0	NA	NA	2.37E+03	0.99	NA	NA
Dibenz[a,h]anthracene	6.01E-02	NA	1.0E-05	3.5E-05	6.19E-01	NA	1.0E-05	8.1E-05
Dichlorobromomethane	8.13E+00	0.018	1.0E-05	3.8E-05	5.81E+02	0.028	1.0E-05	8.1E-05
Dichloromethane	1.40E+02	1.0	5.5E-06	2.1E-05	2.65E+04	1.0	3.5E-06	2.8E-05
Dieldrin	1.70E-03	0.041	1.0E-05	7.7E-05	1.81E-03	0.043	1.0E-05	8.1E-05
Diethyl phthalate	1.46E+04	1.0	NA	NA	4.32E+04	0.99	NA	NA
Dimethyl Phthalate	2.08E+05	1.0	NA	NA	1.10E+06	1.0	NA	NA
Di-n-Butyl phthalate	1.73E+03	1.0	NA	NA	4.45E+03	1.0	NA	NA
Dinitrophenols	4.68E+01	1.0	NA	NA	5.25E+03	1.0	NA	NA
Endosulfan Sulfate	6.13E+01	1.0	NA	NA	8.79E+01	1.0	NA	NA
Endrin	2.92E-01	1.0	NA	NA	2.99E-01	1.0	NA	NA
Endrin Aldehyde	2.93E-01	1.0	NA	NA	3.00E-01	1.0	NA	NA
Ethylbenzene	3.86E+01	0.019	1.0E-05	3.5E-05	3.27E+02	0.031	9.9E-06	8.1E-05
Fluoranthene	1.26E+02	1.0	NA	NA	1.38E+02	1.0	NA	NA
Fluorene	8.50E+02	1.0	NA	NA	5.29E+03	1.0	NA	NA
Heptachlor	2.62E-03	0.015	1.0E-05	8.1E-05	2.69E-03	0.015	1.0E-05	8.2E-05
Heptachlor Epoxide	1.29E-03	0.28	1.0E-05	8.0E-05	1.33E-03	0.29	1.0E-05	8.1E-05
Hexachlorobenzene	9.36E-03	0.026	9.9E-06	7.9E-05	9.73E-03	0.027	1.0E-05	8.2E-05
Hexachlorobutadiene	6.49E+00	0.28	1.0E-05	3.8E-05	6.23E+02	0.44	1.0E-05	8.1E-05
Hexachlorocyclohexane (Technical)	1.72E-01	NA	1.0E-05	3.6E-05	5.79E-01	NA	1.0E-05	8.1E-05
Hexachlorocyclopentadiene	1.39E+02	1.0	NA	NA	5.46E+03	1.0	NA	NA
Hexachloroethane	8.79E+00	0.73	1.0E-05	3.4E-05	3.20E+01	1.0	8.2E-06	6.8E-05
Indeno[1,2,3-cd]pyrene	6.03E-01	NA	1.0E-05	3.5E-05	6.18E+00	NA	1.0E-05	8.2E-05

Table 5. Alternate AWQC for the State of Washington (Assuming Relative Source Contribution = 1.0)

Chemical	Water + Organism				Organism Only			
	aAWQC (ug/L)	HQ at 90th Percentile [1]	ELCR at 50th Percentile [2]	ELCR at 99th Percentile [2]	aAWQC (ug/L)	HQ at 90th Percentile [1]	ELCR at 50th Percentile [2]	ELCR at 99th Percentile [2]
Isophorone	5.29E+02	0.11	1.0E-05	3.8E-05	3.24E+04	0.18	1.0E-05	8.1E-05
Lindane (gamma-BHC)	2.80E-01	0.062	1.0E-05	3.6E-05	9.46E-01	0.10	1.0E-05	8.1E-05
Manganese [4]	3.29E+03	1.0	NA	NA	NA	NA	NA	NA
Methoxychlor [4]	1.17E+03	1.0	NA	NA	NA	NA	NA	NA
Methyl bromide	3.25E+01	1.0	NA	NA	1.47E+03	1.0	NA	NA
Nickel	3.99E+02	1.0	NA	NA	1.69E+03	1.0	NA	NA
Nitrates [4]	3.74E+04	1.0	NA	NA	NA	NA	NA	NA
Nitrobenzene	4.66E+01	1.0	NA	NA	2.74E+03	1.0	NA	NA
Nitrosamines	3.45E-03	NA	1.0E-05	3.9E-05	4.52E+00	NA	1.0E-05	8.2E-05
N-Nitrosodibutylamine	9.36E-02	NA	1.0E-05	3.9E-05	7.41E+00	NA	1.0E-05	8.1E-05
N-Nitrosodiethylamine	3.42E-03	NA	1.0E-05	3.9E-05	4.51E+00	NA	1.0E-05	8.1E-05
N-Nitrosodimethylamine	1.01E-02	0.054	1.0E-05	3.9E-05	1.02E+02	0.084	1.0E-05	8.1E-05
N-Nitrosodi-n-propylamine	7.31E-02	NA	1.0E-05	3.9E-05	1.71E+01	NA	1.0E-05	8.2E-05
N-Nitrosodiphenylamine	6.21E+01	NA	1.0E-05	3.7E-05	2.03E+02	NA	1.0E-05	8.1E-05
N-Nitrosopyrrolidine	2.45E-01	NA	1.0E-05	3.9E-05	1.17E+03	NA	1.0E-05	8.2E-05
PCBs	2.15E-03	NA	1.0E-05	8.0E-05	2.17E-03	NA	1.0E-05	8.2E-05
Pentachlorobenzene	1.42E+00	1.0	NA	NA	1.49E+00	1.0	NA	NA
Pentachlorophenol	1.21E+00	0.011	1.0E-05	3.7E-05	3.07E+01	0.017	1.0E-05	8.2E-05
Phenol	7.01E+03	1.0	NA	NA	8.48E+05	1.0	NA	NA
Pyrene	6.38E+02	1.0	NA	NA	3.96E+03	1.0	NA	NA
Selenium	1.15E+02	1.0	NA	NA	4.11E+03	1.0	NA	NA
Tetrachloroethene	1.27E+02	1.0	6.1E-06	2.1E-05	7.76E+02	1.0	3.7E-06	3.0E-05
Thallium	1.07E+00	1.0	NA	NA	2.32E+00	1.0	NA	NA
Toluene	1.82E+03	1.0	NA	NA	2.97E+04	1.0	NA	NA
Toxaphene	9.14E-03	NA	1.0E-05	8.1E-05	9.37E-03	NA	1.0E-05	8.1E-05
trans-1,2-Dichloroethylene	4.66E+02	1.0	NA	NA	5.04E+04	1.0	NA	NA
Trichloroethene	1.06E+01	0.93	1.0E-05	3.7E-05	1.87E+02	1.0	6.7E-06	5.5E-05
Vinyl Chloride	3.66E-01	0.0052	1.0E-05	3.8E-05	8.24E+01	0.0081	1.0E-05	8.1E-05
Zinc	5.98E+03	1.0	NA	NA	2.52E+04	1.0	NA	NA

Notes:

aAWQC = alternate ambient water quality criterion
ELCR = excess lifetime cancer risk
HQ = hazard quotient
NA = not available/not applicable
ug/L = micrograms per liter

[1] Hazard quotient calculated only for chemicals for which a reference dose (RfD) is available.
[2] Excess lifetime cancer risk calculated only for chemcials for which a cancer slope factor (CSF) is available.
[3] Arsenic criteria is blank because in public forums the Washington Department of Ecology has stated they may consider an alternative approach for arsenic criteria.
[4] No bioconcentration factor (BCF) available; criteria are based on drinking water exposure only.

Table 6. Alternate AWQC Derived Using USEPA-Recommended Relative Source Contribution Factors

Chemical		USEPA RSC	Water + Organism aAWQC (ug/L)		Organism Only aAWQC (ug/L)	
			RSC = 1	USEPA RSC	RSC = 1	USEPA RSC
1,1-Dichloroethene		0.2	1.16E+03	2.31E+02	3.54E+04	7.07E+03
1,2,4-Trichlorobenzene	[1]	0.2	1.11E+01	1.11E+01	4.09E+01	4.09E+01
1,2-Dichlorobenzene		0.2	1.74E+03	3.49E+02	6.39E+03	1.28E+03
1,4-Dichlorobenzene	[1]	0.2	7.29E+01	7.29E+01	4.50E+02	4.50E+02
Antimony		0.4	9.35E+00	3.74E+00	1.58E+03	6.34E+02
Cadmium	[2]	0.25	1.17E+01	2.93E+00	NA	NA
Chlorobenzene		0.2	4.55E+02	9.10E+01	7.70E+03	1.54E+03
Chromium III		0.2	3.34E+04	6.69E+03	3.72E+05	7.43E+04
Chromium VI	[1]	0.2	9.41E-01	9.41E-01	1.69E+01	1.69E+01
Copper		0.2	8.34E+02	1.67E+02	4.40E+03	8.79E+02
Cyanide		0.2	1.40E+01	2.80E+00	2.37E+03	4.74E+02
Endrin		0.2	2.92E-01	5.84E-02	2.99E-01	5.97E-02
Ethylbenzene	[1]	0.2	3.86E+01	3.86E+01	3.27E+02	3.27E+02
Hexachlorocyclopentadiene		0.2	1.39E+02	2.78E+01	5.46E+03	1.09E+03
Lindane (gamma-BHC)	[1,3]	0.5	2.80E-01	2.80E-01	9.46E-01	9.46E-01
Methoxychlor	[2]	0.2	1.17E+03	2.34E+02	NA	NA
Thallium		0.2	1.07E+00	2.14E-01	2.32E+00	4.63E-01
Toluene		0.2	1.82E+03	3.63E+02	2.97E+04	5.94E+03
trans-1,2-Dichloroethylene		0.2	4.66E+02	9.32E+01	5.04E+04	1.01E+04

Notes:

aAWQC = alternate ambient water quality criterion
NA = not available/not applicable
RSC = relative source contribution
ug/L = micrograms per liter
USEPA = United States Environmental Protection Agency

[1] AWQC is based on carcinogenic health endpoint; RSC adjustment does not affect the AWQC because the AWQC is driven by the carcinogenic endpoint.
[2] No bioconcentration factor (BCF) available; criteria are based on drinking water exposure only.
[3] Average of USEPA-recommended range of RSCs.

