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Washington State Department of Ecology
PO Box 47600
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RE: Comments on Proposed Human Health Criteria and Implementation Tools Rule Proposal dated January 12, 2015

The National Council for Air and Stream Improvement, Inc. (NCASI) is an independent, nonprofit membership organization that provides technical support to the forest products industry on a wide range of environmental issues. An important part of our mission is to help ensure that regulatory decision making is based on sound science. In this capacity, NCASI reviewed the January 2015 *Proposed Human Health Criteria and Implementation Tools Rule Proposal*.

We appreciate Ecology's efforts to carry out this multi-year rule making process in a thorough and transparent manner. In particular, we found Ecology's Policy Forum to be an excellent process for educating the public on the many science and policy considerations that go into developing water quality criteria. While we recognize that most of the decisions made as part of this rule making are policy choices, good policy should be based on good science. To that end, we offer the following comments.

Ecology has based the proposed criteria on a fish consumption rate (FCR) of 175 g/day as an average over a 70 year lifetime. However, this choice does not appear to be based on available data, which indicate that 175 g/day overstates consumption by the general population (by an order of magnitude) as well as the great majority of tribal members in Washington. Ecology's own analysis of tribal fish consumption study data (Fish Consumption Rates Technical Support Document, Publication no. 11-09-050, September 2011) indicates that the claim made in this proposal that 175 g/day is "*representative of average FCRs*" for Washington's tribal populations is incorrect. Rather, as discussed below, it represents approximately the 95^{th} percentile tribal consumption rate. Thus, Ecology is proposing criteria based on the consumption rates of a few of the highest consuming residents in the state. Coupled with Ecology's selected values for other risk management factors (1×10^{-5} excess lifetime cancer risk for carcinogens and a hazard quotient equal to 1.0 for non-carcinogens) that EPA considers appropriately protective of general populations, a FCR of 175 g/day yields water quality criteria that are clearly protective of high consuming populations well beyond what EPA has historically considered sufficient.

Given this situation, we believe that Ecology should provide some technical justification for its FCR selection. NCASI performed an analysis, using data provided by Ecology (shown in Table 1 in Attachment A) which shows that the average consumption rate based on Washington tribal study data only is approximately 71 g/day and that 175 g/day is approximately equivalent to the 95th percentile tribal consumption rate. Thus, if Ecology intended to select a FCR reflecting "average" consumption of all fish (including all salmon and store-bought fish) by tribal populations based on the available studies, 71 g/day would be the appropriate value.

However, as NCASI has noted previously, the decision to include all salmon in the FCR is not based on good science because the vast majority of the contaminants found in these fish are accumulated in marine waters outside of state jurisdiction. NCASI has developed an alternative tribal FCR distribution including salmon at a rate nominally reflecting accumulation of pollutants by salmon in waters of the state only (Table 1 in Attachment A) based on estimated life history factors for each species. The resulting distribution has an arithmetic mean of approximately 49 g/day. As discussed in Attachment A (Sections 3 and 4), we believe that this value also overstates average tribal member exposure to chemicals accumulated by salmon in state waters. NCASI believes that Ecology should use this kind of science-based analysis of readily available data to select a fish consumption rate for use in developing water quality criteria. It is also worth noting that 49 g/day is conservative (by a factor of 2.8) compared to EPA's default recommended FCR for the general population of 17.5 g/day, which represents the 90th percentile fish consumption rate.