Table 7. Comparison of Alternate AWQC to National AWQC

Chemical		Water + Organism		Organism Only	
		aAWQC (ug/L)	National AWQC (ug/L)	aAWQC (ug/L)	National AWQC (ug/L)
1,1,1-Trichloroethane	[1]	4.61E+04	NA	1.42E+06	NA
1,1,2,2-Tetrachloroethane		2.50E+00	1.70E-01	1.35E+02	4.00E+00
1,1,2-Trichloroethane		8.78E+00	5.90E-01	5.29E+02	1.60E+01
1,1-Dichloroethene		1.16E+03	3.30E+02	3.54E+04	7.10E+03
1,2,4,5-Tetrachlorobenzene		9.71E-01	9.70E-01	1.06E+00	1.10E+00
1,2,4-Trichlorobenzene		1.11E+01	3.50E+01	4.09E+01	7.00E+01
1,2-Dichlorobenzene		1.74E+03	4.20E+02	6.39E+03	1.30E+03
1,2-Dichloroethane		5.62E+00	3.80E-01	1.24E+03	3.70E+01
1,2-Dichloropropane		1.40E+01	5.00E-01	9.17E+02	1.50E+01
1,2-Diphenylhydrazine		5.63E-01	3.60E-02	6.80E+00	2.00E-01
1,3-Dichlorobenzene		1.74E+03	3.20E+02	6.39E+03	9.60E+02
1,3-Dichloropropene		5.11E+00	3.40E-01	7.11E+02	2.10E+01
1,4-Dichlorobenzene		7.29E+01	6.30E+01	4.50E+02	1.90E+02
2,3,7,8-TCDD		1.96E-07	5.00E-09	2.09E-07	5.10E-09
2,4,5-Trichlorophenol		1.61E+03	1.80E+03	3.59E+03	3.60E+03
2,4,6-Trichlorophenol		1.41E+01	1.40E+00	2.64E+01	2.40E+00
2,4-Dichlorophenol		6.13E+01	7.70E+01	2.92E+02	2.90E+02
2,4-Dimethylphenol		3.39E+02	3.80E+02	8.45E+02	8.50E+02
2,4-Dinitrophenol		4.67E+01	6.90E+01	5.26E+03	5.30E+03
2,4-Dinitrotoluene		1.63E+00	1.10E-01	1.15E+02	3.40E+00
2-Chloronaphthalene		9.71E+02	1.00E+03	1.57E+03	1.60E+03
2-Chlorophenol		7.40E+01	8.10E+01	1.47E+02	1.50E+02
2-Methyl-4,6-Dinitrophenol		1.85E+00	1.30E+01	5.78E+01	2.80E+02
3,3-Dichlorobenzidine		4.73E-01	2.10E-02	9.61E-01	2.80E-02
4,4-DDD		1.04E-02	3.10E-04	1.05E-02	3.10E-04
4,4-DDE		7.39E-03	2.20E-04	7.43E-03	2.20E-04
4,4-DDT		7.38E-03	2.20E-04	7.44E-03	2.20E-04
Acenaphthene		6.56E+02	6.70E+02	9.84E+02	9.90E+02
Acrolein		5.89E+00	6.00E+00	9.21E+00	9.00E+00
Acrylonitrile		8.13E-01	5.10E-02	8.36E+00	2.50E-01
Aldrin		1.59E-03	4.90E-05	1.70E-03	5.00E-05
alpha-BHC		4.90E-02	2.60E-03	1.65E-01	4.90E-03
alpha-Endosulfan		6.10E+01	6.20E+01	8.79E+01	8.90E+01
Anthracene		6.37E+03	8.30E+03	3.97E+04	4.00E+04
Antimony		9.35E+00	5.60E+00	1.58E+03	6.40E+02
Arsenic (Inorganic)	[2]	NA	NA	NA	NA
Barium	[3]	4.70E+03	1.00E+03	NA	NA
Benz[a]anthracene		6.02E-01	3.80E-03	6.18E+00	1.80E-02
Benzene		3.34E+01	2.20E+00	1.73E+03	5.10E+01
Benzidine		1.52E-03	8.60E-05	6.72E-03	2.00E-04
Benzo[a]pyrene		6.02E-02	3.80E-03	6.17E-01	1.80E-02
Benzo[b]fluoranthene		6.02E-01	3.80E-03	6.19E+00	1.80E-02
Benzo[k]fluoranthene		6.01E+00	3.80E-03	6.17E+01	1.80E-02
Beryllium	[1]	4.42E+01	NA	4.16E+02	NA
beta-BHC		1.72E-01	9.10E-03	5.80E-01	1.70E-02
beta-Endosulfan		6.13E+01	6.20E+01	8.78E+01	8.90E+01
Bis(2-Chloroethyl)ether		4.50E-01	3.00E-02	1.78E+01	5.30E-01
Bis(2-Chloroisopropyl)ether		7.24E+00	1.40E+03	7.82E+02	6.50E+04
Bis(2-Ethylhexyl) Phthalate		2.21E+01	1.20E+00	7.44E+01	2.20E+00
Bis(Chloromethyl)ether		1.74E-03	1.00E-04	9.74E-03	2.90E-04
Bromoform		6.38E+01	4.30E+00	4.55E+03	1.40E+02
Butylbenzyl phthalate		9.62E+01	1.50E+03	1.72E+02	1.90E+03
Cadmium	[1,3]	1.17E+01	NA	NA	NA
Carbon Tetrachloride		6.63E+00	2.30E-01	1.03E+02	1.60E+00

Table 7. Comparison of Alternate AWQC to National AWQC

Chemical		Water + Organism		Organism Only	
		aAWQC (ug/L)	National AWQC (ug/L)	aAWQC (ug/L)	National AWQC (ug/L)
Chlordane		2.68E-02	8.00E-04	2.75E-02	8.10E-04
Chlorobenzene		4.55E+02	1.30E+02	7.70E+03	1.60E+03
Chlorodibromomethane		5.99E+00	4.00E-01	4.30E+02	1.30E+01
Chloroform		1.62E+01	5.70E+00	1.16E+03	4.70E+02
Chlorophenoxy Herbicide (2,4-D)	[3]	2.34E+02	1.00E+02	NA	NA
Chromium III	[1]	3.34E+04	NA	3.72E+05	NA
Chromium VI	[1]	9.41E-01	NA	1.69E+01	NA
Chrysene		6.02E+01	3.80E-03	6.16E+02	1.80E-02
Copper		8.34E+02	1.30E+03	4.40E+03	1.30E+03
Cyanide		1.40E+01	1.40E+02	2.37E+03	1.40E+02
Dibenz[a,h]anthracene		6.01E-02	3.80E-03	6.19E-01	1.80E-02
Dichlorobromomethane		8.13E+00	5.50E-01	5.81E+02	1.70E+01
Dichloromethane		1.40E+02	4.60E+00	2.65E+04	5.90E+02
Dieldrin		1.70E-03	5.20E-05	1.81E-03	5.40E-05
Diethyl phthalate		1.46E+04	1.70E+04	4.32E+04	4.40E+04
Dimethyl Phthalate		2.08E+05	2.70E+05	1.10E+06	1.10E+06
Di-n-Butyl phthalate		1.73E+03	2.00E+03	4.45E+03	4.50E+03
Dinitrophenols		4.68E+01	6.90E+01	5.25E+03	5.30E+03
Endosulfan Sulfate		6.13E+01	6.20E+01	8.79E+01	8.90E+01
Endrin		2.92E-01	5.90E-02	2.99E-01	6.00E-02
Endrin Aldehyde		2.93E-01	2.90E-01	3.00E-01	3.00E-01
Ethylbenzene		3.86E+01	5.30E+02	3.27E+02	2.10E+03
Fluoranthene		1.26E+02	1.30E+02	1.38E+02	1.40E+02
Fluorene		8.50E+02	1.10E+03	5.29E+03	5.30E+03
Heptachlor		2.62E-03	7.90E-05	2.69E-03	7.90E-05
Heptachlor Epoxide		1.29E-03	3.90E-05	1.33E-03	3.90E-05
Hexachlorobenzene		9.36E-03	2.80E-04	9.73E-03	2.90E-04
Hexachlorobutadiene		6.49E+00	4.40E-01	6.23E+02	1.80E+01
Hexachlorocyclohexane (Technical)		1.72E-01	1.23E-02	5.79E-01	4.14E-02
Hexachlorocyclopentadiene		1.39E+02	4.00E+01	5.46E+03	1.10E+03
Hexachloroethane		8.79E+00	1.40E+00	3.20E+01	3.30E+00
Indeno[1,2,3-cd]pyrene		6.03E-01	3.80E-03	6.18E+00	1.80E-02
Isophorone		5.29E+02	3.50E+01	3.24E+04	9.60E+02
Lindane (gamma-BHC)		2.80E-01	9.80E-01	9.46E-01	1.80E+00
Manganese	[3]	3.29E+03	5.00E+01	NA	NA
Methoxychlor	[3]	1.17E+03	1.00E+02	NA	NA
Methyl bromide		3.25E+01	4.70E+01	1.47E+03	1.50E+03
Nickel		3.99E+02	6.10E+02	1.69E+03	4.60E+03
Nitrates	[3]	3.74E+04	1.00E+04	NA	NA
Nitrobenzene		4.66E+01	1.70E+01	2.74E+03	6.90E+02
Nitrosamines		3.45E-03	8.00E-04	4.52E+00	1.24E+00
N-Nitrosodibutylamine		9.36E-02	6.30E-03	7.41E+00	2.20E-01
N-Nitrosodiethylamine		3.42E-03	8.00E-04	4.51E+00	1.24E+00
N-Nitrosodimethylamine		1.01E-02	6.90E-04	1.02E+02	3.00E+00
N-Nitrosodi-n-propylamine		7.31E-02	5.00E-03	1.71E+01	5.10E-01
N-Nitrosodiphenylamine		6.21E+01	3.30E+00	2.03E+02	6.00E+00
N-Nitrosopyrrolidine		2.45E-01	1.60E-02	1.17E+03	3.40E+01
PCBs		2.15E-03	6.40E-05	2.17E-03	6.40E-05
Pentachlorobenzene		1.42E+00	1.40E+00	1.49E+00	1.50E+00
Pentachlorophenol		1.21E+00	2.70E-01	3.07E+01	3.00E+00
Phenol		7.01E+03	1.00E+04	8.48E+05	8.60E+05
Pyrene		6.38E+02	8.30E+02	3.96E+03	4.00E+03
Selenium		1.15E+02	1.70E+02	4.11E+03	4.20E+03
Tetrachloroethene		1.27E+02	6.90E-01	7.76E+02	3.30E+00

Table 7. Comparison of Alternate AWQC to National AWQC

Chemical	Water + Organism		Organism Only	
	aAWQC (ug/L)	National AWQC (ug/L)	aAWQC (ug/L)	National AWQC (ug/L)
Thallium	1.07E+00	2.40E-01	2.32E+00	4.70E-01
Toluene	1.82E+03	1.30E+03	2.97E+04	1.50E+04
Toxaphene	9.14E-03	2.80E-04	9.37E-03	2.80E-04
trans-1,2-Dichloroethylene	4.66E+02	1.40E+02	5.04E+04	1.00E+04
Trichloroethene	1.06E+01	2.50E+00	1.87E+02	3.00E+01
Vinyl Chloride	3.66E-01	2.50E-02	8.24E+01	2.40E+00
Zinc	5.98E+03	7.40E+03	2.52E+04	2.60E+04

Source:

USEPA. 2013a. National Recommended Water Quality Criteria: Human Health Criteria Table. Accessible via: http://water.epa.gov/scitech/swguidance/standards/criteria/current/index.cfm. Last updated: August 22.

Notes:

aAWQC = alternate ambient water quality criterion
MCL = Maximum Contaminant Level
NA = not available/not applicable
ug/L = micrograms per liter

[1] This chemical is regulated based on the MCL.
[2] Arsenic criteria is blank because in public forums the Washington Department of Ecology has stated they may consider an alternative approach for arsenic criteria.
[3] No bioconcentration factor (BCF) available; criteria are based on drinking water exposure only.

ARCADIS

Attachment A

Development of a Fish Consumption Rate Distribution for Residents of the State of Washington

DEVELOPMENT OF A FISH CONSUMPTION RATE DISTRIBUTION FOR RESIDENTS OF THE STATE OF WASHINGTON

A fish consumption rate distribution representative of the entire population of Washington State residents was developed for use in calculating water quality criteria for the protection of human health using either probabilistic or deterministic methods. National fish consumption rate (FCR) data published by EPA (USEPA 2002, 2011) were used as the basis for estimating FCRs for the general population and tribal rate data published by Washington State Department of Ecology (WDOE 2011, 2013) were used to estimate tribal consumption rates. The general population distribution was adjusted to reflect: (1) consumption of fish and shellfish from freshwater and near-shore marine habitats only; and (2) the portion of salmon consumption accounting for contaminants acquired by salmon in waters of the state. The tribal distribution was only adjusted to account for contaminants acquired by salmon in waters of the state. The two distributions were then combined using weighting factors representing the relative populations of each group.

1. Development of a General Population Fish Consumption Rate

a. Use NCI-adjusted data from the 2003 to 2006 National Health and Nutrition Examination Survey (NHANES) to represent fish consumption rates of the general population of Washington State residents. EPA (USEPA 2011) analyzed these data and generated per capita and consumer-only intake rates for finfish, shellfish, and total fish and shellfish combined. These rates represent intake of all forms of seafood (e.g., purchased, self caught, marine, freshwater, estuarine) for individuals who provided data for two days of the survey.

The "consumers only" data were used for this analysis. Two day average fish intake rates were calculated for all individuals in the database for each of the food items/groups. If a person reported consuming fish on only one day of the survey, their two day average would be half the amount reported for the one day of consumption.

The short-term nature of the NHANES survey methodology has been found to overestimate long-term consumption rates of infrequently consumed foods such as fish (Polissar 2012). To address this problem, researchers at the National Cancer Institute (NCI) developed methodology for estimating the intake of such foods that better represents long-term consumption rates. This methodology addresses biases associated with the day-to-day variation in reported consumption as well as exclusion of fish consumers who did not report eating fish on either day of the survey. Table 1 shows the NCI-adjusted NHANES data as reported by Polissar et al. (2012).

Table 1. Summary of NCI-adjusted NHANES Whole Population Fish Consumption Distribution

Statistic	All Consumers Consumption Rate, All Fish (g/d)	Statistic	All Consumers Consumption Rate, All Fish (g/d)
Mean	18.8	75%	24.8
1%	0.9	80%	28.9
5%	2	85%	34.5
10%	3	90%	42.5
25%	6.2	95%	56.6
50%	12.7	99%	90.8

b. Adjust general population fish consumption data to reflect only freshwater and near-shore marine (estuarine) species. Because the NHANES data are based on total fish consumption, including offshore marine species such as tuna, and because EPA specifically recommends that data used to

represent fish consumption for the purpose of developing human health water quality criteria be based on fish from freshwater and near-shore (estuarine) marine environments only, some means of adjusting the distribution in Table 1 is needed. To make this adjustment, data from US Department of Agriculture's (USDA) Continuing Survey of Food Intake by Individuals (CSFII) 1994 to 1996 were used. Adjustment of the NCI-adjusted NHANES distribution in this manner is based on the assumption that the relative proportions of fresh, near-shore marine, and off-shore marine fish in the American diet have not shifted dramatically in the period of time (about ten years) between the two surveys.

USDA's CSFII survey data (USEPA 2002, Section 5.1.1.1 Table 4) provide estimates of consumption rates of uncooked finfish and shellfish for the US population age 18 and older and were the basis of EPA's current national recommended default fish consumption rate of 17.5 g/day. The data are reproduced herein as Table 2. The reported mean consumption rates of freshwater/estuarine, marine, and all fish were 7.50, 12.41, and 19.91 g/day, respectively. The ratio between the mean freshwater and estuarine (F/E) rate and the all FCR was calculated (0.377) and used as an adjustment factor for the NCI-adjusted NHANES distribution. This ratio represents the average percentage (37.7%) of F/E fish in Americans' total fish diet. It also indicates that on average 62.3% of the fish consumed are from off-shore marine waters.

Table 2. Summary of EPA's Analysis of Uncooked Finfish and Shellfish Consumption Rates (g/person/day) for the CSFII Survey[a]

			90% Interval	
Habitat	Statistic	Estimate	Lower Bound	Upper Bound
Freshwater/Estuarine	Mean	7.50	6.75	8.25
	50th %	0.00	0.00	0.00
	90th %	17.37	14.32	21.58
	95th %	49.59	46.87	55.41
	99th %	143.35	125.27	156.84
Marine	Mean	12.41	11.46	13.37
	50th %	0.00	0.00	0.00
	90th %	48.92	47.10	51.17
	95th %	80.68	77.77	83.45
	99th %	150.77	139.66	164.34
All Fish	Mean	19.91	18.69	21.13
	50th %	0.00	0.00	0.00
	90th %	74.79	71.72	75.71
	95th %	111.35	110.03	114.02
	99th %	215.70	197.09	228.53

[a] USEPA 2002, Section 5.1.1.1 Table 4

Adjustment of the NCI-adjusted NHANES distribution was accomplished by multiplying the mean and each percentile by the F/E adjustment factor (0.377), based on the assumption that the average rate of fresh and estuarine fish consumption can be applied across the entire distribution. Note that ratios between F/E and total fish consumption in Table 2 are 0.232 and 0.445 at the 90th and 95th percentiles, respectively, suggesting that application of the mean ratio is in fact conservative for the majority of consumers (>90%). Table 3 summarizes the "all fish" NCI-adjusted NHANES data and the "fresh and estuarine adjusted" NCI-adjusted NHANES consumption rates.

Table 3. NCI-adjusted NHANES Data Adjusted to Reflect Freshwater and Estuarine Species Consumption Only

Distribution Statistic	All Fish (g/d)[a]	Fresh and Estuarine Species Only (g/d)[b]
Mean	18.8	7.09
1%	0.9	0.34
5%	2	0.75
10%	3	1.13
25%	6.2	2.34
50%	12.7	4.79
75%	24.8	9.35
80%	28.9	10.90
85%	34.5	13.01
90%	42.5	16.02
95%	56.6	21.34
99%	90.8	34.23

[a] from Polissar et al. 2012, Table 4
[b] component of all fish that are freshwater or estuarine fish [all fish x 0.377]

c. Adjust general population distribution to include salmon in proportion to their general population consumption rate and life history spent in fresh and estuarine waters. Scientific studies (e.g., Hope 2012) provide information indicating that some portion of highly bioaccumulative chemicals (e.g., PCBs) found in salmon consumed by Washington residents may be acquired in F/E environments. Thus, the distributions shown in Table 3 were adjusted upward to reflect this information. This was accomplished by adjusting the total salmon consumption rate to reflect only that portion of salmon life history that is spent in F/E waters and the fraction of salmon in the general population total fish diet, and then adding the adjusted salmon consumption rate to the NCI-adjusted NHANES "fresh and estuarine" rates shown in Table 3.

Life history factors (LHFs) were developed for each species of salmon based on information in the technical literature. Derivation of these LHFs is discussed in Appendix A, and Table 4 summarizes the final species-specific LHFs relevant to different waters of the state. As suggested by WDOE (2013), the species-specific LHFs used in this analysis were based on the amounts of time these fish spend in waters of the state from emergence to migration off-shore. For multiple reasons (see Appendix A), this approach probably overstates the accumulation of chemicals from waters of the state. For example, it assumes that accumulation occurs at a constant rate unrelated to growth or trophic level, and it ignores depuration of chemicals acquired in F/E waters.

Table 4. Life History Factors for Different Salmon Species and Different Waters Based on Residence Times in Waters of the State

	Life History Factors (LHFs)		
Species	Non-Puget Sound Waters	Puget Sound Waters Only	Statewide Composite
Chinook/King	0.15	0.40	0.30
Sockeye	0.50	0.60	0.56
Coho	NA	NA	0.19
Chum	0.13	0.28	0.22
Pink	NA	NA	0.24

A single composite salmon LHF for all waters of the state is computed by summing the species-specific (statewide composite) LHFs weighted by the relative amounts of each species consumed as given in EPA's *Exposure Factors Handbook* (USEPA 2011), Table 10-104, Adult Consumption Rate (g/kg-day) for Consumers Only. The information in the table is from an FCR survey conducted by the Suquamish Tribe. It was assumed that the relative amounts of salmon species consumed by the Suquamish tribe are representative of Washington consumers generally. The data from EPA's table are reproduced in part as Table 5 herein, which also shows generation of the final composite LHF for salmon (0.318). Salmon LHFs could be developed based on other information, as discussed in Appendix A.

Table 5. Relative Proportions of Salmon Species Consumed by the Suquamish Tribe and Derivation of Composite Life History Factor for All Salmon

	EPA Consumption Data				LHFs	
Species	n	Mean (g/d)	n x Mean (g/d)	Fraction at Mean	From Table 4	Consumption Weighted
Chinook/King	63	0.200	12.600	0.294	0.30	0.088
Sockeye	59	0.169	9.971	0.232	0.56	0.130
Coho	50	0.191	9.550	0.223	0.19	0.043
Chum	42	0.242	10.164	0.237	0.22	0.053
Pink	17	0.035	0.595	0.014	0.24	0.003
Final Composite LHF						0.318

An adjustment for salmon to the general population FCR distribution also requires an estimate of the fraction of the general population's total fish diet that is comprised of salmon. Information provided by EPA (USEPA 2002) and reproduced in EPA's *Exposure Factors Handbook* as Table 10-28 (USEPA 2011) was used for this purpose. The table, reproduced herein as Table 6, lists mean consumption rates for 64 species of fish from the 1994 to 1996 and 1998 combined CSFII survey data from USDA. Based on these data the fraction of total fish consumption that is comprised of salmon is 0.094 (9.4%).

Table 6. Uncooked Fish Consumption Estimates, US Population – Mean Consumption by Species within Habitat, Individuals of Age 18 and Older

Habitat	Species	Estimated Mean (g/person/day)	Habitat	Species	Estimated Mean (g/person/day)
Estuarine			Marine		
	Shrimp	2.64686		Tuna	4.18375
	Flounder	0.69946		Salmon (marine)	1.77537
	Catfish (estuarine)	0.57463		Cod	1.65997
	Flatfish (estuarine)	0.40395		Clam (marine)	0.87021
	Crab (estuarine)	0.29953		Porgy	0.49466
	Perch (estuarine)	0.21256		Haddock	0.37374
	Herring	0.17937		Crab (marine)	0.34008
	Oyster	0.17395		Pollock	0.3321
	Croaker	0.16936		Whiting	0.30583
	Trout, mixed spp.	0.14568		Lobster	0.25919
	Salmon (estuarine)	0.08819		Scallop (marine)	0.23749
	Anchovy	0.05544		Squid	0.20948
	Rockfish	0.05162		Ocean perch	0.15663
	Mullet	0.04295		Mackerel	0.1456
	Clam (estuarine)	0.02332		Sardine	0.14375
	Smelts (estuarine)	0.00838		Swordfish	0.12595
	Eel	0.00444		Sea Bass	0.12543
	Scallop (estuarine)	0.0016		Pompano	0.11198
	Smelts, rainbow	0.00072		Mussels	0.09969
	Sturgeon (estuarine)	0.00017		Octopus	0.08819
Freshwater				Flatfish (marine)	0.07563
	Catfish (freshwater)	0.57463		Halibut	0.04224
	Trout	0.2414		Snapper	0.03624
	Perch (freshwater)	0.21256		Whitefish (marine)	0.01246
	Carp	0.18153		Smelts (marine)	0.00838
	Trout, mixed spp.	0.14568		Shark	0.00581
	Pike	0.03827		Conch	0.00284
	Whitefish (freshwater)	0.01246		Snails (marine)	0.00206
	Crayfish	0.01024		Roe	0.0014
	Snails (freshwater)	0.00206	Unknown		
	Cisco	0.0017		Fish	0.47575
	Salmon (freshwater)	0.00093		Seafood	0.00394
	Smelts, rainbow	0.00072			
	Sturgeon (freshwater)	0.00017			
All Fish		19.91037			
All Salmon		1.86449			
All Salmon as % of All Fish		9.4%			

[Source: USEPA 2002]

The portion of salmon to be added to the F/E NCI-adjusted NHANES distribution is determined by multiplying the salmon fraction in the total fish diet (.094) by the NCI-adjusted NHANES distribution for all fish and by the composite salmon LHF (0.318). The final general population FCR distribution is shown in column 5 of Table 7.