NCASI also notes that Ecology's use of deterministic calculations using upper percentile (conservative) values for the FCR and other exposure factors yields water quality criteria whose actual level of protection greatly exceeds that needed to adequately protect all residents of the state, including the tribal populations. Use of probabilistic risk assessment (PRA) using data representing the entire statewide population (including Tribes) avoids this problem, which is known as compounded conservatism. Compounded conservatism results when single point estimates for fish consumption, drinking water consumption, and other risk management and exposure factors, each of which represents a conservative selection, are multiplied together to calculate water quality criteria. The resulting criteria can be so stringent that they protect against human exposure scenarios that would never occur. In contrast, PRA is more transparent in that it makes use of more available data and uses data distributions that represent the exposure behaviors of all residents. Given that the computational tools needed to perform a PRA analysis are readily available and easy to use, and that data for fish consumption rates and other human exposure factors representing all Washington residents have already been compiled, Ecology should use a probabilistic approach to develop its water quality criteria. The attached document, *Derivation of Human Health-Based Ambient Water Quality Criteria: A Consideration of Conservatism and Protectiveness Goals,* is a peer-reviewed, copyrighted article recently approved for publication in the journal ***Integrated Environmental Assessment and Management***, that expounds on the problem of compounded conservatism and ways to avoid it.

Finally, despite the concerns outlined herein, we would again like to express our appreciation to Ecology for its sustained efforts to carry out this rule making in a highly professional and transparent manner.

Sincerely,

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ATTACHMENT A

DEVELOPMENT OF A FISH CONSUMPTION RATE DISTRIBUTION FOR WASHINGTON'S GENERAL TRIBAL POPULATION

Washington State Department of Ecology (WDOE) has presented results from surveys characterizing fish consumption by the Tulalip, Squaxin, Suquamish, and Columbia River (Nez Perce, Umatilla, Warm Springs, and Yakama) tribes. WDOE used these data to develop a composite fish consumption rate (FCR) distribution by weighting the individual (tribal-specific) distributions based on relative populations. The resulting composite distribution was presented as Scheme 6 in Table C-4 of *Fish Consumption Rates Technical Support Document: A Review of Data and Information about Fish Consumption in Washington*, ver. 1.0 (WDOE 2011). This distribution, shown in Column 1 in Table 1, represents all fish consumption by the general tribal population of Washington State.

Table 1. Derivation of Fish Consumption Rate (FCR) Distribution for the General Tribal Population of Washington State (g/d)

	[1]	[2] [1] * 0.46	[3] [1] * (1 - 0.46)	[4] [2] * 0.314	[5] [3] + [4]
	All Fish[a]	Salmon[b]	Non-Salmon[c]	Fresh/Estuarine Apportioned Salmon[d]	Final Washington Tribal Population FCR[e]
mu	4.0083				
sigma	0.7158				
Mean	71.12	32.72	38.40	10.27	48.68
1%	10.41	4.79	5.62	1.50	7.13
5%	16.96	7.80	9.16	2.45	11.61
10%	22	10.12	11.88	3.18	15.06
25%	33.97	15.63	18.34	4.91	23.25
50%	55.05	25.32	29.73	7.95	37.68
75%	89.22	41.04	48.18	12.89	61.07
80%	100.55	46.25	54.30	14.52	68.82
85%	115.6	53.18	62.42	16.70	79.12
90%	137.77	63.37	74.40	19.90	94.30
95%	178.69	82.20	96.49	25.81	122.30
99%	291.03	133.87	157.16	42.04	199.19

[a] composite tribal distribution No. 6 from WDOE 2011, Table C-4 (tribal-specific distributions weighted according to relative population); assumes 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 life history factor (salmon x 0.314)
[e] final FCR (non-salmon + salmon fraction)

The distribution in Column 1 of Table 1 reflects consumption of all fish (including salmon) and seafood reported by the surveyed populations regardless of source. Under these conditions, the mean tribal FCR specific to Washington's tribal population is 71 g/d and the 95th percentile FCR is 179 g/d (Table 1). However, even though all surveyed tribal populations reported that a high percentage (62-96%) of total consumption was of locally harvested organisms (e.g., WDOE 2013), these consumption rates may include store-bought fish and so may overstate consumption of organisms harvested from waters of the state.