Table 7. General Population Fish Consumption Rate Distribution Adjusted for Fresh and Estuarine Species and for Salmon Life History

	(1)	(2) (1) * 0.377	(3) (1) * 0.094	(4) (3) * 0.318	(5) (2) + (4)
	NCI-Adjusted NHANES Consumption, All Fish (g/d)[a]	Fresh/ Estuarine Fish Only (g/d)[b]	Salmon Only (g/d)[c]	Fresh/Estuarine Life History Apportioned Salmon (g/d)[d]	Final General Population FCR (g/d)[e]
Mean	18.8	7.09	1.77	0.56	7.65
1%	0.9	0.34	0.08	0.03	0.37
5%	2	0.75	0.19	0.06	0.81
10%	3	1.13	0.28	0.09	1.22
25%	6.2	2.34	0.58	0.19	2.52
50%	12.7	4.79	1.19	0.38	5.17
75%	24.8	9.35	2.33	0.74	10.09
80%	28.9	10.90	2.72	0.86	11.76
85%	34.5	13.01	3.24	1.03	14.04
90%	42.5	16.02	4.00	1.27	17.29
95%	56.6	21.34	5.32	1.69	23.03
99%	90.8	34.23	8.54	2.71	36.95

[a] from Polissar et al. 2012, Table 4
[b] component of all fish that are freshwater or estuarine [all fish x 0.377]
[c] component of all fish that is salmon [all fish x 0.094]
[d] consumption of salmon associated with waters of state based on composite residence time LHF [salmon x 0.318]
[e] final general population FCR [F/E + apportioned salmon fraction]

2. Development of a Tribal Population Fish Consumption Rate

a. Use data from Washington tribal population surveys to represent fish consumption rates of the total tribal population of Washington State. Data from four tribal fish consumption surveys were used by WDOE to develop composite tribal distributions using different weighting schemes. Scheme No. 6 from *Fish Consumption Rates Technical Support Document, A Review of Data and Information about Fish Consumption in Washington*, version 1.0 (WDOE 2011), Table C-4 (tribal-specific distributions weighted according to relative population) was chosen to represent the fish consumption rates of Washington tribal members. The data are shown in Table 8, column 1.

b. Adjust tribal population distribution to include salmon in proportion to their tribal population consumption rate and life history spent in fresh and estuarine waters. The composite tribal distribution is adjusted to exclude the time salmon spend in the off-shore marine environment. To estimate the fraction of salmon consumed by these tribes, data provided in WDOE's *Fish Consumption Rate Technical Support Document*, version 2 (WDOE 2013) were used, reproduced here as Table 9. The amount of anadromous fish as a percentage of the total fish and shellfish diet for these tribes ranges from 23% for the Suquamish Tribe to about 66% for the Squaxin Island Tribe. The Tulalip Tribe seafood diet is about 46% anadromous fish. Data for the Columbia River Inter-Tribal Fish Commission (CRITFC) tribes are not directly comparable to the other tribal data because the survey did not reflect any consumption of shellfish. Nonetheless, CRITFC tribes ate anadromous fish equivalent to about 48% of all harvested fish from all sources. If one assumes that the CRITFC tribes consume only small amounts of shellfish relative to finfish, then 48% represents an approximate maximum value for the CRITFC tribes. A simple average of these percentage values for each of the four tribes (46% anadromous fish) was used to make this adjustment.

Table 8 shows adjustments to the composite tribal FCR distribution. Briefly, the total tribal fish consumption distribution was multiplied by the fraction of salmon in the tribal fish diet (0.46) and the composite salmon LHF (0.318). This "waters of the state" adjusted salmon consumption rate was then added to the non-salmon consumption rate to generate the final tribal FCR distribution.

Table 8. Composite Distribution of Washington Tribal Fish Consumption Rates Weighted Based on Relative Population

	(1)	(2)	(3)	(4)	(5)
		(1) * 0.46	(1) * (1 - 0.46)	(2) * 0.318	(3) + (4)
	All Fish (g/d)[a]	Salmon (g/d)[b]	Non-Salmon (g/d)[c]	Fresh/Estuarine Apportioned Salmon (g/d)[d]	Final Washington Tribal Population FCR (g/d)[e]
mu	4.0083				
sigma	0.7158				
Mean	71.12	32.72	38.40	10.40	48.81
1%	10.41	4.79	5.62	1.52	7.14
5%	16.96	7.80	9.16	2.48	11.64
10%	22	10.12	11.88	3.22	15.10
25%	33.97	15.63	18.34	4.97	23.31
50%	55.05	25.32	29.73	8.05	37.78
75%	89.22	41.04	48.18	13.05	61.23
80%	100.55	46.25	54.30	14.71	69.01
85%	115.6	53.18	62.42	16.91	79.33
90%	137.77	63.37	74.40	20.15	94.55
95%	178.69	82.20	96.49	26.14	122.63
99%	291.03	133.87	157.16	42.57	199.73

[a] composite tribal distribution No. 6 from WDOE 2011, Table C-4, (tribal-specific distributions weighted according to relative population); assume 100% of tribal populations are consumers and all fish are from waters of the state
[b] component of all fish that is salmon [all fish x 0.46]
[c] component of all fish that is not salmon [all fish - salmon]
[d] consumption of salmon associated with waters of state based on composite residence time LHF [salmon x 0.318]
[e] final FCR [non-salmon + salmon fraction]

Table 9. Summary of Washington Tribal Fish Consumption Survey Data (g/day)

	Fish Source	50th %tile	Mean	75th %tile	90th %tile	95th %tile	% of All Fish at Mean
Tulalip Tribe							
All fish	All sources	44.5	82.2	94.2	193	268	100.0
Finfish	All sources	22.3	44.1	49.1	110	204	53.6
Shellfish	All sources	15.4	42.6	40.1	113	141	51.8
Non-anadromous	All sources	20.1	45.9	52.4	118	151	55.8
Anadromous	All sources	16.8	38.1	43.3	92.1	191	46.4
Squaxin Island Tribe							
All fish	All sources	44.5	83.7	94.4	206	280	100.0
Finfish	All sources	31.4	65.5	82.3	150	208	78.3
Shellfish	All sources	10.3	23.1	23.9	54	83.6	27.6
Non-anadromous	All sources	15.2	28.7	32.3	70.5	95.9	34.3
Anadromous	All sources	25.3	55.1	65.8	128	171	65.8
Suquamish Tribe							
All fish	All sources	132	214	284	489	797	100
Shellfish	All sources	64.7	134	145	363	615	63
Non-anadromous	All sources	102	169	219	377	615	79
Anadromous	All sources	27.6	48.8	79.1	133	172	23
CRITFC Tribes							
All finfish	All harvested	40.5	63.2	64.8	130	194	100
Non-anadromous	All harvested	20.9	32.6	33.4	67	99.9	52
Anadromous	All harvested	19.6	30.6	31.4	63.1	94.1	48

3. Development of an Overall Fish Consumption Rate Reflecting General Population and Tribal Fish Consumption

The general population and tribal population composite FCR distributions are combined to produce a single distribution for Washington. This is accomplished by weighting the two distributions according to the sizes of their respective populations. Population statistics reported in *Fish Consumption Rate Technical Support Document*, version 2 (WDOE 2013) were used for this purpose. The data are shown in Table 10, along with tribal and non-tribal weighting factors.

The final overall FCR distribution is shown in Table 11.

Table 10. Washington State Population Statistics (WDOE 2013)

Population	Numbers	Weighting Factors
Current total	6724540	
Adults	5143186	
Fish consuming adults	3805958	
Tribal	103869	
Adults (est. as 70%; assume 100% consumers)	73523	
Fish consuming non-tribal adults	3732435	0.981
Fish consuming tribal adults	73523	0.0193

Table 11. Final Overall Fish Consumption Rate Distribution for Washington State Including Consumption of Salmon Weighted to Reflect Bioaccumulation of Chemicals in Waters of the State Only Based on Salmon Life History Factors

Statistic	Tribal Population Composite FCR (g/d)[a]	General Population Composite FCR (g/d)[b]	Final Overall Washington FCR (g/d)[c]
mu			
sigma			
Mean	48.81	7.65	8.44
1%	7.14	0.37	0.50
5%	11.64	0.81	1.02
10%	15.10	1.22	1.49
25%	23.31	2.52	2.92
50%	37.78	5.17	5.80
75%	61.23	10.09	11.08
80%	69.01	11.76	12.87
90%	94.55	17.29	18.79
95%	122.63	23.03	24.95
99%	199.73	36.95	40.09

[a] final composite tribal distribution
[b] final general population distribution
[c] final composite distribution [(tribal x 0.019)+(gen pop x 0.981)]

Summary

A fish consumption rate distribution representative of the entire population of Washington State residents was developed. National FCR data published by EPA (USEPA 2002, 2011) were used as the basis for estimating FCRs for the general population, and tribal rate data published by WDOE (2011, 2013) were used for tribal consumption rates. The general population distribution was adjusted to reflect: (1) consumption of fish and shellfish from freshwater and near-shore marine habitats only; and (2) the portion of salmon consumed reflecting contaminants acquired by salmon in waters of the state. The tribal distribution was only adjusted to account for contaminants acquired by salmon in waters of the state. The two distributions were then combined using weighting factors representing the relative populations of each group. Table 12 provides a summary of the data and rationale used in developing this overall fish consumption rate distribution for Washington residents.

Table 12. Summary of Data and Rationale Used in Developing a Fish Consumption Rate Distribution for Residents of the State of Washington

	Fish Consumption Aspect	Data Source	Rationale	Comments
1a	Starting dataset for developing Washington-tailored general population FCR distribution	NHANES data from EPA's 2011 *Exposure Factors Handbook*, Table 10-12, Consumer-Only Intake of Total Finfish and Shellfish Combined (g/kg-day), Edible Portion, Uncooked Fish Weight, adjusted using NCI methodology	Used by EPA to establish default FCR rate, used by Florida to develop Florida-tailored FCR distribution; NCI methodology adjusts for short-term recall bias and bias associated with exclusion of fish consumers who did not report fish consumption on either of two survey events	There are no Washington-specific fish consumption data representing the entire population; this dataset reflects fish consumption rates nationally, consumers only, entire population
1b	Adjustment to exclude off-shore marine fish from NCI- NHANES distribution	USDA Continuing Survey of Food Intake by Individuals (CSFII)	Used by Florida to develop Florida-tailored FCR distribution	This adjustment is applied to entire NCI-NHANES distribution; adjusts distribution to reflect consumption of fish from freshwater and estuarine (near-shore marine) habitats only, per EPA guidance
1c	Adjustment to include portion of salmon consumed to account for contaminants acquired in waters of the state	See items 1c (i), (ii), and (iii) below	NHANES and CSFII survey data classify salmon as marine species; this adjustment 'adds back' a portion of salmon consumed based on (i) LHFs for each of five major species, (ii) relative fractions of each species consumed, and (iii) estimated fraction of salmon in total fish and shellfish diet of Washington residents	Adjustment is species-weighted composite salmon LHF multiplied by fraction of salmon in total fish and shellfish diet; value is multiplied by each percentile of the NCI-NHANES <u>total</u> fish consumption distribution; values are then added to NCI-NHANES freshwater and estuarine only distribution

	Fish Consumption Aspect	Data Source	Rationale	Comments
1c(i)	Salmon life history factor	Technical literature on species-specific behavior and life history	Development of LHFs for five major salmon species based on estimated time salmon spend in waters of the state as a fraction of total lifetime prior to return as adults for spawning	Approach may overestimate contaminant body burden acquired in waters of the state (e.g., salmon gain more than 95% of body mass in marine environment), so is believed to be conservative approach
1c(ii)	Salmon species relative consumption fractions	Suquamish tribal data as given in EPA's 2011 *Exposure Factors Handbook*, Table 10-104.	The only Washington-specific data on salmon species consumption rates; may not be representative of total state population	Relative rates for each salmon species used to weight LHFs to develop single composite LHF for all salmon
1c(iii)	Fraction of salmon in total general population fish and shellfish diet	EPA's 2011 *Exposure Factors Handbook*, Table 10-28, mean consumption rates for 64 species of fish from the 1994 to 1996; 1998 combined USDA CSFII survey data	Assumes data are representative of fish consumption for general population of Washington State	Based on these data, salmon fraction for general population consumer is 0.094 (9.4% of total fish and shellfish consumed)
2a	Starting dataset for developing Washington-tailored tribal population FCR distribution	*Fish Consumption Rates Technical Support Document, A Review of Data and Information about Fish Consumption in Washington*, Ver. 1.0 (WDOE 2011), Table C-4, (tribal-specific distributions weighted according to relative population)	Represents all tribal fish consumption survey results	Individual tribal survey distributions were weighted according to relative populations of each surveyed tribe

	Fish Consumption Aspect	Data Source	Rationale	Comments
2b	Adjustment to include portion of salmon consumed to account for contaminants acquired in waters of the state	See items 1c (i), (ii) above and 2b(i) below	NHANES and CSFII survey data classify salmon as marine species; this adjustment 'adds back' a portion of salmon consumed based on (i) LHFs for each of five major species, (ii) relative fractions of each species consumed, and (iii) estimated fraction of salmon in total fish and shellfish diet of surveyed Washington tribes	Adjustment is species-weighted composite salmon LHF multiplied by fraction of salmon in total fish and shellfish diet; value is multiplied by each percentile of composite tribal total fish consumption distribution; values then added to composite tribal non-salmon consumption rate distribution
2b(i)	Fraction of salmon in total tribal fish and shellfish diet	Tribal data presented in *Fish Consumption Rates Technical Support Document, A Review of Data and Information about Fish Consumption in Washington*, Public Review Draft, ver. 2.0, August 27, 2012	The only Washington-specific tribal data on salmon consumption rates as a fraction of total fish and shellfish consumption	Simple average of four tribal FCR surveys used to represent whole tribal population of state; value is 0.46, meaning that 46% of average tribal fish consumption consists of salmon and other anadromous fish
3	Develop population-weighted overall Washington FCR based on general population and tribal composite FCR distributions and Washington population data	General population and tribal composite FCR distributions as described in 1 and 2 above; Washington population data from *Fish Consumption Rates Technical Support Document, A Review of Data and Information About Fish Consumption in Washington*, ver. 2 (WDOE 2013)	Population-based weighting schemes provide a way to combine general population and tribal FCR data into a single distribution that represents all fish consumers	

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APPENDIX A

LIFE HISTORY FACTORS FOR PACIFIC SALMON (01-13-2014)

1.0 INTRODUCTION

One of the primary factors to consider in deciding whether to include salmon in a fish consumption rate (FCR) used in deriving Clean Water Act (CWA) human health water quality criteria is when/where salmon accumulate their ultimate body burden of the relevant chemical(s). Traditionally, EPA has recommended against including salmon in these FCRs because it was accepted that, for bioaccumulative chemicals, the majority of a chemical-specific body burden in a returning adult salmon is acquired in the Pacific Ocean (in the case of Pacific Northwest salmon), and not in the fresh and/or estuarine waters under jurisdictional control of a state. However, this assumption has been challenged as part of the ongoing process in Washington State, and various stakeholders have argued that salmon must be included in the FCR for various reasons, including the cultural importance of salmon to tribal and other residents of the state.

A review of the technical literature shows that there are sufficient (albeit limited) data to conclude that the vast majority of the body burden of bioaccumulative chemicals in adult Chinook salmon is acquired during the marine phase of that species' life history. The data were developed by various researchers who measured chemical-specific body burdens in both out-migrating juvenile fish and returning adults belonging to the same runs. In all cases where these kinds of data have been developed, the researchers have concluded that >95% of the body burdens were acquired in the marine phase of the Chinook life history (Cullon et al. 2009; O'Neill and West 2009). However, these data are specific to Chinook salmon, and because each species of salmon has a unique life history it may not be appropriate to assume that what holds for Chinook also holds for coho, sockeye, chum, or pink salmon. Thus, there is some uncertainty regarding where these other species acquire their ultimate body burdens of bioaccumulative chemicals.

In response to this uncertainty, the Washington Department of Ecology (WDOE) has proposed use of what this report will call life history factors (LHFs) as a means of apportioning total body burden in adult salmon between different phases of a salmon's life history. As proposed, these LHFs reflect the relative amount of time salmon spend in different environments or geographic locations, and would be used to apportion the ultimate body burden in returning adults between these environments or geographic locations. Subsequently, the fraction of the burden acquired in waters of the state could be used to adjust the actual consumption rate for salmon included in the FCR.

The assumption inherent in this model is that the body burden of bioaccumulative chemicals in returning adult salmon is a linear function of time. This is the basis for the site-use factors WDOE has proposed as a means of accounting for salmon consumption when developing human health benchmarks for sediment cleanups (WDOE 2012). Thus, there is precedent in Washington for this kind of apportionment, and WDOE has prepared a Technical Issue Paper (TIP) summarizing information on the life-histories of Chinook, coho, sockeye, chum, and pink salmon as part of developing this concept (WDOE 2013). However, WDOE did not identify specific numeric LHFs for each species. This paper takes this next step using WDOE's TIP as the primary information resource; other sources of information were used only in instances where there were clear gaps in the TIP.

For the purposes of this exercise, consistent with scope of the CWA, LHFs were developed for waters of the state. In this context, waters of the state include all fresh and estuarine waters, Puget Sound, and all marine waters within three miles of the Washington coastline.

Section 2 addresses development of species-specific LHFs for Pacific Northwest salmon based on residence time. Section 3 offers some discussion supporting the position that LHFs based on residence time overstate the significance of bioaccumulation during the early stages of salmon life history. LHFs based on where body mass is acquired (i.e., where salmon grow) are likely to provide a more accurate measure of where salmon acquire their ultimate cumulative body burdens of bioaccumulative chemicals, and Section 4 addresses development of these alternative mass-based LHFs.

2.0 LIFE HISTORY FACTORS BASED ON RESIDENCE TIMES

2.1 Chinook Salmon

Table A1 summarizes LHFs for stream- and ocean-type Chinook salmon and resulting composite LHFs for all Chinook.

2.1.1 *Stream-Type Chinook Salmon Life History*

Excerpts from Ecology's TIP are quoted as the basis for developing the LHFs listed in Table A1.

Page 5. "After emergence, stream-type Chinook spend a year or more in the river before migrating downstream."

Different LHFs were calculated using one and two years residence in freshwater.

Page 5. "Once entering the marine environment, stream-type Chinook spend very little time in the estuaries before migrating towards coastal waters."

In this analysis, residence in estuarine waters prior to migration to coastal waters is approximated as 15 days. This decision was informed by the residence time of ocean-type Chinook, which WDOE cites as being a few weeks (which we interpret to mean three weeks); i.e., stream-type Chinook spend <21 days in estuarine environments, and 15 days was assumed.

Page 6. "Further, juvenile salmonids do not limit their use of estuarine habitats to their natal estuaries, as juvenile salmonids have also been found to enter and utilize non-natal estuaries during their marine near shore migration."

WDOE provided no indication of how much time juvenile Chinook salmon spend in these near-shore environments, so LHFs were calculated ignoring this behavior.

Page 6. "Salmonids mature in oceanic and coastal waters from 1 to 6 years, although 2 to 4 years is more typical, before returning to their natal streams to spawn."

LHFs were calculated using two, three, and four years.

2.1.2 *Ocean-Type Chinook Life History*

Excerpts from Ecology's TIP are quoted as the basis for developing the LHFs listed in Table A1.

Table A1. Life History Factors for Chinook Salmon[a]

Type	Residence Time (days) FW[b]	Est.[b]	Marine[b]	Age at Spawing (days)	(years)	LHFs FW+Est.[c]	Marine	Notes[d]
Stream-Type	365	15	730	1110	3.0	0.342	0.658	"a year or more in the river before migrating downstream"; "spend very little time in the estuaries"; "2 to 4 years is more typical"
	730	15	730	1475	4.0	0.505	0.495	
	365	15	1095	1475	4.0	0.258	0.742	
	730	15	1095	1840	5.0	0.405	0.595	
	365	15	1460	1840	5.0	0.207	0.793	
	730	15	1460	2205	6.0	0.338	0.662	
Ocean-Type (immediate)	50	21	730	801	2.2	0.089	0.911	"migrates to ocean soon after yolk resorption"; "a few weeks in the estuary"
	50	21	1095	1166	3.2	0.061	0.939	
	50	21	1460	1531	4.2	0.046	0.954	
Ocean-Type (most common)	105	21	730	856	2.3	0.147	0.853	"migrate to marine habitats at 60 to 150 days post hatching"; "a few weeks in the estuary"
	105	21	1095	1221	3.3	0.103	0.897	
	105	21	1460	1586	4.3	0.079	0.921	
Ocean-Type (poor conditions)	365	21	730	1116	3.1	0.346	0.654	"juveniles remain in fresh water for a year"
	365	21	1095	1481	4.1	0.261	0.739	
	365	21	1460	1846	5.1	0.209	0.791	
Average Stream-Type	547.5	15	1095	1657.5	4.5	0.339	0.661	average freshwater residence assuming 3 y in marine habitat
Average Ocean-Type	105	21	1095	1221	3.3	0.103	0.897	"most common" life history assuming 3 y in marine habitat
LHFs for non-Puget Sound waters →						0.15	0.85	LHFs assuming 80% of Chinook are ocean-type fish; Puget Sound residency not incorporated (Sec 2.3)
LHFs for Puget Sound Waters only →						0.40	0.60	LHFs for Puget Sound <u>only</u> Chinook incorporating residency and assuming 80% are ocean-type fish (Sec 2.3)
Composite LHFs for all waters of the state →						0.30	0.70	state-wide composite LHFs incorporating residency of Puget Sound Chinook assuming 60% Puget Sound fish (Sec 2.3)

[a] all information extracted from WDOE's TIP (WDOE 2013)
[b] FW = freshwater; Est. = estuarine water; marine = marine water
[c] FW+Est. = time spent in waters of the state (combined time spent in freshwater plus estuarine water only)
[d] excerpts from WDOE's TIP in quotation marks

Page 5. WDOE (2012) describes three distinct behaviors (phases) for ocean-type Chinook fry:

1. The "immediate" phase – fish that migrate to the ocean "…soon after yolk resorption…"
2. The "most common" phase – the most common life history for ocean-type fry "…is to migrate to marine habitats at 60 to 150 days post hatching…"
3. The "poor conditions" phase – "During years of poor environmental conditions…ocean-type juveniles remaining in fresh water for a year, although this is relatively uncommon."