Inclusion of salmon in this FCR distribution (Table 1, column 1) is controversial because the majority of the body burden of bioaccumulative chemicals found in returning (adult) salmon is accumulated in the oceans, not in freshwater. Thus inclusion of salmon in any FCR overstates exposure to pollutants sourced within Washington State, and the effect of including salmon in an FCR used to calculate human health water quality criteria is to set goals that are unattainable by actions that Washington State can take on its own.

WDOE (2013) has provided data sufficient to estimate the fraction of tribal-specific FCRs contributed by consumption of salmon (summarized in Table 2). The amount of salmon (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, with an arithmetic mean of 46%. As summarized in Columns 2 and 3 of Table 1, this mean value was used to back out consumption of salmon from the general FCR distribution given in Column 1 of that table; that is, Column 3 in Table 1 gives the general tribal FCR distribution excluding all salmon.

Table 2. 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[a]							
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[b]							
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[c]							
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[d]							
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

[a] WDOE 2013 Table 23
[b] WDOE 2013 Table 24
[c] WDOE 2013 Table 26
[d] WDOE 2013 Table 21

The FCR distribution in Column 3 of Table 1 does not include consumption of any salmon, and so does not account for tribal exposure to whatever fraction of the ultimate pollutant body burden in returning adult fish might have been acquired as juveniles in fresh and/or estuarine (F/E) waters of the state (e.g., Hope 2012). WDOE anticipated this issue and proposed use of site-use factors based on residence time as a means of apportioning the fraction that might be accumulated in F/E vs. offshore waters (WDOE 2011, 2013). To this end, NCASI undertook a detailed analysis of salmon life histories (Appendix A), which resulted in species-specific life-history factors (LHFs, Table 3) representing the fraction of total pollutant body burden in returning adult fish acquired in F/E waters of Washington State.

Table 3. Life History Factors for Different Salmon Species and Different Waters Based on Residence Times in Waters of the State[a]

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

[a] see Appendix A

To obtain a single composite LHF for salmon in general, the species-specific statewide composite LHFs in Table 3 were combined after weighting based on the amounts of each species consumed by members of the Suquamish Tribe (USEPA 2011). This derivation is summarized in Table 4, and resulted in a single statewide LHF of 0.314. The composite LHF was then used to estimate the fraction of the pollutant body burden present in returning (adult) salmon that might have been acquired during time spent in waters of the state. This fraction was added back to the non-salmon FCRs to obtain a final FCR distribution for the general tribal population of Washington State (Column 5 in Table 1) reflecting exposure to contaminants acquired by fish from waters of the state.

Table 4. Relative Proportions of Salmon Species Consumed by the Suquamish Tribe and Derivation of Composite Life History Factor for All Salmon

	EPA Consumption Data[a]				LHFs	
Species	n	Mean (g/d)	n x Mean (g/d)	Fraction at Mean	From Table 4	Consumptio n Weighted
Chinook/King	63	0.200	12.600	0.294	0.30	0.088
Coho	50	0.191	9.550	0.223	0.56	0.125
Sockeye	59	0.169	9.971	0.233	0.19	0.045
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						0.314

[a] EPA 2011

As discussed in Appendix A, Section 3, LHFs based on residence time almost certainly overstate the relative magnitude of bioaccumulation during the early life stages of salmon life history. That is, LHFs based on residence time almost certainly overstate human exposure to pollutants acquired from waters of the state. As discussed in Appendix A, a more appropriate basis for apportioning when/where bioaccumulative chemicals are acquired by salmon might be relative growth; that is, when/where salmon acquire body mass. Appendix A, Section 4, describes derivation of a single composite, consumption-weighted, LHF for salmon based on where salmon acquire biomass. The result was 0.086 (Appendix A, Table A8), which is ≈3.5 times smaller than the single composite (consumption-weighted) LHF based on residence time. Thus, use of LHFs based on residence times should be considered conservative.

Summary

An FCR distribution representative of the general tribal population of Washington State residents was developed. An initial composite distribution was taken from WDOE (2011), and was adjusted to reflect the portion of salmon consumed by tribal members reflecting contaminants acquired by salmon in waters of the state. Table 5 provides a summary of the data and rationale used in developing the final FCR distribution for Washington tribal members, which is given in Column 5 of Table 1. Ultimately, this final distribution should be considered conservative in that it almost certainly overstates human exposure to pollutants sourced from waters of the state because 1) it potentially includes consumption of organisms not sourced from waters of the state and 2) it relies on residence time LHFs instead of growth rate-based LHFs to apportion bioaccumulation of pollutants by salmon in waters of the state.

References

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United States Environmental Protection Agency (USEPA). 2011. *Exposure Factors Handbook*, 2011 Ed. EPA/600/R-090/052F. Washington, DC: United States Environmental Protection Agency, Office of Research and Development.

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Washington State Department of Ecology (WDOE). 2013. *Fish Consumption Rates Technical Support Document: A Review of Data and Information about Fish Consumption in Washington*, Ver. 2.0 Final. Publication No. 12-09-058. Olympia, WA: Washington State Department of Ecology, Toxics Cleanup Program.

Table 5. Summary of Data and Rationale Used in Developing Fish Consumption Rate Distribution for Tribal Residents of the State of Washington (presented in Table 1)

Table 1 Column	Description/Purpose	Data Source	Rationale	Comments
[1]	Starting dataset for developing Washington-specific tribal population FCR distribution	WDOE 2011, Table C-4; tribal-specific distributions weighted according to relative population	Represents all tribal fish consumption survey results reflecting Washington tribes	Individual tribal survey distributions weighted according to relative populations of each surveyed tribe
[2] and [3]	Adjustment to exclude all salmon	WDOE 2013, Tables 21, 23, 24, and 26; tribal-specific consumption rates of salmon as relative percent of total consumption	Same dataset used to develop composite FCR distribution	Adjustment applied to entire tribal distribution; adjusts distribution to reflect consumption of all fish except salmon
[4]	Adjustment to add back portion of salmon reflecting bioaccumulation from waters of the state	See items [4](i), [4](ii) below	Consistent with WDOE 2013 proposal	Adjustment is species-weighted composite salmon LHF multiplied by salmon-specific consumption rate (added back to consumption rate excluding salmon)
[4](i)	Salmon LHF	Technical literature on species-specific behavior and life history (primarily from WDOE 2013); see Appendix A	Development of LHFs for five major salmon species based on time salmon spend in waters of the state as a fraction of total lifetime prior to return as adults for spawning (residence time as proxy for bioaccumulation)	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
[4](ii)	Relative consumption of different salmon species	Suquamish tribal data from USEPA 2011, Table 10-104	Washington-specific data on tribal consumption of different salmon species	Relative consumption rates for each salmon species used to weight LHFs to develop single composite LHF for all salmon

(Continued on next page.)

Table 1 Column	Description/Purpose	Data Source	Rationale	Comments
[5]	Final tribal-specific FCR distribution including fraction of total salmon consumption reflecting bioaccumulation from waters of the state	Table 1 columns [3] and [4] summed		Final distribution includes consumption of all fish but only the fraction of salmon reflecting bioaccumulation in waters of the state

APPENDIX A

LIFE HISTORY FACTORS FOR PACIFIC SALMON
(02-13-2015)

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 human health water quality criteria is when/where salmon accumulate their ultimate body burden of relevant chemicals. Traditionally, EPA has recommended against including salmon in these FCRs because it was accepted that for bioaccumulative chemicals a majority of the 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 (F/E) 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 State 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 the 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 and consistent with scope of the Clean Water Act, LHFs were developed for waters of the state. In this context, waters of the state include all F/E 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 (all tables are in Section 6 herein).