In this analysis, we assumed that the "immediate phase" spend 50 days in freshwater (an arbitrary number meant to include migration to the natal estuary), the "most common" phase spend 105 days (the average of the reported range) in freshwater, and the "poor conditions" phase spend 365 days in freshwater.

Page 5. "Once reaching the marine environment, they then spend a few weeks or longer rearing in the estuary."

An estuarine residence time of 21 days was used for all phases of ocean-type Chinook.

Page 6. "Salmonids mature in oceanic and coastal waters from 1 to 6 years, although 2 to 4 years is more typical, before returning to their natal streams to spawn."

LHFs were calculated using two, three, and four years.

2.1.3 *Discussion and Final LHF for Chinook Salmon*

As shown in Table A1, the LHFs for stream- and ocean-type Chinook differ. As a consequence, consumption of Chinook would, ideally, be broken out based on life history and the appropriate LHF applied to each type. Alternatively, if all Chinook are lumped together, composite LHFs are required. However, information on the relative fraction of the overall Chinook population that belong to each life history type are required to generate LHFs for lumped Chinook, and this information was not provided in the TIP.

According to Healey (1991), the ocean-type life history is "typical" of Pacific North American Chinook populations south of 56°N, which includes all of Washington and Oregon. More specifically, stream-type runs represent only 0 to 12% of Chinook runs in smaller rivers, and 14 to 48% of Chinook runs in larger rivers. However, Table 1 in Healey (1991) also indicates that 78% of Columbia River spawning runs and 88% of Sixes River (southern Oregon coast) runs are ocean-type. This information suggests that about 80% of Chinook salmon caught and consumed in Washington are ocean-type fishes. Thus, using the average stream- and ocean-type LHFs extracted from WDOE's TIP (Table 1), composite LHFs for Chinook salmon would be nominally 0.85 and 0.15 for marine and fresh plus estuarine waters, respectively, meaning that the LHF for waters of the state would be 0.15. However, this LHF does not account for a third life history not addressed by the TIP, which is Puget Sound residency throughout the full marine-phase of Chinook life history.

Puget Sound is known to support populations of resident Chinook and coho salmon (Chamberlin 2009; Rohde 2013). These fish spend the marine-phase of their life history in Puget Sound proper, meaning the LHF for waters of the state would be 1 for these specific fish. Based on information presented by WDOE (2013), 60% of the salmon harvested in Washington were caught in marine waters, and WDOE identified 60% of these as Puget Sound salmon. Of the 40% of salmon caught in freshwaters, WDOE estimated that 57% were harvested in Puget Sound streams. Thus, overall, approximately 60% ([0.6 x 0.6]+[0.4 x 0.57]) of the salmon harvested in Washington are estimated to originate from Puget Sound. Although not all these fish are Chinook, in this analysis we assume that this proportion applies to all salmon except pink salmon (100% of which are assumed to be Puget Sound fish); that is, we assume that 60% of the Chinook

caught and consumed in Washington are from runs originating in Puget Sound. Regardless, not all Puget Sound Chinook exhibit full residency in Puget Sound.

Although full residency is a well known phenomenon, there is very little information indicating what fraction of Puget Sound Chinook exhibit this life history. Chamberlin (2009) studied the role of multiple factors on the tendency of Puget Sound Chinook to exhibit full residency (in Puget Sound) and concluded that 30% of Puget Sound Chinook salmon display this behavior (i.e., 30% of Puget Sound Chinook have a waters of the state LHF of 1). Chamberlin's conclusion is generally consistent with that of O'Neill and West (2009), who estimated that full residency was exhibited by between 29 and 45% of Puget Sound Chinook. Here, Chamberlin's estimate is used to calculate a composite waters of the state LHF of 0.40 ([0.7 x 0.15]+[0.3 x 1]) specific to Puget Sound Chinook.

This value is notably larger than the waters of the state LHF for non-Puget Sound Chinook (0.15) but is only applicable to Puget Sound Chinook. For other Chinook (e.g., Columbia River runs), the appropriate waters of the state LHF remains 0.15. Based on the same information, a composite waters of the state LHF for all Chinook would be 0.3 ([0.4 x 0.15]+[0.6 x 0.4]). This final value is the appropriate waters of the state LHF for use when considering Chinook on a statewide basis.

2.2 Coho Salmon

Table A2 summarizes LHFs for coho salmon.

2.2.1 *Coho Salmon Life History*

Excerpts from WDOE's TIP are quoted as the basis for developing the LHFs listed in Table A2.

Page 7. "For populations in and around Washington State, returning adult Coho salmon are generally 3-year-olds, and spend approximately 18 months in fresh water and 18 months in marine habitats."

Page 7. "After emerging, the fry generally remain within freshwater streams for a year or two before migrating downstream."

LHFs were calculated assuming one and two year periods.

Page 8. "Emergence has been detected from March to July."

In this analysis we assume emergence in mid-April.

Page 8. "Although some fry migrate to marine waters soon after emergence, the majority disperse both up- and downstream, remaining in streams to rear as juveniles for one to two years before migrating downstream."

LHFs were calculated assuming one and two year periods.

Page 8. "Within this region, Coho smolts typically leave fresh water and migrate to marine habitats to enter the smolting process in the spring (April to June). Once entering marine waters, Coho smelts spend little time rearing in estuaries, instead migrating toward coastal waters."

Migration was assumed to begin in mid-May.

Page 8. "Although some Coho salmon move to offshore waters, typically subadults continue to feed and mature in these coastal waters of the northeast Pacific."

Page 8. "The majority of Coho originating from Washington streams migrate to coastal waters off Oregon and Washington, with low numbers occurring in Oregon and British Columbia waters."

Table A2. Life History Factors for Coho Salmon[a]

Residence Time (days)			Age at Spawing		LHFs		
FW[b]	Est.[b]	Marine[b]	(days)	(years)	FW+Est.[c]	Marine	Notes[d]
547.5		547.5	1095	3.0	0.500	0.500	"18 months in fresh water and 18 months in marine habitats"
395		471	866	2.4	0.456	0.544	"1y" in FW (mid-April emergence and mid-May migration to saltwater = 13 months) followed by 1, 2, or 3 "summers" in marine water (15.5 months = 2 summers)
395		836	1231	3.4	0.321	0.679	
395		1201	1596	4.4	0.247	0.753	
760		471	1231	3.4	0.617	0.383	"2y" in FW (mid-April emergence and mid-May migration to saltwater = 25 months) followed by 1, 2, or 3 "summers" in marine water (15.5 months = 2 summers)
760		836	1596	4.4	0.476	0.524	
760		1201	1961	5.4	0.388	0.612	
					0.47	0.53	average LHFs for 3.4 year old fish excluding Puget Sound residency (Sec 3.2)
LHFs for non-Puget Sound waters →					0.50	0.50	LHFs based on 18 months in marine water, a 3 y life span, and excluding Puget Sound residency (Sec 3.2)
LHFs for Puget Sound Waters only →					0.60	0.40	LHFs for Puget Sound <u>only</u> coho incorporating residency (Sec 3.2)
Composite LHFs for all waters of the state →					0.56	0.44	state-wide composite LHFs incorporating residency of Puget Sound coho assuming 60% Puget Sound fish (Sec 3.2)

[a] all information extracted from WDOE's TIP (WDOE 2013)
[b] FW = freshwater; Est. = estuarine water; marine = marine water
[c] FW+Est. = time spent in waters of the state (combined time spent in freshwater plus estuarine water only)
[d] excerpts from WDOE's TIP in quotation marks

Page 9. "While some adult male Coho salmon return after spending only one summer at sea, the majority of Coho return after spending two, and sometimes three, summers at sea. There are some run timing differences between coastal and inland Washington stocks of Coho salmon, but adults begin returning to estuaries and outlets of their natal streams from July to September."

In this analysis, we assume return in September, and LHFs were calculated assuming two and three summers at sea.

2.2.2 *Discussion and Final LHF for Coho Salmon*

The timing of specific events in the life history of coho is variable at the scale of months. This level of variability is significant if it is accepted that the majority of returning adults are around three years old. This variability is reflected in the various LHFs shown in Table A2, which shows LHFs for marine residency ranging from 0.383 to 0.679 for 3.4 year old fish, depending on whether it is assumed they spent one or two years in freshwater. However, the average of these two marine LHFs is 0.53, which is essentially the same as obtained by assuming that coho split their life between fresh and estuarine waters, or near-shore waters vs. marine waters. Thus, the final LHFs for coho salmon are taken as 0.5 and 0.5 for marine and fresh plus estuarine waters, respectively, meaning that the final LHF for waters of the state would be 0.5.

However, similar to Chinook, some fraction of Puget Sound coho salmon also exhibit full residency in Puget Sound proper (e.g., Rohde 2013), and for these fish the waters of the state LHF would be 1. Following the work of Chamberlin (2009) on Chinook salmon, Rohde (2013) attempted to characterize the relative fraction of Puget Sound coho exhibiting this life history, and estimated that 3.4% are true residents, 61.3% migrate outside Puget Sound, and the behavior of the remaining 35.3% is ambiguous. Assuming 50% of the ambiguous fish are in fact residents means that approximately 21% of Puget Sound coho exhibit full residency, and the waters of the state LHF for these fish is 1. The associated composite waters of the state LHF for all Puget Sound coho is 0.6 ([0.79 x 0.5]+[0.21 x 1]). For other coho (e.g., Columbia River runs) the appropriate waters of the state LHF remains 0.5. Following the analysis for Chinook (i.e., assuming that 60% of the coho caught in Washington are from Puget Sound runs), the composite statewide waters of the state LHF for coho salmon is 0.56 ([0.4 x .5]+[0.6 x 0.6]).

2.3 Sockeye Salmon

Table A3 summarizes LHFs for sockeye salmon.

2.3.1 *Sockeye Salmon Life History*

Excerpts from WDOE's TIP are quoted as the basis for developing the LHFs listed in Table A3.

Page 9. "Sockeye salmon have one of the most diverse patterns of life history among Pacific Northwest salmon species. For example, age at out-migration to marine systems from their natal streams not only varies between systems, and within systems, but can vary among related individuals."

Page 10. "The hatched alevin then take an additional 24 to 60 days to emerge from the gravel as fry, with warmer temperatures reducing the time for emergence. Sockeye salmon emerge as fry generally in April or May, with some variability associated with temperature."

In this analysis we assume emergence on May 1 (approximately 42 days post-hatch, meaning hatch in mid-March).

Table A3. Life History Factors for Sockeye Salmon[a]

Type	Residence Time (days)			Age at Spawing		LHFs		Notes[d]
	FW[b]	Est.[b]	Marine[b]	(days)	(years)	FW+Est.[c]	Marine	
Stream-Type	457		730	1187	3.3	0.385	0.615	to marine water at age 1; assume hatch mid-March, emergence by May 1 (42 days post-hatch), 1 y residence, and then out-migration (50 days); "limited" use of estuary
Stream-Type	457		1095	1552	4.3	0.294	0.706	
Stream-Type	457		1460	1917	5.3	0.238	0.762	
						0.306	0.694	average of all age fish
Ocean-Type	92		730	822	2.3	0.112	0.888	to marine water first year (assume hatch mid-March, emergence by May 1 (42 days), and immediate out-migration (50 days); "limited" use of estuary
Ocean-Type	92		1095	1187	3.3	0.078	0.922	
Ocean-Type	92		1460	1552	4.3	0.059	0.941	
						0.083	0.917	average of all age fish
Ocean-Type	457		730	1187	3.3	0.385	0.615	to marine water at age 1
Ocean-Type	457		1095	1552	4.3	0.294	0.706	
Ocean-Type	457		1460	1917	5.3	0.238	0.762	
						0.306	0.694	average of all age fish
Composite LHFs for all waters of the state →						0.19	0.81	composite LHFs assuming 50:50 split between stream- and ocean-type (92 days FW residence) (Sec 4.2)

[a] all information extracted from WDOE's TIP (WDOE 2013)
[b] FW = freshwater; Est. = estuarine water; marine = marine water
[c] FW+Est. = time spent in waters of the state (combined time spent in freshwater plus estuarine water only)
[d] excerpts from WDOE's TIP in quotation marks

Page 10. "Regarding their entry into marine waters, two types of sockeye salmon occur: the ocean-type (or sea-type) that migrates to marine waters in the first year of their life, and the stream-type that may rear in rivers and lakes for a year or more before migrating to marine habitats."

LHFs were calculated for both scenarios. In all cases, it was assumed that out-migration peaks on May 1.

Page 10. "Juvenile sockeye in Washington generally migrate from their nursery lakes to marine habitats in March and continuing through June, with peak out-migration occurring in April and May. Upon entering marine waters, estuarine use by juvenile sockeye salmon (smolts at this point) is limited, although some ocean-type sockeye may use these habitats before migrating toward coastal waters."

Here we assume peak migration occurs on May 1 for both ocean- and stream-type, and we assume this migration takes 50 days.

Page 10. "Sockeye spend 2 to 4 years at sea before returning to their natal systems to spawn."

In this analysis, LHFs were calculated using two, three, and four years.

2.3.2 *Discussion and Final LHF for Sockeye Salmon*

LHFs for stream-type and ocean-type sockeye differ only if it is assumed that ocean-type fish out-migrate immediately following emergence. If these ocean-type fish rear in freshwater for a full year after emergence, they effectively become stream-type fish with respect to their LHF. However, WDOE gives no information indicating what fraction of these ocean-type fish exhibit this life history. As a consequence, this life history for ocean-type fish is ignored.

WDOE's TIP is also mute on what fraction of sockeye salmon exhibit stream- vs. ocean-type life histories. Likewise, no information regarding what fraction of each type spends two, three, or four years at sea was provided in the TIP. As a consequence, LHFs for each life history type were calculated as the average of the LHFs for fish spending two, three, and four years at sea. Subsequently, composite LHFs were calculated assuming a 50:50 split between stream- and ocean-type fish. The resulting composite LHFs are 0.81 and 0.19 for marine and fresh plus estuarine waters, respectively, meaning that the final statewide composite waters of the state LHF is 0.19.

2.4 Chum Salmon

Table A4 summarizes LHFs for chum salmon.

2.4.1 *Chum Salmon Life History*

Excerpts from WDOE's TIP are quoted as the basis for developing the LHFs listed in Table A4.

Page 11. "Similar to pink salmon or ocean-type Chinook, juvenile chum migrate from their freshwater redds to marine waters almost immediately after emergence."

Page 11. "The alevins remain in the gravel another 30 to 50 days, until their yolk sac is absorbed."

Here we assume 40 days.

Table A4. Life History Factors for Chum Salmon[a]

Residence Time (days)			Age at Spawing		LHFs		
FW[b]	Est.[b]	Marine[b]	(days)	(years)	FW+Est.[c]	Marine	Notes[d]
121	42	932	1095	3.0	0.149	0.851	fish migrate to ocean after minimal residence in estuarine waters
121	42	1297	1460	4.0	0.112	0.888	
					0.130	0.870	average of 3 and 4 year old fish
121	426.5	547.5	1095	3.0	0.500	0.500	fish stay in Hood Canal/Puget Sound until age 1.5 y (this time in coastal marine water assigned to "Est")
121	426.5	912.5	1460	4.0	0.375	0.625	
					0.438	0.563	average of 3 and 4 year old fish
LHFs for non-Puget Sound waters →					0.13	0.87	LHFs for non-Puget Sound chum based on average age fish (Sec 5.2)
LHFs for Puget Sound waters only →					0.28	0.72	LHFs for Puget Sound only chum using average age fish and assuming 50:50 split between two life histories (Sec 5.2)
Composite LHFs for all waters of the state →					0.22	0.78	statewide composite LHFs assuming 60% Puget Sound fish (Sec 5.2)

[a] all information extracted from WDOE's TIP (WDOE 2013)
[b] FW = freshwater; Est. = estuarine water; marine = marine water
[c] FW+Est. = time spent in waters of the state (combined time spent in freshwater plus estuarine water only)
[d] excerpts from WDOE's TIP in quotation marks

Page 11. "Most chum salmon fry spend only a few days to a few weeks rearing in fresh water before migrating toward marine habitats from March to May. A much smaller number of fry may rear in freshwater streams but migrate to marine waters by the end of their first summer."

This "much smaller number" of fry is excluded from this analysis, and the post-hatch time in freshwater prior to out-migration is assumed to be 21 days ("a few weeks"). Out-migration is assumed to peak on April 1.

Page 11. "Chum salmon utilize estuarine habitats for a few more weeks before migrating to coastal, then offshore waters."

This suggests estuarine residence is ≈21 days.

Page 12. "Most chum fry enter estuaries by June and leave them by mid to late summer."

This appears to conflict with the statement (page 11) that chum utilize estuarine habitats for a "few more weeks." Thus, this analysis assumes arrival in June and a six week (42 days) residence in estuarine waters (i.e., fish leave natal estuaries in mid-July). This means that migration time to the natal estuary is assumed to be two months (60 days).

Page 12. "The Hood Canal shoreline is said to serve as a nursery and rearing habitat for a significant portion of all chum salmon originating from Washington State rivers."

WDOE gives no information on the amount of time these fish spend in this habitat. However, the indication that a significant portion of chum salmon manifest this life history means they should be accounted for in any LHFs, and our analysis assumes that 50% of Puget Sound chum exhibit this behavior.

Page 12. "A number of age 2 chum salmon do occur within Puget Sound waters, although the absence of age 3 chum suggests that all chum salmon spend some time rearing in the Pacific Ocean."

It is not clear what age 2 means (e.g., in the second year of life, i.e., 1.01 years; over 2 years old, i.e., in the third year of life). In this analysis, it is assumed that these fish move out of Puget Sound at age 1.5 years (547.5 days old). This assumption concerning residence time is also meant to encompass Puget Sound fish that utilize Hood Canal for rearing.

Page 12. "In general, chum salmon originating from Washington streams and rivers, and rearing in the open ocean, do not return as mature adults until age 3 or 4."

LHFs were calculated assuming both three and four years.

2.4.2 *Discussion and Final LHF for Chum Salmon*

Table A4 gives LHFs for three and four year old chum assumed to migrate to marine waters after minimal residence in estuarine waters (assumed as 42 days) following 121 days in freshwater. These LHFs are relevant to chum originating outside of Puget Sound/Hood Canal. For these fish, the waters of the state LHF is estimated to be 0.13 (average of three and four year old fish).

For Puget Sound/Hood Canal chum, one important unknown is the fraction of the total population spending "additional" time rearing in Hood Canal/Puget Sound prior to migrating to the Pacific Ocean proper, and just exactly how much time they spend in these waters prior to this final out-migration. As noted, we assume these fish migrate to the Pacific Ocean at age 1.5 years (547.5 days). This corresponds to 121 days in freshwater followed by 426.5 days in estuarine waters and Hood Canal/Puget Sound combined, and Table A4 gives LHFs for age three and four year old Puget Sound chum according to these assumptions. However, not all Puget Sound chum exhibit this life history. Because the TIP gives no information indicating what fraction of Puget Sound fish follow this life history, we have arbitrarily

assumed 50%. Thus, the final LHF for Puget Sound chum is a composite of the two life histories equally weighted. The resulting LHFs are 0.72 and 0.28 for marine and fresh plus estuarine waters, respectively, meaning that the waters of the state LHF for Puget Sound chum is 0.28 ([0.5 x 0.13]+[0.5 x 0.438]).

Composite LHFs for statewide use were calculated assuming that 60% of the chum salmon harvested in Washington are Puget Sound fishes. The resulting values are 0.78 and 0.22 for marine and fresh plus estuarine waters, respectively, meaning that the statewide composite waters of the state LHF for chum salmon is 0.22 ([0.4 x 0.13]+[0.6 x 0.28]).

2.5 Pink Salmon

Table A5 summarizes LHFs for pink salmon derived from the information provided by WDOE (2013).

2.5.1 *Pink Salmon Life History*

Excerpts from WDOE's TIP are quoted as the basis for developing the LHFs listed in Table A5.

Page 13. "Pink salmon only live for 2 years, with very little variability."

Page 13. "As pink salmon adults spawn near river mouths, and fry migrate downstream immediately after emergence, this salmon species spends the least amount of time in fresh water."

The fact that pink salmon spawn near the mouth of their natal river suggests that the time required for migration to estuarine waters is minimal. This analysis assumes migration takes 10 days.

Page 13. "Although some smaller coastal and Columbia River runs occur, within Washington State two of the rivers supporting the largest pink salmon runs are the Snohomish and Puyallup."

This statement is consistent with essentially all pink salmon in Washington State originating from Puget Sound.

Page 14. "Once the yolk sac is depleted, the alevins emerge as fry some 41 to 64 days (average 52 days) post hatching."

The 52 day average is used herein.

Page 14. "There is little or no fresh water rearing as pink salmon fry migrate seaward upon emergence from the gravel, and so their downstream migration also occurs in March and April."

Based on this and other statements in WDOE's TIP, migration was assumed to begin immediately following emergence.

Page 14. "Pink salmon originating from Puget Sound and Hood Canal streams and rivers appear to use near shore areas extensively for early rearing during their first few weeks of entry into marine habitats."

This suggests nominally 21 days (a "few weeks") in estuarine waters.

Page 14. "While little is known about their behavior as the fry are exiting Puget Sound proper, Hiss (1994, as cited in Hard et al 1996) found that fry occurrence in Dungeness Bay (near Sequim) peaked in April and they were gone by late May."

Assuming that peak migration manifests on April 1, the observation that fry are no longer present in Dungeness Bay by late May suggests two months (60 days) residence in near-shore waters of Hood Canal/Puget Sound prior to out-migration to the Pacific Ocean.

Table A5. Life History Factors for Pink Salmon[a]

Residence Time (days)			Age at Spawing		LHFs		
FW[b]	Est.[b]	Marine[b]	(days)	(years)	FW+Est.[c]	Marine	Notes[d]
62	106.5	561.5	730	2	0.231	0.769	fry emerge 52 days post-hatch; estimate 10 days to migrate to estuary for a total of 62 days in FW; 3.5 months in estuary/near-shore waters prior to migration to marine waters; 2 y total life span
183		547	730	2	0.251	0.749	based on 18 months rearing in marine water and 24 month life span
LHFs for all waters of the state[e]					0.24	0.76	average LHFs

[a] all information extracted from WDOE's TIP (WDOE 2013)
[b] FW = freshwater; Est. = estuarine water; marine = marine water
[c] FW+Est. = time spent in waters of the state (combined time spent in freshwater plus estuarine water only)
[d] excerpts from WDOE's TIP in quotation marks
[e] all pink salmon assumed to be Puget Sound fish

Page 14. "Findings suggest that most out-migrating pink salmon enter the open ocean by late summer or early fall."