2.1.1 *Stream-Type Chinook Salmon Life History*

Excerpts from Ecology's TIP are quoted as the basis for developing the LHFs 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 was informed by the residence time of ocean-type Chinook, which WDOE cites as being a few weeks (we interpret this 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 in Table A1.

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 (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, 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 would be 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 suggests that about 80% of Chinook salmon caught and consumed in Washington are ocean-type fishes. 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 F/E waters, respectively, so the LHF for waters of the state would be 0.15. However, this 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, so the LHF for waters of the state would be 1 for these 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 in the tendency of Puget Sound Chinook to exhibit full residency 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 salmon.

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 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 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."

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 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 F/E waters, respectively, meaning that the final LHF for waters of the state would be 0.5.

However, as with Chinook salmon, some fraction of Puget Sound coho salmon 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 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 0.5]+[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 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, hatch in mid-March).

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 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. Composite LHFs were then 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 F/E waters, respectively; 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 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.

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). 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). This assumption concerning residence time also includes 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 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 F/E 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 F/E 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 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 rivers 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.

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 that 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 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 F/E 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 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.

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 is because bioaccumulation is a reversible process, such 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.

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 in 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 LHFs 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, 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 discussed in 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 that 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, so 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 time in near-shore marine waters rearing prior to completing migration to the Pacific Ocean. However, as discussed in 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, so 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.

5.0 REFERENCES

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6.0 TABLES

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

Type	Residence Time (days) FW[b]	Est.[b]	Marine[b]	Age at Spawning (days)	(years)	LHFs F/E[c]	Marine	Notes[d]
Stream-Type	365	15	730	1110	30.	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	
Stream-Type average	547.5	15	1095	1657.5	4.5	0.339	0.661	average freshwater residence assuming 3 y in marine habitat
Ocean-Type average	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[e]
LHFs for Puget Sound waters only ⇨						0.40	0.60	LHFs for Puget Sound only Chinook incorporating residency and assuming 80% are ocean-type fish[e]
Composite LHFs for all waters of the state ⇨						0.30	0.70	statewide composite LHFs incorporating residency of Puget Sound Chinook assuming 60% Puget Sound fish[e]

[a] all information extracted from WDOE's TIP (WDOE 2013)
[b] FW = freshwater; Est. = estuarine water; marine = marine water
[c] F/E = 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] see Section 2.1.3

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

Residence Time (days)			Age at Spawning		LHFs		
FW[b]	Est.[b]	Marine[b]	(days)	(years)	F/E[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 mon) followed by 1, 2, or 3 "summers" in marine water (15.5 mon = 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 mon) followed by 1, 2, or 3 "summers" in marine water (15.5 mon = 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 y old fish excluding Puget Sound residency[e]
LHFs for non-Puget Sound waters →					0.50	0.50	LHFs based on 18 mon in marine water, a 3 y life span, and excluding Puget Sound residency[e]
LHFs for Puget Sound waters only →					0.60	0.40	LHFs for Puget Sound only coho incorporating residency[e]
Composite LHFs for all waters of the state →					0.56	0.44	statewide composite LHFs incorporating residency of Puget Sound coho assuming 60% Puget Sound fish[e]

[a] all information extracted from WDOE's TIP (WDOE 2013)
[b] FW = freshwater; Est. = estuarine water; marine = marine water
[c] F/E = 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] see Section 2.2.2

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

Type	Residence Time (days)			Age at Spawning		LHFs		Notes[d]
	FW[b]	Est.[b]	Marine[b]	(days)	(years)	F/E[c]	Marine	
Stream-Type	457		730	1187	3.3	0.385	0.615	to marine water at age 1; assume hatch mid-March,
Stream-Type	457		1095	1552	4.3	0.294	0.706	emergence by May 1 (42 d post-hatch), 1 y
Stream-Type	457		1460	1917	5.3	0.238	0.762	residence, then out-migration (50 d); "limited" use of estuary
						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,
Ocean-Type	92		1095	1187	3.3	0.078	0.922	emergence by May 1 (42 d), and immediate out-
Ocean-Type	92		1460	1552	4.3	0.059	0.941	migration (50 d); "limited" use of estuary
						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	statewide composite LHFs assuming 50:50 split between stream- and ocean-type (92 days FW residence[e]

[a] all information extracted from WDOE's TIP (WDOE 2013)
[b] FW = freshwater; Est. = estuarine water; marine = marine water
[c] F/E = 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] see Section 2.3.2

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

Residence Time (days)			Age at Spawning		LHFs		
FW[b]	Est.[b]	Marine[b]	(days)	(years)	F/E[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 y 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 is 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 y old fish
LHFs for non-Puget Sound waters ⇒					0.13	0.87	LHFs for non-Puget Sound chum based on average age fish[e]
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[e]
Composite LHFs for all waters of the state ⇒					0.22	0.78	statewide composite LHFs assuming 60% Puget Sound fish[e]

[a] all information extracted from WDOE's TIP (WDOE 2013)
[b] FW = freshwater; Est. = estuarine water; marine = marine water
[c] F/E = 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] see Section 2.4.2

Table A5. Life History Factors (LHFs) for Chum Salmon[a]

Residence Time (days)			Age at Spawning		LHFs		
FW[b]	Est.[b]	Marine[b]	(days)	(years)	F/E[c]	Marine	Notes[d]
62	106.5	561.5	730	2	0.231	0.769	fry emerge 52 d post-hatch; estimate 10 d to migrate to estuary, total of 62 d in FW; 3.5 mon 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 mon rearing in marine water and 24 mon 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] F/E = 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

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

Species	Tribal Consumption Data[a] n	Mean (g/d)	n x Mean (g/d)	Diet Fraction at Mean[b]	Species-Specific LHFs LHF[c]	Consumption Weighted
Chinook (King)	63	0.200	12.6	0.294	0.300	0.088
Coho	50	0.191	9.55	0.223	0.560	0.125
Sockeye	59	0.169	9.971	0.233	0.194	0.045
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 residency-based LHF for salmon			➡	0.314

[a] consumption data for Suquamish Tribe from USEPA 2011, Table 10-104
[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

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 ratio (smolt/adult)

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

Species	Tribal Consumption Data[a] n	Mean (g/d)	n x Mean (g/d)	Diet Fraction at Mean[b]	Species-Specific LHFs LHF[c]	Consumption Weighted
Chinook (King)	63	0.200	12.6	0.294	0.182	0.053
Coho	50	0.191	9.55	0.223	0.135	0.030
Sockeye	59	0.169	9.971	0.233	3.72×10^{-3}	8.65×10^{-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			➡	0.084

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

ATTACHMENT B

Derivation of Human Health ‐ Based Ambient Water Quality Criteria: A Consideration of Conservatism and Protectiveness Goals

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ABSTRACT

Under the terms of the CleanWater Act, criteria for the protection of human health (Human Health AmbientWater Quality Criteria [HHWQC]) are traditionally derived using US Environmental Protection Agency (USEPA) recommended equations that include parameters for exposure assessment. To derive "adequately protective" HHWQC, USEPA proposes the use of default values for these parameters that are a combination of medians, means, and percentile estimates targeting the high end (90th percentile) of the general population. However, in practice, in nearly all cases, USEPA's recommended default assumptions represent upper percentiles. This article considers the adequacy of the exposure assessment component of USEPA recommended equations to yield criteria that are consistent with corresponding health protection targets established in USEPA recommendations or state policies, and concludes that conservative selections for exposure parameters can result in criteria that are substantially more protective than the health protection goals for HHWQC recommended by USEPA, due in large part to the compounding effect that occurs when multiple conservative factors are combined. This situation may be mitigated by thoughtful selection of exposure parameter values when using a deterministic approach, or by using a probabilistic approach based on data distributions for many of these parameters.

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