This suggests residence in estuarine waters for more than two months.

Page 14. "However, like some Chinook, and Coho, a small portion of the pink salmon population appears to adopt residency in Puget Sound for the marine phase of the life cycle."

WDOE gives no information on what fraction of pink salmon exhibit this behavior.

Page 14. "Once reaching estuarine and marine habitats, pink salmon migrate towards the open ocean within the first couple of months. By September the majority of pink salmon migrate hundreds of miles out in the open sea to grow and mature."

Assuming migration from freshwater to estuarine water peaks on April 1 suggests that pink salmon spend anywhere from two to five months in estuarine (near-shore) waters of Hood Canal/Puget Sound prior to out-migration to the Pacific Ocean. In this analysis, we assume an average of 3.5 months (106.5 days).

Page 14. "They spend approximately eighteen months rearing in the open ocean before their eastward migration to their natal streams and rivers."

LHFs were calculated assuming 18 months in marine waters and a 24 month total life span.

2.5.2 *Discussion and Final LHF for Pink Salmon*

Table A5 gives two sets of LHFs based on the information presented by WDOE (2013). The difference between these two estimates is minimal, and the final LHFs are taken as the mean of the two. Thus, the resulting LHFs for pink salmon are 0.76 and 0.24 for marine and fresh plus estuarine waters, respectively. The final LHF for pink salmon reflecting time spent in waters of the state is 0.24.

For pink salmon that spend their marine phase in Puget Sound, the resulting LHF reflecting time in waters of the state would be 1. However, no information on what fraction of pink salmon manifest this life history was found, while WDOE (2013) noted that only a "small portion" of the overall pink salmon population exhibit Puget Sound residency. As a consequence, this full residency life history is not accounted for in the final waters of the state LHF.

2.6 Composite Residency-Based LHF for all Washington Salmon

Sections 2.1 through 2.5 address development of LHFs for individual salmon species based on residence times. However, there may be circumstances in which a single composite LHF for all Washington salmon will be required. One approach to developing such a composite LHF is to sum the species-specific LHFs after weighting each by a factor reflecting species-specific consumption rates of Washington consumers. One source of these consumption rates is EPA's Exposure Factor Handbook (USEPA 2011), which gives species-specific consumption rates for adult members (consumers only) of the Suquamish Tribe in Table 10-104. Although this tribe consumes more shellfish than other tribal data would suggest, it was assumed that the relative amounts of the different salmon species consumed are representative of Washington consumers generally, including high-end tribal consumers. The data from EPA's table is reproduced in part as Table A6 herein, which also shows generation of a single composite LHF for salmon in general (0.32) based on the species-specific LHFs.

A composite salmon LHF could be developed based on other information such as commercial landings, but such data do not necessarily reflect consumption habits of Washington residents.

Table A6. Derivation of Composite Residency-Based Life History Factor for All Salmon Species based on Tribal Consumption Pattern

	Tribal Consumption Data[a]				Species-Specific LHFs	
Species	N	Mean (g/d)	n x Mean (g/d)	Diet Fraction at Mean[b]	LHF[c]	Consumption Weighted
Chinook (King)	63	0.200	12.6	0.294	0.300	0.088
Sockeye	59	0.169	9.971	0.233	0.560	0.130
Coho	50	0.191	9.55	0.223	0.194	0.043
Chum	42	0.242	10.164	0.237	0.222	0.053
Pink	17	0.035	0.595	0.014	0.241	0.003
			composite LHF for salmon		→	0.318

[a] consumption data for Suquamish Tribe from Table 10-104 in USEPA 2011
[b] fraction of overall salmon consumption attributable to each species
[c] species-specific LHFs from Sections 2.1 to 2.5, Tables A1 to A5

3.0 DISCUSSION OF LIFE HISTORY FACTORS BASED ON RESIDENCE TIMES

As seen in Section 2, LHFs for Washington salmon can be developed based on residence time. However, in addition to uncertainty regarding residence times of different salmon species (or specific runs) in different environments or geographic locations, the available data also manifest a high degree of variability. Thus, the resulting LHFs must be considered gross approximations. Despite this, there are factors that inform the potential for bias in the residence time LHFs presented in Section 2, and these factors suggest that, in general, residence time LHFs overstate the magnitude of bioaccumulation in early life stages of salmon life history.

One such factor is, ironically, time. This results because bioaccumulation is a reversible process, meaning that organisms are accumulating and depurating bioaccumulative chemicals simultaneously. Indeed, it is the ratio (accumulation rate/depuration rate) that underpins chemical- and organism-specific bioaccumulation factors. Once an organism moves from one environment (geographic location) to another, the probability that the specific molecules of a chemical acquired in the first environment/location will depurate increases with the time spent in the second environment/location. This probability increases when the first environment/location is more contaminated than the second, which is the exact scenario relevant to Puget Sound salmon that spend time in the Pacific Ocean proper. Apportioning body burdens based on residence time thus tend to overstate the contribution of accumulation during the early life stages to the ultimate body burden in returning adult Puget Sound salmon.

Beyond this, the assumption that an organism acquires bioaccumulative chemicals at a constant rate is analogous to assuming a fixed bioaccumulation factor. This assumption might hold for an organism that is static, that is, an organism that is not undergoing any physiological changes, feeds at a fixed trophic level, and exhibits either no growth or a constant rate of growth, but it is clearly a gross oversimplification for salmon, which exhibit extremely complex life histories. Thus, a more appropriate basis for apportioning when/where bioaccumulative chemicals are acquired might be relative growth, that is, when/where salmon acquire body mass. Section 4 describes an initial attempt to develop such LHFs.

4.0 LIFE HISTORY FACTORS BASED ON GROWTH

The literature contains many statements (e.g., Quinn 2005) to the effect that salmon acquire the majority of their body mass during the marine phase of their life cycle; that is, while feeding in the ocean (or Puget Sound for true resident fish). For this analysis, the generalized summary of body mass presented by Quinn (2005) is taken as representative; these data are summarized in Table A7, which also gives nominal mass-based LHFs reflecting the relative body masses of out-migrating smolt and returning adult salmon.

Table A7. Generalized Weights of Salmon as they Enter the Ocean and as Returning Adults[a]

	Chinook	Coho	Sockeye	Chum	Pink
Smolt weight (g)	5-18	18	10	0.4	0.22
Adult weight (kg)	7.22	3.02	2.69	3.73	1.63
LHF[b]	0.00249	0.00596	0.00372	0.00011	0.00013

[a] from Quinn 2005, Table 16.3
[b] calculated as simple ration (smolt/adult)

By definition (Quinn 2005), smolts are the final stage in salmon development prior to migration to true marine waters. This means the difference in body mass between smolt and adult fish reflects growth in marine waters, and the information provided in Table A7 indicates that all five species of Pacific Northwest salmon acquire >99% of their adult body mass during the marine phase of their life history. Thus, if it is assumed that these fish spend this portion (the marine phase) of their life outside waters of the state, the mass-based LHFs given in Table A7 are the relevant waters of the state LHF. However, some salmon spend a portion of their marine life history in waters of the state. Unfortunately, as noted (Section 3), residence time cannot be used to apportion growth among different habitats or geographic locations. Thus, without higher resolution mass data (i.e., measured mass of fish at multiple ages corresponding to species-specific shifts in habitat usage), the only distinction that can be made is between those fish that exhibit nominally full residency in waters of the state (i.e., Puget Sound) during their marine phase and those that exhibit full residency in the Pacific Ocean during this phase. Adjustments to the mass-based LHF given in Table A7 reflecting this life history (full residency in Puget Sound) are discussed on a species-specific basis.

4.1 Chinook Salmon

Based on the analysis presented in Section 2.1.3, approximately 60% of the salmon, including Chinook, are caught and consumed in Washington are Puget Sound fish. Of these Puget Sound Chinook, about 30% are resident fish. Thus, 18% of all Chinook (0.6 x 0.3) are Puget Sound residents which, by definition, have an LHF equal to 1. For the remaining 82%, the default mass-based LHF is that given in Table A7. Thus, the single composite mass-based LHF for Chinook salmon reflecting waters of the state is 0.182 ([0.82 x 0.00249]+[0.18 x 1]).

4.2 Coho Salmon

Following the analysis for Chinook, 60%of coho salmon are considered to be Puget Sound fish, and 21% of these are assumed to be full time residents of Puget Sound (Section 2.2.2). Thus, 13% (0.6 x 0.21) of all coho are Puget Sound residents which, by definition, have a waters of the state LHF equal to 1. For the remaining 87%, the default mass-based LHF is that given in Table A7. Thus, the single composite mass-based LHF for coho reflecting waters of the state is 0.135 ([0.87 x 0.00596]+[0.13 x 1]).

4.3 Sockeye Salmon

WDOE's TIP gives no information on what fraction of Puget Sound sockeye salmon exhibit full residency in Puget Sound, so there is no basis for parsing sockeye as Puget Sound or non-Puget Sound fish. This means that the only mass-based LHF for sockeye is that given in Table A7. Thus, the single mass-based LHF for Sockeye salmon reflecting waters of the state is 0.00372.

4.4 Chum Salmon

As discussed in Section 2.4.2, some chum spend some time rearing in Hood Canal/Puget Sound prior to migrating to the Pacific Ocean. However, as also discussed (Section 4.0), without data there is no way to identify the fraction of ultimate adult body mass chum acquire during this period. Beyond this, the TIP provides no information suggesting any chum salmon take up full residency in Puget Sound. Thus, there

is no basis for modifying the mass-based LHF for chum given in Table A7, meaning that the final mass-based LHF for chum salmon reflecting waters of the state is 0.00011.

4.5 Pink Salmon

As noted in WDOE's TIP (Section 2.5.1 herein), some pink salmon spend some time in near-shore marine waters rearing prior to completing migration to the Pacific Ocean. However, as discussed (Section 4.0), without data there is no way to identify the fraction of ultimate adult body mass these fish acquire during this period. Beyond this, the TIP states that only "a small portion of the pink salmon population appears to adopt residency in Puget Sound for the marine phase of the life cycle." Thus, there is no basis for modifying the mass-based LHF for pink salmon given in Table A7, meaning that the final mass-based LHF for pink salmon reflecting waters of the state is 0.00013.

4.6 Composite Mass-Based LHF for all Washington Salmon

Table A8 summarizes calculation of a single composite mass-based LHF for all Washington Salmon according to Section 2.6.

Table A8. Derivation of Composite Mass-Based Life History Factor for All Salmon Species based on Tribal Consumption Pattern

	Tribal Consumption Data[a]				Species-Specific LHFs	
Species	N	Mean (g/d)	n x Mean (g/d)	Diet Fraction at Mean[b]	LHF[c]	Consumption Weighted
Chinook (King)	63	0.200	12.6	0.294	0.182	0.053
Sockeye	59	0.169	9.971	0.233	0.135	0.031
Coho	50	0.191	9.55	0.223	3.72×10^{-3}	8.28×10^{-4}
Chum	42	0.242	10.164	0.237	1.10×10^{-4}	2.61×10^{-5}
Pink	17	0.035	0.595	0.014	1.30×10^{-4}	1.80×10^{-6}
			composite mass-based LHF for salmon		→	0.086

[a] consumption data for Suquamish Tribe from Table 10-104 in USEPA 2011
[b] fraction of overall salmon consumption attributable to each species
[c] species-specific LHFs from Sections 4.1 to 4.5

5.0 REFERENCES

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